

MICROCLIMATE MODIFICATION AND WEED GROWTH IN
TRADITIONAL MILLET/COWPEA AND MILLET/ SORGHUM/COWPEA
INTERCROPS IN THE SUDAN SAVANNA OF NIGERIA

BY

CHALES UDUAK UDO-INYANG

A thesis submitted to the Postgraduate School, Ahmadu Bello
University, Zaria in partial fulfillment for the award of
Master of Science degree.

Department of Soil Science
Faculty of Agriculture
Ahmadu Bello University
Zaria

DECLARATION

I hereby declare that this thesis was written by me and that it is a record of my own independent 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.



U.C. Udo-Inyang

Date 8-08-96

The above declaration is hereby confirmed.



Pro. J.J. Owonubi
Chairman
Supervisory Committee

Date 4/3/97

CERTIFICATION

This thesis entitled "Microclimate modification and weed growth in traditional Millet/Cowpea and Millet/Sorghum/Cowpea intercrops in the Sudan Savanna of Nigeria" by Udo-Inyang Uduak Charles meets the regulations governing the Degree of Master of Science, Ahmadu Bello University, Zaria and is approved for its literary presentation and contribution to Scientific knowledge.



Prof. J.S. Owonubi
Chairman
Supervisory committee

Date 4/3/97



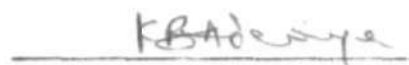
Prof. C.J. Stigter
Member
Supervisory committee

Date 28/5/97



Prof. V.O. Chude
Member
Supervisory committee

Date 11/3/97



Prof. K.B. Adeoye
Member
Supervisory committee

Date 14/04/98



Prof. V.O. Chude
Head of Department

Date 11/3/97



Dean
Postgraduate school

Date 16/9/98

DEDICATION

To the Holy Spirit

ACKNOWLEDGEMENT

I owe the successful conclusion of this work to God Almighty for His manifold abundance towards me in all things. My profound appreciation also goes to the Netherlands Government for sponsoring this work under the auspices of the Traditional Techniques of Microclimate Improvement (TTMI) project in which collaborated the Ahmadu Bello University (Geography Department), the Institute for Agricultural Research (Soil Science Department) and Wageningen Agricultural University (Meteorology Department), The Netherlands. I am particularly indebted to the duo of Profs. J.J. Owonubi and C.J. Stigter for their meticulous guidance throughout the course of this work. I am also grateful to Prof. V.O. Chude for his invaluable advice and love. My sincere appreciation goes to my senior colleague, K.O. Oluwasemire, for giving me unhindered access to his wealth of experience. Tunji, I love you.

I thank all staff of ILTA Kano and particularly Moh'd Isiaku, Hakeem and Yarama Ndirpaya for their unquantifiable support; my regards also go to the duo of Victoria Yiliwa and Yemi. To all staff of Agricultural Research Station Kano, and particularly to Dr. E.C. Odion and the officer-in-charge, Mr Mayaki, I say I am grateful.

I am indebted to many of my friends for their unalloyed loyalty during the trying days of this study. To Dr. Ahamba, Dr Ante, Dr. Adom, Dr. Ndububa, Dr. Komolafe, Dr. Oladokun, Emmanuel Aladi, Osas Ekeiozuwa, Emmanuel Ukpe, Emmanuel Ntuk, Aniefiok Udoekong, U.T. Ntia, Paul Ekpeowo, Ubong Ukpe and my cousin Emmanuel Matthew, I say thanks.

My deepest appreciation goes to my family members. I am grateful to Dr. Udo-Inyang and his wife Florence for their lavished spiritual and physical support. I am grateful to my parents Mr. and Mrs. C.A. Udo-Inyang for laying in me the right foundation upon which this stride is built.

I acknowledge all members of Christ Harvesters Church Zaria, and Living Faith Church, Kano for their untiring spiritual fireworks that single handedly made the "lines to

fall unto me in pleasant places" in the course of this study. My appreciation also go to Mr. John for typesetting draft of this work.

Finally, for want of space, I cannot possibly mention all persons that were instrumental to the realisation of this study. To those whose names are not mentioned, from my heart of hearts, I do appreciate your manifold contributions.

ABSTRACT

Crop environment and weed interaction were assessed in millet/cowpea and millet/cowpea/sorghum cropping systems under traditional and improved agronomic conditions in the Sudan Savanna zone of Nigeria. The specific objectives of the experiment were to measure the effect of the intercropping on light transmission, assess the effect of intercropping on the soil and canopy temperature, and to quantify the effect of the intercropped environment on the type, yield and frequency of weed growth. One variety of millet (EX bornu), two varieties of sorghum (1CSV-400 and Gaya Early) and two varieties of cowpea (Dan-ilia and IT89KD-3/4) were used for this study in the intercropped combination. Two fertility levels (organic manure and inorganic fertilizer) were also employed. Microclimatological and plant indices measured include light transmission, soil temperature, canopy temperature, weed frequency, weed and crop shoot biomass.

Results show that canopy temperature, soil temperature, and light transmission within the canopy were lower in the intercropped combinations than in the sole, weed dry weights were also lower on the average in the intercrops than in sole plots, although sole crops of millet and sorghum were planted at a higher density than the intercrops. In intercropping combinations associated with sorghum, sorghum 1CSV-400 was observed to be more efficient in suppressing weeds than the local Gaya Early variety. It was also observed that *Digitaria horizontalis* and *Cyperus esculentus* showed the highest frequency of occurrence for both trials. This study indicates that controlling the weed regime of the cropping systems of the study area is dependent upon understanding the light reactions of these two notorious weeds.

