THE MICROENVIRONMENT OF A CEREAL BASED INTERCROP AT SAMARU. NORTHERN NIGERIA

By

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CERTIFICATION

This thesis titled *"The Microenvironment of a Cereal Based Intercrop in the Northern Guinea Savanna Zone of Nigeria"*, by Joshua Olalekan Ogunwole, meets the regulations governing the award of the degree of **Doctor of Philosophy** of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of information have been specifically acknowledged by means of references.

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DEDICATION

To Bimpe, Ifeoluwapo and Bolatito.

That He who is able to do all things will

show us mercy and have compassion upon our lives. Amen.

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ABSTRACT

Depending on soil and climatic characteristics particularly, rainfall, crop production in northern Nigeria can be limited by inefficient use of nutrient especially, nitrogen and phosphorus, or by inefficient use of water. Intercropping system evolved as a common practice in response to mitigating those limitations. This is because intercropping may utilize these resources at greater efficiency and produce higher total yields than the monocrops. The objective of this study was to characterize the nature of the environment and examine its effect on productivity under different cropping system with a view to recommend a component technology to farmers.

The sorghum/maize combination is a popular intercrop in the Northern Guinea Savanna. From the perspective of what the farmer does, field studies spanning three seasons (1996-1998) were conducted on a fairly drained Typic Haplustalf in Samaru. The experimental design was a randomized complete block design with twelve different cropping systems, which revolved around two sorghum varieties namely, Ihe local 'farafara' and Ihe improved SAMSORG-14.

Results of climatic analyses revealed abundant solar radiation (400 cal cm^{-2} day^{-1}) in Samaru, which raised its potential for crop production. Analysis of rainfall events revealed a progressive drier condition with years with rainfall amount falling below the long term mean (1050 mm) and, the probability of drought is high at the beginning and end of the growing season. The soils of the area are structurally poor with low native fertility and poor water holding capacity.

Generally, crop observaticn have shown greater and efficient use of resources under intercropping. Peak light interception (780%) was attained at 70 DAS, same for peak leaf area index (3.35). Leaf area index and fractional light interception followed a sigmoidal pattern; after emergence, they both increase linearly up to maturity and then decrease at a diminishing rate due to leaf senescence. Light use efficiency ranged from 4.67g MJ^{-1} in the Farafara/ Maize/Cowpea-R to 1.75 g MJ^{-1} in the monocroppcd maize. This further confirm the efficient use of light resources by intercropping systems.

Local 'Farafara' recorded higher grain yield and seed weight both in mixture or when planted sole. Stand intercrop favours higher grain yield over the row planting pattern. The Land Equivalent Ratio (LER) showed SAMSORG-14/MAIZE/COWPEA mixtures having the highest value of 1.69 in 1996 compared to the 1.60 in the FARAFARA/Maize/Cowpea mixtures. This indicate a more efficient space usage over the monocrop. In addition, results of water use (efficiency) showed intercropping to more efficiently use water than the monocropped component. The Farafara/Maize/Cowpea mixtures produced 12.5 kg ha^{-1} dry matter for every unit millimeter of water utilized while the monocropped Farafara and SAMSORG-14 produced only 7.5 kg ha^{-1} and 3.9 kg ha^{-1} dry matter respectively for same unit of water. The higher performance of the local Farafara tends to be due to its strong adaptation and restriction to the Northern Guinea Savanna, which is the zone of study.

Results on environmental factors showed a high negative relationship between intercrop yield and rainfall amount. This shows that rainfall distribution and not necessarily the amount is the factor that improve crop yield. In addition time (date of planting) was seen to have a strong relationship to yield. When crops are planted early, yield obtained doubled those of late sown ones.

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CHAPTER I

INTRODUCTION

1.1 Motivation

Nigeria, with its large land area of about 924,000 km^2 and an estimated population of about 100 million (1992 Census puts it at 88.5 million) is mainly an agrarian society. Over seventy percent depend largely on small subsistence (traditional agriculture) farmlands (Baker, 1974; Luning, 1961; Olatunbosun, 1975; Ogungbile and Olukosi, 1991). The country has been classified into three main ecological zones: (i) the Tropical Rainforest in the south, (ii) the Guinea Savanna in the geographical middle belt and, (iii) the Sudano-Sahelian zone in the north. The Guinea savanna zone may be further subdivided namely, the dry Northern Guinea bordering the Sudano-Sahelian zone, and the moist Southern Guinea which flanks the Rainforest zone. Over half of the country's arable land mass lies within the Northern Guinea and the Sudano-Sahelian zones. Most of the farmers in these zones, particularly the former, practice intercropping. This system is preferred because it reduces risk and maximizes farmers' income (Swindale, 1979; Norman *et al.*, 1982).

Rapid growth in the population have made 'true' shifting cultivation where the settlement is moved to be rare. Permanent cropping or farming system with a compound farm system based on major staples is prevalent (Okigbo and Greenland, 1977). Besides, in the few areas where the fallow agricultural system is still being practised, it has had to assume shortened period with attendant decline in soil fertility and sustainability. As a result, introduction of new agricultural technologies such as improved seeds, use of

appropriate chemical fertilizer, adaptation and use of alternative farming were embarked upon to maximize productions. While new agricultural technologies may, in the long term, be probable solution to declining soil fertility and sustainable agriculture; in the short term there is the need to improve the traditional cropping system to cope with the food demands. A probable improvement might involve intensification of crop production within the major climatic and edaphic constraints (Boserup, 1965).

Prior to 1990, food problems (or crisis) in Nigeria were less apparent. Droughts and poor and declining harvests have met with emergency relieve measures such as importation of grains and selling them at subsidized rates (Owonubi, 1985; Ojo, 1991). Even since then Nigeria like many other African countries have succeeded more in establishing institutions and programmes than evolving definite policies to solve food problems and deteriorating agricultural productivity (Abdullahi, 1980; Abalu, 1981). Failure of such programmes and institutions was readily appreciated by one of the initiators fifteen years after the Operation Feed the Nation (OFN) programme could not solve the then food crisis and he puts it thus: "The failure of major agricultural policy of African governments is to overlook the development of human resources for increasing agricultural output. It is also vital that programs be initiated which will be capable of mobilizing small-scale farmers for more efficient use of (all locally available) agricultural resources" (Obasanjo, 1991).

1.2 Research Problem

There has continued to be a poor adoption of monocropping systems by farmers of Nigeria and West Africa in general. This may not be unconnected with the perceived risk of complete crop failure in bad years. Hence,

intercropping or multiple cropping is the most widely adopted farming system by the small scale farmers.

A significant feature of multiple cropping is a greater dependability of returns compared with sole cropping. This is important at all levels of production but especially to small scale farmers at low yield levels where alternatives to production are much more restricted and the farmer therefore has to be more certain that his investments of labour and capital are protected (Andrews and Kassam, 1977). As long as agriculture continues to be dominated by small holder agriculture in the West African Semi-arid Tropics, there appears to be no technical reason why intercropping should not continue to play an important role in food production of the region (Fussell and Serafini, 1985).

This poor adoption of monocropping systems by farmers in most West African countries have revived research interest in intercropping systems. This revival continues largely because research has demonstrated that intercropping can have many advantages over monocropping (Lightfoot and Tayler, 1987).

Although, research on intercropping in West Africa is a recent phenomenon, Baker *et al.* (1982) reported extensive research undertaken on intercropping in the early thirties. Between 1930 – 1960, colonial administrators and researchers concentrated their research and extension efforts on sole cropping.

Reports from works performed showed that intercropping can increase total grain yield (Willey, 1979; Steiner, 1982). On closer inspection from data from farmers field reveals that both increases and decreases may occur

(Lightfoot and Tayler, 1987). This finding have been supported by some studies but not by others. In addition to this, a possible explanation for the conflicting evidence could be because most of the experiments were conducted under high levels of management and inputs and in wetter climates other than the semi-arid tropics.

A serious criticism of current research is that the high levels of inputs and management used on research stations often produce results that bear little relation to the farmers circumstances for which they are intended.

1.3 Aim and Objectives

In an effort to increase the relevance of research to farmers, our approach considers the farmers' objectives and circumstances to determine whether or not intercropping has advantages over monocropping in the Nigerian savanna condition in terms of higher productivity and greater stability.

This study was initiated specifically to:

(i) identify and describe the nature of the climatic elements (specifically, light and water) and the soil characteristics influencing agricultural production.

(ii) compare the patterns of growth and light interception in the sorghum intercrop and sole sorghum and maize crops to provide evidence on the performance of the systems.

(iii) examine the effects of the climatic elements (light and water) on the productivity of the intercropping systems.

1.4 Scope and Aspects of the Study

The term "micro-environment" is an abstract concept. It refers to the environment of a few metres from the ground on which plants are growing. Micro-environment can only be grasped by means of comprehensive calculations. Since it includes the sum total of all individual meteorological and other physical occurrences at a given place.

Therefore, micro-environment could be defined as the consequential special conditions that develop or prevails due to the influences exerted by different climatic elements (light, rainfall, temperature, wind etc), their interactions and the influences exerted by topographic variation and the underlying surface on the air layer, below the agreed level of about two metres which is the air layer close to the ground (Geiger, 1965). It is in this atmospheric layer (i.e. 2 m from the ground) that plants grow, especially young plants, which are exceptionally sensitive to weather fluctuations.

The micro-environment in this study is primarily discussed in terms of climatic elements and soil nutrient composition. Keeping in view the pertinent features of the monocropping and intercropping systems of the studied area.

1.5 Definition of Concepts/Terminology

Micro-environment: This is the prevalent conditions of the air layer from about 2 metres near the ground, due to the microclimatic, topographic and vegetative influences exerted on it.

Microclimate: This describes the prevailing distribution near the ground of various quantities including light, temperature, wind speed, rainfall

and humidity around the habitation of the crops, which is about two metres near the ground.

Multiple cropping: This is the intensification of cropping in time and space dimensions. It is the growing of two or more crops on the same field in a year.

Intercropping: It is the growing of two or more crops simultaneously on the same field. The crops are not necessarily sown at exactly the same time and their harvest times may be quite different.

Component crop: It refers to either of the individual crops making up the inter-cropping situation.

Sole (mono) crop: This refers to a component crop being grown alone and unless otherwise indicated is assumed to be grown at optimum population and spacing.

Crop combination: It refers to the various component crops that makes up a particular mixture.

Cropping pattern: The yearly sequence and spatial arrangement of crops or of crops and fallow on a given area.

Cropping system: the cropping patterns used on a farm and their interaction with farm resources, other farm enterprises, and available technology which determine their make up.

Pedon: This is the smallest soil volume needed to describe and sample a soil body. The maximum size area is 10 m^2 while the minimum is 1 m^2 depending on the nature of the cyclic variations within the horizons.

1.6 Organization and Presentation of the Research

After a detailed review of relevant literature that have a bearing on the agrometeorological aspect of intercropping, the method of the research study will be presented. The organization of the research will fall roughly into three categories: a detailed characterization of the nature of the rainfall, light and soil properties of the studied area; a presentation of the three years field trials which will include the treatments, plot layout and the mode of management; and the various materials, instrumentation and physiological measurements observed.

The presentation of the research results will focus on the results of the rainfall, light and soil characterization and its implication on crop production; the sole and intercropping conditions; the effect of the measured climatic elements on the performance of both the monocrop and the intercropping systems.

An attempt at modeling the relationship between the various climatic elements and crop growth parameters and yield will be presented.

Finally, the potential, deficiencies and limitation including areas of future further examination will be suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter deals primarily with the eco-physical studies of the savanna region generally. It provides information on climate, soils and crops needed to assess the impact of the environment and the basis of cropping practices and systems. Such information highlights potentials and constraints, in addition to the land use pattern that had evolved over years as a consequence of these environmental factors.

This chapter also, reviewed works done in other places that has a bearing to micro-environmental effects on cropping pattern and performance.

2.2 Physical Environmental and Ecological Basis of Crops and Cropping in the Savanna

The savanna have been defined as "an area of seasonal tropical vegetation in which there is closed or nearly closed ground cover of grasses at least 0.8 m high, with flat, usually cauline leaves. The vegetation is usually burnt annually, and trees and shrubs 'are often present" (Sanford and Isichei, 1986).

2.2.1 Physical environment of the savanna

The Nigerian savanna is predominantly an agricultural region which accounts for about seventy percent (665,600 square km) of the geographical area of Nigeria. It is located between latitude 07° to 14°N and longitude 03° and 15°E. In addition, over 85% of the country's arable land mass lies within the region (Kowal and Knabe, 1972).

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The greater part of the region forms an undulating plain lying at a general elevation which vary from about 450 to 690 m above sea level. The southern boundary of the savanna is roughly demarcated by the lowlands of the Niger-Benue valley, mostly less than 180 m above sea level.

There are two major drainage system in the Nigerian savanna; the Niger-Benue river system and the inland drainage area of Lake Chad. North of these two rivers, the land rises irregularly to rolling or gently undulating plains referred to as the "High plains of Hausaland" (Kowal and Knabe, 1972), which is occasionally interrupted by groups of granite inselbergs in the north east, the plain descends into the inland drainage basin of Lake Chad.

The "Hausa Plains" is underlain predominantly by igneous and metamorphic rocks of the Pre Cambrian to lower Palaeozoic Basement Complex. Granites, gneisses, migmatites, quartzites and Schists are the dominant rock types in the area (Bennett *et al.*, 1979). Although, Jurassic intrusives known as younger granites are also present (LRD Report, 1974).

The soils of the Nigerian savanna is predominantly of the ferruginous tropical soils (Klinkenberg and Higgins, 1968). They are highly weathered soils and markedly laterised by the loss of silica. The resulting free metal oxides from a high proportion of the clay fraction and often coat the quartz and crystalline clay particles of kaolinite. The soil aggregates are usually very small, and very unstable under wet conditions. The water holding capacity of the soil is a function of its structural composition. The soils are very weakly buffered and have a very small exchange capacity. The total content of available plant nutrients in these soils is very small due to runoff, soil erosion and leaching effect (Kowal and Knabe, 1972).

2.2.2 General atmospheric circulation

The surface distribution of the atmospheric pressure in the Nigerian savanna. is strongly influenced by regions of high pressure found at thirty (30°) degrees latitude in both hemispheres. Generally, air flows from these anticyclones (high pressure belts) to an area of low pressure near the equator.

These flows which are further enhanced by a series of mechanisms responsible for maintaining the global energy balance, through poleward transmission of energy (Jagtap, 1994), meet in the Inter-Tropical Convergence Zone (ITCZ). The converging air rises to about 2 km, where a strong vertical temperature gradient prevents further upward motion (Kassam, 1988).

The agricultural significance of this, is that rising air expands, cools and if sufficiently moist, may be saturated with water vapour, resulting in cloud formation and rain. Therefore, the Inter-Tropical Convergence Zone is potentially a region of rainfall.

2.2.2.1 Precipitation

The major type of precipitation in Nigeria is rainfall. The occurrence and distribution of rains in Nigeria further influenced by the orography of the area (Semazzi and Sun, 1997), although, the movement of air masses largely influences rainfall events. These air masses include the Tropical Maritime and the Tropical Continental. The Tropical Maritime air mass is associated with the dust laden Northeast Trade Winds which bring harmattan (Jagtap, 1994). Therefore, the general pattern of precipitation in Nigeria is associated with the movement of the ITCZ.

Rainfall in Nigeria decreases from south to north in amount, duratio and intensity; from an all year round distribution in the coastal south to onl three months of rain in the far Sahelian north. Over 3000mm of annua rainfall is recorded in the coastal south while, less than 600mm of rain fall annually in the Sahel (Maduakor, 1991).

Most cropping in Nigeria continues to be under rainfed condition. Therefore, the characterization of rainfall is essential for the improvement of sustainable food production systems to meet the demand of the ever increasing populace.

Generally, rainfall continues to be the limiting constraint to most dry land crop production systems. This is because of the low water holding capacity of the soil and the unreliable rainfall in this dry land region (Payne *et al.*, 1990). Stroosnijder and Hoogmoed (1984), reported evaporation as high as 2mm day^{-1} and drainage as negligible on a farmer's millet field in the dry savanna area. They concluded that water was the principal limiting constraint to millet production in their site.

Dewit (1958), suggested that where water is in short supply, the amount transported must equal the available water, corrected for evaporation and other "unavoidable losses" such as drainage and runoff. Where water is not limiting, the transpired amount of water is in general less than the available amount of water. In areas where the seasonal variability in rainfall is large which in turn influences the profile moisture content and distribution, the response of any applied water could be variable. Sivakumar and Huda (1983) demonstrated moisture dynamics with several crops within a growing season and inferred that, depending on the time of planting, the crop response could again vary.

2.2.3 Vegetation of the Nigerian savanna

The dominant effect of climate on natural vegetation and the distribution of crops in Nigeria is clear (Kowal and Knabe, 1972). Many classifications of the savanna based on climate, flora and edaphic features exist. This is so because tropical savanna vegetation has structural and functional characteristics that enable it to exhibit seasonal rhythms of growth and productivity (Cole, 1986). Most savannas in their natural state are mainly woodlands, i.e. have open stands of trees whose crowns form canopies 8 to 20 m or more in height. The crowns of adjacent trees are often in contact but not interlocking. Although, cultivation have profoundly modified the natural vegetation (Isichei and Akobundu, 1994).

The zonation of the Nigerian savanna vegetation by Keay (1959) has enjoyed wide recognition and usage. It divides the Nigerian savanna vegetation into four, roughly running parallel across the country from the south northwards. This include the Southern Guinea, Northern Guinea, the Sudan and Sahel savanna.

2.2.3.1 Ecology of the Northern Guinea savanna

The Northern Guinea savanna occupies about 35% (230,000 square km) of the entire savanna land of Nigeria. Mean annual rainfall is between 1000 to 1400 mm and humid days ranged from 240 to 300 days. The Isoberlinia woodlands are widespread in this ecological zone (Keay, 1959). These woodlands are mostly associated with plinthite and quartzite ridges. They have a thin but continuous main canopy of *Isoberlinia doka* and *Isoberlinia tomentosa*. Other common trees include *Parkia biglobosa* and *Terminalia* spp. Prominent grasses

are the *Andropogon gayanus*, *Hyparrhenia* spp. and *Schizachyrium* spp. which dominate the herb layer.

Moisture have been identified as a major environmental determinant of savannas, with fire, soil nutrients and, in some cases, herbivores as important modifiers of the basic structure of the vegetation (Johnson and Tothill, 1985). The Northern Guinea savanna is the agroecology of the studied area.

2.2.4 Crops and farming systems in the Northern Guinea savanna

The prevailing cropping systems in this zone are commodity and co-commodities based (Okigbo, 1994; Ogungbile *et al.*, 1999), but at the same time they reflect specific resource management systems related to the prevailing environmental conditions and the culture of the people. These factors in addition to the level of technological development and resource availability (Norman, 1974) constitute the basis of diversity in the number of crops grown and variation in cropping and farming systems.

The main reason these complex systems are found instead of each of their components being grown individually as sole crops, is the fact that they involve crops that require low external inputs but considerable human effort. They are the best way to confront climatic hazards and allow a better utilization of crop space (where land is the limiting factor).

2.2.4.1 Farming systems

The farming system in Nigeria, like any other area, is determined by a combination of physical, socioeconomic and political factors. The physical environment for instance, determines broadly the type of crops to be grown.

Since, there is yet limited technology at farmers' level to modify the environmental condition of their areas.

Cultivation in the Nigerian Savanna particularly, the Northern Guinea is principally rainfed, despite the push for increased hectarage under irrigation. Food production will continue to rely heavily on rainfed farming in the area. This is because of the limited availability of water and technology for exploiting same. The main traditional crops include sorghum, maize, pearl-millet, groundnut, cotton and cowpea. These are grown either as sole crops, in discrete mixtures or as intercrops.

In spite of the consideration accorded sole cropping, as an index of progressive farming, there has been little shift to sole cropping by the low input farmers in Nigeria (Baker, 1975). Over the years, farmers have adopted farming practices that aim at minimizing the adverse effects of constraints imposed by physical factors like unreliability of rainfall in onset, duration, cessation and intensity, high rates of evapotranspiration and unpredicted period of drought (Okigbo, 1994).

Farmers in the area commence the farming season with land preparation. Traditionally, this farming operation (i.e. tillage) is done by hand or by animal traction; involving a fairly complex method of ridge cultivation. The ridge cultivation has a number of advantages in that, through the process of ridge preparation, it is ensured that the ash and plant residues – enriched topsoil is concentrated at the root zone. In addition, the ridge improves aeration for plant roots while, the furrows act as open drains which can again be cross-tied to conserve both water and soils in areas where water is deficient and rapid drainage is not desired.

2.2.4.2 Intercropping patterns

In Nigeria, standard or rigid patterns of intercropping are not clearly defined. Different farmers grow crops in a number of different combinations (Yayock, 1979), hence no clearly defined cropping pattern exists within anyone agroecological zone. However, farmers tend to adapt by making sure that the less nutrient demanding species are frequently relay intercropped into the high nutrient demanding species. Specific intercropping systems have evolved in different regions probably in response to the prevailing edaphic and climatic conditions and, socio-economic preferences. Though a large number of crop species may be encountered in the intercropping, there are usually two or three major crops that are dominant components (Norman, 1972). Four major systems based on the dominant crops can be distinguished in northern Nigeria (Steiner, 1982). In the derived savanna transition zone and in parts of the Southern Guinea Savanna, the traditional cropping systems are based on yam; which normally planted in the first year after bush clearing. Yams are often intercropped with cowpea, maize, cassava, vegetables and plantains.

The maize-based cropping system dominates most of the Southern Guinea savanna. It is usually intercropped with cassava, yams and cowpea. In this agroecology, the maize/cassava intercrop has been identified as a very productive combination, and widely practised. The cropping system typical of the Northern and part of the Sudan Savannas are the sorghum-based systems (Fig. 2). Major crops in these systems are millet, groundnut, and cowpea. Though, maize is fast gaining relevance, most especially, in the Northern

Guinea Savanna, sorghum still remains the principal cereal crop in the area (Olukosi *et al.*, 1991; Elemo, 1991; Freeman, 1994).

Since, a relationship tends to exist between the amount of rain, its variation at the beginning and end of rains, farmers tend to place emphasis on the hydrological factors in making any farm operational decisions (Norman *et al.*, 1982).

2.2.4.3 Review on intercropping systems

The bulk of the food consumed in Nigeria is produced in small farming systems which are characterized by land holding ranging in hectarage from 0.5 to a few hectares. There is limited mechanization and the wide range of multicropping systems is an indication of the resource-poor farmers' preference for crop mixtures.

Andrews and Kassam (1977) defined intercropping as the "growing of two or more crops simultaneously on the same field." The crops are not necessarily sown or harvested at the same time, but are cultivated for a significant part of the growing season (Willey, 1979). Intercropping is a common practice among small-scale farmers and farmers with the least access to irrigation. It is a potential system which will boost productivity over space and time. It provides farmers with a variety of returns from land and labour, which increases the efficiency with which scarce resources are used and, reduces farmers' dependence on a single crop, which is susceptible to environmental and economic fluctuations.

When two or more crops are intercropped, one would expect better interception of sunlight energy, more effective utilization of water and

nutrient, and a higher exploration of the growing factors related to the environment (Willey and Osiru, 1972; Osiru and Willey, 1974). The success of an intercropping system depends on the choice of crops which have to be grown and their proper management. Most crops grown in intercrops are crops of dissimilar growth patterns, such that the peak period of growth does not coincide. Hence, crops of varying maturity duration are usually chosen so that a quick maturing crop completes its life cycle, before the grand period of growth of the other crop starts.

In the intercropping system there are two broad ways of classification. One is the replacement mixture, where one genotype replaces a proportion of another genotype. Such mixtures are generally of "like genotype". The second is the additive or superimposed mixtures. In this mixture, one genotype is added to the other (or others) so that the final plant population is considerably more than if either genotype had been sown sole. These mixtures generally consist of "unlike genotypes". It is suggested that replacement mixtures are made up of crops from the same phenological group, whereas genotypes in superimposed mixtures are usually drawn from different phenological groups. Also, it is not out of place to find short- and long-duration crops in mixtures (Baker, 1979).

2.2.4.4 Arrangements in intercropping systems

Intercropping system could be mixed such that the canopy is devoid of row distinction. In row-intercropping, one or more crops are planted in rows. In the case of strip intercropping, the crops are planted simultaneously in different strips wide enough to permit independent cultivation but narrow

enough for the crops to interact agronomically. When a crop is grown during the part of the life cycle of another, i.e. a second crop is planted after the first crop has attained its reproductive stage of growth, but before it is ready for harvest, it is termed Relay intercropping (Andrews and Kassam, 1977). In most relay intercrop, the planting of the demanding crops (mainly cereals) during the early part of the cropping cycle, and following them with less nutrient demanding leguminous or root crop (i.e. cowpea or cassava respectively) is usually the farmers' practice (Kang, 1985).

2.2.4.5 Component crops and intercropping systems in the Northern Guinea Savanna

The sorghum/millet intercrop which used to be the most predominant in this Northern Guinea savanna agroecology (Norman, 1974), is fast giving way to the sorghum/maize intercrop. This is because maize has been gaining popularity as a component mixture with sorghum, also, maize have been found to yield better than the standard sorghum/millet mixtures (Elemo, 1991). In addition, its yield advantage, its vigour, adaptation to wide spacing, ease of weeding and its ability to fairly compete with weeds are added advantage that advanced maize popularity. Furthermore, maize grain does not deteriorate rapidly in storage (IITA, 1992) and these could attract farmers to adopting maize over millet. Although, these are crops of similar habit, their demand period differ resulting in greater utilization of the environment to achieve greater yield. The entrance of maize into the cropping system of this agroecology was enhanced through the availability of inorganic fertilizer and improved management technology and the elevation of adaptable varieties (Elemo, 1991).

The traditional sorghum varieties are the tall, loose panicle, late maturing photo- period-sensitive genotype. The maize varieties popular in the area are the early maturing (95 days), streak resistant, open pollinated types. While, the preferred traditional cowpea variety are largely the spreading, photosensitive and late maturing (85-90 days) types. They are adapted to low plant population with good fodder quality.

2.2.4.6 Farmers' practice under intercropping

The first farming operation once the rains are established is tillage and the ridge and furrow cultivation system is the practice. Sorghum and maize are sown immediately the rains are established (late May to early June). They are sown right on the ridges in wide rows and at intra-row spacing of about 25cm. Two seeds of maize and about five or more seeds of sorghum are individually planted in the opened seed holes.

The density and arrangement vary depending on farmers' preference. The dominant density ratio is 1:1 while the row intercropping system is the preferred arrangement by most farmers (Baker, 1975).

Unlike in the Sudano-Sahelian agroecology, where cultivation is mostly done by cattle owners and droppings from the animals are collected and used in improving the soil fertility status (Oluwasemire, 1997), farmers in the Northern Guinea Savanna depend principally on inorganic fertilizers and available household waste (Norman, 1982; Freeman, 1994). Popular fertilizer used are the combined Nitrogen, Phosphorus and Potassium (N:P:K) fertilizer, the straight fertilizers like Urea (Uyovbisere and Lombin, 1991) and single super phosphate (SSP). This (Urea) could be applied in two to three split

doses: immediately after crop emergence, two or three weeks after crop emergence and four to six weeks after emergence.

Weeding is done manually with the aid of a local hand hoe, the first weeding is done between two to four weeks after sowing (Oluwasemire, 1997), during which the thinning of the sorghum and maize are done. The second weeding commences at six weeks after planting. This is later followed by a remoulding of ridges, which usually coincide with the plants seven to eight weeks of age.

Maize is usually harvested first between mid September to late September leaving the sorghum to grain fill into the dry weather. Sorghum harvest is done mid October to early November. Thereby, relying on soil residual moisture to grain fill.

2.2.4.7 Intercropping management and yield

Fertilizer recommendations based on sound research findings are yet to be made for various crop mixtures in Nigeria (Enwezor *et al.*, 1989). Fertilizer requirement for intercropping systems may often differ considerably from the mere addition of fertilizer requirements of the individual crops. This is because, growing two crops in association may result either in better exploitation of soil resources or in competition between the crops for nutrients and other growth factors.

Roy and Braun (1982) are of the opinion that the farmers' objectives to a large extent, influence the amount of fertilizers to be used in intercropping system. They inferred that in subsistence intercropping systems, the level of fertilizer is generally low as available supplies of fertilizer are often limited.

Fertilization practices to ensure adequate nutrient supply are more rigorous with mixed cropping. The problem of fertilization becomes more important when shorter fallow cycles and longer cropping periods are introduced into the traditional system (Kang, 1982).

Bradfield (1970) recommended fertilizer rates by summing up the estimated requirements for each crop; though technically sound, this may not be the most efficient method (Kang, 1982). It is important, when developing fertilizer practices for intercropping systems particularly, for marginal farmers, that the economics of such practices also be considered simultaneously with their biological potential (Oelsligle *et al.*, 1976). Enwezor *et al.* (1989), suggested fertilizer application of 125% of that recommended for each component on a pro-rata basis to each crop in cereal mixtures. This is because they believed each crop would be able to yield some 25% more than if grown sole. Other additional suggestion was the application of fertilizer particularly nitrogen, by reference to the most demanding cereal of the mixture.

2.3 Micro-environmental Factors and Cropping Practices

The brief description of the air circulation pattern also explains other important meteorological factors related to agriculture (Konate, 1984). These meteorological factors include temperature, radiation, wind, etc. The mixture of these quantities and their variations operated on and influences growth and development of crops (Owonubi *et al.*, 1995). The variations could be brought about by changes in the nature and moisture content of the soil, differences in surface slope, type and height of the growing vegetation (Geiger *et al.*, 1995). Hence, information on the response of crops to their environment can be derived from the nature of its microclimate (Ong, 1984).