TABLE OF CONTENTS

DECLARATION	ii
CERTIFICATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xi
LIST OF FIGURES	xiii
CHAPTER 1	
INTRODUCTION	1
1.1 Objective of the Study	3
1.2 Study Justification	4
CHAPTER 2	
LITERATURE REVIEW	5
2.1 Definition of Microclimate	5
2.2 Definition of Weeds	5
2.3 Effects of Weeds on Crops	6
2.3.1 <i>Competitive effects</i>	7
2.3.2 <i>Allelopathic effects</i>	8
2.3.3 <i>Weeds as hosts for pests and diseases</i>	9
2.4 Microclimate Modification in Intercrops	10
2.4.1 <i>Weed response to shade</i>	14
2.4.2 <i>Intercropping and weed suppression</i>	17
2.5 Solar Radiation Capture and Use in Intercrops	20
2.5.1 <i>Radiation capture in intercrops</i>	22
2.5.1.1 <i>Light interception over time</i>	22
2.5.1.2 <i>Light interception in space</i>	24

	1x
2.5.2 Radiation use in intercrops	28
2.5.2.1 Assimilate production	29
2.5.2.2 Assimilate partitioning and crop yield	31
CHAPTER 3	
MATERIALS AND METHODS	33
3.1 Experimental Site/Soil Type and Geology	33
3.2 Crop Varieties Planted	34
3.3 Experimental Treatment	34
3.4 Experimental Design/Replication	35
3.5 Seedbed Preparation	35
3.6 Time of Planting	36
3.7 Soil Measurements	37
3.8 Radiation Measurement	42
3.9 Soil Temperature Measurements	44
3.10 Canopy Temperature Measurements	45
3.11 Weed Inventory	46
3.12 Meteorological Data	46
CHAPTER 4	
RESULTS	47
4.1 Weed Biomass	47
4.2 Weed Frequency	51
4.3 Canopy Temperature	60
4.4 Soil Temperature	66
4.5 Light Transmission	73
4.6 Grain Yield	87
CHAPTER 5	
DISCUSSION	93
5.1 Weed Biomass/Frequency	93

5.2	Effect of Intercropping Millet and Cowpea with Sorghum ICSV-400	98
5.3	Effects of Intercropping Millet and Cowpea with Sorghum Gaya Early	99
5.4	Effects of Intercropping Millet with Cowpea	100
5.5	Light Transmission and Weed Biomass	101
5.6	Weed Biomass and Crop Yield	102
CHAPTER 6		
	SUMMARY AND CONCLUSION	104
	REFERENCES	106
	APPENDIX A: MIJIBIR WEATHER DATA, 1994	119
	APPENDIX B: MIJIBIR WEATHER DATA, 1995	120

LIST OF TABLES

Table 1	Pre-planting soil analysis	38
Table 2	Post-harvest soil analysis	40
Table 3a	Effect of cropping systems on weed biomass 1994	49
Table 3b	Effect of cropping systems on weed biomass 1995	50
Table 4a	Percent relative incidence of weeds (frequency of occurrence on JD 244 (1994 2nd weeding)	53
Table 4b	Percent relative incidence of weeds (frequency of occurrence on JD 274 (1995 3rd weeding)	54
Table 5a	Percent relative incidence of weeds (frequency of occurrence) on JD 182 (1995 1st weeding)	56
Table 5b	Percent relative incidence of weeds (frequency of occurrence) on JD 213 (1995 2nd weeding)	57
Table 5c	Percent relative incidence of weeds (frequency of occurrence) on JD 244 (1995 3rd weeding)	58
Table 6a	Percent contribution of individual weed to total weed biomass on JD 182 (1995 1st weeding)	61
Table 6b	Percent contribution of individual weed to total weed biomass on JD 213 (1995 2nd weeding)	62
Table 6c	Percent contribution of individual weed to total weed biomass on JD 244 (1995 3rd weeding)	63
Table 7	Effect of cropping systems on canopy temperature	64
Table 8a	Percentage light transmission within cropping arrangement (1994)	74
Table 8b	Percentage light transmission within cropping arrangement (1995)	76

Table 9a	Effect of cropping system on light transmission (1994)	88
Table 9b	Effect of cropping system on light transmission (1995	89
Table 10a	Effect of cropping systems on grain yield (1994)	91
Table 10b	Effect of cropping systems on grain yield 1995	91

LIST OF FIGURES

Figure 1	Planting pattern/crop arrangement	41
Figure 2	Weather data for 1994/95 seasons	48
Figure 3	Average soil temperature at 1 week before 2nd weeding (1994)	67
Figure 4	Average soil temperature at 1 week before 3rd weeding (1994)	68
Figure 5	Average soil temperature at 1 week before 1st weeding (1995)	69
Figure 6	Average soil temperature at 1 week before 2nd weeding (1995)	71
Figure 7	Average soil temperature at 1 week before 3rd weeding (1995)	72
Figure 8	Light transmission within millet/sorghum/ cowpea 1994)	78
Figure 9	Light transmission within millet/cowpea 1994)	80
Figure 10	Light transmission in sole crop (1994) .	81
Figure 11	Light transmission within millet/sorghum/ cowpea (1995)	83
Figure 12	Light transmission within millet/cowpea (1995)	84
Figure 13	Light transmission in sole crop (1995) .	85
Figure 14	Effect of cropping system on weed biomass (1994)	94
Figure 15	Effect of cropping system on weed biomass (1995)	95

CHAPTER 1

INTRODUCTION

In the tropics, weed interference causes severe yield reductions in field crops and losses can well exceed 50%. For maize and cassava, losses up to 60% have been reported (Akobundu, 1979; Ayeni *et al.*, 1984). The time spent on weeding is the principal limiting factor to the size of a farm that a subsistence farmer cultivates; this therefore makes weed suppression a major agricultural concern.

The traditional method used by peasant farmers to control weeds is hoeing, using household labour since hiring of labour is usually expensive. For such farmers, use of herbicides is hampered by high cost and non-availability of chemicals. The training, experience and precision required for efficient use of the contaminating herbicides is also a limitation. There is an urgent need to study alternative methods of weed control acceptable to them. Intercropping is one of such methods.

Most intercropping combinations are reported to suppress weed growth by providing an early ground cover, either due to the use of high plant populations or the use of a fast growing component crop (Steiner, 1982; Evans, 1972). Thus the use of low-canopy crops as smother crops for biological weed control is receiving attention (Shetty and Rao, 1979; Akobundu, 1981). In Nigeria, it is common to sow for that purpose cowpea into established sorghum, millet or maize. Similar methods are also common in most other West African countries. In Asia, crop associations of maize and

4
groundnut, mungbean, or sweet potato are excellent for reducing weed growth, yield losses and weeding time (Moody, 1978). Intercropping cassava with beans proved to be an efficient means of reducing weed growth in central America.

The success of an intercropping system in suppressing weed growth depends primarily on crop micro-climate. Light (Photosynthetic Active Radiation, PAR) is one of the major climatic factors influencing crop-weed balance. It is well known that intensive cropping and the use of crop management practices that improve the shading capacity of crops increase the efficiency of biological weed control methods. Soil Shading observed in any given crop canopy is a dynamic feature that varies with the relative rates of crop and weed growth, crop duration and location (Shetty *et al.*, 1977). Competitive capacity of plants is determined in part by their ability to intercept light and by the capacity to suppress the growth and development of other plants, such as shade-sensitive weeds which may occur in the shade created by crop canopies (Keely and Thullen, 1978).

There is a considerable number of studies on light interception in several crops and crop combinations in the semi-arid tropics. Sivakumar and Virmani (1984) suggested that intercropping of short-duration and fast-growing cereal crops such as maize or sorghum with the slow growing pigeon-pea could establish a quick ground cover, enabling high photosynthetic photon flux density (PPFD) interception (high shading) levels. Natarajan and Willey (1980b) showed from measurements of light interception at ground level that a sorghum/pigeon-pea intercrop could attain 80% interception in about 50 days after planting. They also suggested that

poor light interception by pigeon-pea after the sorghum harvest could be increased by higher plant population density and better plant distribution. Keedy *et al.* (1969) reported from light interception measured at ground level that a groundnut/pearl millet intercrop could achieve 75% light interception in about 50 days after planting. These studies showed the high shading capacity of different cropping systems of the semi-arid tropics, thus indicating the potential to suppress the growth of associated weeds. It also buttressed the importance of understanding the PAR balance within crop canopies if crop manipulation is to be used to reduce weeding problems in traditional agriculture.

1.1 Objective of the Study

Crop/weed interaction in intercropping systems depends on various physical, biological and management factors. Understanding the dynamics of intercropping with a view to shifting the crop/weed balance in favour of crops is imperative, because there is a dearth of such studies in Nigeria in general, and in the Nigerian Sudan savanna in particular. It is in this realization that this study was conceived. Specifically, the objectives of the study were to:

- (a) measure the effects of some important intercropping systems of northern Nigeria on light transmission;
- (b) assess the effects of such intercropping on the soil and canopy temperature, and
- (c) to quantify the effects of the intercropped environment on the type, yield and density of weed growth.

1.2 Study Justification

As indicated in the above review, the preponderance of weed is a serious problem, especially in developing countries where the farming systems are basically having low external inputs. In some seasons, steady rainfall without dry spells encourages weed infestation, as there is hardly enough time to dry and kill the weeds after weeding. Whereas good the rains are necessary for crop establishment, weed infestation is a related problem and should be reduced or eradicated. Recent reports have confirmed that intercropping millet with cowpea reduces striga damage by reducing the growth and seed production of the parasitic weed striga *hermonthica*. The reduction was attributed to the cooler soil temperature resulting from the shade caused by the modified microclimate (Webb, 1994). This supports an earlier finding in Ghana and in The Gambia as reported by Carson (1989). A quantification of the microclimate that operates in intercrops would therefore help in understanding these aspects of the controlling of striga virulence. Such field studies are lacking in Nigeria. Since economic conditions force farmers to put emphasis on low external input sustainable agriculture in the tropics, the manipulation of the traditional cropping systems for optimal resource use and weed suppression is becoming of even more interest and herein also lies the justification for this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Microclimate

Microclimate, the climate near the ground, is the climate in which plants and animals live (Rosenberg, 1974). It is otherwise known as the biological climate. Information about the response of a crop to its environment can be derived from the nature of its microclimate-the regime of radiation, temperature, humidity, carbon dioxide and wind between the top of the canopy and soil surface (Monteith, 1973). It is the interaction of these environmental regimes with crops and the atmosphere that constitute the crop microclimate (Stigter, 1994a). Over the last two decades, interest has grown again in the potential of management and manipulation of microclimate to protect and improve yields (Stigter, 1994b).

2.2 Definition of Weeds

There are many widely used definitions of weeds. Blatchely (1912) defined a weed as a plant out of place, or growing where it is not wanted. Harper (1955) defined a weed as a plant that grows spontaneously in a habitat that has greatly been modified by human action. In line with the latter definition, Harland and De Wet (1965) considered a weed as a generally unwanted organism that thrives in habitats disturbed by man. Aldrich (1984) defined a weed as a plant that originated under a natural environment and, in

response to imposed and natural environments, evolved, and continues to do so, as an interfering associate with crops.

Oxford English Dictionary (OED) defines a weed as "a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation". Akobundu (1987) observed that the OED definition of weed is technically incomplete as it is a common knowledge that not all weeds are herbs. Accordingly, Akobundu (1987) opined that "a plant is therefore a weed either because it interferes with human activities and/or welfare, or because it occurs spontaneously in human-disturbed habitats".

2.3 Effects of Weeds on Crops

In the tropics where the agricultural system is that of low external inputs, weeds are serious pests and have been underestimated over the years. A majority of farmers in the tropics are subsistence farmers who do not have access to herbicides and/or can't afford them. Consequently, very much labour is spent in combating weeds. Weeds are therefore associated with the drudgery that characterizes peasant agriculture in the tropics.

The influence of weeds in crop production is the cumulative effect of all possible negative interactions inherent in crop-weed associations. Burkholder (1952) described ten possible interactions occurring among plants and three of them are relevant to weed/crop associations. These are discussed below.

2.3.1 *Competitive effects*

Research on the effect of weed competition on crop yields has been an integral part of weed studies for many years and there is considerable information on the nature and extent of weed interference in many crops. Weed interference reduces crop yields as the weed competes with crops for space and limiting resources - nutrients, light, water, oxygen and carbon dioxide. Aldrich (1984) defined competition as "the relationship between two or more plants in which the supply of a growth factor falls below their combined demands". This ultimately leads to crop losses.

Losses caused by weeds have been reviewed by many workers (Sweet and Minotti, 1980; Zimdahl, 1980; Radosevich and Holt, 1984; Akobundu, 1987). Akobundu (1980) estimated that losses caused annually by uncontrolled weeds in maize fields in Ghana, Kenya and Nigeria amounted to 55, 34 and 40% respectively. Choudhary and Lagoke (1982) observed 47 to 85% reduction in pod yields from groundnut field trials in the Northern Guinea and Sudan savanna of Nigeria. In a cotton trial in the Nigerian savanna, a 71 to 97% loss in seed-cotton yield due to weeds was reported (Lagoke and Choudary, 1982). Globally, it has been estimated that weeds cause 5% loss in the agriculture of the most developed countries, 10% in less developed countries, and about 25% in the least developed countries (Akobundu, 1987).