The interaction of agrometeorological factors and crop systems provide, in quantitative terms, crop responses to their growing environment (Kanemasu, 1986). Such interactions enable the growing areas of the crop plants to be analysed in relation to agroecological and climatic factors. The result of this analysis can be used advantageously for increasing and stabilizing yields; this is because it enables the development of strategies that would reduce crop vulnerability to hazards of climate. The knowledge of agrometeorological interaction with crop plants can further contribute to the search for ways to increase the availability of water, to increase the demand for the water for crop use and to improve the water use efficiency of the crop plants (Rosenberg, 1984; Stigter, 1994).

The optimum time of sowing, establishment and survival of a crop depends to a large extent on agrometeorological factors (Sivakumar *et al.*, 1984) such as water supply and drying characteristics of the specific environment.

2.3.1 Micro-relief and cropping

Geiger *et al.* (1995) revealed meteorological variables not only subject to vertical changes near the ground but also vary horizontally within short distances. Sloping ground is usually described by its slope angle or gradient and these, determine the slope situation or exposure. When the sun is shining, slopes of different inclination and orientation receive different amount of radiant energy, and the equalizing currents of air set in motion (i.e. upslope or anabatic winds) determine the microclimate (Geiger *et al.*, 1995).

On a level ground, slope microclimate is restricted to the lowest few meters of the atmosphere but when the land has strong relief, microclimate must be extended further. The climate of a slope has a great significance to agriculture particularly, cropping. It decides the quality of arable land and the possibility of cultivating certain plant species. Suzuke (1941), explained two months early sales of strawberries at Tokyo, in advance of the main crop, as the effect of exposure climate. The early strawberry were grown on the steep terraces of Shizuoka. The differences in climate between two opposite sides of a mountain valley could be as a result of the different amounts of radiation received which will dictate the crop type and cropping practices.

2.3.2 Soil characteristics and cropping

The varied nature of soil surface could be attributed as a cause of the extreme diversity of microclimate. The soil consists of particles of different types, differing in density, grain size, thermal conductivity and water content (Geiger *et al.*, 1995).

It is difficult to isolate the pure influence of the soil upon the surface microclimate but all other factors are influenced by the nature and state of the soil. Soil moisture affect both the amount of evaporation and the surface albedo (Geiger *et al.*, 1995). Furthermore, the availability of plant nutrients in soil could determine how much water a plant will extract from the soil. Usually, when soil conditions are disadvantageous, improvements can be brought about by adding certain constituents as soil amendments.

Unfavourable soil properties can be improved by relatively simple means. Besides, alternation of soil coloration using organic matter, mixing soil

through tillage and mixing elements like mulch to soil improve its quality particularly, soil moisture conservation, prevention of excessive cooling or even enhance soil warming. Adéoye (1984) reported higher moisture content in 0-0.1 m soil layer of mulch plots as compared with the unmulched plot. He inferred reduction in evaporation as a result of mulching as responsible for the high soil moisture content. In addition, high maize grain yield was reported under the favourable soil environment of grass mulch.

2.3.3 The microclimatology of crops

The integration of the soil, crop and climatic information into usable and practicable region-specific recommendation is important in improving cereals production. The knowledge and understanding of weather effects upon crop yield and performance permit the climatological determination of probabilities of agriculturally favourable weather over a region, which is essential for intelligent economic planning.

The qualitative dependency of crop growth and development upon the weather is universally accepted, but attempts to quantify these complex relationship generally have not been sufficiently well established to encourage the explicit use of climatology in long range planning.

2.3.3.1 Temperature, heat flux and cropping

A qualitative and quantitative analysis of the effect of temperature shows that qualitatively the occurrence of certain threshold temperatures may influence crop growth and development (Konate, 1984). Temperature exert a major effect on the rate at which crop plants develop and on processes of expansion and extension (Ong and Monteith, 1984). To interpret temperature

effects on plant growth is often difficult because temperature in a crop canopy vary both with time and space.

Ong and Monteith (1984) showed a relationship between number of grains per panicle of millet as a function of mean air temperature. They indicated an optimum temperature of 22 to 25°C for millet. In pearl millet, Fussell *et al.* (1980) found out that high temperature (33/28°C, day/night) during vegetative, stem elougation and grain development lowered grain yields by reducing basal tillering, number of grains per inflorescence and single grain weight. Low temperatures (21/16°C) when imposed at different growth stages had different effects on grain yield.

The flux of sensible heat into the ground is a term of considerable magnitude in the crop canopy budget (Hogstrom, 1974) particularly, in temperate regions where ground heat flux can be of the same magnitude as the turbulent fluxes of sensible heat and water vapour during day time in summer. In the tropics, values of ground heat flux are small because of small diurnal variation in soil temperature and relatively constant radiation regime (Kowal and Kassam, 1973).

Ground heat flux only accounted for 39% of the net radiation received at Samaru under maize cultivation. Kowal and Kassam (1973), reported a daily average ground heat flux to range from 14 $cal.cm^{-2}$ day^{-1} to 11 $cal.cm^{-2}$ day^{-1} during initial and period of maximum crop cover. In addition, Owonubi (1981) calculated average range of ground heat flux to be between 3 – 5 ly day^{-1} under cowpea growth.

comfortably contained within the moisture availability period. Failure to match these characteristics can result in reduction in yield and quality.

2.3.3.3 Light and phototropic considerations

After seedling emergence, both temperature and light influence yield. Light determines the rate of growth (i.e. dry matter production) at any stage of development. Radiation is a source of different forms of energy used by the plant for metabolic processes and dry matter production. Crops use only 2 to 4% of the global radiation for photosynthesis (Konate, 1984).

Gallagher and Biscoe (1978), have shown that dry matter production is almost proportional to intercepted radiation during the vegetative growth of cereals.

Peacock and Heinrich (1982), found that highest crop growth rate for sorghum, at 43.6g m^{-2} day^{-1} which was achieved at a plant population of 646000 plants per hectare and average radiation of 26.5 MJ m^{-2} day^{-1}. Higher irradiance level experienced in the semi arid tropics (17-25 MJ/m^2 per day), favoured high potential dry matter accumulation. Since dry matter production is almost proportional to intercepted radiation, during the vegetative growth of most cereals, such accumulation levels will depend on the crop canopies intercepting all incoming radiation. Yet, in intercropping, shading could reduce the energy available to one or more of the crops. For the advantage of intercropping to be further enhanced, changing the spatial arrangement of the component crops is therefore important for good yield. Crop arrangements that tend to group rows of tall crops may increase the availability of light to the shorter compound of the system. In this way, space allocation of component

crops could be altered without any alteration in the component population density (Singh, 1981). Spatial arrangements have been reported to have effects on yields in a sorghum/legume system. Although, its effect on sorghum was only marginal (Singh 1981; Waghmare *et al.*, 1982).

Isopleths of PAR in sole crop canopies measured near noon have been reported as being highly related to the distribution of leaf area. Hence, for an intercrop, wider rows would provide more PAR for a longer period to an intercrop than narrow rows (Tsay *et al.*, 1987). When millets were arranged at a row ratio of 1:3 with groundnut in an intercrop, result of intercepted PAR was the same with the mono crops (Marshall and Willey, 1983).

Crop productivity per unit incident radiation can only be improved through adoption of a cropping system that either increases the interception of solar radiation and/or maintains higher radiation use efficiency (RUE). A higher intercrop yield appeared to be achieved by an increased efficiency in converting light energy into dry matter and not really by any increase in the amount of light energy intercepted which might have been due to the combined intercrop canopy and resulting in light being more efficiently spread over a great surface of the leaf (Reddy and Willey, 1981).

2.3.3.4 Evapotranspiration and consumptive use in crops

Transpiration plays a necessary role in plant growth and development. The same stomata that exchange carbon-dioxide for photosynthesis permit the diffusion of water vapour into the atmosphere. the transpiration stream cools the plants and transports nutrients from the soil water reservoir to the plant organs. Hence, transpiration is closely correlated with photosynthesis.

Plant transpiration depends on such variables as net radiation, ambient temperature, vapour pressure and soil moisture content. For conditions of adequate water supply and complete cover, evapotranspiration (ET) may be determined from net radiation and mean air temperature (Priestly and Taylor, 1972; Jury and Tanner, 1975) or from solar radiation, mean air temperature and leaf area index (Kanemasu *et al.*, 1976). Tanner *et al.* (1960) postulated that the total ET from maize canopies would depend primarily on the magnitude of transpiration. Based on the supposition, net radiation, mean air temperature are the climatic factors that primarily influence transpiration.

Sumayao *et al.* (1977), showed transpiration from a well watered sorghum as being primarily energy dependent and relatively unaffected by plant stomata. Stomata are only important flow regulators under water stress condition, when water transport through soil-plant-atmosphere-continuum (evaporative cooling) is reduced and leaf temperature elevated above air temperature. Kowal and Kassam (1973) reported total maize ET during a twelve (12) decade measurement to be 514 mm. Out of which 365 (71%) was transpired through the crop and 149 mm (29%) was evaporated from the soil.

Evapotranspiration could be a poor indicator of crop productivity when crop canopies are sparse. This is because when the leaf area index (LAI) and radiant energy interception are low, evaporation from the soil surface (Esc) could account for about 100% of evapotranspiration. As LAI begins to increase, Transpiration (T) becomes increasingly larger, and both LAI and T values reaches a maximum just before crop anthesis in cereals. During grain filling, as leaf senescence occur and LAI falls, T values decreases and Esc values rose.

Payne *et al.* (1990), reported in a Nigerian millet field in 1985, a cumulative ET equal to rainfall, suggesting that water supply was the primary limiting constraint to millet production in that year. Innes and Black-Well (1981) inferred that ET decreases at any stage in irrigated wheat, once irrigation is stopped. When plots which had been subjected to drought were re-irrigated, an immediate increase in ET was observed. As ET increases, the total dry matter generally increases.

Raghavuh and Singh (1982) reported that a crop like sorghum will evapotranspire about 300 g of water for producing 1 g of dry matter.

2.3.3.5 Water use and cropping

Under rainfed agriculture, the total amount and distribution of available water to crops, as well as the length of the growing season constitute important climatic factors influencing crop yields (Owonubi, 1981). Seasonal water use of a crop will depend on the green leaf duration of the crop plants. Near-maximum water use usually occurs at leaf area index (LAI) of about 2.5 to 3.0. In arid regions without irrigation, the crop may never attain LAI values this high however, under favourable water conditions, the LAI will often exceed 3.0 (Kanemasu *et al.*, 1984).

Late maturing genotypes will usually have more leaves and their seasonal water use higher because of a longer active growing period. Other factors which influence crop water use include plant density, row spacing, genotype and irrigation. At Samaru, water use of 471.6 mm and 358.1 mm were reported (Owonubi, 1981), for two cowpea varieties. The variety with the higher water use had the longer growing season.

The amount of water loss to evaporation and transpiration of a crop plant particularly, in areas with low, unreliable rainfall is not a good index of evaluating the performance of a crop plant. Water use efficiency (WUE) is a measure of how efficiently a crop plant uses water to build up biomass. The term "Water Use Efficiency" is often used to describe the basic relation between growth and water use (or evapotranspiration). It is a useful tool in the evaluation of crop performance particularly in dry areas.

In crop species, the transpiration may not vary widely, the water use efficiency (WUE) based on evapotranspiration (ET) will vary considerably because, it depends on the climate, crop and soil factors (Gregory, 1986).

$$\text{WUE} = \frac{Biological\ yield\,(kgha^{-1})}{Crop\ evapotranspiration\,(mm)} \qquad (1)$$

This expression defines the efficiency with which a crop system utilizes soil water in units of $kgha^{-1}\ mm^{-1}$. Cooper (1983), expanded the expression by introducing two concepts, i.e. seasonal crop ET which he defines "as sum of its two components; namely transpiration (T) and evaporation from the soil surface under the crop (Esc); thus:

$$ET = T + Esc \qquad (2)$$

Cooper's second concept was to express biological yield as the product of seasonal crop transpiration (T) and seasonal transpiration efficiency (TE) thus:

$$\text{Biological yield} = T \times TE \qquad (3)$$

Transpiration efficiency, he defined "as the efficiency of dry matter production per millimetres of moisture transpired with units of $kgha^{-1}\ mm^{-1}$.

Now, substituting equations (5) and (6) into equation (4), we have

$$WUE = \frac{T \times TE}{T + Esc} \quad (4)$$

Simplifying the expression further, it will give;

$$WUE = \frac{TE}{1 + \frac{Esc}{T}} \quad (5)$$

The efficient use of water is therefore, crucial to improving crop yield in dry land agriculture. In order to increase dry matter production and crop yields, there must be an increase in the amount of water available to the crop and an increase in the efficiency of usage. In addition, high soil fertility status will significantly modified the efficiency of water use. Lomas *et al.* (1974), presented evidence of the effect of fertilizer application to markedly increase yields in maize crops without any appreciable change in water use.

Morries *et al.* (1990), observed that "an intercrop of two species often use water more efficiently than a monocrop of either species can use it." The intercrop have been reported to use more water than the sole crops (Stigter and Baldy, 1993), but more efficiently, resulting in a higher water use efficiency (WUE) than their component monocrops (Natarajan and Willey, 1980; Hulugalle and La, 1986; Stigter and Baldy, 1993).

WUE for total dry matter production in sorghum, just before anthesis was reported to be poorer in plots with ground cover when compared with sorghum/sunflower intercrop. The probable reason might be water extraction in sunflower was at deeper layers than sorghum and vitrilobata cover crop (Leach and Foale, 1987). Also, Reddy and Willey (1981) found the total water use higher in pearl-millet/groundnut intercrop and the total WUE was improved over the sole crops because of a greater proportion of the water used

by the crops rather than lost as evaporation from the surface. However, intercropping sorghum and cowpea in Botswana were not better than the component sole crops. But Norman suggested that it was probably due to period of very dry condition when the experiment was conducted and under a very poor management and input scene (Norman, 1974).

2.4 Approaches to Investigating the Micro-environment/Cropping Relationships

Agrometeorological research in food production systems deals with the quantification of crop plant responses to their environment. This is a complex biophysical and biochemical system and requires multidisciplinary teams to adequately identify and prioritize the issues limiting food production. Agrometeorological knowledge can be used advantageously for increasing and stabilizing crop production in different environment.

Basic information about the climate, soils and crops is required. It is not sufficient to have monthly averages of temperature and rainfall. The present approach is developing a physiologically-based model which dynamically responds to daily weather inputs (temperature, rainfall and radiation). Modeling growth and development of crop offers considerable potential to assist with agrotechnology transfer, crop management decision-making, research guidance, and understanding and synthesizing results of past and present research projects (Wilkerson *et al.*, 1983; Wilkerson *et al.* , 1985; Boote *et al.*, 1986).

2.4.1 Crop-weather models

Agricultural production is primarily dependent upon crop variety, soil, weather and management practices. Crop weather models are useful in

quantifying the response of specific production factors singly or in combinations on crop growth and development (Huda *et al.*, 1980). These models could be used as research tools in planning alternative strategies for cropping, land use and water management practices for a range of agroclimatic situations. The use of models to assess risk and to evaluate management and cropping strategies has been an active research area.

Newman (1974) distinguished basically between two modeling approaches: modeling based on mathematically formulated relationships with empirical constants when necessary ("deterministic approach"), and modeling involving some type of statistical-regression technique of fitting empirical relationships between climatological variables and crop-production statistics ("Stochastic approach").

Jensen (1975) categorized models into three types: statistical models, physiological models, which are the state-of-the-art and statistically based crop/weather soil-moisture models.

A great deal of modeling work has been directed to individual processes involving crop growth and development such as modeling evaporation (Ritchie, 1972), photosynthesis (Duncan *et al.*, 1967), water balance (Baier and Dyer, 1980), Probability of occurrence of particular weather events (Virmani *et al.*, 1978). Growth-simulation models are available for corn (Splinter, 1973), soybean (Cuny *et al.*, 1975), cotton (Stapleton *et al.*, 1973) and sorghum (Arkin *et al.*, 1976).

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Huda *et al.* (1980) proposed a dynamic crop-growth modeling which will suit the present purpose. In this kind of approach, the inputs to the model include the crop, soil, and weather factors affecting crop yields. This model

will require periodic sampling of dry matter during the season as against the one where final yield measurement used in model validation.

All the crop-weather models are sole crop based, there is a need to develop a simple and reliable intercrop growth and development model.

2.4.2 Heat and water balance approaches

Temperature, as previously mentioned, affects the rate of several processes of crop development. Plant development ceazes below a certain minimum temperature and above some optimum temperature, plant development decreases drastically. Between these two limits, the plant development rate increases linearly with the increase in temperature. Daily progression of plant development can be precisely described by the growing degree day approach (Ritchie and Alagarswamy, 1989).

This approach calculate daily termal time (DTT) accumulation when the daily minimum temperature (TEMPMN) is above the temperature at which leaf appearance rate was zero (TBASE) and daily maximum temperature (TEMPMX). Hence

$$DTT = (TEMPMX + TEMPMN)/2.0 - TBASE \quad (6)$$

The cumulative DTT is used to determine the duration of various phenological stages and to drive the model through time.

The relationship between rainfall, crop growth or yield operates through the water balance. Water balance usually uses measurements of rainfall and piche or pan evaporation. Water balance accounts for all water entering, leaving and remaining in the soil during a specified length of time. Soil water balance models have been developed to further explain the

dynamics of soil water. The most commonly used model to evaluate the soil water balance of crop or fallow land (Ritchie and Godwin, 1989):

$$S = P + I - EP - ES - R - D \quad (7)$$

Where

P = Precipitation

I = *Irrigation*

S = Change in soil water storage/quantity of soil water

D = Drainage from the profile

ES = Evaporation from soil

R = Runoff

EP = Evaporation from plants.

Since it is concerned with water dynamics in the soil-plant-atmosphere system, it deals principally with the capacity of the soil water reservoir, its depletion and replenishment and its effective management for crop production.

The soil water balance is based upon the principles of conservation of mass. It defines any change in the amount of stored water in a soil volume over a given time interval as equal to the difference in the quantity of water added to and removed from the soil. In crop production studies, it is necessary to quantify the water balance to a depth corresponding with maximum root penetration under rainfed conditions. If lateral and capillary flow are negligible, gains are restricted to rainfall. If also, runoff is negligible, the water removed is due to evapotranspiration and drainage. The water balance is an evidence that rainfall per se does not determine dry matter and yield formation, but the duration over which water is available to the roots (above a certain minimum level) and the daily rates of supply to the crop.

2.4.3 Micrometeorological models

Energy balance, water balance and environmental humidity are the main parameters affecting crop production and disease and insect pests infestation. The coupling of models of water balance and physiology of crops will permit evaluation of the impact of water constraints on the basic plant processes such as photosynthesis, leaf extension, etc.

Monteith *et al.* (1989) developed "Resource Capture Model" based on the assumption that two processes dominate most contemporary models of crop growth: resource capture and the distribution of metabolites to organs with different functions.

Hargreaves (1984) reported a model that relates evapotranspiration to crop yield. This model was based on the fact that transpiration and photosynthesis are inextricably connected. The model was normalized to avoid or minimize the non-uniqueness between years and location thus:

$$(1 - Ya/Ym) = Ky(1 - Eta/Etm) \quad (8)$$

where

Ya = *actual yield*

Ym = potential (or maximum) yield

Ky = *yield response factor*

Eta = actual crop evapotranspiration

Etm = *Maximum (or potential) evapotranspiration*

Kowal and Knabe (1972) developed models that relates degree latitude to annual rainfall, start, retreat and duration of rainfall, etc. Most of these models were simple regression models. Furthermore, Lomas *et al.* (1974) also used regression model to compare yield of maize with water use for three different experiments.

An energetic-photo-thermal development model was proposed by Sierra (1977) to describe the combined effects of solar radiation, photoperiod and air temperature on crop development in four soybean cultivars. Also, Agnew (1991) used a soil water balance model developed for millet in Niger to estimate the occurrence of agricultural drought conditions. Nicholson and Lare (1991) used the Lettau climatonomy model to simulate long term changes of surface water balances in the Sahel. The model is a numerical solution to the integration of the simple hydrologic balance equation:

$$P = E + N + dm/dt \qquad (9)$$

where

P = rainfall

E = evapotranspiration

N = runoff

m = exchangeable soil moisture.

It requires that two of the three annual means of P, E and N be known.

An operational soil water balance model "WATERMAN," which is compatible with the IBSAT data format was proposed by Abdulmumin *et al.* (1991). The program has three main applications: (i) daily and periodic soil water balance, (ii) monitoring the daily water content in various layers and (iii) irrigation or supplementary irrigation scheduling, with or without considerations of rainfall probabilities. The model simulation broadly agrees with trends of soil water contents reported by Kowal (1968).

CHAPTER 3

MATERIALS AND METHODS

3.1 The Study Area

The study area is located within the Institute for Agricultural Research (IAR) experimental farms at Samaru (Fig. 1), on the high plains of northern Nigeria. The soil belongs to the Alfisols group (USDA System - Moberg and Esu, 1991) which has developed on deeply weathered Pre-Cambrian Basement Complex rocks but overlain by aeolian drift of varying thickness. Apart from the effects of geologic erosion, poor soil management and conservation practices for many centuries have resulted into both macro and micro soil nutrient deficiencies (Jones and Wild, 1975; Smith, 1982).

Samaru-Zaria is characterized by tropical continental type of climate with alternating wet and dry seasons which varies markedly in intensities and durations (Kowal, 1969; Kowal and Knabe, 1972), with attendant effects on agricultural productivity. Daily maximum temperature is in the high twenties and the mean minimum is about 12°C (Hore, 1970). The distribution of rainfall is unimodal and annual rainfall varies between 900 and 1200 millimetres: it is concentrated into less than five months of about 100 rain days. Rains start in May, peak in August and end in September/October.

The present vegetation in the area is at best, a re-growth or cultivated to stabilize the soil and combat land degradation. The rainy season is probably the only period in the year where maximum soil cover prevents to a certain degree soil loss by rainfall/runoff processes. Even so, because of poor land

management practices and conservation large areas remain unprotected. Thus, much of what can be referred to as vegetation consist of low shrubs with tufts and grass in between mainly *Isoberlinia doka Isoberlinia tomentosa, Andropogoneae* and *Parkia*. Scattered fruit trees such as mangos, Baobab, shea butter, parkia trees are left because of their economic uses (Isichei and Akobundu, 1994). Being a dominantly rural area, land use is mainly for sedentary farming. However, presently, two rural land uses are recognised: Upland rainfed farming and the valley bottom land/wetland ("fadama") cultivation. The former is seasonal and the crops grown are relatively of low value per hectare and the latter supports crops of high value per hectare and is farmed intensively all year round. While on the upland farms the dominant crops are millet, maize, sorghum, cotton, cowpea and groundnut; those on the "fadama farms" sugar cane, tomato and market garden vegetables (Norman, 1974).

3.2 Characterization of climatic resources: Data and analysis

3.2.1 Rainfall

Rainfall data for 71 years (1928-1998) were obtained from the Meteorological Unit located on the experimental farms of the IAR Samaru, Zaria. Using the data, a few statistics were determined including means ($\bar{x}$), standard deviation (σ) and coefficient of variability (CV). Also, in order to subject the data to secular trend analysis, their conformity to Gaussian normal distribution were checked using the standardized Fisher's coefficients of skewness (z_i). The z_i gives the tendency of the distribution to depart from normal in the balance of its two sides, or to be lopsided. In addition, the standardized Fisher's coefficient of Kurtosis, (z_j) was adopted to test how near

the distribution conform to the normal curve (Granger 1979; Brazel *et al.*, 1988).

Now, if the absolute value of either statistics is greater than 1.96, a significant deviation from normality is indicated at 95 percent confidence level (Anyadike, 1992; Anyadike, 1993; Oladipo and Ochi, 1993).

For a test for trend in the rainfall distribution against randomness, the Mann-Kendall rank statistics, τ (Kendall and Stuart, 1961) was used to indicate monotonic increase or decease in the average values between the beginning and the end of the series (Anyadike, 1993).

A student's 't' test was also used to determine if the distribution showed a significant change between subperiods and, subperiods were compared with the whole period. Other statistical tests performed on the rainfall data include the Cramer's moving statistics (tk) used to test the stability of the means of subperiods and whole period and the time series analysis of moving averages applied to estimate the secular trend of the series (i.e. cyclical and irregular variations).

3.2.2 Light

For the characterization of light resources, sixteen years record of sunshine hours were obtained from the Meteorological Office of the Institute for Agricultural Research (IAR) and mean, standard deviation and coefficient of variability were calculated. Attempts were made to use the sunshine hours to determine global radiation using the formula of Kowal (1973:

$$Rg = RA\left(a + b\left(\frac{n}{N}\right)\right) \qquad (10)$$

where;

Rg is the global radiation

RA* is the incoming radiation at the top of the atmosphere.

a is the regression constant (0.235)

b is the regression coefficient (0.55)

n is the measured sunshine hours

N is the maximum number of possible sunshine hours.

Equation (10) was used to predict radiation and this was compared with the measured average daily radiation of 1966-69 using the chi-squared test of significance.

3.3 Characterization of Edaphic (soil) resources

In an attempt to characterize the soil, a profile pit was sunk at the farm to a depth of 1.80m to examine morphological characteristics of the soil using the soil colour booklet (Munsell colour – 1992).

Disturbed soil samples were collected at each horizon for particle size analysis (Gee and Bauder, 1986), soil pH (Mclean, 1982), organic carbon (Nelson and Sommers, 1986), available phosphorus (Olsen and Sommers, 1986), total nitrogen (Bremner and Mulvaney, 1986), exchangeable cations (Thomas, 1982) and cation exchange capacity (1N NH_4OAc) following the standard laboratory procedures (Rhoades, 1986). Physical properties analysed include soil bulk density (Blake and Hartge, 1986), saturated hydraulic conductivity using the constant head method of Klute and Dirksen (1986), water holding capacity and total porosity (by calculation).

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* RA for various month were obtained from Kowal and Knabe (1972).

3.4 The Field Experiments

3.4.1 *Treatments and treatment combinations*

The trial was made up of three crops which are two varieties of sorghum (local Farafara and SAMSORG-14); maize (TZESR-W) and Cowpea (Kannanado). The local Farafara (Guinea Caudata), is a late maturing, medium yielding white grained land race with potential yield of 1,800 to 3,000 kg ha^{-1} (IAR, 1989). The second sorghum variety is an improved variety referred to as SAMSORG-14 (formerly, referred to as Kano Sorghum Variety-KSV8). It is tall, medium maturing (140-150 days) with fairly long with elliptical and semi compact ear head; tan coloured glume, white seed and tolerant to striga. Potential yield is within the range of 1,500 to 3000 $kgha^{-1}$ (IAR, 1989).

The TZESR-W is an early, streak resistant, white seeded maize variety. The local cowpea variety, Kanannado, is the spreading cowpea type, highly tolerant to drought was used.

Two different spatial arrangements were imposed: row intercropping; where the component crops will be on different rows and the stand intercropping arrangement; where the component crops are at alternate stand on the same row. The various monocrops of the component crops were also planted to serve as control.

The trial therefore, is made up of twelve treatment combinations namely:

1. Sole Farafara
2. Sole SAMSORG-14
3. Sole Kanannado
4. Sole TZESR-W

5. Farafara/TZESR-W – (R)
6. Farafara/TZESR-W/Kanannado – (R)
7. SAMSORG-14/TZESR-W – (R)
8. SAMSORG-14/TZESR-W/Kanannado – (R)
9. Farafara/TZESR-W – (S)
10. Farafara/TZESR-W/Kanannado – (S)
11. SAMSORG 14/TZESR-W – (S)
12. SAMSORG 14/TZESR-W/Kanannado – (S)

The 'R' and 'S' in parentheses represent row intercropping and stand intercropping arrangement respectively.

The field experiments consist of farm plots layout, plants arrangement and management/monitoring; instrumentation and data collection procedure and schedules.

3.4.2 Field layout and trials

The experiment was undertaken under rainfed condition for three rainy seasons. Inorganic fertilizers (N:P:K and Urea) were used to maintain soil fertility. Nitrogen was applied in two split doses. 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} were applied to sole maize. Sole sorghum received 64 kg N ha^{-1}, 32 kg P_2O_5 ha^{-1} and 15 kg K_2O ha^{-1} while, the mixtures received 92 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1} and 22.5 kg K_2O ha^{-1}. The treatments were laid out in a randomized complete block design replicated three times. Randomization was done in two folds: the crop mixtures were first randomized followed by the monocrops. This was done to minimize shading effects. The land was disc ploughed, harrowed and ridged at 0.75m inter-row spacing. Then the field was

marked out into three blocks, each having twelve plots. Each plot had a gross plot size of $36m^2$ (4.5 m x 8 m).

3.4.3 Field experimental management

All the seeds planted were each dressed with a fungicidal and insecticidal seed treatment "Apron Plus 50DS" (active ingredient: 10% metalaxyl, 6% carboxin and 34% furathiocarb) at the rate of 10 gms to each of 1kg maize and sorghum seeds and 10 gms to 2 kg cowpea seeds. Maize and sorghum seeds were sown at 0.25 m intra-row spacing on 15th June in 1996, 2nd July in 1997 and 15th July in 1998. In 1998, the first planting was done on the 25th June, but a long dry spell which followed immediately after, affected germination and emergence. The actual date of re-sowing was on 15th July. All plant stands were thinned to one plant per stand at crop establishment. Monocrop plots for maize and sorghum were planted at the optimum plant population of 55,555 plants per hectare while, in the intercrop the same total population was adopted with half being maize and the other half, sorghum ("replacement mixture").

A pre-emergence application of Gramaxone (active ingredient: paraquat) at 350 mls in 20 litres of water was applied immediately after sowing. Hoe weeding was performed at three and six weeks after planting. Ridge-moulding was at eight weeks after planting. Immediately after this, Kanannado was planted in plots that bear the cowpea treatments. Cowpea was planted within the intercrop at 0.4 m intra-row spacing and at 0.2 m in the monocrop plot. It was only in the 1998 season that cowpea was planted 6 WAP.

Fertilizer application was performed in two split doses for nitrogen. First application was done two weeks after planting using N:P:K (25: 10: 10) and later at four weeks after planting using urea to top dress. Monocrop maize and sorghum received a total of 120 kgN/ha and 64 kgN/ha respectively, while the intercrops received 92 kgN/ha. Monocrop cowpea plot received no fertilizer amendment. In the 1997 trial, the fertilizer (NPK) used were those of the "nagari" brand which later was found to be universally adulterated.

Field observations revealed heavy infestation of stem borer and it was immediately checked with Vetox 85 at 100 gms per 20 litres of water at eight and ten weeks after planting. Cowpea received one spray of Sherpa plus (in 1998 only) at 100 mls to 20 litres of water to check pod insect pests infestation.

3.4.4 Measurement of canopy development and biomass production

Plant samples were harvested from designated area of the plots starting from when they are 4 weeks old. Two plant stands cut at ground level were sampled on a weekly basis in all the plots. In the plots, two plant stands of each of the crops were harvested. Leaf area measurement was determined using a leaf area meter (C1-202 Logitech Scanman, USA). A calibration of the equipment was obtained by passing 25 cm^2 rectangular plate through the instrument before use. The cumulative value recorded per whole stand when leaflets were passed through the leaf area meter becomes the total leaf area, and expressed in square centimetre (cm^2). The leaf area index (LAI) was calculated as:

$$LAI = \frac{\text{Total Leaf Area Measured } (cm^2)}{\text{Area of land covered by the plant } (cm^2)} \qquad (11)$$

Dry matter yield was obtained when the harvested plants were oven dried at 70°C for 48 hours and weighed. Plant height was measured with a metre rule from the ground level to the top of with the flag leaf extended.

3.4.5 Measurement of PAR

Radiation interception by plants was measured using the sunfleck ceptometer (Decagon Devices Inc, Pullman, WA). This instrument uses 80 sensors at 1cm intervals along a line probe to measure radiation. The probe, scans the sensors, when inserted into a crop canopy, through a microprocessor and the average reading is displayed on a panel. Measured incident radiation is recorded in μmol $m^{-2}S^{-1}$ (Oluwasemire, 1997). Radiation measurements were taken above and below the crop canopy. The ratio gives the fraction of photosynthetic active radiation (PAR) reaching the ground, from which radiation interception is calculated.

$$\text{Intercepted PAR} = 1 - \frac{\text{PAR measured above canopy}}{\text{PAR measured below canopy}} \qquad (12)$$

Radiation measurements were taken at two week interval from 4 weeks after planting (WAP) of the cereal crops during the 1996 season. During the 1997 and 1998 cropping seasons, radiation measurement were taken between 12:00 hr and 14:00 hr and on cloudless days. A measurement recording using the sunfleck ceptometer is an average of twenty readings per point within every plot. Two measurement pairs per plot were taken in all years of the trial.

3.4.6 Moisture content determination

Gravimetric soil sampling were carried out to determine moisture content. The soil samples were weighed and oven dried at 105°C for 48 hours before a further weighing for moisture content determination.

Moisture content were determined thus:

$$\theta = \frac{(Ms + Mw)) - MS}{Ms} \ (gg^{-1}) \qquad (13)$$

where, Ms = weight of oven dried soil

Mw = weight of water in soil

Gravimetric moisture content is converted to volume wetness (θv) by multiplying with the bulk density ρ_b) of the corresponding layer.

$$\theta v = Qg \, . \, \rho_b \ (cm^3 \ cm^{-3}) \qquad (14)$$

This also can be expressed on depth basis (θd) by multiplying with its corresponding depth (d).

$$\theta d = \theta v.d \ (m) \qquad (15)$$

A neutron scatterer was used to measure soil moisture in the field. Two access tubes of 1.4 m were installed using a drilling auger on every plot; one beside each component cereal crop to a uniform depth of 1.30m, with 0.1 m exposed above the soil. The neutron probe, which is the source of the neutron scatterer is lowered into the access tubes at twenty centimetre depth and the corresponding counts were recorded. The counts recorded at each depth were divided by a standard count which was the count in water to obtain the count ratio. The regression calibration of Jensen *et al.* (1991) was adopted for determining soil moisture content under this method. The calibration regression equation is:

$$\theta = 16.73 * r - 0.35 \qquad (16)$$

where

θ = moisture content

r = count ratio.

3.4.7 Water intake characteristics of the soil

A double ring infiltrometer was used to determine the water intake characteristics of the soil at bare and under the different mixtures. The infiltrometer with inner ring diameter of 0.30 m and outer ring of 0.55 m were driven into the soil using a driving plate. Water was applied into the outer cylinder first before the inner one. This was to allow time to prevent lateral flow in the inner ring. A float with measuring rods and a stop-watch were used to record drop in water head with time for 3 hours.

3.4.8 Yield

Maize stand were left after physiological maturity on the field so that the cobs be allowed to dry in the field, right on the stalk, and harvesting was done only when they were properly dried.

At harvest, maize cob, sorghum heads and cowpea pods were harvested, dried and weighed. A thousand seed in the case of sorghum and a hundred each for both maize and cowpea were counted and weighed.

3.4.9 Data analysis

The agronomic parameters taken were subjected to analysis of variance separately for both years, and combined, using the GLM procedure of SAS incorporated. Also, regression analysis of yield and planting dates, rainfall amount and cumulative daily thermal time were evaluated.

CHAPTER 4

ANALYSIS OF DATA

4.1 Characterization and Description of the Data Sets

4.1.1 Light

Table 1 illustrates the average annual sunshine hour over a 16 year period (1979 – 1994). Statistically, there is no significant variation in the sunshine hours over the years. The coefficient of variability was very low (0.28%), the means and median values are 7.33 and 7.32 hours respectively. The mode in sunshine hour was an average of 8.7 hours in the month of November. When compared with the averages of 1954 – 1968 (Kowal, 1973), the duration of sunshine seems to be decreasing as the years increase. Although, chi-square values reveal a non-significance in the two sunshine duration averages (Table 1). The unique position of Samaru on the globe (latitude 11° 11'N) probably placed duration of sunshine in the high range.

The calculated annual global radiation is 4735 cal cm^{-2} $year^{-1}$ with a daily average of 400 cal cm^{-2} day^{-1} (Table 1). The distribution of the calculated global radiation is comparatively uniform throughout the year. The calculated average daily radiation values range from 450 cal cm^{-2} day^{-1} (in November) and 340 cal cm^{-2} day^{-1} (in August). The absence of harmattan dust and the presence of a clearer sky due to the recoded rains probably contributed to the high value of the average daily radiation in November.

All through the period of the growing season, there is a steady decline in calculated radiation values from 440 cal cm^{-2} day^{-1} (in May) to about 340 cal cm^{-2} day^{-1} (in August). When the calculated radiation values were compared

with the measured averages for 1966-1969 (Kowal, 1973), a significant difference was observed except for the month of November (Table 1). The large differences may probably be due to increasing cloudy sky during the rains and the recent high intensity of the harmattan dust over the sky.

Table 1. Sunshine hour and global radiation in Samaru, Nigeria.

Month Of the Year	16 years average (1979-1994) Sunshine hours	Calculated Chi-square Values	Global Radiation (Cal cm^{-2} day^{-1}) Calculated	Measured (1966-69)	Calculated Chi-square value
January	7.62	0.012NS	386	473	19.61**
February	7.48	0.003NS	396	534	48.09**
March	6.83	0.034NS	393	547	60.35**
April	7.16	0.004NS	377	513	49.06**
May	7.79	0.029NS	437	514	13.57**
June	7.14	0.005NS	387	486	25.33**
July	6.38	0.128NS	352	447	25.64**
August	6.04	0.227NS	336	440	32.19**
September	6.94	0.241NS	396	474	15.36**
October	8.19	0.101NS	446	506	8.07**
November	8.70	0.256NS	449	483	2.58NS
December	7.68	0.017NS	382	458	15.12**
Mean	7.33		401		
Median	7.22		390		

NB: The 16 years averages were compared with the mean.
** shows highly significance at 1% LS while, NS mean non-significant.

4.1.2 Water (Rainfall Characteristics)

The basic statistical descriptors of rainfall for Samaru are presented in Table 2.

The long term mean (LTM) annual rainfall is 1050.1mm and over 95% of the rains fall in the months of April to October. Rainfall values for Samaru showed a fairly high temporal variability with coefficient of variability (CV) of 16.4%. Rainfall over Samaru is highly variable both inter yearly and seasonally. For example, the lowest mean monthly rainfall of 170.4mm was recorded in August 1989, the highest occurred in August, 1991 with 329.0mm. Also, 1954 recorded the wettest year (1481.8mm) and some thirty years later, 1983, the annual rainfall recorded was less than half (608.2mm, see Figure 2).

When the rainfall data was divided into two subperiods of 35 years each, the first subperiod (1929-1963) had a rainfall mean which exceeded the long term mean (1050.1mm, Table 2). This is expected because a number of wettest years are included in the first subperiod as already discussed above. Again, the seven decadal periods, show a decreasing trend in the mean annual rainfall. In fact, the mean annual rainfall of 29 out of the last 50 rain years were glaringly below the long term mean (Figure 2). It is a serious tendency towards inadequate rainfall in the area.

The 71 year rainfall data for Samaru displayed a positive, non-significant skewness and a negative, non-significant Kurtosis levels (Table 2). These indicated that the rainfall data conforms to normality but with a broad hump at the peak (Yeoman, 1977).

IBRAHIM

Table 2. Rainfall variability, normality and trend over Samaru (1928-1998).

Variable	Long Term Mean (mm)	Coefficient of Variability (%)	Skewness (Z_1)	Kurtosis (Z_2)	Mean Kendall Rank Statistics (T)	Cramer (tk)	Student's 't' test
1928-1998	1050.1	16.4	0.77	-0.18	0.98	-	-
1929-1963	1103.95	15.2	1.11	-0.8	1.00	3.09	-
1964-1998	990.08	15.8	-0.12	-0.12	1.00	-3.54	-
Subperiod							0.35
1929-1938	1124.24	10.5	0.34	-0.87	0.64	2.99	-
1939-1948	1066.74	15.7	1.29	-0.24	0.64	0.33	-
1949-1958	1035.60	17.9	0.42	-0.81	0.64	1.74	-
1959-1968	1076.75	13.2	0.48	-0.18	0.64	0.53	-
1969-1978	1012.75	14.3	-0.18	-0.64	0.64	-0.72	-
1979-1988	946.59	17.8	-0.57	-0.32	0.64	-1.93	-
1989-1998	966.45	14.8	0.64	-0.15	0.64	-1.57	-

*The test statistics is ± 1.96.

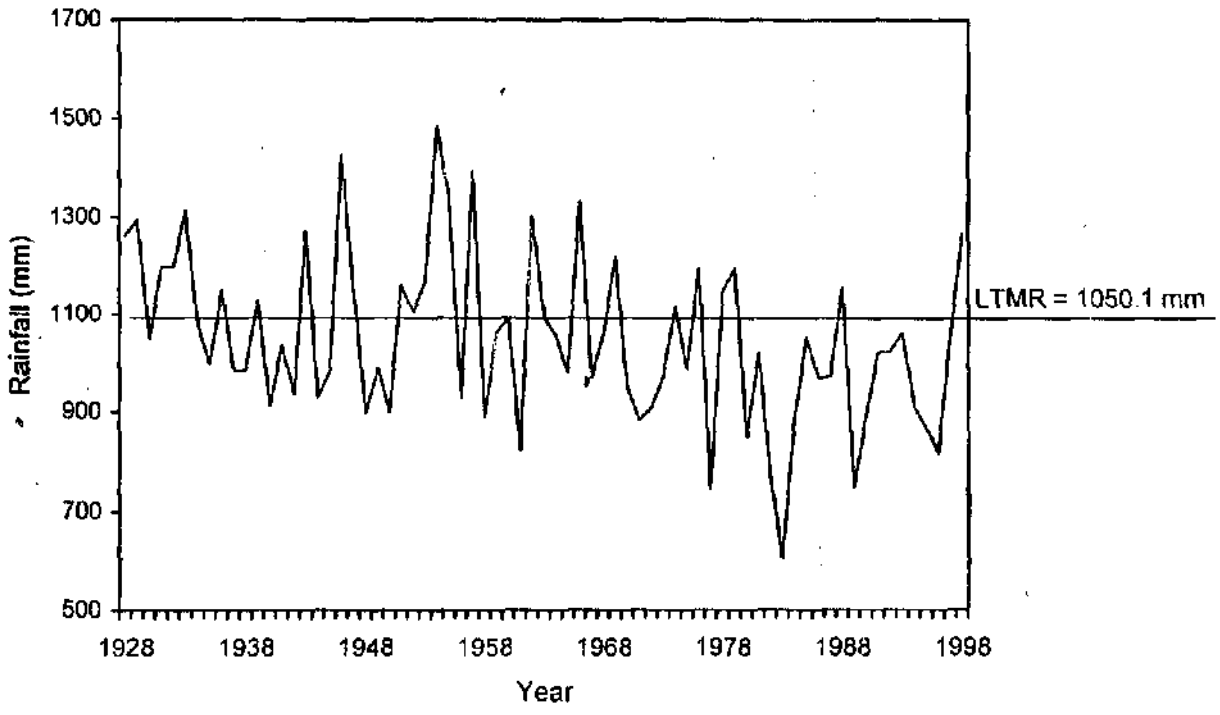


Fig. 2: Variability in Rainfall Amount in Samaru (1928-1998).

While the Mann-Kendall rank statistics provided non evidence of a significant trend in the rainfall data, the results of Cramer's test indicate that subperiods 1929-1963, have significantly higher rainfall than the whole period and that the rest period was not significantly different except for lower rainfall values were observed between 1969 and 1998. This is an indication that those periods were lower than normal (Oladipo and Ochi, 1993). The student's 't' test showed no significant change in rainfall amount between the early subperiod (1929-1963) and the latter subperiod (1964-1998).

Five year running means computed for annual rainfall values for Samaru showed an oscillatory trend (Figure 3) in the pattern of the smoothed curve. The periods of increase rainfall amount are evident and these are 1994-1948 and 1952-1957. In between, are periods of decreased rainfall and, the longest lasting from 1969 to 1998.

4.1.3 Soils

4.1.3.1 Morphological characteristics

The morphological characteristics and classification of the pedon studied are shown in Table 3. The soils are very deep soils, over 150cm. The Ap horizon showed evidences of marked disturbance due to cultivation hence, it is a ploughed layer.

The medium fragments in the soil include occasional to abundant, red (2.5YR4/8) and strong brown (7.5YR5/8), subangular iron nodules. At depths of about 100cm, the sizes and concentrations of the iron nodules and manganiferrous concretions increase greatly probably due to impeded drainage which is characterize most of the soils. The soil structures are dominantly moderately developed, medium subangular blocky types: this

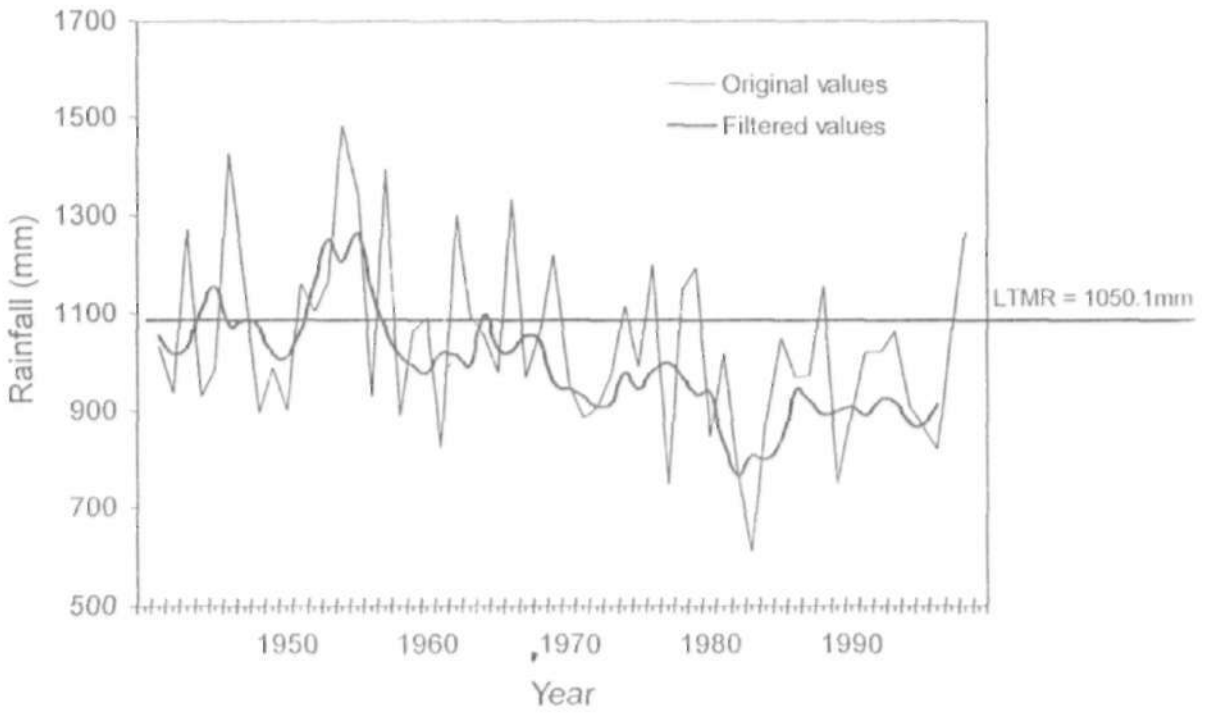


Fig. 3: Fluctuations in annual rainfall at Samaru.

Table 3. Morphology and classification of the pedon at Samaru.

Horizon	Depth (cm)	Munsell colour (moist)	Mottling	Texture	Structure	Consistency	Boundary	Miscellaneous Feature
			Isohyperthermic, fine loamy, mixed Typic Haplustalf					
AP_1	0-18	10YR5/4	-	L	1msbk	fr	cs	Fine roots Few fine quartz grain
AP_2	18-33	10YR4/6	-	L	2msbk	fr	gs	Few fine roots Quartz and mica grains
Bt_1	33-57	7.5YR5/6	-	Scl	2msbk	fi	cs	-
Bt_2	57-84	10YR6/8	2.5YR5/8	Cl	2msbk	fi	cs	-
Bt_3	84-112	10YR6/6	2.5YR4/8	C	2msbk	fi	cs	Few iron and manganese concretions.
Bt_4	141-180	10YR6/6	7.5YR5/8	C	2msbk	fi	gs	Few iron and manganese concretions.

*Munsell chart abbreviations and numbers).

could be as a result of the high clay contents and the preponderance of bivalent cations (Ca^{2+} and Mg^{2+}) over the monovalent cations (K^{+} and Na^{+}) on the exchange complex and have caused the soil to be well flocculated (Kparmwang *et al.*, 1998).

The Ap horizons have soils with a friable (moist) consistency which increased to firm (moist) with increase in depth. The poor aggregation at the lower layers could be due to the high clay content of the soil. The soil horizon boundary in the pedon indicated a clear and smooth condition up to the Bt_2 but at the lower horizons the boundary became gradual and smooth. This gives an indication of a high degree of soil development and horizon differentiation at the upper than in the lower horizon. Also, occurrence of iron and manganese nodules and concretions with increasing clay content in the subsurface horizons suggested probability of eluviation – illuviation and clay lessivation within the pedon.

4.1.3.2 Chemical characteristics of the soils

The chemical properties of the soils are presented in Table 4. Its particle size distribution show a loam Ap horizons and at Bt_2 becoming clay textured in the lower horizons. There is a sharp rise in the clay fraction creating a conspicuous bulge in clay content, at Bt_1 and Bt_3 horizons. This explains the sudden change in the textural class from loam to clay at Bt_1/Bt_2.

Leaching is substantial and evident in the soil reactions which are in the moderately to strongly acidic range and the pH values increase slightly with depth.

Low level of organic carbon recorded is probably due to continuous cropping, rapid organic matter mineralization and annual bush burning (Esu

Table 4. Physico-chemical properties of the pedon at Samaru.

Horizon	Depth (cm)	Particle Size Analysis			USDA Textural Class	PH 1: 2.5		Organic Carbon $kgkg^{-1}$	Total nitrogen (gkg^{-1})	Available phosphorus $(mgkg^{-1})$	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	C.E.C. (cmol kg^{-1})	Base Saturation (%)
		Clay (%)	Silt (%)	Sand (%)		Water	0.01M $CaCl_2$									
Ap_1	0-18	15	44	41	Loam	5.7	4.5	6.0	0.56	6.44	9.98	0.5	0.08	0.05	15.6	67.9
Ap_2	18-33	21	40	39	Loam	5.5	4.7	2.4	0.36	4.70	11.2	0.4	0.06	0.08	18.7	63.1
Bt_1	33-57	31	38	31	Clay loam	5.6	4.8	2.6	0.56	1.42	15.0	0.7	0.11	0.11	20.4	77.8
Bt_2	57-84	43	32	25	Clay	5.8	5.0	1.7	0.36	1.15	13.7	1.3	0.14	0.10	20.8	73.1
Bt_3	84-112	43	32	25	Clay	5.9	5.1	1.7	0.36	0.63	16.2	1.0	0.16	0.11	22.7	77.2
Bt_4	112-141	39	36	25	Clay loam	5.5	4.8	1.3	0.18	0.76	16.2	1.6	0.20	0.15	24.1	75.2
Bt_5	141-180	39	34	27	Clay loam	5.6	4.7	1.3	0.18	0.63	16.2	1.4	0.15	0.12	23.9	74.9

and Ojanuga, 1985). Also, total nitrogen and available phosphorus values are low and these decrease with increase in profile depth. Exchangeable calcium is high throughout the profile but magnesium is moderate at the AP-Bt_1 horizon and increased to high throughout the profile. While the exchangeable sodium ranged from low to medium throughout the profile, potassium was, low in the AP-Bt_2 horizons.

The cation exchange capacity is high and increases with profile depth. Base saturation is medium, with every horizon having values exceeding 50%. Again, the profile distribution of the percent base saturation is indicative of translocation to deeper horizons due to leaching.

4.1.3.3 Physical characteristics

Soil physical characteristics measured include bulk density, total soil porosity (calculated from bulk density and particle density), saturated hydraulic conductivity and field capacity. Table 5 shows the variation in the measured parameters.

Table 5. Physical properties of the pedon at Samaru.

Horizon	Depth (cm)	Bulk Density Mg m-3	Total porosity (%)	Saturated hydraulic Conductivity m day^{-1}	Field capacity (0.3 kPa) -%-	Permanent Wilting point (15 kPa) -%-
Ap_1	0-18	1.63	38	0.70	11.10	6.10
Ap_2	18-33	1.71	35	7.21	14.30	9.70
Bt_1	33-57	1.64	38	2.23	15.20	6.90
Bt_2	57-84	1.50	43	16.64	12.70	8.30
Bt_3	84-112	1.41	46	6.06	12.50	6.70
Bt_4	112-141	1.45	45	0.61	11.80	7.70
Bt_5	141-180	1.45	45	0.66	12.50	7.60

The soil bulk density was generally high from the Ap_1 horizon down to the Bt_5 horizon. For the loam textured horizons, a bulk density of 1.50Mgm-3 is manageable to root penetration. For clay loams and other clay textured soils, bulk density values exceeding 1.45 and 1.35 Mgm^{-3} respectively, will severely impede plant root penetration and growth. This will result to lodging conditions in plant which consequently, reduced the yield of the crop. Total soil porosity values increase gradually from 35% in the lower AP horizon with increase in soil profile (Table 5) up to 46% at a depth of 112cm in the Bt_3 horizon. The low values in the surface horizons is a reflection of the poor structural condition and the lack of stability of the aggregates, which leads to compaction (Kowal, 1970).

Value of saturated hydraulic conductivity is a reflection of the drainage at the Ap_1 horizon. Values in the Ap_2, Bt_1 and Bt_2 horizons, show increasing trend in response to the increase in the total porosity at those depths. The sharp fall and fluctuations in the values of saturated hydraulic conductivity from Bt_3 are probably due to the textural discontinuity and blockages caused by clay cutans that occupy the pore spaces in those lower horizons. Deposition of silty harmattan dust and dispersal of particles caused by direct rainfall impact could be suggested for the comparatively low saturated hydraulic conductivity values observed in the surface Ap1 horizon.

The measured values of field capacity range from about 11 to about 15 percent in Bt_1 horizon, and decreasing tendency with increase in profile depth. Kowal (1970) submitted that such lower values are possible in sedentary soils in Samaru where the profile contain some gravel. The values of the permanent wilting (Table 5) range from 6 to about 10 percent and the closely follow the changes in profile's clay content.

4.1.3.4 Classification of Soil

Based on the USDA Soil Taxonomy (Soil Survey Staff, 1990). The diagnostic criteria for the classification of the soil include an Ustic soil moisture regime and, a thermic soil temperature regime which is associated with the tropics. The pedon is characterized by an Ochric epipedon and an argillic B horizon with a high base saturation. Therefore, the pedon fits into the suborder Ustalfs. The profile is a simple one and, it belongs to the Great Group Haplustalfs. It is classified at the family level of Soil Taxonomy as isohyperthermic fine clayey, mixed Typic Haplustalf.

4.2 Pattern of LAI, Light Interception, Biomas and Grain Yield

4.2.1 Sorghum leaf area index (LAI)

In the 1996 cropping season, sorghum leaf area index (LAI) iacreased with days after sowing (DAS). Mixtures involving sorghum variety – SAMSORG-14, recorded higher sorghum leaf area index than those of 'FARAFARA'. Peak leaf area index was reached at 70 DAS in all the treatments (Fig. 5). At 70 DAS, leaf area index range from 3.08 (SAMSORG-14/maize/cowpea-s) to 2.35 in mono-cropped "FARAFARA'. Mixtures containing SAMSORG-14 seems to grow faster than the others and had approached a peak 56 DAS (Fig. 4). At 70 DAS, the sorghum leaf area index of FARAFARA/Maize/cowpea-s and FARAFARA/maize-R were not statistically different with the mixture with the highest LAI. These two treatments were also at par with those of the SAMSORG-14/Maize-R mixtures. The leaf area index (LAI) of the monocropped sorghum varieties performed comparatively lower than those of the mixtures. This could be an indication of complementary advantage in sorghum leaf area index when in mixtures over the monocropped ones. Monocropped SAMSORG-14 produced more cover (LAI) than the monocropped 'FARAFARA' in the experiment.

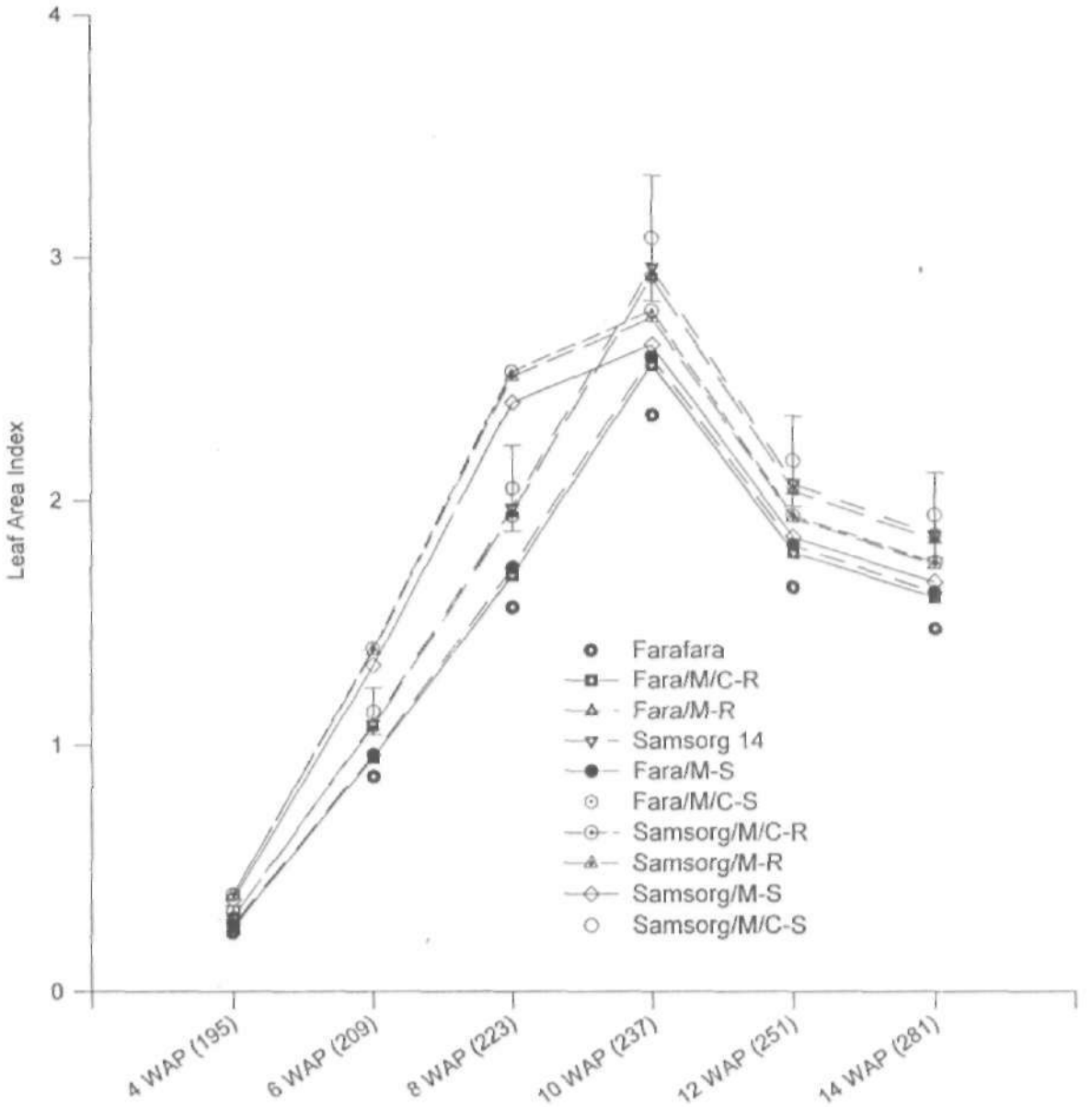


Fig. 4: Changes in sorghum leaf area index as affected by different cropping systems in the 1996 cropping season.