Weed density is one of the important biological factors affecting the crop/weed balance. In a trial to examine the competitive effect of two weeds at different densities on

the growth and yield of sorghum (two weed species were tested-*Digitaria ciliaris*, a grass, and *Corchorus olitorius*, a dicot), it was found that increased weed density adversely affected crop yields. The effect was more pronounced with *olitorius* than with *ciliaris* at high density levels. At low densities (up to 100 plants/m²), *Digitaria* was found to be more competitive with sorghum than the dicot *Corchorus* (ICRISAT, 1979/1980).

2.3.2 Allelopathic effects

The term allelopathy was first coined by Molisch (1937) to refer to any biochemical interaction among plants including micro-organisms. Weeds may interfere in crop production not only through competition, but also through allelopathy. It is understood that certain weed species or some of their parts release into their environment allelopathic substances (Decandolle, 1932; Ripley, 1941; Gruner, 1961; Abdul-Wahab and Rice, 1967; Muller, 1969; Tukey, 1969; Horowitz and Friedman, 1971; Rice, 1974). Whereas Molisch's definition includes both detrimental and beneficial interaction, Rice (1974) defined allelopathy as "any direct or indirect harmful effect by one plant (including micro-organisms) on another through the production of chemical substance that escape into the environment". By accepting Rice's definition, competition can be definitively separated from allelopathy. Whereas plant competition occurs through a reduction or removal of a growth factor needed by

both plants, allelopathy occurs by the addition of a toxic factor by one plant to the environment of another.

Allelopathic effects have been noted for several weed plants; Rice (1965) noted that flowering spurge (*Euphorbia corollata* L.) inhibited nitrifying bacteria. Prostrate spurge (*Euphorbia supina* Raf.) also inhibited several strains of nitrogen-fixing and nitrifying bacteria (Rice, 1969). Several studies have also been conducted on the phytotoxicity of leafy spurge (*Euphorbia esula*) extracts. In a study of 23 plant species representing 16 families, aqueous foliage extracts of leafy spurge inhibited germination and seedling growth of wheat and peas (Le Tourneau *et al.*, 1956).

Johnson grass is also reported to exhibit allelopathy. In a study of the effects of Johnson grass weed on soybean, Abdul-Wahab and Rice (1967) reported that Johnson grass rhizomes living or decaying in the soil exude, contain or produce substances that can affect soybean growth. They concluded that in addition to direct competition and allelopathic effects during their active growth, Johnson grass plants are also potentially harmful during or after decay of their residues. This was corroborated by Rose *et al.* (1984).

2.3.3 Weeds as hosts for pests and diseases

Studies have shown that weeds may serve as alternative hosts for insects and plant diseases. Akobundu (1987) quoted Bendixen (1983) as reporting that some tropical weeds such as *Cyperus rotundus* L., *Cynodon dactylon* L. Pers, *Echinochloa*

colona L.Link, *Eleusine indica* L. Gaert, *Imperata cylindrica* L. Beauv., *Portulaca oleracea* L., *Amaranthus spinosus* L. and *Cyperus esculentus* L. serve as vectors for nematodes and arthropods. Other weeds such as *Cyperus distans*, *Panicum maximum* and *Pennisetum purpureum* are host for insect pest borers (Akobundu, 1987).

In a study of weed control in an oil palm nursery, Ndon (1982) observed that increased weed competition in the nursery led to a greater susceptibility of the seedling to blight diseases in the dry season and decreased plant stand at 12 months after sowing. Enyinnia (1982) also reported that weeds of the Euphorbiaceae family serve as alternate hosts for the cassava mealybug *Phenacoccus manihoti* (Matt-Ferr) and green spider mite *Mononychellus tanajoa* (Bon dar) which accounted for over 60% reduction in tuber yield.

2.4 Microclimate Modification in Intercrops

The growth environment encountered by crops in intercropping is often strikingly different from that in sole crops, the nature and degree of the difference depending strongly on the plant type of the associated crops. The environmental modification usually has a significant effect on the growth and yield of the crops. The most obvious modification of the environment in an intercrop is where a short statured component is shaded by a taller one. Consequently, capture of (PAR) by the shorter crop is reduced. This may result in the reduction in growth and yield of this shorter crop, although this is not always the case

(Baldy and Stigter, 1995). Shading may also lead to increased plant height which can favour lodging (Trenbath and Harper, 1973; Chui and Shibles, 1984). Other environmental conditions could also be modified by shading, even to the benefit of a shorter component crop. For example, reduction in air temperature under shade may favour the growth of an understorey crop, particularly when the ambient temperature in a sole crop of it is supra-optimal (Midmore *et al.*, 1988b), or when the sole crop is water stressed (Harris *et al.*, 1987). Environmental modification may also lead to an increase in yield of the understorey crop in intercropping compared to sole cropping. Midmore *et al.* (1988a) observed this in potato intercropped with maize at low density.

The soil environment is also modified by intercropping. Some effects (e.g. a change in temperature) may last for only the duration of intercrop growth; while others (e.g. soil fertility) may persist for a long time after the intercrop is harvested. Improved ground cover achieved by an additive intercrop contributes to reduced soil erosion and hence better retention of soil fertility, particularly when spreading type cultivars are used as the shorter component (Stoop, 1986).

The moisture environment immediately below the soil surface is commonly improved by intercropping. As the soil surface under an intercrop is not as exposed as in sole crops, evaporative loss from it is reduced. In a drying cycle, the moisture content of the surface soil layer is often higher under intercrop than under sole crop (Midmore

et al., 1988b; Olanatan, 1988b; Ikeorgu *et al.* 1989).

Ensuring good ground cover by intercropping can also reduce runoff and increase infiltration (Olanatan, 1988b). Increased infiltration rate in an intercrop may also be caused by increased earthworm activity as a result of lower soil temperature (Hulugalle and Ezumah, 1991). However, in an additive intercrop, soil water availability may be reduced rapidly because of the more rapid development of leave area and hence higher water use (Fukai and Trenbath, 1993).