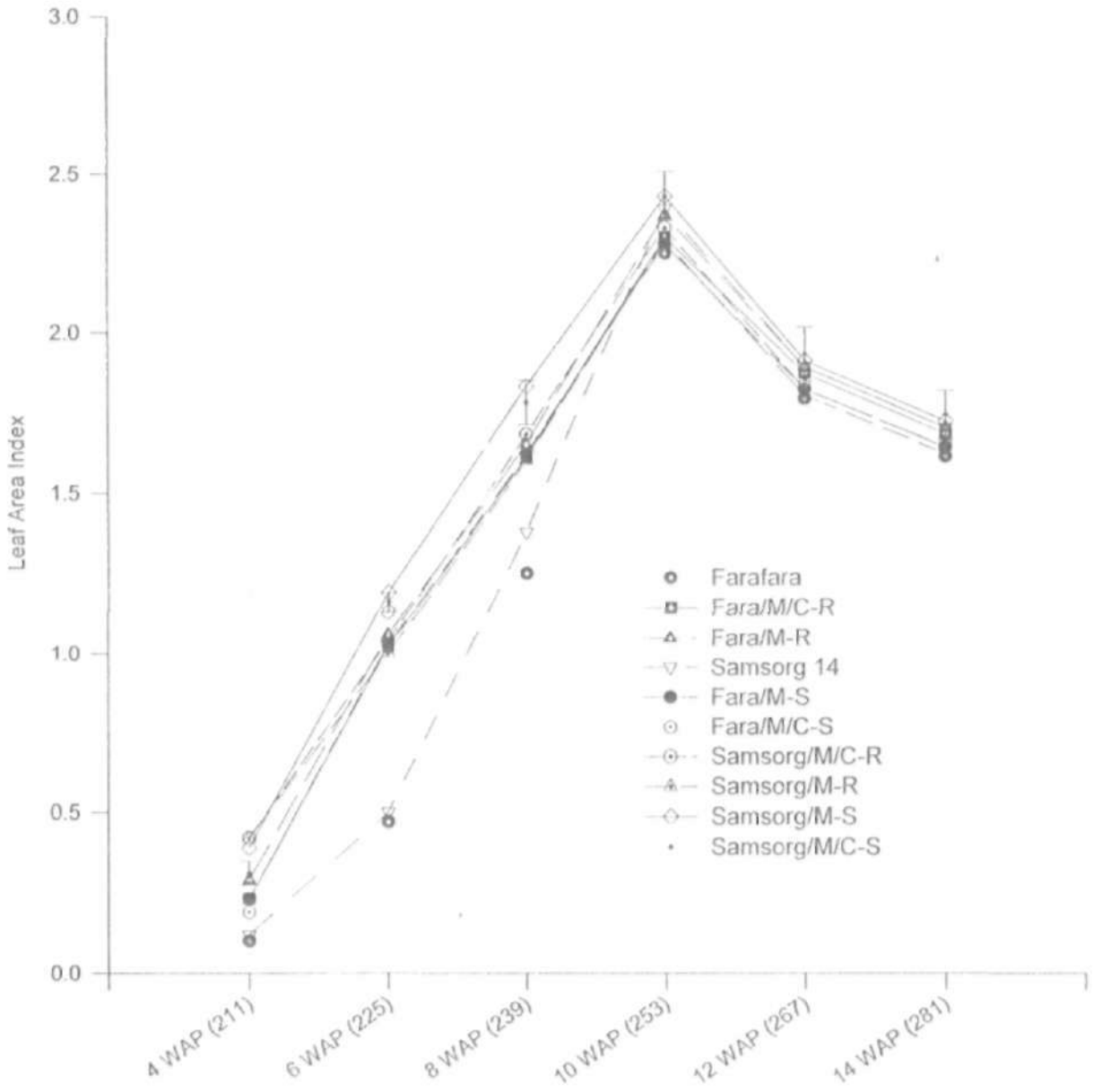


Fig. 5: Changes in sorghum leaf area index as affected by different cropping systems in the 1997 cropping season.

Just as in the previous cropping season, peak LAI in the 1997 cropping season was reached at 70 DAS. The SAMSORG-14/Maize-S mixtures recorded the highest LAI (2.25) mixtures of SAMSORG-14/Maize-S were superior in leaf cover (i.e. LAI) than all the other treatments throughout the growing season (Fig. 5). At 70 DAS, monocropped 'FARAFARA' was not significantly different in LAI from all other mixtures which had 'FARAFARA' as a component crop. Among the SAMSORG-14 mixtures, only SAMSORG-14/maize-R could be said to be at par with the mono-cropped FARAFARA at peak LAI (Fig. 5).

During the season (1997), all the SAMSORG-14 mixtures had higher values of LAI than those of the FARAFARA. FARAFARA/Maize-R was the only mixture that was at par in LAI with the SAMSORG-14 mixtures.

The LAI of the two monocropped sorghum varieties (FARAFARA and SAMSORG-14) were not statistically different at 28 and 42 DAS. As from 56 DAS, monocropped SAMSORG-14 began to record higher values of LAI and continued until it reached a peak of 2.40 at 70 DAS.

In the 1998 cropping season, values of LAI for sorghum varieties were very different from those of the two previous seasons. The FARAFARA/Maize/Cowpea mixtures attained peak LAI at 56 DAS. The other varieties attained their LAI peaks at 70 DAS (Fig. 6). Also, highest values of LAI (2.74) were recorded in both FARAFARA/Maize/Cowpea mixtures and SAMSORG-14/Maize/Cowpea-S.

All the other mixtures were not significantly different in values of LAI at 70 DAS. Monocropped FARAFARA had higher values of LAI than the improved SAMSORG-14 which recorded the least value of LAI (1.53).

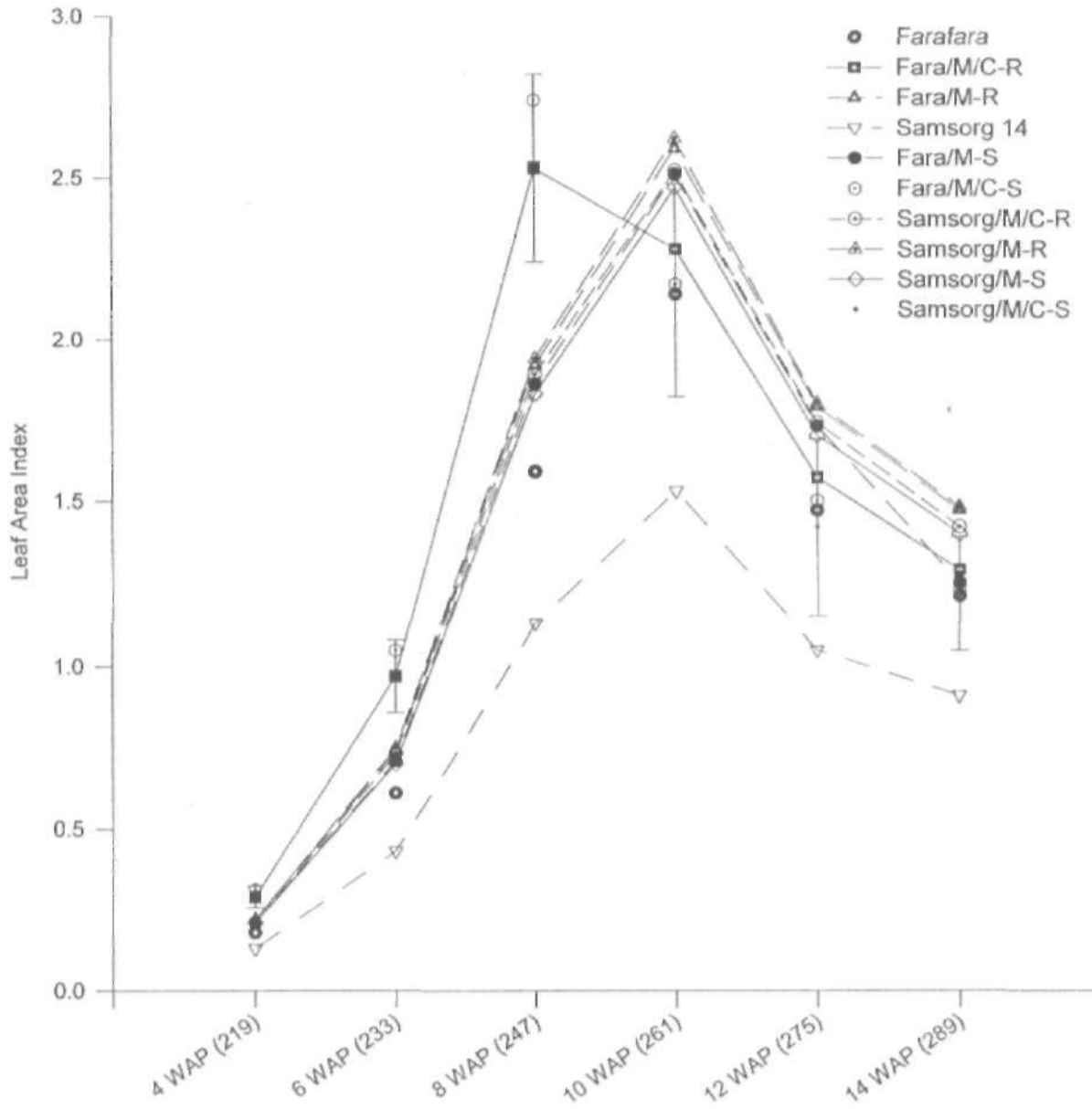


Fig. 6: Changes in sorgnum leaf area index as affected by different cropping systems in the 1998 cropping season.

4.2.2 Maize leaf area index

In the 1996 cropping season, values of LAI rapidly increased in maize up to about 70 DAS before a sharp decline. There was no significant difference in the values of maize LAI among all the treatments (Fig. 7). Except in the case of one treatment, values of maize LAI were generally higher in mixtures involving 'FARAFARA' than in the monocropped maize. Highest value of maize LAI, 3.35, was recorded in the FARARARA/maize-S, but 3.1 (the lowest value) was recorded in the FARAFARA/Maize/Cowpea-R treatment.

The maize in the SAMSORG-14 mixtures seems to have a higher LAI in the 1997 cropping season and this started quite early (≤ 28 DAS). They performed significantly better in LAI than the maize component in the FARAFARA mixtures (Fig. 8). Although, by 42 DAS, the maize in the FARAFARA mixtures started recovering from the slow start. Unlike in the previous cropping season, peak LAI (3.05) was recorded at 56 DAS with the monocropped maize performing better than all other maize component in mixtures. The maize component in the SAMSORG-14/Maize/Cowpea-R had the least LAI, 2.7. This could be due to competition for nutrient among the maize plants on the same row. From 70 DAS, a rapid decline in values of LAI was obtained in all the maize (Fig. 8).

Again, in 1998 cropping season, maize growth was slow at the beginning in all mixtures containing FARAFARA. Most of the maize in the SAMSORG-14 mixtures have values of LAI similar with that of monocropped maize up to 42 DAS (Fig. 8). Peak LAI was attained at 56 DAS where all values of LAI were statistically insignificant. Most of the mixtures under the row arrangement seems to perform better than those of the stand arrangement.

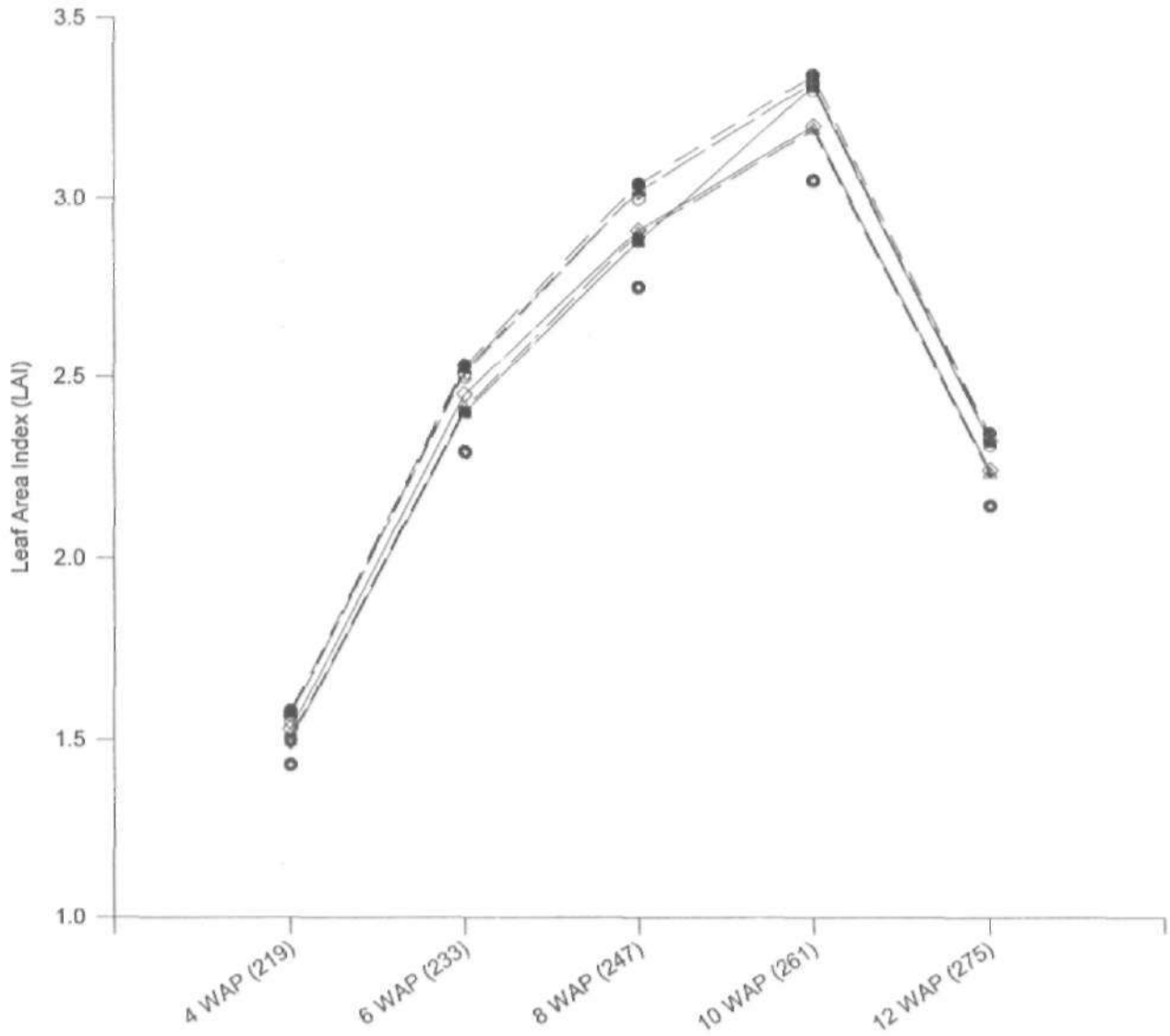


Fig. 7: Changes in leaf area index for maize as influenced by different systems in the 1996 cropping season.

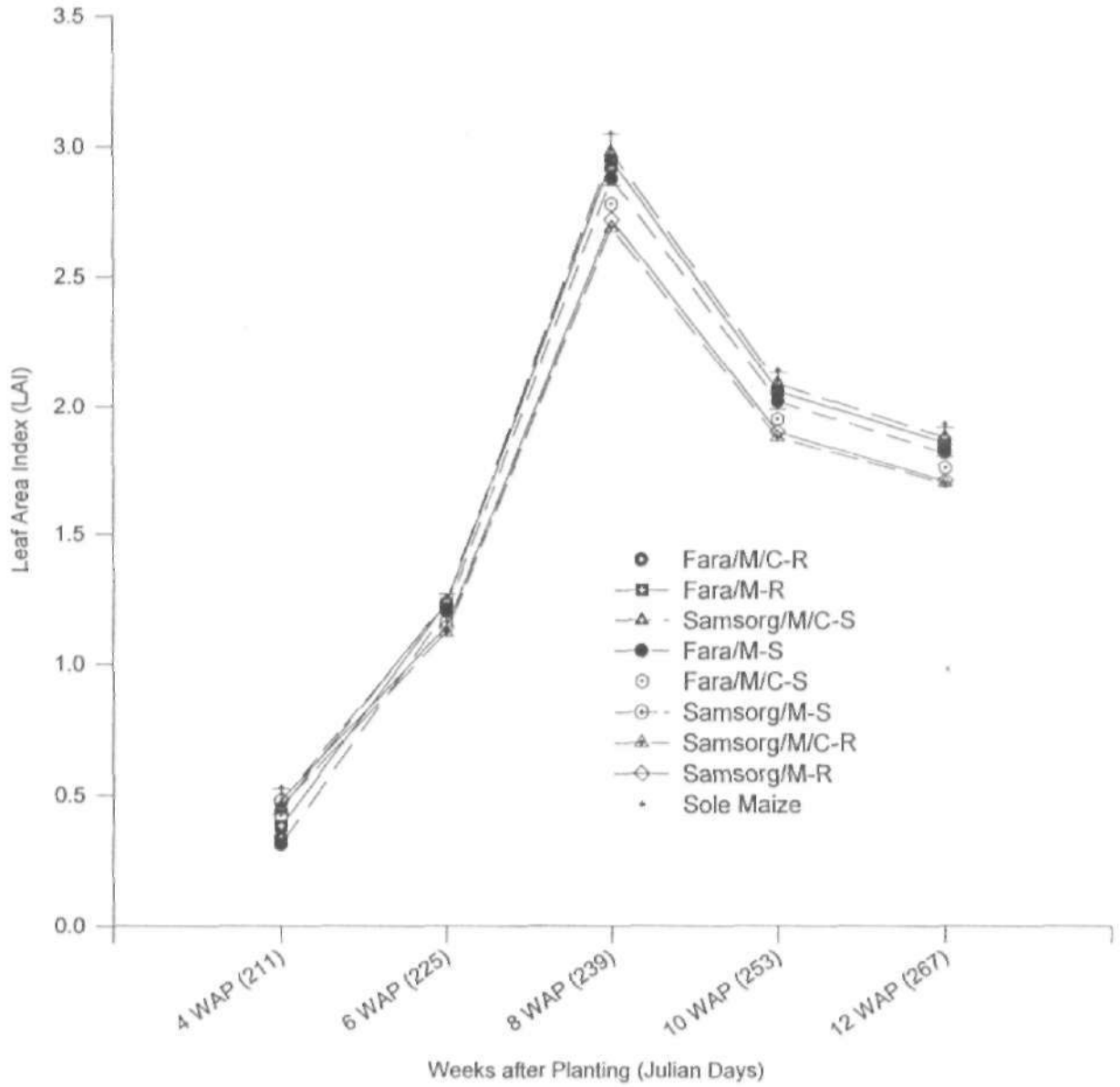


Fig. 8: Changes in leaf area index for maize as influenced by different systems in the 1997 cropping season.

Highest LAI (2.97) was recorded in SAMSORG-14/Maize/Cowpea-R while, FARARARA/Maize-S had the lowest value of LAI (2.53).

4.2.3 Total leaf area index

Total leaf area index which is an indication of the crop canopy cover showed monocropped maize having superior cover over all the other treatments from 28 DAS to the peak at 70 DAS (Fig. 9). The monocropped FARAFARA had the lowest cover which was followed by the monocropped SAMSORG-14. The intercrop treatment had covers intermediate of the monocropped maize and monocropped sorghum.

In 1997 season, monocropped maize recorded highest cover and peak cover was at 56 DAS before a drastic decline. The intercropped treatments had peak LAI at 56 DAS with a more gradual decline (Fig. 10). The monocropped sorghum varieties had peak cover at 70 DAS with FARAFARA recording higher cover density than the SAMSORG-14.

Fig. 11 showed maize retaining superiority in canopy cover up to 56 DAS in 1998 along with it, most of the FARAFARA mixtures recording peak cover at 56 DAS. For monocropped sorghum and mixtures involving SAMSORG-14, peak cover was at 70 DAS.

Generally, maize produced a higher canopy cover than any of the mixtures up to its peak before a drastic decline. In mixtures, decline in total Leaf Area Index is more gradual hereby, maintaining a fairly moderate cover over a longer period of time. Total canopy cover was lowest in the monocropped sorghum and its decline gradual.

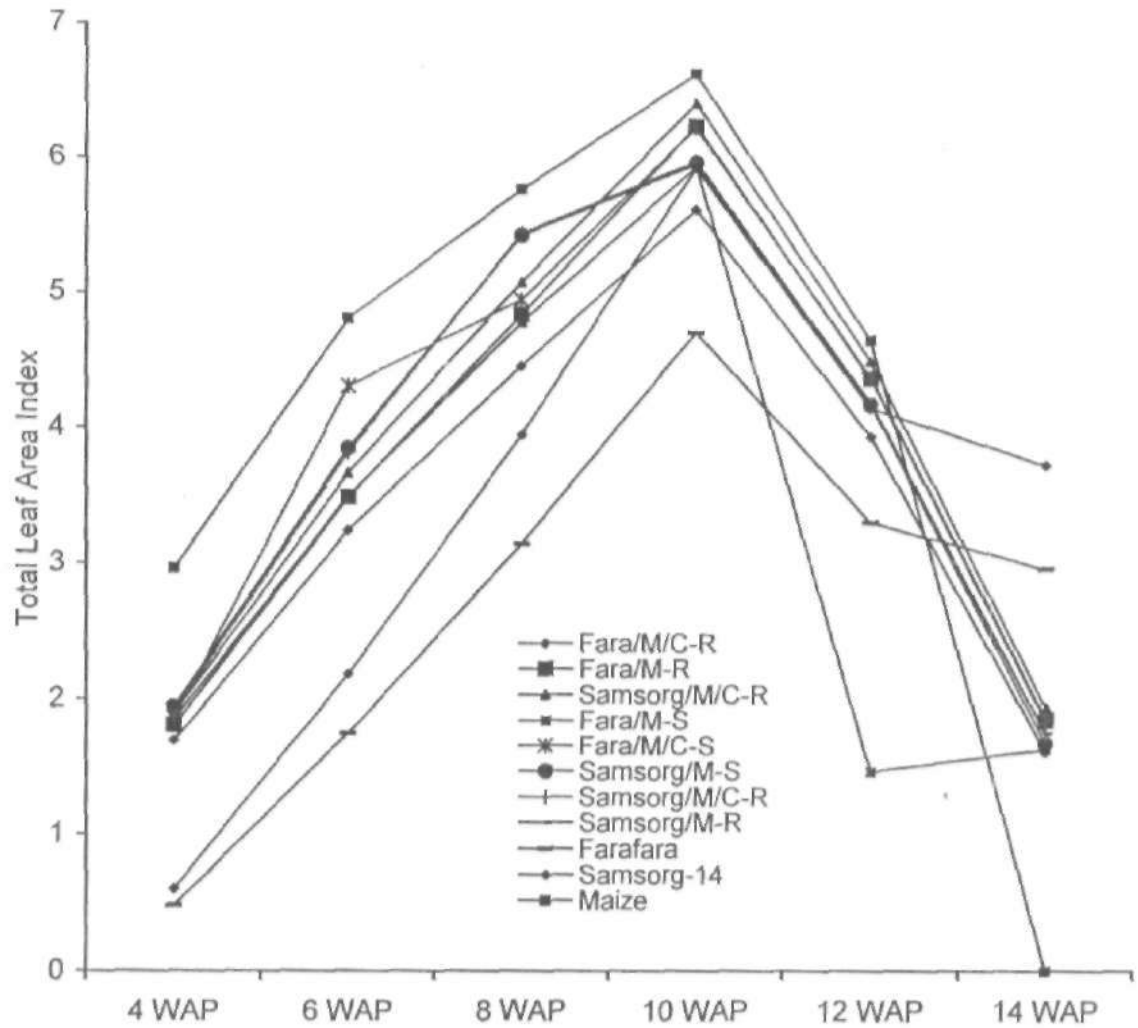


Fig. 9: Leaf area index under different cropping system in the 1996 cropping season.

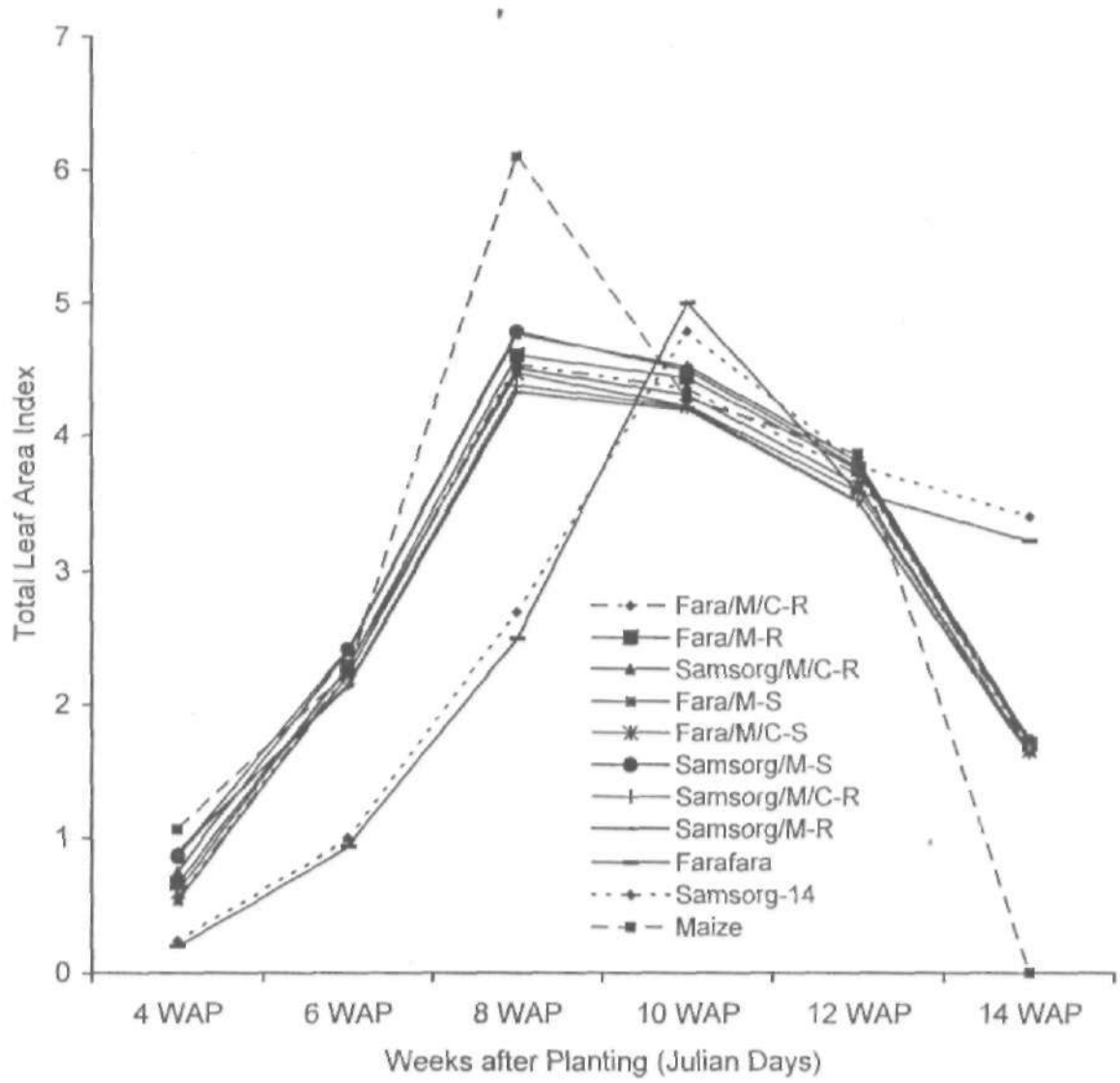


Fig. 10: Leaf area index under different cropping system in the 1997 cropping season.

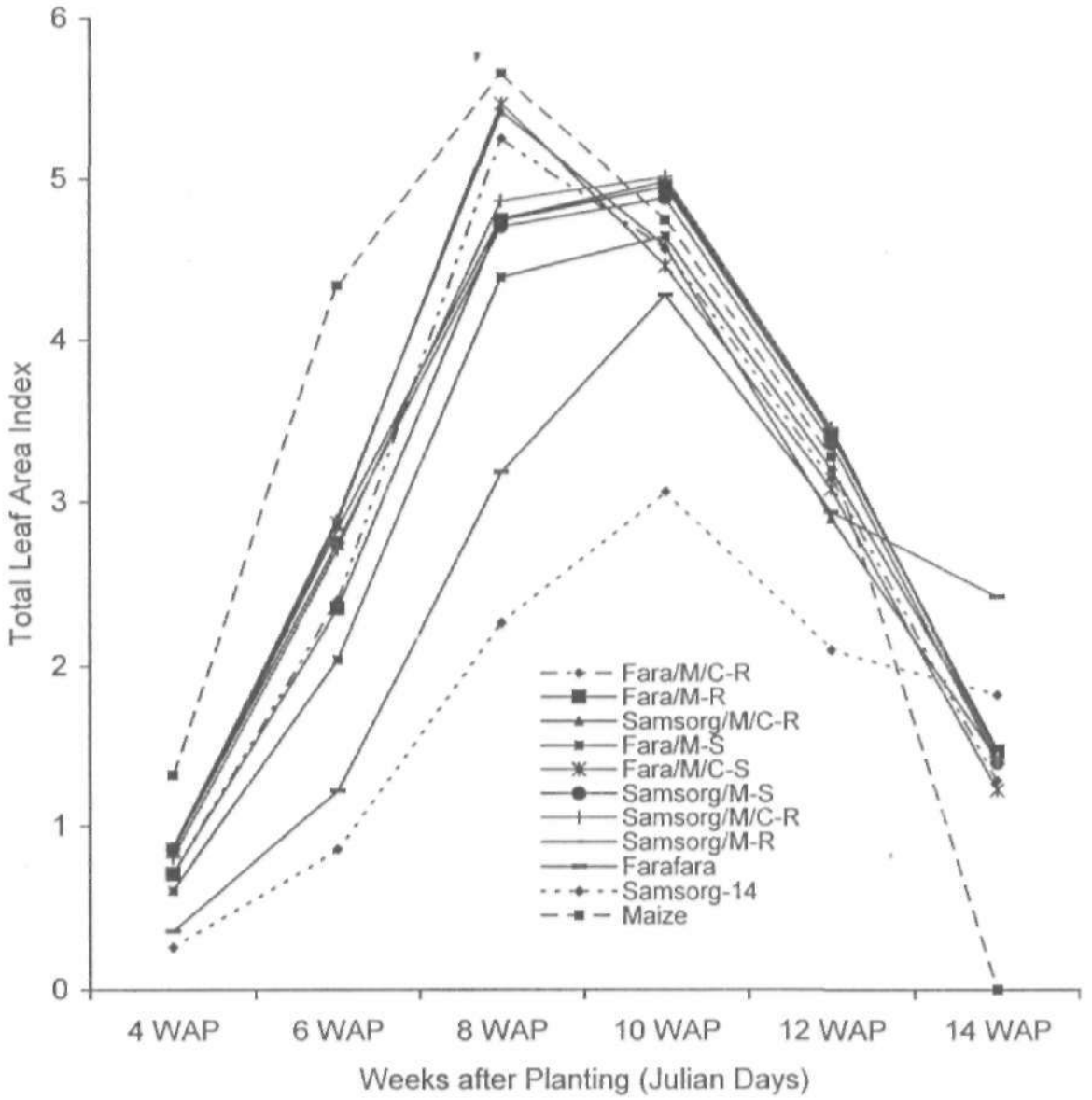


Fig. 11: Leaf area index under different cropping system in the 1998 cropping season.

4.2.4 Light (PAR) interception by sorghum

In the 1996 cropping season, the light fraction intercepted (photosynthetic active radiation) increased very rapidly from 42 DAS and, reaching a maximum of 83% at about the time of peak LAI (70 DAS) but then decline quite sharply (Fig. 12). Light interception was significantly higher in mixtures with stand arrangement than the row intercropping, and this continued up to 56 DAS. The SAMSORG-14/Maize-S mixtures attained maximum interception at 56 DAS. Monocropped SAMSORG-14 was similar (at par) with some of the mixtures with stand arrangement. But for SAMSORG-14/Maize-R mixtures, all treatments have very similar values of light interception at 70 DAS. SAMSORG-14/Maize/Cowpea-S recorded the highest light interception. At 84 DAS, there was a sharp drop and this could be due to senescence of the lower leaf. Light interception was similar throughout the growing period of the two monocropped sorghum variety.

In the 1997 cropping season, the profiles of intercepted light were similar to those of 1996 (Fig. 13). Higher light interception was recorded with the stand arrangement. Peak of light interception was at 70 DAS of which all the treatments but for monocropped 'FARAFARA' and FARAFARA/Maize-R, were statistically similar. Maximum light interception was at 89% by the mixtures involving cowpea in stand arrangement. Among the monocropped treatments, SAMSORG-14 intercepted more light than FARAFARA. The superiority displayed by mixtures in stand arrangement may not be unconnected with the maize plant interspacing two sorghum plants thus, increasing the fraction of light intercepted.

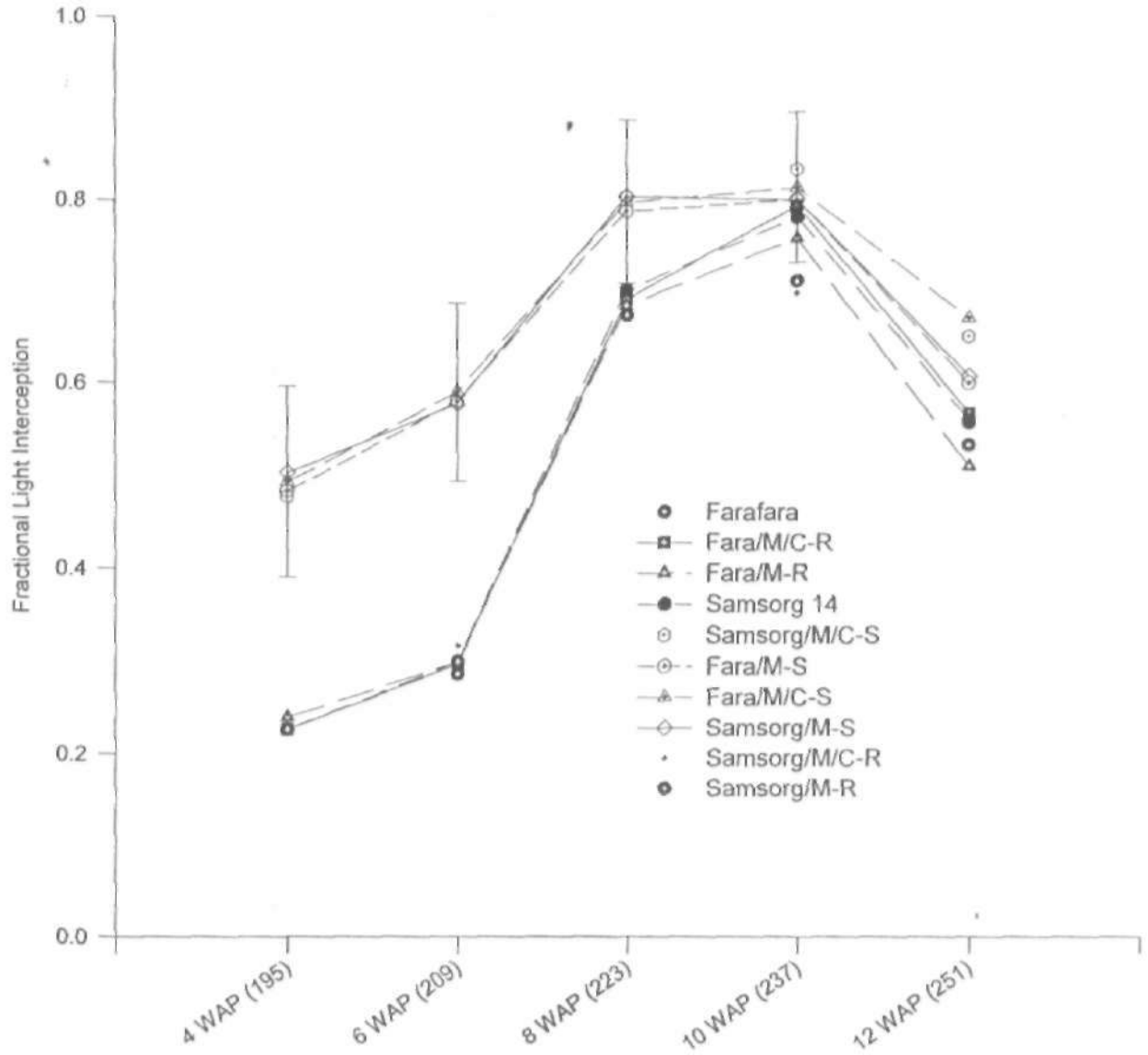


Fig. 12: Canopy light interception for sorghum during 1996 growth season.

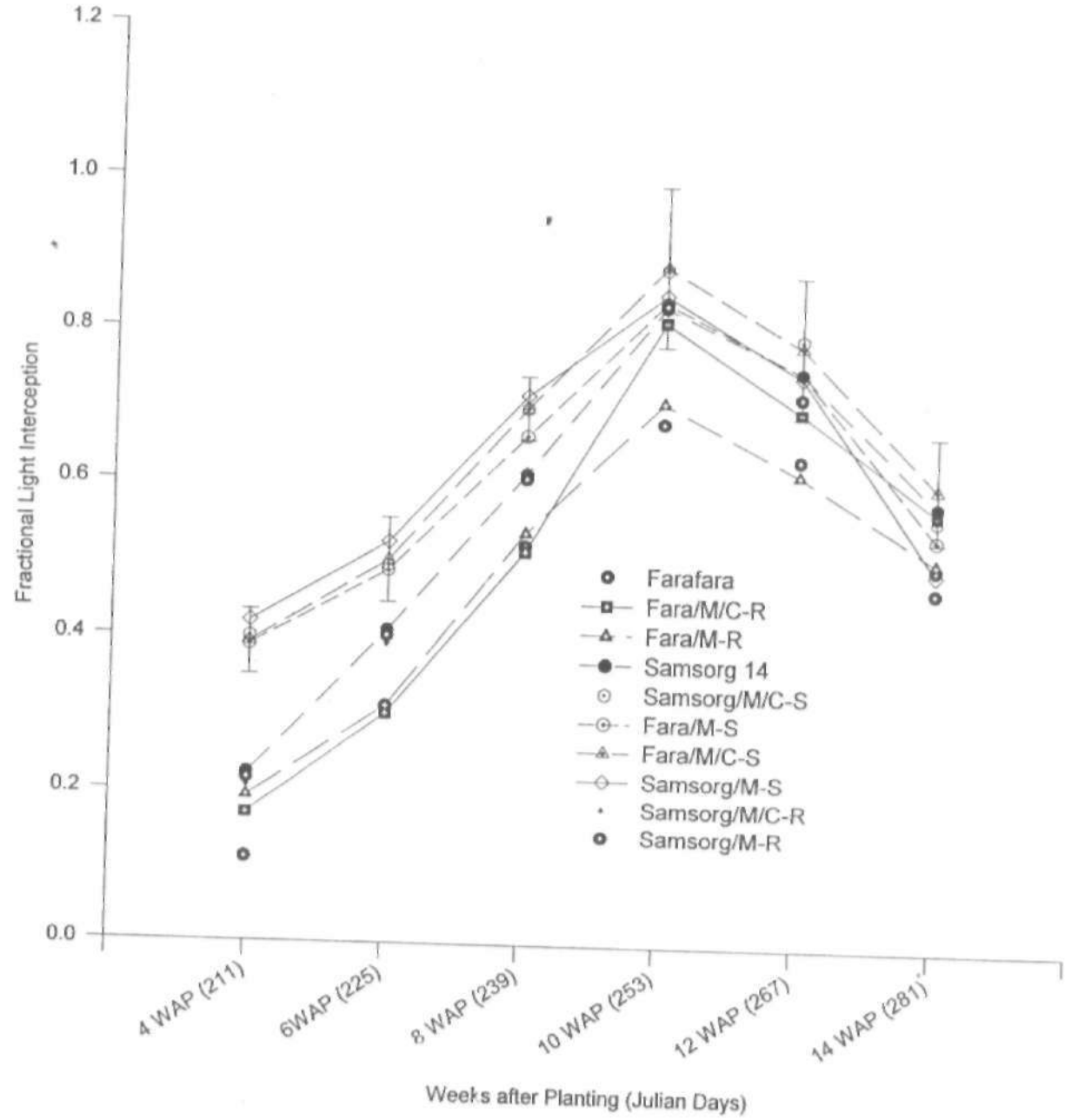


Fig. 13: Canopy light interception for sorghum during 1997 growth season.

In the 1998 cropping season, light interception was similar in all the treatments at the early stage of growth (≤ 28 DAS). Between 42 and 56 DAS, the mixtures in stand arrangement intercepted more photosynthetic light energy than the others. Peak light interception was recorded at 84 DAS (Fig. 14) and there was no significant difference in the fraction of light intercepted by the treatments. Maximum light intercepted was 85% by FARAFARA/Maize/Cowpea-S while, monocropped FARAFARA had the least value (70%). When compared with the previous seasons, there was a delay of 14 days to attain peak light interception.

4.2.5 Light (PAR) interception by maize

Maize showed no significant difference in amount of light intercepted in all the treatments (Fig. 15) in the 1996 cropping season. The monocropped maize had the maximum interception of 89% at 56 DAS and this was maintained up to 70 DAS (81%) before a drop which could probably be due to leaf senescence mixtures with row arrangement intercepted higher light fraction than those with stand arrangement. The reduction in the latter might be due to the presence of sorghum plants interspacing the maize stands.

During the 1997 cropping season, monocropped maize intercepted the highest fractional light of all the treatments under study and was closely followed by the treatments in row arrangement (Fig. 16). Their peak light interceptions were reached at 56 DAS. For maize in stand arrangement, peak interception was at 70 DAS. Maximum light interception was 90% for monocropped maize and ≥ 84% in mixtures with row arrangement. Fractional light intercepted by maize in mixtures with stand arrangement were still

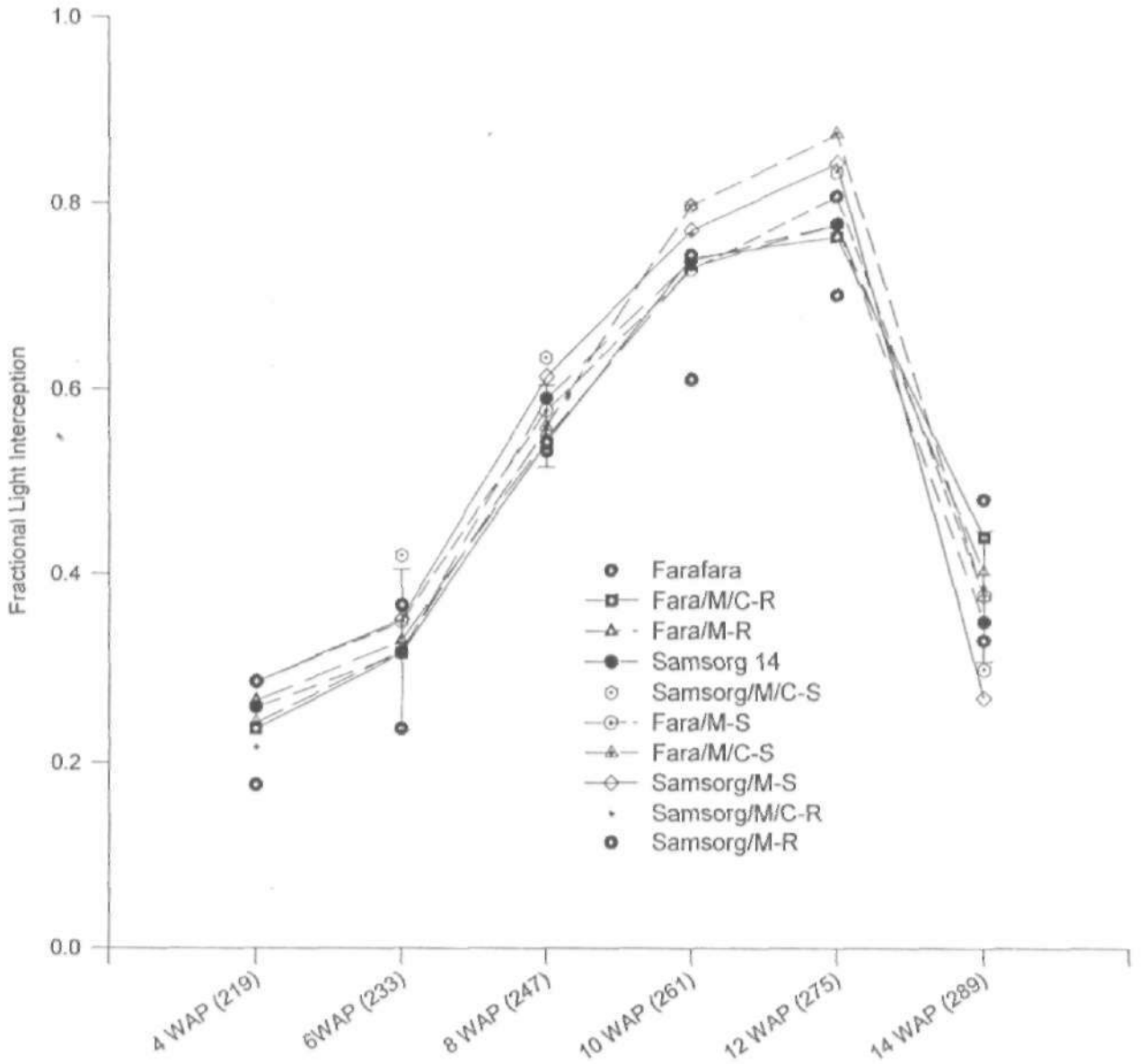


Fig. 14: Canopy light interception for sorghum during 1998 growth season.

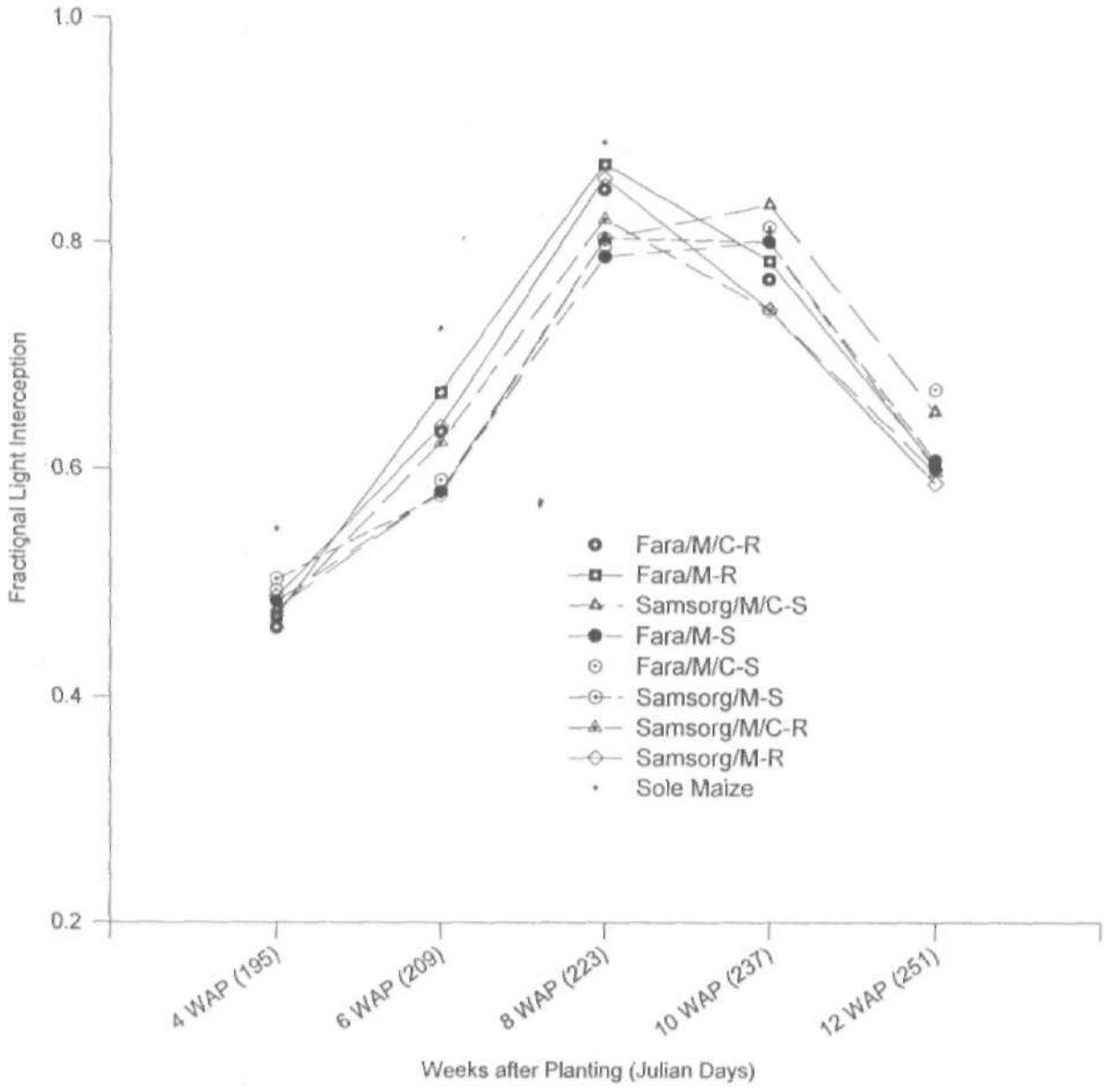


Fig. 15: Canopy light interception for maize during 1996 growth season.

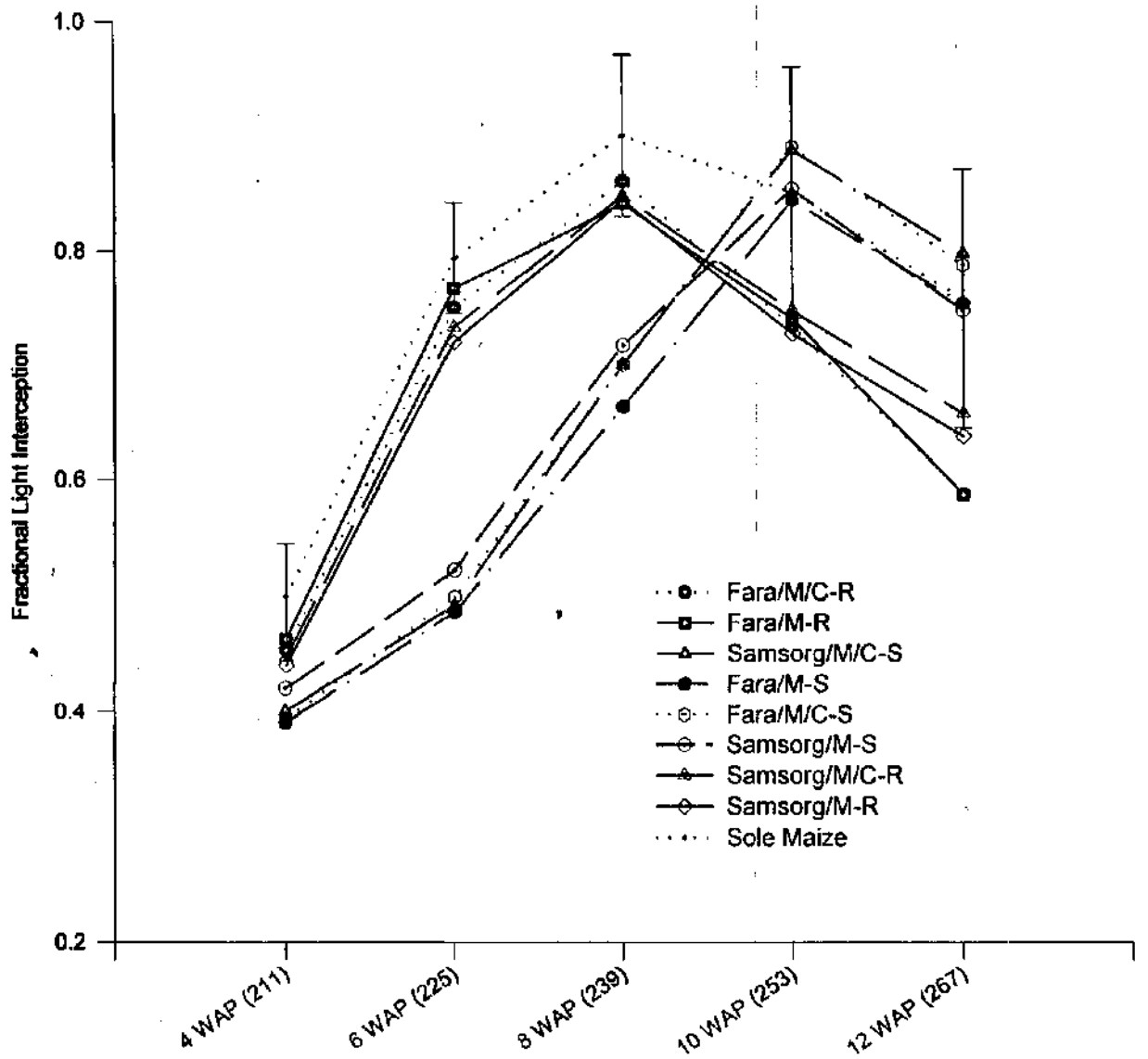


Fig. 16: Canopy light interception for maize during 1997 growth season.

substantial even at 84 DAS probably because the time of peak light interception of sorghum coincided with that of the latter.

The trend of light interception by maize in 1998 cropping season was fairly similar to the pattern of those of 1996 season (Fig. 17). There was no significant difference in the fraction of light intercepted by maize in all the treatment up to 56 DAS. From then on the monocropped maize displayed superiority over the others. Peak of light interception was at 56 DAS in monocropped maize and crop mixtures with row arrangement. For mixture with stand arrangement the peak was at 70 DAS followed by a sharp decline particularly for mixtures in row treatment.

4.2.6 Dry matter yield

Dry matter production is one of the tool used in evaluating the potential for biomass production from solar radiation and rainfall (Sivakumar and Huda, 1983). Daily dry matter production is based on the amount of intercepted PAR. Dry matter yield data was collected, when above ground harvested plants are oven dried at 70°C for 48 hours and weighed.

4.2.7 Sorghum dry matter yield

There was a significant difference in sorghum dry matter yield among the treatments in the 1996 cropping season (Fig. 18). Monocropped SAMSORG-14 had early start in dry matter yield at 56 DAS but monocropped 'FARAFARA' superceded it in dry matter as from 70 DAS. Mixtures with 'FARAFARA' generally yielded more dry matter than those of SAMSORG-14. Generally, the monocropped sorghum had higher dry matter yields than sorghum in mixtures throughout the growing season. Dry matter yields

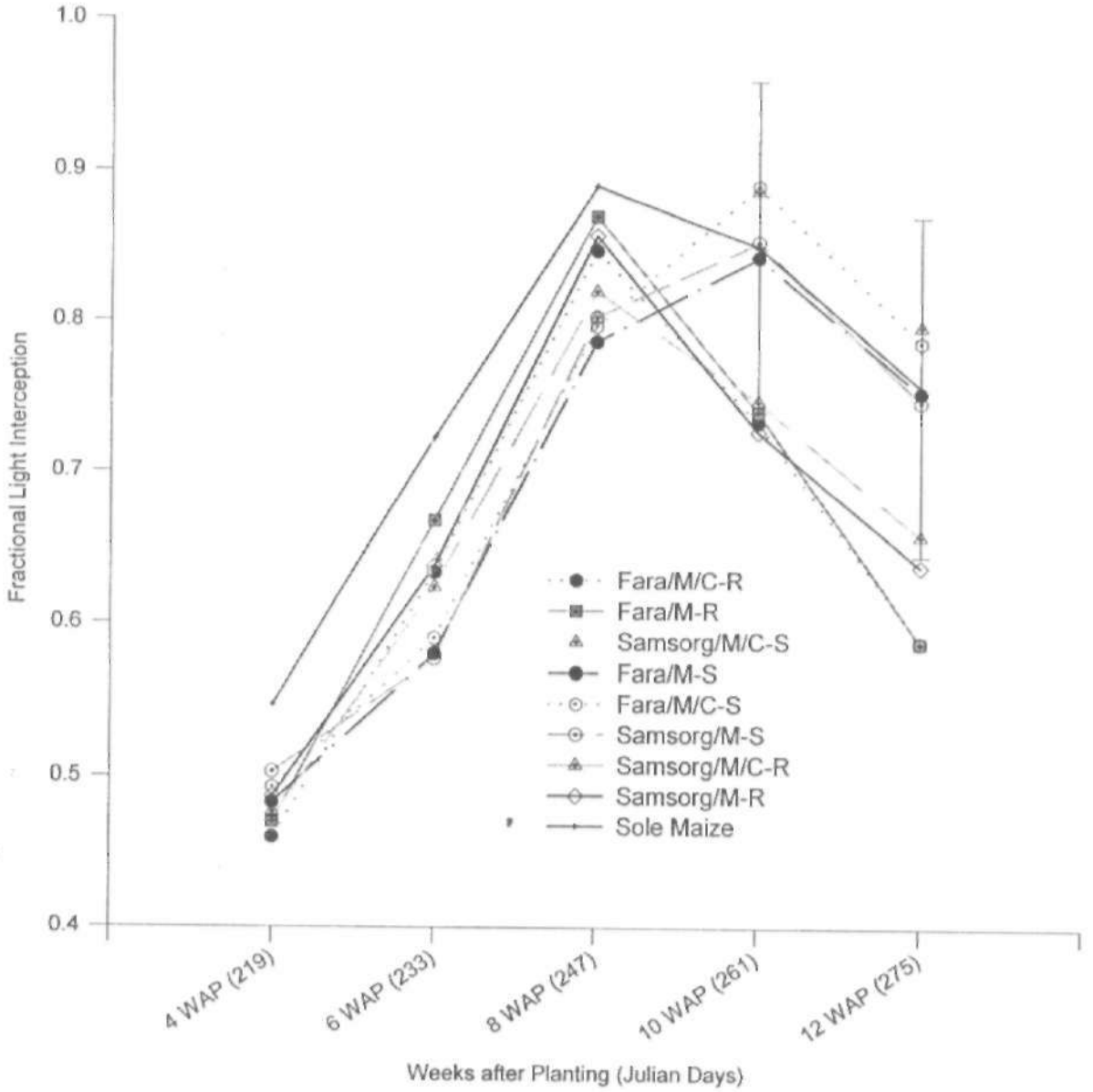


Fig. 17: Canopy light interception for maize during 1998 growth season.