Shading by the heavier leaf canopy of an intercrop also reduces soil temperature (Olanatan, 1988b). This may assist the emergence of young plants of temperate species with low optimum temperatures, as was found, for example, with potato planted in maize (Midmore *et al.*, 1988b). Carson (1989) suggested that reduced soil temperature under a sorghum/groundnut intercrop may favour sorghum because of a reduced density of *Striga*, a parasite with a high optimum temperature for germination.

Reduced soil temperature and increase moisture conditions due to intercropping may favour multiplication and growth of some soil micro-organisms. For example, Singh *et al.* (1986) have reported greater populations of active soil bacteria under maize/legume intercrops. Similarly, Wahua (1984) found increased numbers of rhizosphere bacteria, which were associated with a higher total nitrogen and potassium in an intercrop of maize with melon (*Colosynthis vulgaris*). Effects of intercropping on N fixation by rhizobium is

reviewed by Stern (1993), and synergism for P uptake is discussed by Morris and Gazzily (1993).

From the above discussion, it could be surmised that the microclimate of an intercrop is modified when there is a large overlap in the period of active growth of both crops. For example, Ong *et al.* (1991) observed that in a groundnut/pearl millet intercrop of 80-105 days duration, the onset of linear growth rate was between 35-40 days for both crops and the overlaps lasted for 40 days. The development of the leaf area index was also similar for both crops, peaking at 50-55 days. Such a system has a complex above ground interaction resulting in changes in the properties of the canopy for intercepting rain and light and also as a shelter for pests and pathogens. However to be efficient, these crops have to be complementary in space. On the other hand, a system with a wide difference in crop duration (sorghum/pigeon-pea intercrop), with a sorghum duration of 90-70 days, is known to experience very small above ground interaction as pigeon-pea flowers at 120 days, well after the sorghum has been harvested; this shows complementarity in time. Consequently, the microclimate of the former has received more attention than that of the latter. It is also important to note that the growing periods of the varieties used and planting densities of sole crops and intercrops as well as the limiting factors of the environment in which they grow should be properly specified for sufficient understanding of yield advantages occasioned by the modification of the microclimate (Stigter and Baldy, 1995).

2.4.1 *Weed response to shade*

The competitive ability of plants is governed, in part, by the efficiency with which they utilize light. Different plants growing together at different heights create light diminution within the plant canopy. This is due to the "filter" condition of the different plant leaves. Intercropping therefore alters the light environment of component crops, especially in the degree of shading experienced by plants growing in an understory.

The effects of shading on plant physiology and morphology have been studied extensively (Evans and Wardlaw, 1976; Hawkins, 1982; Caldwell, 1987). Change in light quality can alter plant form. As light penetrates a green leaf canopy, its spectral composition is altered. The absorption of PAR in the 0.4 to 0.7 μ m waveband and reflection and transmission of near infra-red radiation (> 0.73 μ m) results in an increase in the far-red:red ratio. The effect is greater in shaded regions than in sunflecks (Allen *et al.*, 1976) and at low solar elevation angles (Sinclair and Lemon, 1973). Such shifts in spectral balance have been shown to affect photomorphogenetic processes. Increased internode elongation, reduced branching and reduced leaf production are typical responses to the increase in the far-red:red ratio at lower levels in a canopy (Holmes and Smith, 1975). Developmental responses to light quality could be important in determining the impact of a taller component on canopy development of a shorter component in an intercropping system. Kretschmer *et al.* (1977) have shown that the stimulus

for beans to climb was related to the red:far-red ratio of the light environment, a potentially important factor in maize/bean intercrops.

Hawkins (1982) summarised the effects of shade on the physiology and structure of leaves. Generally, leaves that develop in shade are thinner, increase in area, and display more horizontal orientation. Photosynthetic rate per unit area in such leaves is lower under high light but equivalent or greater under low light. While shading reduces light interception, causing reduction in biomass production and partitioning to leaves, smaller leaf dry weights are often offset by an increase in specific leaf area (SLA) (Keating and Carberry, 1993).

Black *et al.* (1969) and Garner (1962) have reported differences in light requirements among plant species. Black *et al.* (1969) classified many weeds as photosynthetically efficient; that is, the weeds continue to fix increasing amount of carbon dioxide as light intensity increases to nearly full sunlight. If competitive plants or crops are efficient at high light intensities, rapid shading will decrease the photosynthetic rates and suppress their growth, for example of the underlying weeds.

The potential of shade for suppressing weed growth has been demonstrated (Baake and Gaessler, 1945; Keely and Thullen, 1978; Patterson, 1979; 1980). Baake and Gaessler (1945) suggested that cultivation and the shade provided by grain sorghum were instrumental in controlling silver nightshade.

The specific effects of shade on different temperate weed species have been extensively studied. Plant height, dry matter accumulation and reproduction are usually diminished by shade (Cooper, 1966; Keely and Thullen, 1978; Patterson, 1979 1980). Relative and total pigment content and leave anatomy may also be altered by shade (Bjorkman and Holmgren, 1963; Boardman, 1977; Cooper and Qualls, 1967; Crookston et al., 1975). Reducing irradiance brings about a decline in relative photosynthetic rates (Boardman, 1977; Crookston et al., 1975; Patterson, 1979). Shade may impair the regrowth potential of perennial weeds by depleting the carbohydrate stored in the vegetative reproductive structures (Baake and Gaessler, 1945).

Measuring the amount of irradiance intercepted by crops provides an estimate of the shading potential of some agronomic crops. Knake (1972) collected data during August in Illinois and reported that corn (*Zea mays* L.) provided 92 to 97% shade at the soil surface. Keeley and Thullen (1978) reported shade levels of 80 to 90% in cotton and grain sorghum furrows. Crops such as alfalfa, velvet beans (*Stizolobium deeringian* (small) Bort.), jackbeans (*Canavalia ensiformis* L DC), and lime beans (*Phaseolus limensis* Macf.), rapidly shading the soil, indeed suppressed the growth of purple and/or yellow nutsedge by shading (Loustalot, 1954; Bell et al., 1962; Magalhaes, 1969; Botha, 1971). William and Warren (1979) also demonstrated that crops which rapidly shade the soil surface require less maintenance for purple nutsedge control than slower growing crops. They reported

that garlic (*Allium sativum* L) needed to be free of purple nutsedge competition for 13 weeks as compared to 4 weeks for more competitive crops, such as green beans (*Phaseolus vulgaris* L.).

In a trial to quantify the response of some common semi-arid tropical weeds to light (ICRISAT, 1979/1980), four test weed species were employed - *Dactyloctenium aegyptium*, *Amaranthus viridis*, *Tridax procumbens*, and *Cyperus rotundus*. Among these four weeds, *Cyperus rotundus* emerged as the most sensitive to shading. *C. rotundus* grown under bamboo shade frames that transmitted different levels of PAR showed marked reduction in height, leaf area index (LAI) and dry weight as the available light intensity was reduced from 50 to 10%. The correlation coefficient relating to per cent PAR and dry matter was found to be 0.93 and this indicated the sensitivity of the weed to shading. It was also observed that a small amount of shading affected the seed production and tuber formation considerably, indicating the potential of shading in reducing the propagation of this perennial weed.

2.4.2 Intercropping and weed suppression

Multiple cropping is the major cropping system employed by subsistence farmers in the tropics. Multiple cropping may be defined as growing more than one crop on the same piece of land during one calendar year (Akobundu, 1987). According to Akobundu (1987), crops grown on the same piece of land in one year may be separated in time (sequential cropping) and space. He concluded that intercropping is the separation of

crops in space. Moody and Shetty (1979) defined intercropping as the growing of two or more cultivars of the same or different crops simultaneously on the same piece of land.

The ability to suppress weeds better than a sole crop is one of the benefits attributed to intercropping and this is due to the more complex ground cover provided by crop canopies in intercropping systems (Geertz, 1963; Webster and Wilson, 1966; Walters, 1971; Enyi, 1973; Akobundu, 1980). All crops in all cropping systems are sensitive to weed competition if the weeds occur before the crops develop full canopy cover. The competitiveness of weeds in any short term cropping system depends largely on which plant (weed or crop) makes better use of available space. In order for intercrops to be effective in controlling weeds, they must be able to show complementarity in space by utilizing space more effectively than a sole crop (Moody, 1978).

There are numerous reports to the fact that weed infestation is less in certain intercrops than in sole crops. Rahaja (1973) observed that the growing of intercrops prevents usurpation of space by weeds. De (1974) suggested that planting an early maturing crop of either mung bean (*Vigna radiata* L. Wikzek) or cowpea (*Vigna unguiculata* L. Walp) as an intercrop in cotton (*Gossypium hirsutum* L) may help in effectively utilizing the vacant spaces between the cotton rows without detriment to the yield of the crop components. Moody (1978) reported that the growing of a number of crops in close proximity to one another so that the plant density

is greater than in sole cropping should result in greater competition against weeds and thus reduce the need for weeding. Also, when maize was intercropped with sweet potato or groundnut, Bantilan and Harwood (1973) observed that weed growth was less in the intercrop than in the sole crops of sweet potato, groundnut or maize. However, a real intercrop does not just add the two densities of single crops. That weed suppression occurs in such very dense intercrops normally indicates competition between the components.

Despite the claims by many workers on the weed suppressing ability of intercrops (Webster and Wilson, 1966; Bantilan and Harwood, 1973; Raheja, 1973; Moody, 1978), there are still conflicting reports on the labour requirements of intercropping systems. Norman (1973) reported that intercropping results in a saving in labour. He opined that such reasoning has been based on the premise that weeding is less critical in intercropping, and that some operations such as planting of the second crop and weeding of the first could be combined. This was corroborated by Harwood (1974). On the other hand Day (1978) is of the opinion that the need for weed control in intercropping is as great as that of sole crops. Also Shetty (1978) reported that the critical period of weed competition in intercrops could be longer than in sole crops. He observed that sorghum needed to be maintained weed free for only the first 4-5 weeks of crop growth; whereas for the sorghum/pigeon-pea intercrop, the weed free period had to be extended to 7 weeks. Suryatna (1976) had earlier reported that significantly more time was needed to

weed a corn/cassava intercrop than a cassava sole crop. He reported that in northern Nigeria, intercrops required about 90% more labour input during June to July - the peak weeding period - than sole crops.

2.5 Solar Radiation Capture and Use in Intercrops

The issue of the capture and use of resources in an intercropping system is practically one of the managed degree of competition between component crops. Efficient use of resources is a major reason usually given for intercropping; and this objective is achieved by manipulating the way component crops compete for the available resources of solar radiation, water and nutrients.

Solar radiation provides the energy for the photosynthetic processes which ultimately set the potential for crop productivity (Loomis and Williams, 1963; Warren-Wilson, 1969; Goudriaan, 1982). PAR which is utilized by green leaves, conservatively makes up about 50% of global shortwave radiation (Szeicz, 1974). Daily incoming radiation at the outer limit of the earth's atmosphere is a predictable quantity (Monteith, 1973; Gates, 1980) and although reflection due to clouds and atmospheric turbidity affects the amount transmitted through to the surface of the earth, daily and seasonal patterns in attenuation of solar radiation can be adequately estimated at most locations (Goldberg *et al.*, 1979; Bristow and Campbell, 1984). Solar radiation is more reliable, compared to the high variability that is possible in the supply of water and nutrients to the plants.

(Keating and Carberry, 1993). However, as solar radiation is a flux of electromagnetic energy, it must be intercepted and utilized immediately to energize the photosynthetic process. It cannot be stored for later use. Neighbouring plants therefore compete for solar radiation by direct interception. The supply of other resources and the influence of factors such as pests and diseases act to reduce productivity from the potential set by the incident radiation regime.

There exists extensive literature on the interception and use of solar radiation by plants both in sole crops and in mixtures (Donald, 1963; Black, 1971; Owonubi *et al.*, 1975; Harper, 1977; Monteith, 1981; Caldwell, 1987; Owonubi and Kanemasu, 1982; Caldwell, 1987). Research on sole crops frequently deals with the efficient spatial capture and use of solar radiation by manipulating plant population or canopy architecture (Duncan, 1971; Rhodes and Stern, 1978). Research on mixtures has concentrated on the competition for resources between species; the emphasis in the case of competition for light has been placed on the ability of one species to compete with and shade another. An effective competitor captures resources quickly, but this does not necessarily result in the most efficient harvesting of the light energy (Caldwell, 1987).