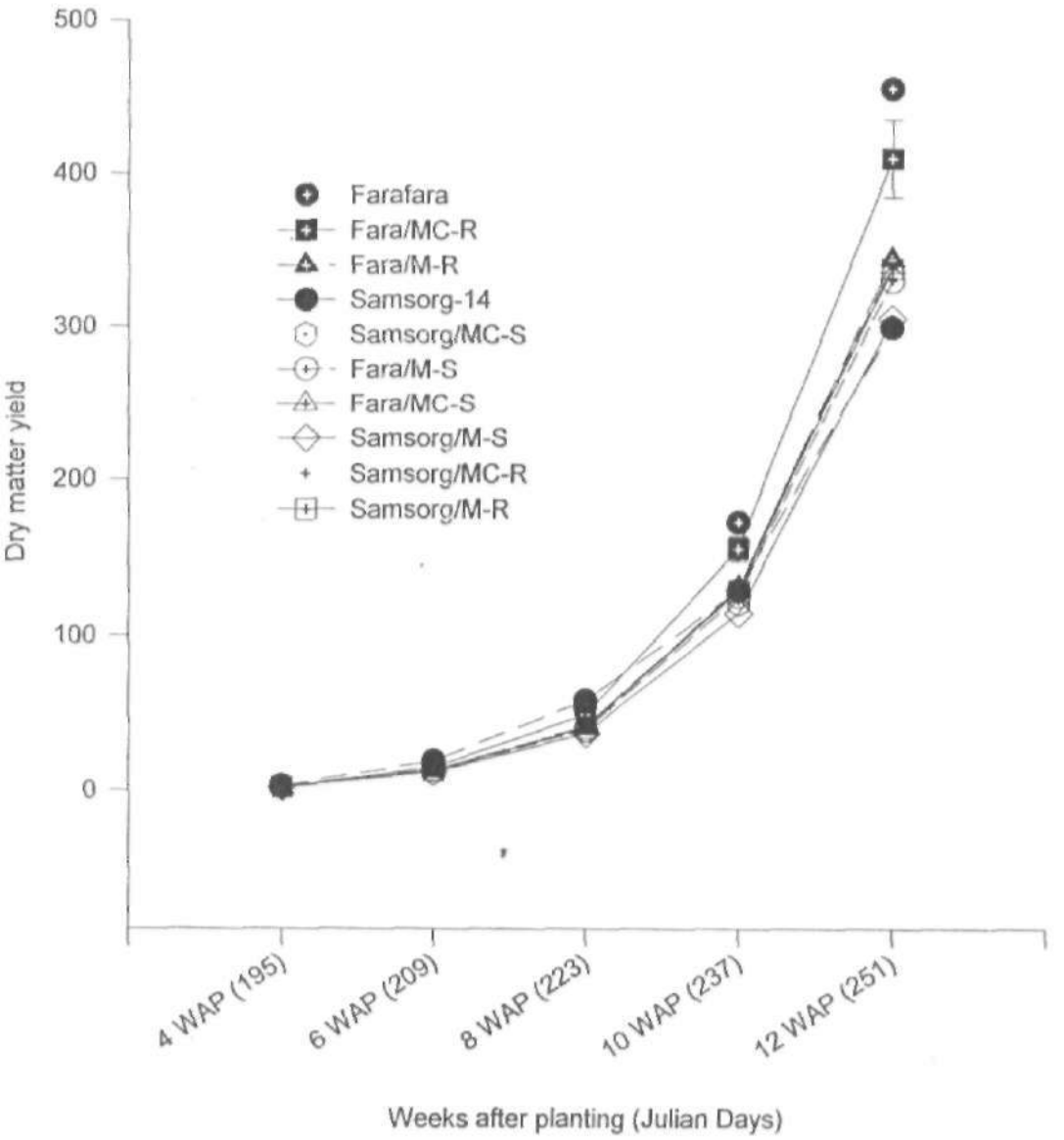


Fig. 18. Sorghum dry matter yield under different cropping systems in 1996 season.

favoured monocropped SAMSORG-14 throughout the 1997 season. Also, the mixture containing SAMSORG-14 performed better than those with 'FARAFARA' (Fig. 19). The SAMSORG-14/Maize-S mixtures produced higher sorghum dry matter yield than all other mixtures with the lowest yield in the FARAFARA/maize mixtures. In 1998 cropping season, monocropped SAMSORG-14 total dry matter yield was superior until 84 DAS when sorghum in the SAMSORG-14/Maize-S mixtures recorded higher dry matter yields throughout the season (Fig. 20). Mixtures with FARAFARA recorded lower sorghum dry matter yield than those containing SAMSORG-14. Monocropped FARAFARA had the lowest yield, even at 84 DAS.

4.2.8 Maize dry matter yield

Monocropped maize recorded a significantly higher dry matter yields in the 1996 cropping season (Fig. 21). Although, it yield were similar statistically with that of SAMSORG-14/Maize/Cowpea-S up to 70 DAS. In the year under review in mixtures produced higher dry matter yield in mixtures with SAMSORG-14 as component cropsthan with those of FARAFARA. The FARAFARA/ maize/Cowpea-R recorded about thelowest yield. Unlike in the previous season, maize dry matter yield in 1997 season was significantly higher in the FARAFARA/Maize-S mixtures followed by the SAMSORG-14/Maize-R mixtures up to 56 DAS (Fig. 22). In 1998, monocropped maize was significantly superior in dry matter yield than any of the other treatments (Fig. 23). Dry matter yield in FARAFARA/Maize-R mixtures were higher than maize dry matter yields in the SAMSORG-14/Maize-R mixtures. Although values of dry matter yield were low in this season, they were generally higher than those of 1997 cropping season.

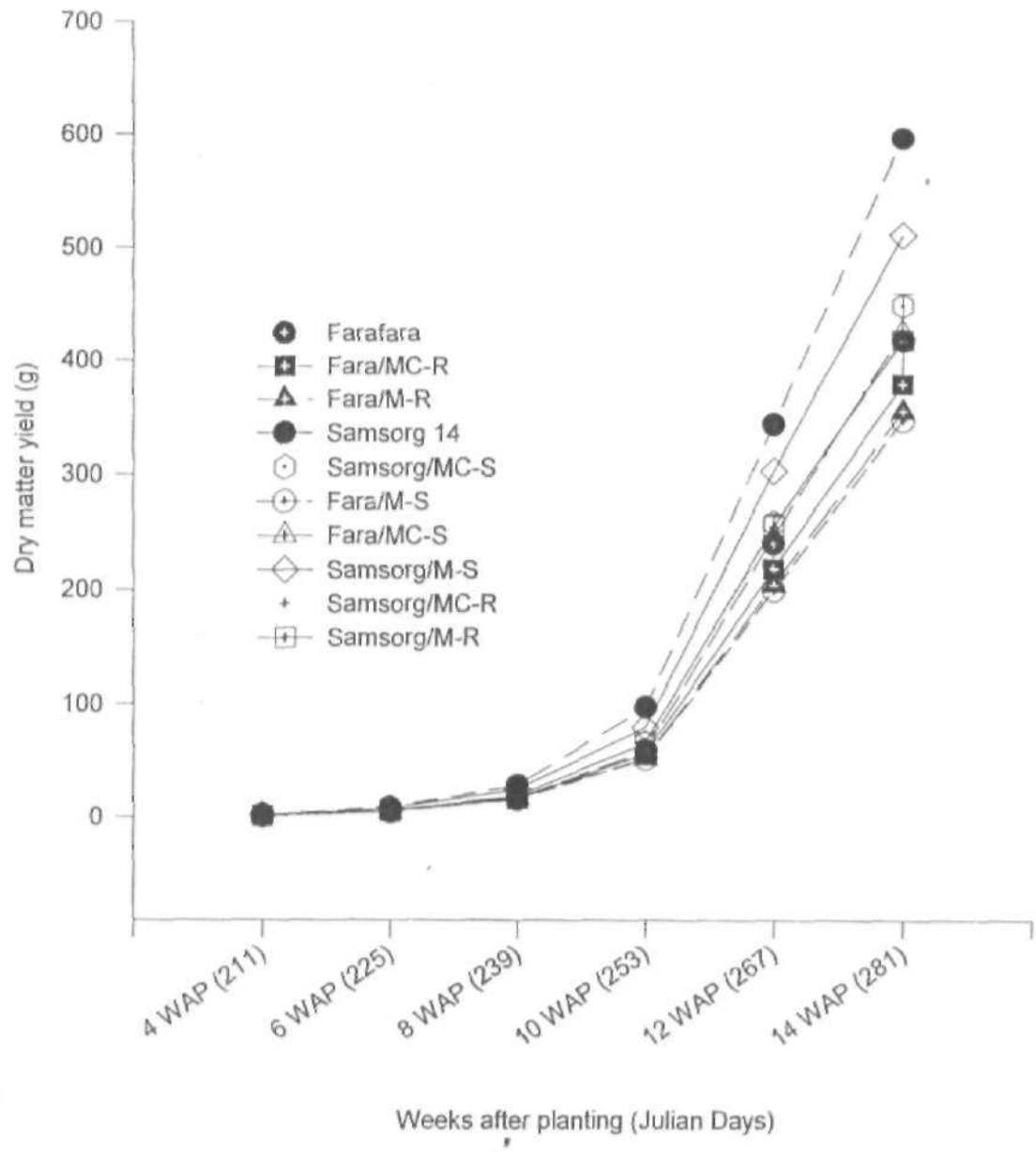


Fig. 19. Sorghum dry matter yield under different cropping systems in 1997 season.

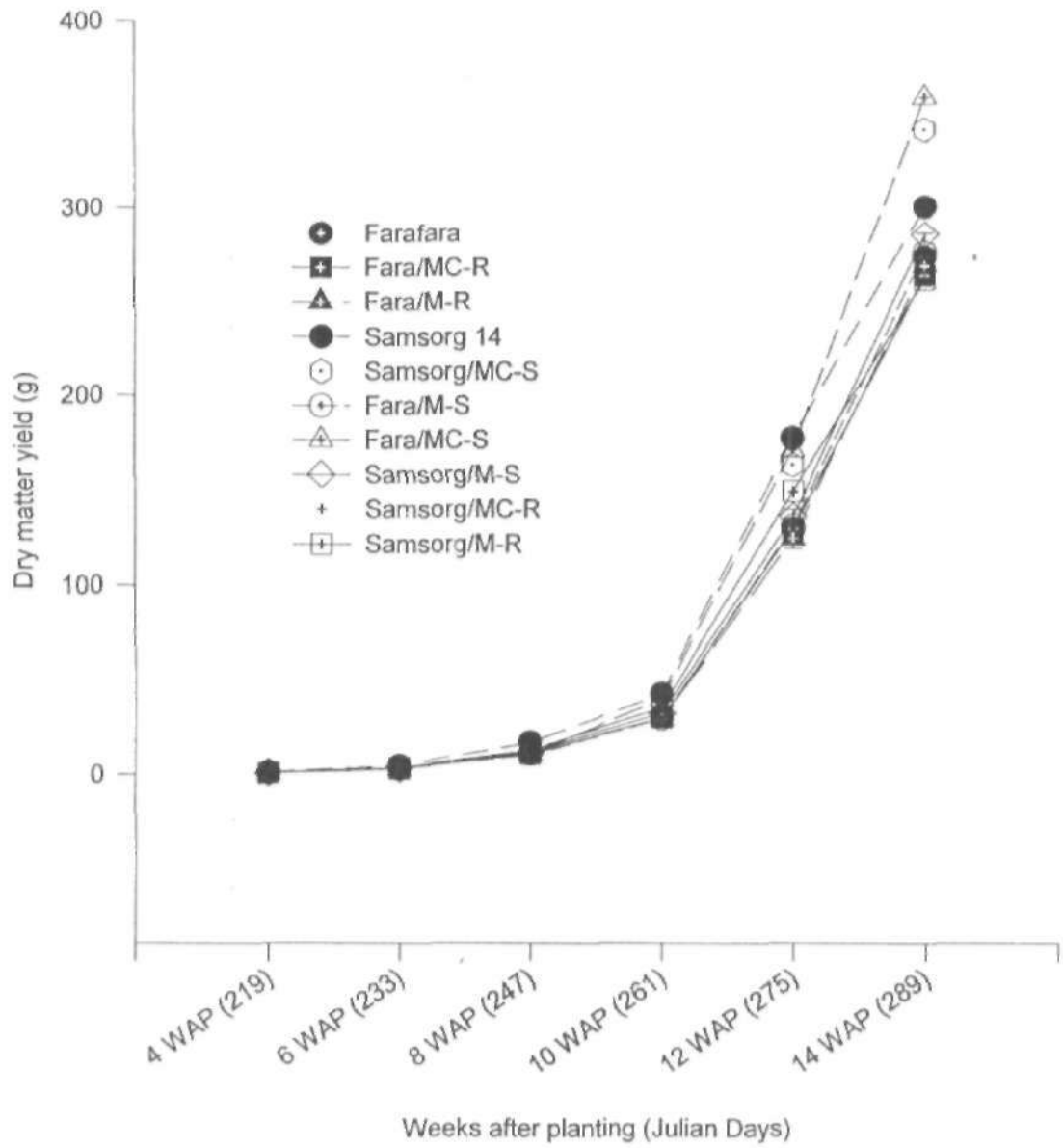


Fig. 20. Sorghum dry matter yield under different cropping systems in 1998 season.

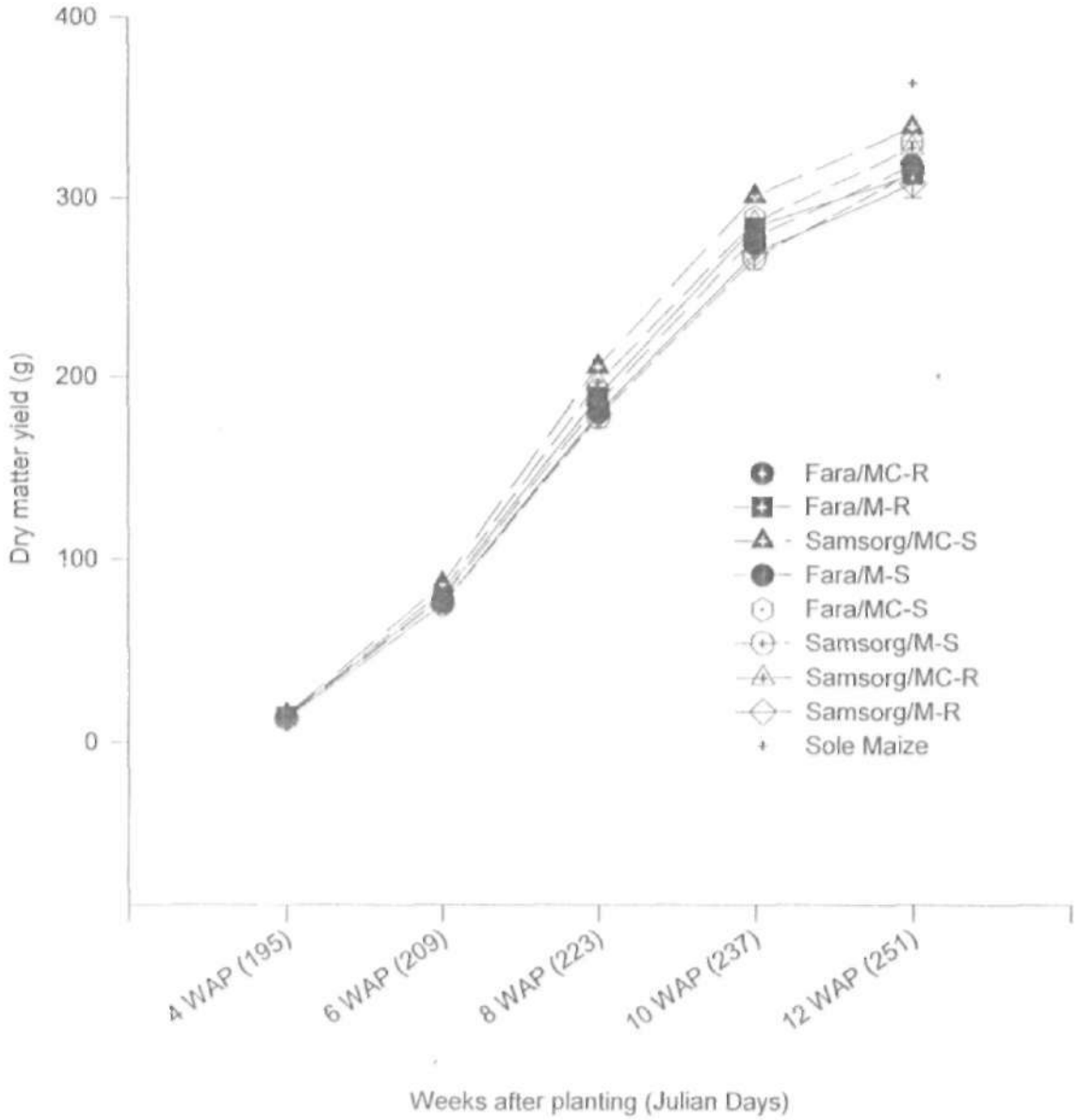


Fig. 21. Dry matter yield of maize under different cropping systems in 1996 season.

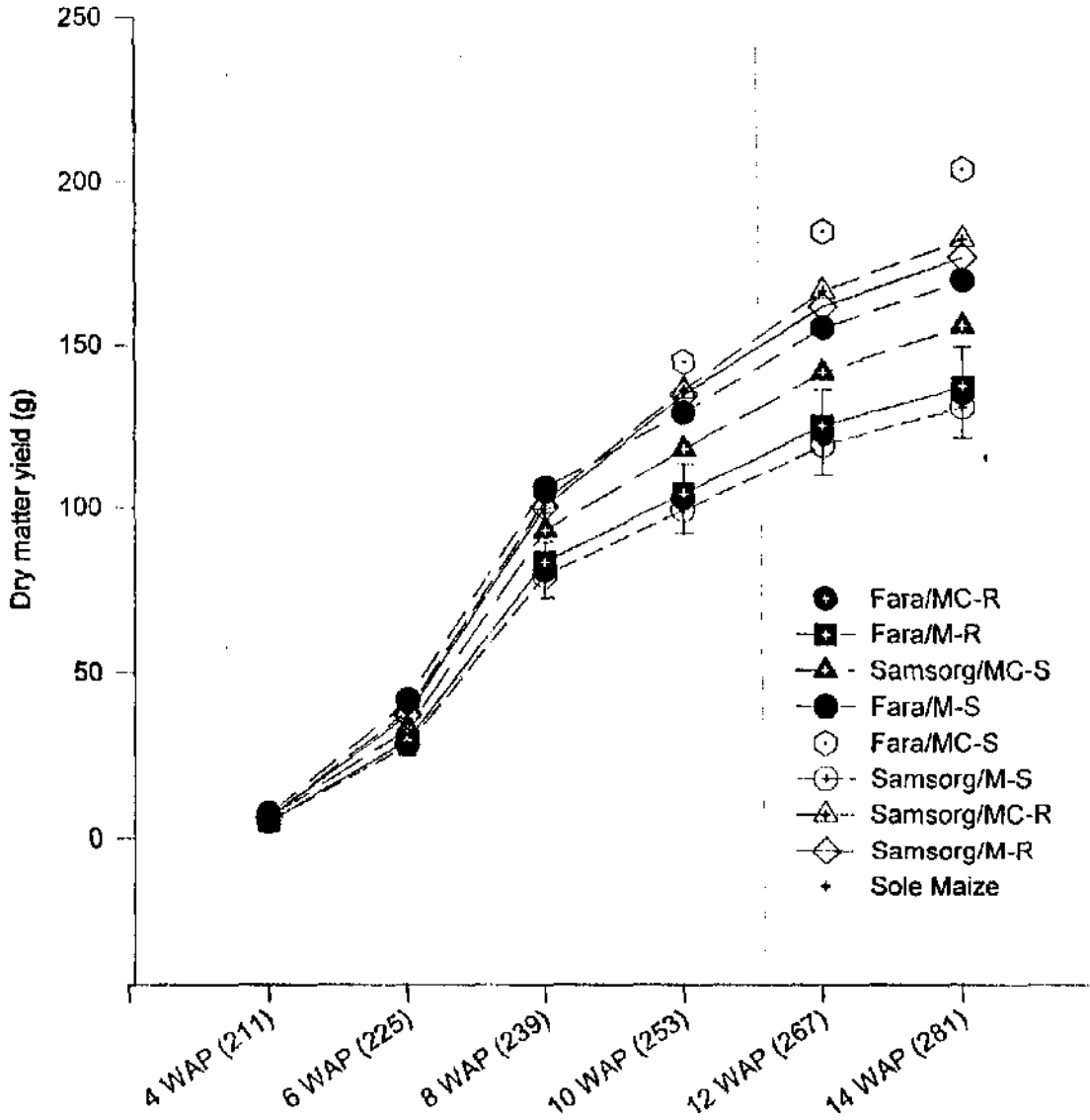


Fig. 22. Dry matter yield of maize under different cropping systems in 1997 season.

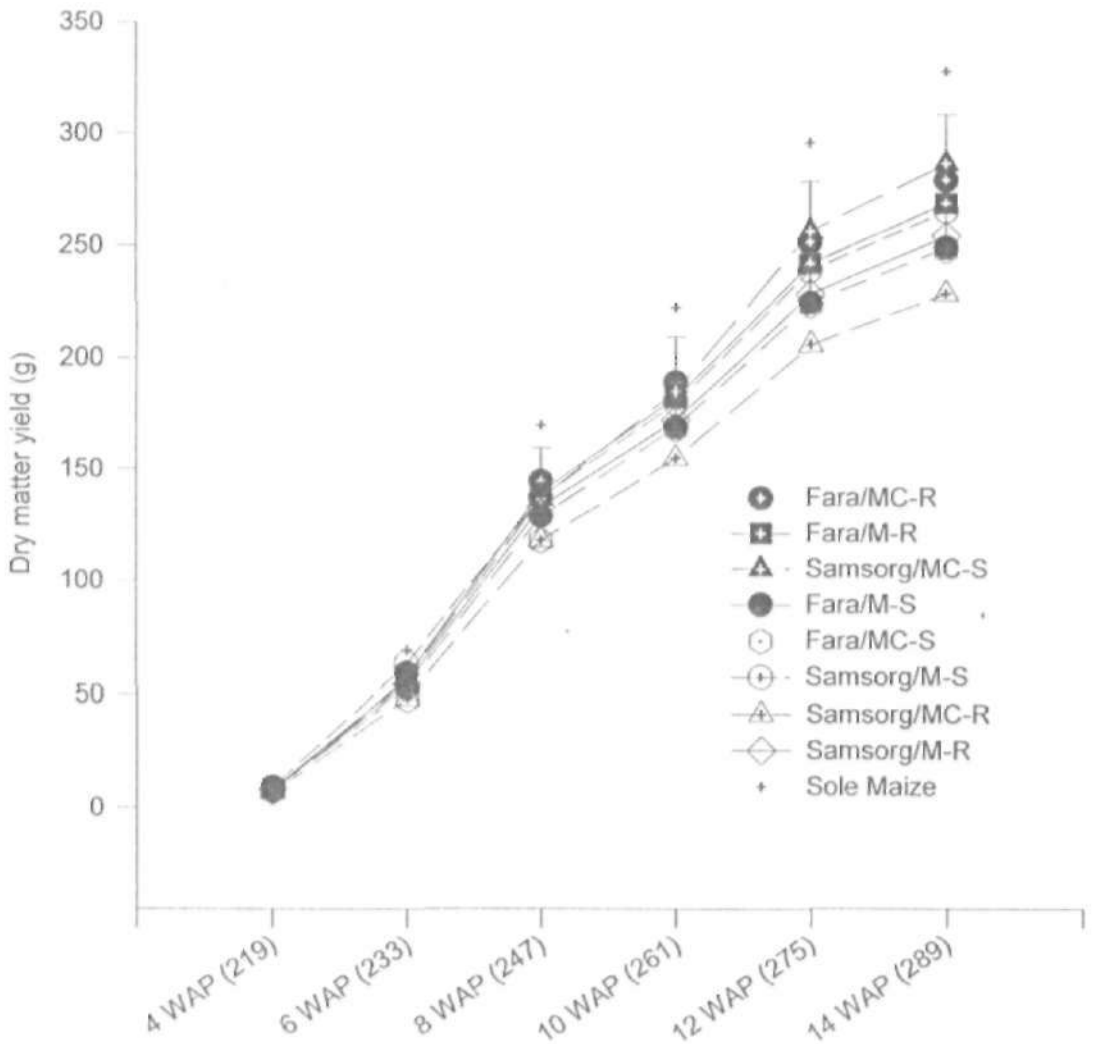


Fig. 23. Dry matter yield of maize under different cropping systems in 1998 season.

4.2.9 Crop canopy development

The leaf development follow a similar pattern with the photosynthetic active radiation (PAR) interception for all the treatments. This is so because there is obviously a direct relationship between PAR interception and leaf area index for crops. Canopy PAR interception and LAI patterns in the sorghum/ maize intercrop reveal its increased efficiency over growing sorghum in pure stand.

The greatest advantages in resource use is achieved due to the manipulation of spatial and temporal differences between the component crops. The differences in heights of the sorghum and maize in the mixtures, with maize growing rapidly in height at the early stage of growth over sorghum makes it possible for maximum interception of radiation in the mixtures over the monocropped sorghum (Fig. 6). This corroborates Singh's (1981) findings that intercrop advantages may be further enhanced by exploiting the various possibility of changing the spatial arrangement of the component crops. Similarly, at the time that maize is approaching leaf scenescence, sorghum is still growing and increasing in dry matter production (Baker, 1979).

Geometry in terms of canopy architecture, showed that the row arrangement favour higher light interception for maize in sorghum/maize mixture while for sorghum, it was the stand arrangement. This is an indication that important advantage can accrue from intercropping situations where the spatial arrangement of a particular crop is easily manipulated without costs to the other crops.

In the 1996 season, when sowing was done early (195JD), there was no significant difference in the LAI and PAR interception between sorghum in

mixtures and, those of their respective monocropped varieties are minimal (Figures 5 and 11). Delayed sowing of sorghum enhances emergence at the peak of rain, making the seedlings liable to waterlogging and perhaps, flooding which will results in poor sorghum stand, poor sorghum performance and lower grain yield (ICRISAT, 1986). This could probably be the reason for the high discrepancies in LAI of the treatments in 1998 (Fig. 7). While sorghum could tolerate waterlogging condition to a certain extent, maize is a very sensitive crop. Late sowing of maize could stunt growth and adversely affect the luxurious growth and performance perculiar to the crop (Schmidt and Frey, 1986).

Maize in particular and cereals in general, are heavy miners of soil nitrogen. Where there is a deficiency or delay in application of inorganic nitrogen to this low fertility soils, would affect crop growth and performance (Enwezor *et al.*, 1989), as was the case in the 1997 cropping season (Figures 6 and 9). Schmidt and Frey (1986), confirm the tendency of higher maize yield due to nitrogen application leading to identical maize yield per plant between monocropped and intercropped maize. To further substantiate the importance of nitrogen in maize performance, it had been reported that yield losses in maize due to intercropping were alleviated to some degree by nitrogen application (Ofori and Stern, 1987). Sorghum could also fail to give optimum performance under a deficient or low soil nitrogen fertility status (Waghmare *et al.*, 1982), although, intercropping advantages are often greater for sorghum under low fertility (Fig. 6) and/or moisture situations (Willey *et al.*, 1982). These reasons could probably be adduced for the poor performance of the cereals (Tables 6 and 7) during the 1997 cropping season.

Generally, differences in crop performance becomes wide particularly, in LAI of maize under inadequate nitrogen fertility and late sowing. Peak leaf area (LAI) for maize in the 1996 season was attained at 70 DAS (Figures 8 – 10). These clearly point to the effect of inadequate nitrogen fertilization and late sowing to reducing plant growth ability and shortening growth periods. These observations are in agreement with the findings of Allison and Daynard (1979) that assimilate which fills the grains of maize is accumulated largely after flowering. But in areas of short growing seasons, a decrease in length of the maize vegetative phase to allow for longer period of maize filling may occur due to accumulation of thermal degree units

4.2.10 Grain yield

One of the most important indices of crop performance and productivity is yield. To achieve full production of a main crop and additional yields of the associated crop is the goal of many resource-poor farmers. His principal concern is yield and yield stability.

4.2.11 Sorghum grain yield

Monocropped FARAFARA yielded more sorghum grain than all other treatments (Table 6). This was only statistically similar with sorghum yield of FARAFARA/Maize/Cowpea-R. The latter mixture was also similar to the yield of the monocropped SAMSORG-14. The least sorghum yield (1276 kg ha^{-1}) was recorded in the SAMSORG-14/Maize-R treatment.

The sorghum grain weight were not significantly different but the mixtures with row arrangement seems to have heavier sorghum seeds than all the other treatments.