2.5.1 *Radiation capture in intercrops*

Great diversity in intercrops results from the various combinations in space and time of planting dates and spatial distribution, leaf size, shape and orientation and plant height. Given this diversity, several reviewers have found it useful to consider resource capture in terms of temporal and spatial dimensions (Norman, 1974; Willey, 1979a&b; Francis, 1989). Planting patterns that do not effectively exploit the available space at any time within the duration of the cropping season will result in incomplete radiation interception and, in cases where other resources are not limiting, lost production. In this section, some case studies are presented that demonstrate temporal and spatial elements of radiation interception in intercropping systems.

2.5.1.1 *Light interception over time*

The two major components of light interception over time are the duration of the crop cycle and the rate of leaf area development between emergence and the attainment of an adequate value of leaf area index to intercept most light. Where the growing season is short, sole crops of short duration and high plant leaf area (LA) per unit of thermal time (LA/UTT) are well adapted, whereas such crops can often waste resources at the end of a longer season. Few crops of long duration exhibit a high value of LA/UTT, one exception being kenaf (*Hibiscus cannabinus* L.) (Carberry and Muchow, 1992). More commonly, crops of long duration, such as cassava, sugarcane or pigeon-pea, have low LA/UTT area per

unit of thermal time (LA) (Keating *et al.*, 1982; Wallace *et al.*, 1990) and therefore show an extended period during which radiation is lost during early crop development. Intercropping of short duration, LA/UTT high crops with crops of long duration but low LA/UTT can therefore provide the opportunity for enhanced temporal capture of radiant energy.

The combination of a short season cereal and long season pigeon-pea is the best documented example of enhanced radiation interception through better temporal patterns of canopy development. The majority of reports on this system comes from India, involving sorghum (Natarajan and Willey, 1980a&b, 1985; Rao and Willey, 1983b), maize (Sivakumar and Virmani, 1980, 1984) and millet (Rao and Willey, 1983a). Reddy *et al.* (1989) also reported on pigeon pea intercropped with groundnut. Characteristically, the pattern of light interception in such intercrops initially follows that of the fast growing component under sole cropping and, later, that of the slower growing component under sole cropping, with a longer growth cycle. As the short season intercrop component generally suffers little competition for light and because of the lengthened total crop duration, cumulative light interception in such intercrops is indeed enhanced compared to that of the short season sole crop as well as the long season sole crop.

Caution is needed in comparing the efficiency of intercropping systems whose components differ in their life cycle. In the above examples, the more complete capture of radiation by the intercrop early in its cycle is often

negated by the drop in light interception after harvest of the shorter season crop (Keating and Carberry, 1993).

2.5.1.2 *Light interception in space*

The enhancement of light interception through better spatial arrangement of component canopies is clearly associated with the temporal distribution of leaf area as discussed in the previous section. However, crops of similar growth duration and rate of leaf area development can still differ in light interception because of differences in their vertical arrangement of foliage due to the canopy architecture, or in horizontal arrangement due to planting pattern. In discussing light interception in space, it is useful to divide intercropping systems into "additive" and "replacement" systems. In an additive system, one crop component is planted in a similar arrangement to its sole crop equivalent and a second component is added, such that total plant density increases. In those systems in which canopy structure can be considered horizontally homogeneous, light interception is essentially one-dimensional. In a replacement intercrop system, a number of rows of one crop component are replaced by a second component with total plant density not necessarily changing. Consequently horizontal canopy structure becomes more heterogeneous, and differences according to horizontal position, in the attenuation of light in the vertical dimension, need to be considered.

In an additive intercrop, canopy structure varies with plant height, reflecting both the canopy characteristics of component species and the impact of their interaction. A relationship in the form of Beer's law can adequately represent the downward attenuation of light within such canopies, although, as in sole crops, the assumption of horizontal homogeneity will not hold early in crop development (Keating and Carberry, 1993). The latter concluded that the extinction coefficients developed for sole crops need not necessarily apply in a mixture of species.

If the extinction coefficients (k) of component canopies are similar and if the intercrop results in increased total leaf area index (LAI) over the corresponding sole crops, then the amount of light intercepted by the intercrop will increase relative to that for the sole crops (Keating and Carberry, 1993). Likewise, the addition of an understorey intercrop with high values for K to crops with low K , would increase the whole canopy extinction coefficient, increasing light interception of the intercrop at a given value of LAI. However, researchers agree that such spatial advantages are difficult to achieve in reality because sole crops, when planted at high densities, can achieve high LAI and close to complete radiation capture themselves. Cases where better spatial cover of the land surface has been achieved with intercrops merely reflects sub-optimal densities in the sole crops - a problem that is reported to confound many intercrop experiments. In some cases, density has been ignored (e.g. Fisher, 1979; Ahmed and Rao, 1982; May 1982; Chui and

Shibles, 1984; Fawusi, 1985; Lightfoot and Taylor, 1987; Lightfoot *et al.*, 1987; Olaniran, 1988a) and in others, while a range of sole crop densities have been examined, optima were not achieved (Fawusi and Wanki, 1982; Tariah and Wahua, 1985; Ssekabembe, 1986). Whereas the requirement that intercrops be compared to sole crops grown at their optimal plant population is widely emphasised (Willey, 1979a), "many experiments purporting some 'intercropping advantage' remain equivocal because of uncertainty over whether the observed advantage is merely a response to planting density, rather than to intercropping *per se*" (Keating and Carberry, 1993).

Changing the spatial arrangement of intercrops, either vertically or horizontally, does modify the balance of interception between component canopies. Consequently, many workers have been attracted to the concept of an ideal canopy structure for intercrops. The most common suggestion is for vertical canopies of narrow leaves, with the upper leaves increasingly angled (lower K values) to allow radiation to penetrate the canopy and avoid light saturation of the upper canopy leave (Willey, 1979a; Fordham, 1983; Trenbath, 1986). Such canopies generally do not occur in natural communities but intercropping provides a means of achieving this canopy structure through management.

There is a dearth of information on the precise estimates of K. Sivakumar and Virmani (1984) reported no significant difference between K values for sole maize (0.64 ± 0.11), sole pigeon-pea (0.69 ± 0.26) and an intercrop (0.66 ± 0.77) whose LAI consisted of 2/3 maize and 1/3 pigeon-pea.