In the 1997 season, the trend in sorghum grain yield was the reverse of the previous season. Here, SAMSORG-14 gave the highest yield and mixtures containing SAMSORG-14 outyielded those of the FARAFARA (Table 6). The FARAFARA/Maize-S had the least yield. Sorghum grain yield were not significantly different between monocropped FARAFARA and FARAFARA/ Maize/Cowpea-R treatments. SAMSORG-14/Maize-R mixtures were also similar in sorghum grain yield.

Table 6. Sorghum yield (kg/ha) and 1000-grain weight (g) (1996–1998 season).

Systems	1996		1997		1998	
	Yield	Grain weight	Yield	*Grain weight	Yield	Grain weight
Farafara	4067a	36.9abc	1038bc	na	556d	32.0b
Farafara/Maize/Cowpea-R	3057ab	38.0abc	1012bc	na	767abd	37.7a
Farafara/Maize-R	1823bc	38.2abc	798c	na	643bc	35.3a
SAMSORG-14	2105bc	35.0c	1942a	na	489d	37.3a
SAMSORG-14/Maize/Cowpea-S	1708c	36.3abc	1280b	na	788ab	36.7a
Farafara/Maize-S	2156bc	35.2bc	759c	na	642bcd	35.3a
Farafara/Maize/Cowpea-S	2473bc	36.9abc	789c	na	813a	37.3a
SAMSORG-14/Maize-S	1602c	38.4ab	1272b	na	622cd	38.0a
SAMSORG-14/maize/Cowpea-R	1903bc	38.0abc	1085bc	na	564d	36.0a
SAMSORG-14/Maize-R	1276c	38.7a	1042bc	na	640bcd	36.0a
Standard error	390	0.99	140.3	-	48.4	0.80

Values with same alphabets are not statistically significant.
*na = non-available data.

The cowpea mixtures in stand arrangement outyielded all other treatments in sorghum grain yield in the 1998 cropping season. The sorghum grain yield of FARAFARA/Maize/Cowpea-R was at par with those of the cowpea mixtures. Monocropped SAMSORG-14 recorded the lowest sorghum grain yield. It is important to note the variation in the performance of the component crops in the mixture during the entire period of the experiment.

Sorghum grain weight had similar weight except for FARAFARA/Maize mixtures in both the row and stand arrangement. Monocropped FARAFARA have the lightest seeds in all the treatments.

4.2.12 Maize grain yield

During the 1996 season, monocropped maize outyielded all the other treatments in grain yield (Table 7). This was followed by SAMSORG-14/ Maize/Cowpea-S which was at par in grain yield with the other mixtures.

There was no significant difference in maize grain weight of all the treatments studied (Table 7). The average weight of maize grains in the 1996 season were heavier than those of 1998.

Table 7. Maize grain yield (kgha^{-1}) and 1000-grain weight (g) (1996-1998).

Systems	1996		1997		1998	
	Yield	Grain weight	Yield	*Grain weight	Yield	Grain weight
Farafara/Maize/Cowpea-R	3667b	26.0	472d	na	1173ab	23.0
Farafara/Maize-R	3930b	26.2	441d	na	982abcd	22.0
SAMSORG-14/Maize/Cowpea-S	4240b	24.9	629bc	na	903bcd	23.3
Farafara/Maize-S	3980b	24.6	840a	na	903bcd	23.7
Farafara/Maize/Cowpea-S	4007b	25.3	873a	na	847cd	22.3
SAMSORG-14/Maize-S	3600b	23.8	536cd	na	907bcd	21.7
SAMSORG-14/Maize/Cowpea-R	4033b	25.4	548cd	na	782d	24.0
SAMSORG-14/Maize-R	3460b	26.3	725b	na	1067abc	23.0
Monocropped maize	5700a	24.6	542cd	na	1190a	24.0
Standard error	384	NS	502	-	83.2	NS

Values with same alphabets are not statistically significant.
*na = data not available.

In the 1997 season, maize yield was highest in the FARAFARA mixtures with stand arrangement. Maize grain yield were generally higher in the stand arrangement than in the row. FARAFARA/Maize-R had the lowest

maize grain yield and this was at par with monocropped maize treatment (Table 7).

Monocropped maize in the 1998 season recorded the highest grain yield which was at par with FARAFARA/Maize/Cowpea-R and the SAMSORG-14/ Maize-R (Table 7). All other mixtures had maize grain yield which were not significantly different from one another. Maize grain yield in SAMSORG-14/ Maize/Cowpea-R recorded the lowest yield.

4.2.13 For cowpea

The monocropped cowpea outyielded the cowpea in mixtures in all the three years of the trial. Cowpea in mixtures performed comparatively poorer than monocropped one (Table 8).

Table 8. Yield of cowpea (kgha ^{1}) in monocropped and intercropped plots.

Systems	1996	1997	1998
Farafara/Maize/Cowpea-R	299	76.5	35.1
Farafara/Maize/Cowpea-S	295	72.3	46.8
SAMSORG-14/Maize/Cowpea-R	219	59.5	42.9
SAMSORG-14/Maize/Cowpea-S	323	85.2	50.7
Monocropped Cowpea	2500	850	390

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4.3 Post Trial Surface Soil Properties

Surface soil bulk density had reduced tremendously in all the treatments. This could probably be as a result of soil tillage operations that breaks and pulverizes the soil (Table 9). This has also improved the total porosity of the surface soil. The mixtures had the highest surface soil bulk density while the lowest was in the tilled, grass fallow plot. This shows a

Table 9. Surface soil properties under different cropping systems after three years of cultivation.

Cropping systems	Particle clay (%)	Size Distribution		Textural class	PH 1:2.5		Organic carbon gkg^{-1}	Total nitrogen kg^{-1}	Available phosphorus (mg kg^{-1})	Exchangeable potassium (cmol)	Bulk density (mgm^{-3})	Infiltration rate (mmhr^{-1})	Total porosity (%)
		Silt (%)	Sand (%)		Water	0.01M cal_2							
Monocropped Sorghum	11	47	42	Loam	5.1	4.7	4.80	0.4	12.55	0.35	1.36	28.97	48.7
Monocropped Cowpea	12	45	43	Loam	5.2	4.8	4.40	0.4	10.08	0.41	1.40	72.00	47.2
SAMSORG-14/Maize/Cowpea	9	50	41	Loam	5.1	4.7	1.90	0.1	9.41	0.33	1.44	17.67	45.7
Monocropped Maize	10	50	40	Loam	5.2	4.8	5.60	0.6	11.66	0.41	1.35	22.83	49.1
Farafara/Maize/Cowpea	10	49	41	Loam	5.1	4.7	2.10	0.2	9.85	0.31	1.42	18.40	46.2
Tilled grass fallow	10	48	42	Loam	6.0	5.7	8.60	0.7	8.96	0.38	1.32	49.17	50.2

possibility of crop types or crop pressure influencing surface bulk density presumably due to their ability to either intercept or allow direct impact of rain drops on the soil.

Steady state soil infiltration rate was generally poor except for the monocropped cowpea, where rates as high as 72 mm hr^{-1} (Table 9) was recorded. This may not be unconnected with the presence of nodules on cowpea roots, which increases its root diameter and broadens the soil pores or channels thereby facilitating water movement and transmission. In cereals, the absence of nodules and the effect of cultivation could probably be the cause for low infiltration rate. This is because some of the natural pores could have been blocked as a result of mechanical disturbance during tillage operations.

Initially, cumulative infiltration was high in monocropped maize treatment than in the monocropped sorghum treatment but as the time of infiltration increases, cumulative infiltration in the monocropped sorghum treatments exceeded those of monocropped maize (Fig. 24). This may be due to their pattern of root distribution. Most roots of maize are found at the upper layers while significant root number exist at lower layers for sorghum. Usually, the abundance of root influences the opening of water channels in soils.

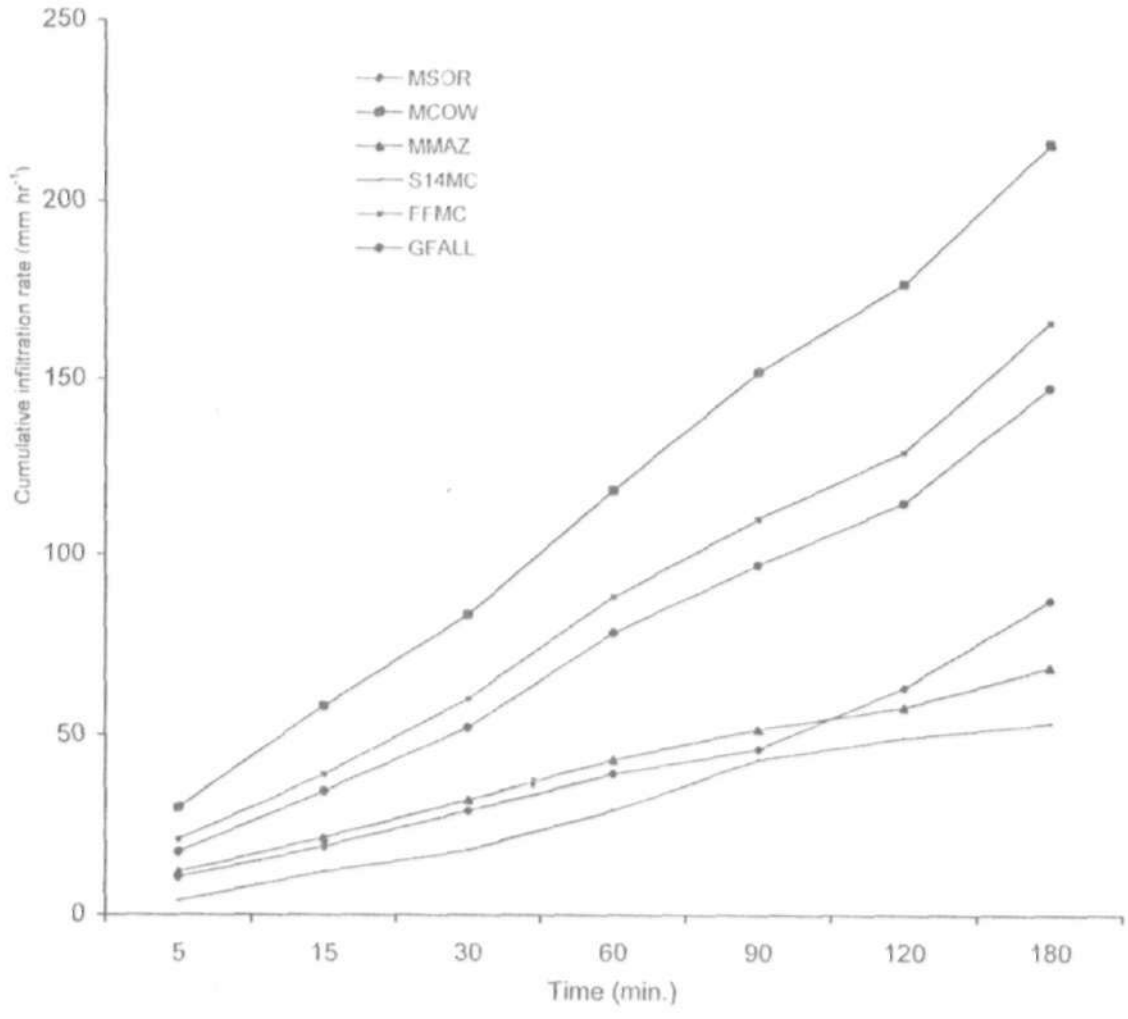


Fig. 24: Cumulative infiltration rate with respect to time under different cropping systems after three years of cultivation.

KEY:

MSOR = Monocropped sorghum
MCOW = Monocropped cowpea
MMAZ = Monocroped maize
S14MC = Samsorg-14/M/C
FFMC = Farafara/M/C
GFALL = Grassed fallow.

Results of surface soil chemical properties (Table 13) showed increase in silt content in the surface soil. This could either be due to tillage mixing that has brought silt from lower layers to the top but surface soil clay content is lower than at the start of the experiment. Therefore, silt deposition due to harmattan dust cannot be ruled out. Surface soil PH have shown a more acidic reaction and this may be due to the effect of fertilizer application particularly, urea. Organic carbon was low since none of the cropping systems was managed with organic inputs. Although, the tilled grass fallow had the highest organic carbon content (Table 9), which could be due to reduced decomposition rate. Total nitrogen content was low despite substantial inorganic nitrogen application in all the system except for the tilled grass fallow and the monocropped cowpea system where no inorganic fertilization was done. This results further confirmed the fact that cereals particularly maize are heavy soil nitrogen miners. The values for available phosphorus was low despite application of inorganic P in most of the system. Mixtures with cowpea have lower available P values. This could be due to the pressure of cereals and cowpea for soil available P. Exchangeable K was generally high in all the systems. In most cases, it is assumed that savanna soils are usually not deficient in K (Jones and Wild, 1975) except under continuous intensive cultivation.

4.4 Significance of the Observed Variations

4.4.1 Crop development

Sorghum plant development was faster in the variety "SAMSORG-14" than in the "FARAFARA". Sorghum growth and development was delayed by

the planting of maize and sorghum on alternate rows. Alternate stand arrangement advanced sorghum development in the mixtures.

Intercropping maize with sorghum was found to enhance maize development than when planted sole in years when sowing was done early. Maize generally developed faster (LAI) than sorghum and at 56 DAS, maximum canopy cover has been attained.

4.4.2 PAR use efficiency

Generally, higher light use efficiency (dry matter production/unit of light intercepted) were recorded in the intercrop over the sole crops. Highest PAR Use Efficiency was found in FARAFARA/MAIZE/COWPEA-R that produced 4.67 g dry matter per unit megajoules of light (Table 10). Mixtures involving 'SAMSORG-14' have a higher conversion efficiency than those involving 'FARAFARA', however, monocropped 'FARAFARA' efficiently converted photosynthetic active radiation than the monocropped "SAMSORG 14",

4.4.3 Yield advantage in mixture

Calculated land equivalent ratio revealed yield advantages in various mixtures over the monocropped systems in all the season trials (Table 11). In 1996 season, SAMSORG-14/maize/cowpea mixtures posses the highest yield advantage. This was followed by the FARAFARA/Maize/Cowpea mixtures. Generally the mixtures with SAMSORG-14 had a higher yield advantage than those of FARAFARA/maize-R.

In 1997 season, mixtures involving FARAFARA demonstrated higher yield advantages over the monocropped systems than the mixtures involving SAMSORG-14. Yield advantages, in some cases, were greater than 2 (Table 11).

Table 10. Total intercepted radiation, above-ground biomas and conversion efficiency in a sorghum based intercropping system, Samaru.

Systems	Intercepted radiation (MJ m^{-2})		Biomas (t ha^{-1})		Conversion coefficient (g MJ^{-1})		
	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize	Both
Sole FARAFARA	713.22	-	24.25	-	3.40	-	3.40
FARAFARA/Maize/Cowpea-R	718.36	1006.64	21.84	16.82	3.00	1.67	4.67
FARAFARA/Maize-R	703.46	1030.26	18.37	16.65	2.60	1.62	4.22
Sole SAMSORG-14	716.91	-	20.64	-	2.90	-	2.90
SAMSORG-14/Maize/Cowpea-S	1019.03	1019.03	17.17	18.06	1.69	1.77	3.46
FARAFARA/Maize-S	998.96	998	17.61	16.94	1.76	1.70	3.46
FARAFARA/Maize/Cowpea-S	1031.97	1031.97	18.14	16.75	1.76	1.62	3.38
SAMSORG-14/Maize-S	1017.42	1017.42	16.27	16.75	1.60	1.65	3.25
SAMSORG-14/Maize/Cowpea-R	708.76	997.8	17.69	17.46	2.50	1.75	4.25
SAMSORG-14/Maize-R	688.26	1017.31	18.05	16.39	2.62	1.61	4.23
Sole maize	-	1107.57	-	19.36	-	1.75	1.75

In the 1998 season, the mixtures in stand arrangement generally had a fairly higher yield advantage over the monocropped systems than those mixtures in row arrangement.

In all the seasons of trial, yield advantage over the mopocropped systems seems to increase with lateness of sowing. An example is the 1998 season, where the stand intercrops had a fairly higher yield advantage over the monocropped and row intercrop.

Table 11. Yield advantage through land equivalent ratio (LER) in mixtures.

Systems	1996	1997	1998
Farafara/Maize/Cowpea-R	1.52	1.94	2.46
Farafara/Maize-R	1.14	1.58	1.99
SAMSORG-14/Maize/Cowpea-S	1.69	2.04	2.50
FARAFARA/Maize-S	1.23	2.19	1.92
FARAFARA/Maize/Cowpea-S	1.42	2.44	2.32
SAMSORG-14/Maize-S	1.39	1.65	2.03
SAMSORG-14/Maize/Cowpea-R	1.69	1.64	1.92
SAMSORG-14/Maize-R	1.21	1.88	2.20

Generally, sorghum grain yield was significantly higher in farafara than those of SAMSORG-14 in the 1996 and 1997 seasons. While, the difference was not significant in the 1998 season (Table 12). This result was in agreement with those reported by Elemo and Ogungbile (1997), for on-farm testing of improved and local sorghum varieties. They reported insignificant differences between the improved and local sorghum. It is not impossible that

low moisture retention capacity. For maize, there could still be enough moisture for grain filling but efficient grain filling is impaired particularly, in medium to late maturing sorghum cultivars.

Among the two sorghum varieties, 'FARAFARA' generally outyielded SAMSORG-14 in 1996 and 1998. But in 1997, SAMSORG-14 was generally higher in grain yield than FARAFARA (Table 6). It may be possible to explain this occurrence, at least in part, by the improved ability of SAMSORG-14 to uptake and efficiently use nitrogen in the low fertility soils. The higher yield of 'FARAFARA' further strengthened the claim that sorghum varieties indigenous to an agroecology could outyield new entries to that of ecology. Grain yield for maize was generally higher when the component sorghum variety – SAMSORG-14 was intercropped with it than when the component crop is FARAFARA (Table 7). Although, the differences in maize grain yield could not be said to be substantial.

The very low grain yield of cowpea (Table 8) in the mixture relative to the monocropped treatment could probably be due to poor light reception. The cowpea emerges when the cereals are at their peak PAR interception with ≥ 80% light interception (section 4.4.3 and 4.4.4) therefore, very minimal radiation get down to them. Although, cowpea plants under sorghum canopy would have an advantage over those plant stands under maize canopy. This is because sorghum would compete less than maize with the associated cowpea. Sorghum, with shorter and narrower leaves will allow better radiation of the cowpea (Faris *et al.*, 1983). This advantage will continue until maize is harvested leaving large 'radiation windows' for the cowpea stands under the maize canopy. In addition, the observed lower cowpea yield in the 1997 and

1998 seasons relative to those of 1996 (Table 8) could be due to delayed planting of the crops in those year. Hence, there probably may not have been enough moisture for the cowpea roots to exploit along side the deeper roots of maize and sorghum.

4.4.5 Yield advantage and stability

Mixtures involving SAMSORG-14 had a clear yield advantages over those involving 'FARAFARA' (Table 9) in 1996 season and a slight edge in the 1998 season. While in 1997, mixture involving 'FARAFARA' exhibited a higher yield advantage over those of SAMSORG-14. This is a further indication adaptability to the stress of its native environment. The slight edge in yield advantage by SAMSORG-14 over FARAFARA mixtures in 1998 may probably not be unconnected to the fact that 'Farafara' is a later maturing variety than SAMSORG-14.

Generally, the three component crop mixtures had a higher yield advantage than the two crop mixtures. This could suggest that the three component crop mixtures may have value despite the poor cowpea yield recorded. The higher yield advantages in the 1997 and 1998 seasons, showed that yield advantages of the intercropping systems were neither reduced by nutrient nor moisture stresses. Stern (1984), explained that higher yield advantages of intercrops under low fertility conditions compared to high fertility conditions could probably be associated with a "nitrogen-saving effect". He argued that, in a replacement mixture, a sub-optimal cereal density should be able to take up more mineral nitrogen per plant than the optimal density monocrop. Stand intercropping arrangement had a generally, fairly higher yield advantage over the row arrangement (Table 11).

One major advantage of intercropping system is its flexibility and stability of yield (Willey, 1979; Stern 1984). The ability of one crop to compensate for the poor performance of others. Here, sorghum compensated in 1997, for the poor performance and reduction in maize yield which was due to nutrient stress. Also in 1998, maize was able to compensate for the drought stress suffered by sorghum due to its late planting. In as much as the resource-poor farmer may be largely concerned with a stable supply of food grain, these crop mixtures may meet his objectives.

4.4.6 Precipitation use efficiency

The erroneous and misleading values obtained under the water use determination which could be due to its estimation from the differences between precipitation and change in water stock (Van Duivenbooden *et al.*, 1999). Losses from deep drainage, runoff and contribution from run on and reverse water flow were neglected which could cause over or under estimation of water use values in crops. Van Duivenbooden *et al.* (1999), suggested "whenever possible, water use efficiency should be replaced with more specific definitions such as precipitation use efficiency, irrigation-use efficiency and transpiration use-efficiency."

The three component crop mixtures recorded highest precipitation use efficiency in all the three years of trial (Table 13). Although, these differences were not significant in all the years among the mixtures but there was a significant difference with those of SAMSORG-14 in 1996 (Table 14). Where 1 mm of water was used to produce 11.46 $kgha^{-1}$ grain yield in the SAMSORG-14/Maize/Cowpea while, for SAMSORG –14/maize it could only produce 9.16 $kgha^{-1}$.

Table 13. Precipitation use efficiencies (kgha-1 mm-1) of different cropping systems, Samaru, 1996 – 1998.

Systems	1996	1997	1998
Monocropped Farafara	7.50	1.38	0.63
Monocropped SAMSORG-14	3.88	2.57	0.56
Monocropped Maize	10.50	0.70	1.35
Monocropped Cowpea	8.40	2.85	1.10
SAMSORG 14/Maize/Cowpea-S	11.56	2.64	1.98
SAMSORG 14/Maize-S	9.59	2.40	1.74
SAMSORG-14/Maize/Cowpea-R	11.34	1.52	1.58
SAMSORG-14/Maize-R	8.73	2.34	1.94
Farafara/Maize/Cowpea-S	12.49	2.30	1.94
Farafara/Maize-S	11.31	1.99	1.75
Farafara/Maize/Cowpea-R	12.94	2.10	2.24
Farafara/Maize-R	10.60	1.64	1.84

The planting arrangement had similar values of precipitation use efficiency in the 1996 and 1997 trials and, this corroborated Owonubi and Kanemasu (1982), who reported similar observations for sorghum genotypes stand. The values of PUE in the three years showed decrease in crops' precipitation use efficiency due to delayed planting (Kumar *et al.*, 1996) and poor soil fertility status (Fussel and Serafini, 1985). The intercrop used more water efficiently than the monocrops and this efficiency increases with earliness of planting. This efficient use of water could probably be due to efficient canopy coverage, which reduces evaporation loss from the ground. An indication that plant water status advantages caused by above ground microclimate in intercrop favours higher precipitation (or water) use efficiency (Stigter and Baldy, 1993).

Precipitation use efficiency was higher in crops involving farafara in 1996 and 1998 trial although, the differences were not significant.

Table 14. "T"-test analyses of variance based on PUE (kgha^{-1} mm^{-1}) means of combined grain yield of crop varieties, arrangements and number of component crops in mixtures of cropping systems, Samaru, 1996-1998.

Parameters	1996	1997	1998
Sorghum yield in varieties			
Farafara	10.97	1.88	1.68
Samsorg 14	9.02	2.29	1.56
Calculated 't' value	1.18	-1.58	0.21
Table 't' (8DF, 5% LS) value	NS	(2.306 NS)	NS
Row vs stand intercrop			
Row	10.90	1.90	1.90
Stand	11.24	2.33	1.85
Calculated 't' value	-0.32	-0.331	0.33
Table 't' (6DF, 5% LS) value	NS	NS	NS
Cowpea mixtures vs Farafara			
Farafara/Maize/Cowpea	12.72	2.20	2.09
Farafara/Maize	10.96	1.82	1.80
Calculated 't' value	1.36	1.88	1.74
Table 't' (6DF, 5% LS) value	NS	NS	NS
Cowpea mixtures vs Samsorg-14			
Samsorg-14/Maize/Cowpea	11.46	2.08	3.68
Samsorg-14/Maize	9.16	2.37	1.84
Calculated 't' value	5.16	-0.517	-0.268
Table 't' (6DF, 5% LS) value	*	(4.303) NS	NS
Cowpea mixtures vs other mixtures			
Mixtures with Cowpea	12.08	2.14	1.94
Mixtures without Cowpea	10.06	2.09	1.82
Calculated 't' value	2.421	0.58	0.836
Table 't' (6DF, 5% LS) value	NS	(2.447) NS	NS

* = Significant
NS = Not significant.

4.5 Micro-environmental Influence on Cereal-based Intercrop

Using the yield data for the three years, a study of the relationship between maize and sorghum yield of the intercrop with certain environmental variables, like amount of rainfall received, time of planting and summation of heat units (Table 15) were determined.

Results showed that even in the dry savanna, too much water or excessively long wet periods can reduce production even in an adapted

variety like sorghum. This agrees with Konate (1984), who showed that millet crop yield will not be more than average even if annual rainfall is above normal. Intercrop yield responded to early planting, the earlier the sowing, the better the crop yield obtained.

A poor R^2 values were obtained when yields were regressed with the sum of temperatures between sowing to harvest. Cocheme and Franquin (1967) reported a parabolic relationship between the productivity of late sorghum varieties and sum of temperature.

Table 15. A simple regression model to describe the relationship between intercrop yield and certain environmental variables.*

Component	Environmental variable	Model	R^2
Maize yield	Vs. rainfall	Y = 5156 – 4.65X	0.58
	Vs. planting date (JD)	Y = 17533 – 87.1X	0.79
	Vs. sum of temperatures	logy = 3.72 – 0.0003X	0.28
Sorghum yield	Vs. rainfall	Y = 3265 – 2.53X	0.60
	Vs. planting date (JD)	Y = 8665 – 40.9X	0.65
	Vs. sum of temperatures	Y = 2.89 + 0.00006X	0.04

*Y = Component crop yield.
X = Environmental variable.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

From Tables 6 to 15 are summaries of the results of the analyses on the performance of the various sorghum-based intercropping systems.

5.2 Description of Environmental Elements

5.2.1 Climatic elements

Samaru is characterized by a fairly uniform pattern of radiation income throughout the year and this make it can area with a high agricultural productivity potential. The difference between the calculated global radiation and the measured average global radiation of 1966-1969 through the months could have been due to changes in intensity of cloud cover during the rainy season and the harmattan dust, during the dry season. In general, solar radiation in Samaru is sufficient for crop growth and development all through the months of the years.

The knowledge of the distribution and duration of light intensity during the growing season is a basic requirement for assessing potential productivity which stands in contrast to the present very low productivity. An example is sorghum with a potential yield of about 3000 $kgha^{-1}$ yielding less than 2000 $kgha^{-1}$ (Table 6).

Rainfall in Samaru are variable, both seasonally and annually. There has been changes in rainfall amount over the years and the trend has been towards reduction thereby making Samaru drier than it use to be. Certainly,

changes in the long term rainfall pattern with time may be explained in terms of changes in the general atmospheric circulation, probably resulting in southward and/or northward movements of climatic zone (Lamb, 1968; 1972). Thus, according to Winstanley (1973), the climatic zones in the northern hemisphere move northward for about a century until around 1930. Since then, there has been a southward movement, hence a general reduction in rainfall totals (Fig. 3) and also, in the decadal averages (Table 2). This may be the reason why 29 out of the last 50 rain years were far below the long-term mean (Fig. 3).

Superimposed on the long term climatic changes are variations in rainfall with a quasi-period of the order of 5 years (Pentade) which revealed an oscillation in the trend of variability (Fig. 4). These short term variation could be associated with changes in solar activities, reasoned from the established fact that rainfall follows sun movement (Kowal and Kassam, 1975). Although, the physical mechanisms by which solar activity and climate are related remain incompletely understood (King, 1973). Nevertheless, it is this type of short term variations in the rainfall that have far reaching implication on crop development and agricultural productivity. Besides, these anomalies in rainfall amount increases the planting risk or agricultural drought as in 1998. Agricultural drought could be said to be any condition that reduces the amount, timing and distribution of rain in such a way that the physical environment of crop is no longer friendly for its optimal growth. This means that the suitability of crops being planted will need to be re-examined because, the growing period for the crops being grown might probably have been shortened.

A casual look through the general rainfall data for Samaru showed that the number of rainy days (wet days) are also highly variable with a general decreasing trend with time. With this condition, high rainfall intensities will prevail at Samaru and this will favour less infiltration, heavy runoff and soil erosion which will have a deleterious effect on the crop.

One notable observation in the rainfall pattern of Samaru is the encroachment of a Sudanian climate. This is characterized by a short rainy season from June to October with peak in July and August and, these months account for about 40 – 45% of the annual rainfall. Years with favourable rainfall events (amount and distribution) do occur at Samaru, and the need to evolve crop management strategies that will maximize production in such years becomes important.

An early identification of the "potential" for each year is a vital step in designing appropriate strategies for increased food production in the area. This can be done through assessment of the extent to which climate variability information is already used and how real time forecasts could be used to enhance crop yield production.

5.2.2 Soil Characteristics

The soils possess an argillic horizon within the profile. Hence, the clay content of these soils increases with depth. Although, the soils are deep Alfisols which has reduced the likelihood of any prevailing event of accelerated soil erosion. The bulk density of the soil increases with depth which could be caused by compaction and by ferralitic fragmental materials that are formed at lower soil depth. Furthermore, the clay content of these soils on the upper portion of the colluvium increases with depth which could

probably be as a result of two processes. First, the downward movement of the finer particles with percolating water (leaching). Second, the upward movement of clay particles caused by the action of termites (Faunal-pedoturbation). The fine particles from the latter process could eventually be lost due to erosion.

Although, the deep soils might mean an effective rooting depths for crops, the advantage might be restricted by the presence of the compact argillic horizon preventing root penetration. This restricted root development on these soil may prevent many sensitive crops from withstanding even moderate drought events. This could probably explain the relatively poor crop yield of the 1998 cropping season.

The relatively low content of clay particles (particularly at the surface soil); the presence of low activity clay minerals (kaolinitic clays) and the tendency to stabilize only minute amounts of decomposed organic matter are all symptoms of a deficiency in structural development. This lack of unstable aggregation is evident by the exhibition of a rapid surface-sealing following rainfall, and crusting with subsequent drying cycles. This crusting would adversely affect plant emergence and consequently, poor crop establishment.

The particle size distribution of the soil in the experimental farm (section 4 and Table 4) encourages slaking, packing and compaction which makes tillage easy when the soil is wet and increasingly difficult and impossible as it dries up, the reason is that the soil become caked. Excessive compaction cannot be ruled out as a result of tillage when the soil is too wet, especially when tractor drawn implements are used. Therefore, only a minimum range of moisture may be available for an optimum tilth. Again, the soil in the experimental farm possess inherently low water retention

characteristics (Table 5), which is compounded by a lack of storage depth (compacted argillic horizon). When considered along side with the mechanical impedence problems the crop-root proliferation is limited. Also as earlier observed, the soils are low in native fertility. Furthermore the soils are deficient in nitrogen with a low phosphorus content and a lack of potassium due to the kaolinitic clay (Venkateswarlu, 1987). Generally, the nutrient holding capacity of this soils are low and this means, there is a need to improve the nutrient status of this soils if appreciable crop yield is envisaged. The poor quality of fertilizer product used in the 1997 cropping season adversely affected the yield of all the component crops in the treatments containing crop mixtures and also in the monocropped treatments (Tables 6 and 7).

5.3 Cropping Characteristics and Rainfall Regimes

Early sowing and evenly distributed rainfall improves the crop growth and development, results in higher water use efficiency (Table 13) and higher intercrop grain yield. Results have shown that too much rainfall, if not properly and evenly distributed can adversely affect crop performance. Hence, there is a strong relationship between intercrop performance and rainfall regime. This becomes more significant when time of sowing is put to bear. Late sowing place the young growing crop in a very wet condition, which hamper their early growth and development.

5.4 Cropping System and Light Interception

The summaries on Table 10 further emphasize the advantage of intercropping systems over the monocrop in the area of high and efficient use

of photosynthetic active radiation. Sole maize intercepted the highest amoung of light (Table 10) but its conversion efficiency was the lowest. Intercropping systems demonstrated its advantage of higher light conversion efficiency. At the time maize is fully developed in the intercrop, sorghum will just be approaching that stage. When senescence start in maize, sorghum will be at its maximum growth stage where its canopy is highest hence, light is used more judiciously and efficiently.

5.5 Performance of the Intercrop over the Various Monocropping Systems

The result of three years of this trial have demonstrated the superiority of the intercropping system over the various monocrops. Intercropping systems harmonizes with the low external input (sustainable) agriculture, which is the farming systems that agrees with the yearnings of farmers in the developing economy; inorganic fertilizer requirements are lower than those of the monocrops, the significant increase in biological yield with this intercrops over the monocrops and the security provided by intercrop even in bad years (e.g. 1997) made it a better option over the monocrop.

In addition to these, intercropping systems have a higher resource use efficiency over the monocrops: they display higher space use efficiency (LER on page 104), higher water use efficiency (page 110), more efficient light use efficiency (page 103) and a better fertilizer use efficiency (page 98).

Manipulating spatial relationship may further improve the efficiency of various resources used.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Traditional agriculture is an economic activity where resources such as land, water, light and human are used. Modern agriculture uses planned technology and emphasizes management practices for conservation. Thus modern agriculture aims at efficient utilization of resources and managing them to achieve high productivity. Between the two systems is what is termed "The Low External Input (Sustainable) Agriculture (LEI(S)A) which formed the thrust of this study. The objective is to optimize agricultural practices at the same time conserving all resources to ensure sustainable productivity.

One of the major strategies of LEI(S)A in sub-Saharan Africa is the promotion of intercropping systems. Intercropping affects both aerial and soil environment.

6.1 Summary of the Study

Monocropping system has failed among farmers of the dry savanna of Nigeria because of the perceived risk of crop failure particularly, in bad years. the preferred cropping system is the intercropping systems which is believed to have advantage over the monocropping in offering security in bad years. The study was initiated to determine whether or not intercropping systems have an advantage over the monocrops in terms of resource utilization, productivity and stability. Furthermore, to investigate the effect of certain environmental factors like rainfall amount, temperature and time on the performance of the intercrop.

This study started by identifying, describing and characterizing the climatic and edaphic scenario of the area in relation to its agricultural potentials. In examining the influence of these elements on the productivity of the intercrops, a three year trial was carried out with eight intercropping combinations involving two sorghum varieties, "FARAFARA" and "SAMSORG-14", one maize variety, TZESR-W and a local cowpea, "Kannanado". The combinations of these component crops form the eight intercrops while, these major crops were also sown sole making a total of twelve treatments.

Total dry matter, photosynethetic active radiation (PAR) interception, leaf area index, precipitation use efficiency and yield were determined and analysed using the analysis of variance through the "SAS" computer package. The Duncan's Multiple Range Test was used to separate the means.

6.2 Conclusions

Results of analyses showed solar radiation to be high (400 cal cm^{-2} day^{-1}) signifying abundant light energy. Since crops occupy a strategic link in the conversion of incoming solar radiation through photosynthesis into energy utilizable by man, it suggests that Samaru has a high potential for increasing crop production.

Rainfall amount has beer below the long-term average (1050 mm) in recent years, with high variability on both seasonal, annual and decadal scales (Table 2). Besides, the small annual total is erratic and unreliable in distribution. This again is a constraint to sustainable agricultural production under traditional farming systems because the farmers have no control over

the negative precipitation. Variabilities causing high probability of extreme dryness to drought condition at the beginning and end of the growing season, limits traditional agricultural system.

The soils of the experimental site are the self-mulching clays, which are plastic when, wet and crack under dry conditions. They are also deep with a high tendency to compact and crust. These characteristics impede root growth and development. Apart from poor infiltration characteristics, the soils also have a low water retention ability. They are low in native nitrogen and phosphorus thereby making nutrient status another important constraint limiting agricultural productivity.

Observations have shown greater and efficient use of resources under the intercropping system particularly, the SAMSORG-14/Maize mixtures. The fraction of light interception increased rapidly from 42DAS and reaching a maximum interception (<80%) at 70 DAS before a sharp decline. Although, monocropped maize recorded the highest maximum light interception, it was not significant with those of the mixtures. While, light interception in mixtures were superior to those of the monocropped sorghum.

The time of maximum light interception coincided with those of maximum canopy cover with Leaf Area Index (LAI) reaching a peak at 70 DAS. SAMSORG-14 grow much faster than Farafara sorghum variety. This is because SAMSORG-14 is a variety that is locally adapted to the drier Sudan savanna zone and, which behaved as an early variety at Samaru, with has a longer growing season. SAMSORG-14 therefore will naturally grow faster than the Farafara, which has local adaptation to the growing season at Samaru.

In maize, canopy cover was similar in all the treatment reaching a highest value of 3.35 in the FARAFARA/Maize-S. Small yield advantages were observed from intercropping system in wet years when sowing was done early at optimum soil fertility level as in 1996 cropping season. This is not usually the case on farmers field. Farmers in most cases plant their crops late and the amount of fertilizers applied to crops is rarely adequate to obtain a sustainable system (Jaiyeoba, 1995; Yusuf, 1996; Ogungbile *et al.*, 1998). The cropping seasons of 1997 and 1993 reflects a sub-optimal soil fertility condition and delayed sowing respectively, and, these results are the reflection of farmers' situation. Yield advantages under the intercropping systems in these two years was enormous. An indication of a low likelihood of total crop failure under intercropping even in very bad years.

Sorghum grain yield was higher in local farafara in 1996 and 1998 over the improved SAMSORG-14 variety (Table 12). This may not be unconnected with the explanation of Curtis (1968a&b) where he suggested many locally adapted sorghum variety to be restricted to a fairly small area and perform extremely well within the locality. Outside this zone, such variety, may give poor yields or fail. In maize, there was no difference in grain yield among the intercrop treatment because most farmers' maize are the improved varieties, which are becoming well adapted to the agroecological zones.

The local Farafara exhibited higher water use efficiency when sown early, an indication of local adaptation. Stand intercrop enhance sorghum yield in mixture while, for maize row intercrop enhance yield though not significant. The three component crop mixtures had a higher yield advantage over the two component crop mixtures though not significant in all the years

in the Farafara component of the mixture. Intercropping used more total nitrogen, and available phosphorus while making the soil more acidic in reaction due to inorganic fertilization.

Furthermore, intercropping had a higher light conversion efficiency over the monocrop. The Farafara/maize/cowpea-R had the highest value of light use efficiency. It produced 4.67 g dry matter per unit megajoules of light intercepted. Generally, mixtures involving SAMSORG-14 have a higher mean conversion efficiency than those involving Farafara. In addition, intercrop yield is increased when rains are evenly distributed and not necessarily to be much.

6.3 *Agricultural Planning Implications*

The principles of local adaptation in Nigeria sorghum, which have been observed in this study, makes it important that local varieties be encouraged and improved upon in their locality. This is because local varieties have been selected over many generations to mature at the end of the rains. When grains which ripens early is planted they are usually mouldy and often attacked by insects, particularly, the sucking bugs, while varieties which flower too late give small yields or may not mature at all, probably due to insufficient water to provide for the needs of the crop during the grain-filling period.

This study has further buttress the importance of early planting on crop performance and yield. Any agricultural planning that will cause farmers to delay planting such as late distribution of fertilizer, etc., should be discouraged. The addition of cowpea would improve the yield advantage,

improve the diet of the farmers and, cause an appreciable cowpea yield along with the cereals when planted early.

Practices that will increase soil native fertility status and improve soil physical and hydraulic properties be pursued. Such practices in addition to inorganic fertilization include organic fertilization using farmyard manure, green manuring and crop residue incorporation. This will help sustain the soil resource base. Hence, fertilizer subsidy by government is one of the ways to encourage farmers to increase agricultural output. Weather-responsive farming system, such that sowing is done as soon as the rain established should be extended to farmers. Even in years where rainfall amount and number of rainy days are low as in 1996 cropping season. Early sowing will give crops an advantage to mature before drought situation comes in. Also water harvesting techniques at farm level (e.g. tie-ridging) need to be studied and extended in such a away that farmers will know when to tie their ridges for different crops to nullify drought effects. Also much tillage and other practices that will reduce evaporation loss until crop canopy cover is fully established need to be extended also.

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6.4 Recommendations and Suggestions for Further Studies

The findings from this study on intercropping supports the assertion that it is an appropriate technology. It has shown that there are important yield and resource utilization advantages to the sorghum based intercropping system. Generally, the locally adapted sorghum variety is recommended because of reasons given in 6.2. Maize grain yield was higher in the Farafara mixtures than in the SAMSORG-14 (Table 14) hence, the Farafara/Maize

mixture is recommended over the SAMSORG-14/Maize mixture. Plant arrangement will depend on farmers' crop preference; if sorghum is preferred stand intercrop is recommended while for maize, the row intercrop is better.

Further research work need to be carried out to improve our understanding about atmospheric process inducing climate variability with a view to making farm level forecast with 75% precision and 90 days advance. Also, studies towards identification of appropriate crop cultivars with optimum physiology, morphology and phenology to suit local environmental condition especially, the pattern of water availability need to be pursued. Such studies for sorghum would need to recognize the local adaptability of sorghum to native environment and ecology. In addition, there is a need for future work to make fertilizer recommendations for the sorghum/maize mixtures under both the replacement and superimposed intercropping systems.

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APPENDIX

FORMULAE FOR STATISTICAL ANALYSES

1. Standard Deviation (ℓ) $\left(\frac{\sum x^2}{N}\right)^{1/2}$

   where [] = deviation between an item of data and the arithmetic mean

2. Coefficient of variability (CV) = $\left(\frac{\ell}{\bar{X}}\right)100$

3. Coefficient of skewness (Z_1):

$$Z_1 = \frac{\left[\sum_{i=1}^{N}(x_i - \bar{x})^3/N\right]\left[\sum_{i=1}^{N}(x_1 - \bar{x})^2/N\right]^{-3/2}}{(\ell/N)^{\frac{1}{2}}}$$

4. Coefficient of Kurtosis (Z_2):

$$Z_2 = \frac{\left\{\left[\sum_{i=1}^{N}(x_i - \bar{x})^4/N\right]\left[\sum_{i=1}^{N}(x_1 - \bar{x})^2/N\right]^{-2}\right\} - 3}{(24/N)^{\frac{1}{2}}}$$

5. Mann-Kendall rank statistics (τ)

$$\tau = \frac{4\sum ni}{N(N-1)} - 1$$

where *ni* is the number of values larger than the *ith* value in the series subsequent to its position in the series of *N* values.

The variance of τ:

$$\delta^2\tau = \frac{(4N+10)}{9N(n-1)}$$

The ratio of τ to its standard deviation $(\tau/\delta\tau)$ is an indication of trend in the data.

6. Cramer's moving statistics (*tk*):

$$tk = \left[\frac{n(N-2)}{N - n(1+\tau_k^2}\right]^{1/2} \tau k$$

where $\tau k = tk = (\bar{x}_k - \bar{x})/S$

$\bar{x}$ = mean of entire record length N

S = standard deviation of the entire record length N

Xk = mean of the subperiod of n years

tk = value of student's t with n-2 degrees of freedom.

7. 't' test statistics (t_d)

$$t_d = \frac{\bar{x}_1 - \bar{x}_2}{\left[\frac{N_1S_1^2 + N_2S_2^2}{N_1 + N_2 - 2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right)\right]^{1/2}}$$

where,

$\bar{X}_1$ & $\bar{X}_2$ Are the means of the two subperiods.

N_1 & N_2 Are the number of years in the data set

S_1 & S_2 Are the standard deviations for the two subperiods

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APPENDIX 2

INTERCEPTED PHOTOSYNTHETIC ACTIVE RADIATION (PAR) BY SORGHUM UNDER DIFFERENT CROPPING SYSTEMS AT SAMARU, NIGERIA

(1996-1998)

CROPPING SYSTEMS	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP	14 WAP
FARAFARA	0.227b	0.287b	0.693bc	0.790ab	0.557bc	
FARAFARA/MAIZE/COWPEA-R	0.227b	0.297b	0.690bc	0.793ab	0.567abc	
FARAFARA/MAIZE-R	0.240b	0.300b	0.683c	0.757abc	0.510c	
SAMSORG-14	0.277b	0.300b	0.700bc	0.780abc	0.560bc	
SAMSORG-14/MAIZE/COWPEA-S	0.477a	0.580a	0.803a	0.833a	0.650ab	
FARAFARA/MAIZE-S	0.483a	0.580a	0.787ab	0.800ab	0.600abc	
FARAFARA/MAIZE/COWPEA-S	0.493a	0.590a	0.797a	0.813a	0.670a	
SAMSORG-14/MAIZE-S	0.503a	0.577a	0.803a	0.800ab	0.607abc	
SAMSORG-14/MAIZE/COWPEA-R	0.243b	0.317b	0.677c	0.697c	0.560bc	
SAMSORG-14/MAIZE-R	0.227b	0.300b	0.673c	0.710bc	0.533c	
STANDARD ERROR	0.035	0.032	0.030	0.028	0.032	

PHOTOSYNTHETIC ACTIVE RADIATION (PAR) IN SORGHUM (1997)

FARAFARA	0.110d	0.313c	0.520d	0.683b	0.637bc	0.500cd
FARAFARA/MAIZE/COWPEA-R	0.170c	0.303c	0.513d	0.817a	0.700abc	0.570abc
FARAFARA/MAIZE-R	0.193bc	0.313c	0.537d	0.710b	0.617c	0.507bcd
SAMSORG-14	0.223b	0.410b	0.613c	0.837a	0.753a	0.580ab
SAMSORG-14/MAIZE/COWPEA-S	0.400a	0.493a	0.700ab	0.887a	0.797a	0.563abc
FARAFARA/MAIZE-S	0.390a	0.487a	0.663b	0.843a	0.753a	0.537abcd
FARAFARA/MAIZE/COWPEA-S	0.393a	0.500a	0.700ab	0.890a	0.787a	0.603a
SAMSORG-14/MAIZE-S	0.420a	0.523a	0.717a	0.853a	0.747a	0.493cd
SAMSORG-14/MAIZE/COWPEA-R	0.207bc	0.393b	0.620c	0.850a	0.747a	0.537abcd
SAMSORG-14/MAIZE-R	0.217b	0.403b	0.607c	0.840a	0.720ab	0.470d
STANDARD ERROR	0.014	0.018	0.014	0.036	0.031	0.023

PHOTOSYNTHETIC ACTIVE RADIATION (PAR) IN SORGHUM (1998)

FARAFARA	0.177	0.237c	0.533d	0.610b	0.700b	0.480a
FARAFARA/MAIZE/COWPEA-R	0.237	0.317bc	0.543cd	0.740ab	0.763ab	0.400ab
FARAFARA/MAIZE-R	0.267	0.330ab	0.547cd	0.730ab	0.777ab	0.403bc
SAMSORG-14	0.260	0.317bc	0.59abc	0.737ab	0.777ab	0.350cd
SAMSORG-14/MAIZE/COWPEA-S	0.287	0.420a	0.633a	0.797a	0.833a	0.300e
FARAFARA/MAIZE-S	0.287	0.350ab	0.577bcd	0.727ab	0.807ab	0.377bc
FARAFARA/MAIZE/COWPEA-S	0.243	0.320bc	0.560cd	0.797a	0.847a	0.377bc
SAMSORG-14/MAIZE-S	0.287	0.353ab	0.613ab	0.770a	0.843a	0.270e
SAMSORG-14/MAIZE/COWPEA-R	0.217	0.320bc	0.557cd	0.767a	0.777ab	0.387bc
SAMSORG-14/MAIZE-R	0.287	0.367ab	0.543cd	0.743ab	0.807ab	0.333cde
STANDARD ERROR	0.044	0.029	0.015	0.041	0.032	0.023

APPENDIX 3

DRY MATTER YIELD (DMY) OF SORGHUM UNDER DIFFERENT CROPPING SYSTEMS AT SAMARU, NIGERIA

(1996-1998)

CROPPING SYSTEMS	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP	14 WAP
FARAFARA	2.741b	17.3b	54.27b	172.67a	455.83a	
FARAFARA/MAIZE/COWPEA-R	2.23c	15.17c	48.70c	155.53b	410.6b	
FARAFARA/MAIZE-R	2.03de	13.17de	40.37de	130.13c	345.37c	
SAMSORG-14	3.12a	19.27a	57.93a	129.10cd	388.1b	
SAMSORG-14/MAIZE/COWPEA-S	1.98e	11.73f	39.20e	120.97de	322.70cd	
FARAFARA/MAIZE-S	2.04de	13.23de	39.10e	125.47cd	330.97cd	
FARAFARA/MAIZE/COWPEA-S	2.10cde	13.57d	41.27d	130.43c	341.03c	
SAMSORG-14/MAIZE-S	1.98e	12.20ef	36.90f	114.60e	305.90d	
SAMSORG-14/MAIZE/COWPEA-R	2.13cd	12.67def	39.37de	125.97cd	332.57cd	
SAMSORG-14/MAIZE-R	2.16cd	13.17de	40.57de	128.53cd	339.33cd	
STANDARD ERROR	0.046	0.34	0.62	2.69	8.53	
DRY MATTER YIELD (g) IN SORGHUM (1997)						
FARAFARA	1.25cde	5.23d	17.73cd	59.03cd	240.17cd	418.03cd
FARAFARA/MAIZE/COWPEA-R	1.27cde	5.30d	16.70d	56.43d	218.23de	379.73de
FARAFARA/MAIZE-R	1.31bcd	5.54cd	16.70d	52.43d	203.90e	354.77e
SAMSORG-14	1.98a	8.90a	28.23a	97.27a	343.4a	597.5a
SAMSORG-14/MAIZE/COWPEA-S	1.43b	6.09c	19.80c	65.97c	258.23c	449.33c
FARAFARA/MAIZE-S	1.17e	5.07d	16.13d	51.63d	199.37e	346.9e
FARAFARA/MAIZE/COWPEA-S	1.19de	5.08d	16.87d	58.90cd	245.97c	425.4cd
SAMSORG-14/MAIZE-S	1.87a	7.82b	24.90b	79.40b	303.13b	511.77b
SAMSORG-14/MAIZE/COWPEA-R	1.32bc	5.62cd	18.67cd	65.17c	251.53c	418.77cd
SAMSORG-14/MAIZE-R	1.33bc	5.63cd	18.80cd	66.03c	254.87c	418.47cd
STANDARD ERROR	0.038	0.232	0.809	2.53	8.37	14.07
DRY MATTER YIELD (g) IN SORGHUM (1998)						
FARAFARA	1.11cd	3.40cd	11.63cd	31.37de	129.03de	272.27de
FARAFARA/MAIZE/COWPEA-R	1.02d	3.26d	11.13cd	30.50de	129.03de	263.60e
FARAFARA/MAIZE-R	1.09cd	3.31cd	11.30cd	30.00c	124.17e	262.20e
SAMSORG-14	1.55a	4.99	17.47a	43.0a	177.20a	301.00c
SAMSORG-14/MAIZE/COWPEA-S	1.18bcd	3.58cd	12.20c	39.33b	162.97b	343.87b
FARAFARA/MAIZE-S	1.07d	3.27cd	11.03d	29.93e	130.40de	275.17de
FARAFARA/MAIZE/COWPEA-S	1.09cd	3.32cd	11.33cd	40.47b	170.77ab	360.33a
SAMSORG-14/MAIZE-S	1.18bcd	3.59c	12.20c	32.80d	135.37d	285.67d
SAMSORG-14/MAIZE/COWPEA-R	1.26bc	3.93b	13.37b	36.00c	148.30c	261.67e
SAMSORG-14/MAIZE-R	1.29b	3.91b	13.27b	35.80c	148.83c	261.47e
STANDARD ERROR	0.050	0.097	0.325	0.849	3.42	4.48

APPENDIX 4

DRY MATTER YIELD (DMY) OF MAIZE UNDER DIFFERENT CROPPING SYSTEMS AT SAMARU, NIGERIA

(1996-1998)

CROPPING SYSTEMS	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP	14 WAP
FARAFARA/MAIZE/COWPEA-R	13.37cd	76.17de	180.53d	274.17cde	316.23cde	
FARAFARA/MAIZE-R	13.97bc	79.60bcd	189.27bc	283.93cd	313.10de	
SAMSORG-14/MAIZE/COWPEA-S	15.13a	86.30a	205.73a	301.20ab	339.57b	
FARAFARA/MAIZE-S	13.83bcd	78.23cde	185.40cd	278.10cde	318.43cde	
FARAFARA/MAIZE/COWPEA-S	14.27b	81.33bc	192.77b	289.20abc	331.13bc	
SAMSORG-14/MAIZE-S	13.17d	75.03e	177.87d	266.40e	314.83cde	
SAMSORG-14/MAIZE/COWPEA-R	14.27b	82.33b	196.73a	286.73bc	328.33bcd	
SAMSORG-14/MAIZE-R	13.13d	75.33e	179.80d	269.10de	308.13e	
SOLE MAIZE	15.53a	88.53a	209.90a	303.3a	363.87a	
STANDARD ERROR	0.217	1.16	2.66	4.66	5.25	

DRY MATTER YIELD (g) IN MAIZE (1997)

FARAFARA/MAIZE/COWPEA-R	5.23d	28.80e	80.67c	102.73d	122.97d	135.20d
FARAFARA/MAIZE-R	5.27d	29.70de	83.17c	104.23d	125.03c	137.17d
SAMSORG-14/MAIZE/COWPEA-S	6.10c	33.33cd	92.80b	117.87c	141.47c	155.90c
FARAFARA/MAIZE-S	7.37a	41.60a	105.80a	129.23b	155.10bc	169.83bc
FARAFARA/MAIZE/COWPEA-S	*7.17ab*	*41.07a*	*105.17a*	*144.80a*	*184.70a*	*203.77a*
SAMSORG-14/MAIZE-S	5.13d	28.30e	79.23c	99.17d	119.03d	130.87d
SAMSORG-14/MAIZE/COWPEA-R	6.47bc	38.57ab	101.70ab	136.07ab	166.47b	182.27b
SAMSORG-14/MAIZE-R	6.30c	37.23b	100.03ab	134.67ab	161.70b	176.77b
SOLE MAIZE	6.17c	35.80bc	98.20ab	127.87bc	153.23bc	168.00bc
STANDARD ERROR	0.253	1.22	2.85	3.58	4.39	4.69

DRY MATTER YIELD (g) IN MAIZE (1998)

FARAFARA/MAIZE/COWPEA-R	8.60bc	59.17bc	144.53b	188.97b	251.37bc	279.00bc
FARAFARA/MAIZE-R	8.30cd	57.10cd	139.50b	181.97b	241.97bc	268.57bc
SAMSORG-14/MAIZE/COWPEA-S	8.13cd	55.93cd	136.67b	185.03b	256.07b	286.50b
FARAFARA/MAIZE-S	7.67d	52.73d	128.83bc	168.77bc	224.47cd	249.13cd
FARAFARA/MAIZE/COWPEA-S	6.97e	47.93e	117.73c	167.8bc	223.17cd	247.77cd
SAMSORG-14/MAIZE-S	9.20b	63.27b	137.20b	179.70b	239.00bc	265.27bc
SAMSORG-14/MAIZE/COWPEA-R	7.03e	48.37e	118.13c	154.77c	205.83d	228.57d
SAMSORG-14/MAIZE-R	7.90d	54.40d	132.90bc	171.77bc	228.47cd	254.07cd
SOLE MAIZE	10.07a	69.43a	169.60a	222.2a	295.53a	328.07a
STANDARD ERROR	0.201	1.382	4.95	6.73	8.95	9.82

APPENDIX 5

INTERCEPTED PHOTOSYNTHETIC ACTIVE RADIATION (PAR) BY MAIZE UNDER *DIFFERENT CROPPING SYSTEMS AT SAMARU, NIGERIA*

(1996-1998)

CROPPING SYSTEMS	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
FARAFARA/MAIZE/COWPEA-R	0.460	0.633ab	0.847	0.767	0.607
FARAFARA/MAIZE-R	0.470	0.667ab	0.870	0.783	0.603
SAMSORG-14/MAIZE/COWPEA-S	0.477	0.580b	0.803	0.833	0.650
FARAFARA/MAIZE-S	0.483	0.580b	0.787	0.800	0.600
FARAFARA/MAIZE/COWPEA-S	0.493	0.590b	0.797	0.813	0.670
SAMSORG-14/MAIZE-S	0.503	0.577b	0.803	0.800	0.607
SAMSORG-14/MAIZE/COWPEA-R	0.473	0.623ab	0.820	0.740	0.597
SAMSORG-14/MAIZE-R	0.487	0.637ab	0.857	0.740	0.587
SOLE MAIZE	0.547	0.723a	0.890	0.810	0.603
STANDARD ERROR	0.036	0.033	0.031	0.028	0.027
		PAR IN MAIZE (1997)			
FARAFARA/MAIZE/COWPEA-R	0.453ab	0.750ab	0.860a	0.733bc	0.587c
FARAFARA/MAIZE-R	0.463ab	0.767ab	0.840a	0.740bc	0.587c
SAMSORG-14/MAIZE/COWPEA-S	0.400cde	0.493c	0.700b	0.887a	0.797a
FARAFARA/MAIZE-S	0.390e	0.487c	0.663b	0.843abc	0.753ab
FARAFARA/MAIZE/COWPEA-S	0.393de	0.500c	0.700b	0.890a	0.787a
SAMSORG-14/MAIZE-S	0.420bcde	0.523c	0.717b	0.853ab	0.747ab
SAMSORG-14/MAIZE/COWPEA-R	0.447bc	0.733b	0.847a	0.747bc	0.657bc
SAMSORG-14/MAIZE-R	0.440bcd	0.720b	0.843a	0.727c	0.637ab
SOLE MAIZE	0.500a	0.793a	0.900a	0.850ab	0.757ab
STANDARD ERROR	0.015	0.016	0.024	0.037	0.038
		PAR IN MAIZE (1998)			
FARAFARA/MAIZE/COWPEA-R	0.460	0.633ab	0.847	0.733bc	0.587c
FARAFARA/MAIZE-R	0.470	0.667ab	0.870	0.740bc	0.587c
SAMSORG-14/MAIZE/COWPEA-S	0.477	0.580b	0.803	0.887a	0.797a
FARAFARA/MAIZE-S	0.483	0.580b	0.787	0.843abc	0.753ab
FARAFARA/MAIZE/COWPEA-S	0.493	0.590b	0.797	0.890a	0.787a
SAMSORG-14/MAIZE-S	0.503	0.577b	0.803	0.853ab	0.747ab
SAMSORG-14/MAIZE/COWPEA-R	0.473	0.623ab	0.820	0.747bc	0.657bc
SAMSORG-14/MAIZE-R	0.487	0.637ab	0.857	0.727c	0.637bc
SOLE MAIZE	0.547	0.723a	0.890	0.850ab	0.757ab
STANDARD ERROR	0.036	0.033	0.031	0.037	0.036