However presentation of data on percentage light interception and LAI presented by Harris *et al.* (1987) did suggest an intercrop canopy where the extinction coefficient of the taller sorghum was lower than that of the understorey groundnut. Wallace *et al.* (1990) studied light extinction in maize/sugarcane mixtures and assessed the properties of the lower sugarcane component by progressively removing areas of the taller maize plants. Extinction coefficients were measured for the mixture and for the sugarcane component in the mixture. Light extinction by the maize component in the mixture was calculated. Extinction coefficients rose with time and the value in the mixture (maximum $K = 0.5$) was intermediate between the sugarcane (maximum $K = 0.26$) and maize (maximum $K = 0.6$) components.

Radiation fluxes in crop/weed mixtures are increasingly receiving attention. Haizel (1972) explored leave area and light interception profiles in mixtures of barley, white mustard and wild oats. While the work was done in pots with the calculated extinction coefficients higher than normally expected in the field, some general principle can be identified. The extinction coefficients for mixtures were generally intermediate between the extreme values obtained from the components in pure stand. Anomalous light interception patterns were obtained in instances where components with contrasting habits of leave display interacted to form a structured canopy. The K values of such a layered canopy increased with depth in the canopy and, because of the structuring of the mixed canopy, could not

have been predicted from a knowledge of light attenuation of either component in pure stand. Leaf area and light interception data from sorghum/pigweed mixtures emphasize the effect of the structure of the upper canopy on light penetration into the canopy (Graham *et al.*, 1988). In sole sorghum crops, light penetrated into the mid canopy levels where most of the leaf area was located. As pigweed population increased, less light penetrated into the canopy, being intercepted in the upper layers by the pigweed. While not calculated by Graham *et al.* (1988), extinction coefficients of the mixtures would have increased as the proportion of the pigweed in the mixture increased (Keating and Carberry, 1993). Examined from a different perspective, Satorre and Ghera (1987) found that the frequency of gaps in the crop canopy at half the height of weed (as determined with the point quadrants method) was the variable that gave the best predictions of the weed biomass.

2.5.2 Radiation use in intercrops

Solar radiation is not only the energy that drives crop productivity by the process of photosynthesis it also determines water use by the processes involved in evaporation and transpiration. Improved productivity per unit incident radiation can result from adoption of a cropping system that either increases the interception of solar radiation and/or maintains higher radiation use efficiency (RUE). Minimising the proportion of radiant energy reaching the ground will ensure efficient utilisation of incident solar radiation and,

in this regard, the previous section directed itself to intercropping systems which have demonstrated temporal and spatial advantages over sole cropping systems. This section will attempt to review the prospects of improving the utilization of the intercepted radiant energy by assessing both the production of assimilates and their partitioning within component crops of intercropping systems.

2.5.2.1 *Assimilate production*

The rate at which a stand produces dry matter, and the amount produced by the time it is harvested, depend on many environmental and physiological factors. In for example Squire (1993), tropical plants are separated into two groups that differ in their rate of dry matter production. He observe (1) that plants with the C3 photosynthetic mechanism, such as rice, legumes, root crops and palms have maximum growth rates of 35-40g per m² per day, their maximum annual production depending on the longevity of the foliage and (2) that plants with the C4 photosynthetic pathway, the tropical cereals and grasses, have corresponding maximum rates of 50-55g per M2 per day, their maximum annual production depending on radiation amounts received.

The principal reason given for the high productivity of intercrops with differing component duration is that the components grow actively at different times and hence competition for resources is less intense than when the components have a similar growth rhythm (Baker, 1981; Okigbo, 1981; Rao, 1986). Taken over the whole growing season, the

resources are captured more completely and used more efficiently than in corresponding sole crops (Fukai and Trenbath, 1993).

When intercrop components have similar growth durations, their peak requirements for resources commonly occur at the same time, resulting in intense competition for limiting resources. Intercropping advantages are not as large or as obvious as those with crops of differing growth durations, and vary from 'substantial' (Rao and Willey, 1980) to 'low' (Rao, 1986), and to negative (Cenpukdee and Fukai, 1992a&b).

Less commonly found in farming systems, intercrops of this type include maize/soybean, a major rainfed cropping system in India, and maize/melon and maize/cowpea in West Africa (Rao, 1986). When farmers choose to grow together crops with similar duration, they tend to combine them in replacement type intercrops, therefore aiming for a plant population density that is usually not much higher in intercrop than in sole crops (Fukai and Trenbath, 1993).

Combinations involving slightly differing duration (millet/sorghum) or mixtures of early and late maturing cultivars of the same species are used in areas of variable growing season length to exploit the occasional favourable season yet insure against total failure in unfavourable seasons (Rao, 1986; Nageswara Rao et al., 1990). If a season is long, the later maturing type takes advantage of the abundant resources, whereas if the season is short, the early maturing type gives a reasonable yield.

2.5.2.2 Assimilate partitioning and crop yield

Assimilate partitioning between the structures of a plant is influenced by all the main environmental and management factors. When competition occurs during the yield production stage, the supply of assimilate to develop the harvested part may be reduced and hence Harvest Index (HI) may be low. Thus HI of a fast maturing crop may be reduced if competition with a later maturing component is severe towards its maturity; for instance, a reduced HI for an early maturing component crop was observed in mungbean when intercropped with sorghum (Balasubramanian and Rao, 1988), and also in soybean and cassava (Tsay *et al.*, 1985, 1988a&b).

On the other hand, when an early maturing component matures well before a late maturing one, the HI of the latter may be similar to or exceed that of the corresponding sole crop. When the removal of the early maturing crop releases the plants from suppression, flowering and grain production occur in a plant that has a smaller vegetative structure than in the corresponding sole crop.

When component crops have similar growth durations, particularly in additive intercrops, HI is commonly reduced relative to that in the sole crop because of severe competition between the component crops during later stages of growth (Rees, 1986). For example, HI of bean of non climbing types was reduced when intercropped with maize, though combined total dry matter increased (Davis *et al.*, 1984). Similarly, in a cassava/pigeon-pea intercrop,

prolonged competition between the component crops reduced the HI of cassava (Cenpukdee and Fukai, 1992c).

Crop yield is related closely to assimilate production during the yield development period of crop growth, although, according to Keating and Carberry (1993), it is difficult to relate yield directly to solar radiation because of factors that influence the relative contributions of assimilates produced pre-anthesis and post-anthesis. Generally, shading and the reduced assimilate production will have the least effect on yield if competition occurs during vegetative growth, and conversely, the greatest effect if it occurs during the reproductive growth phase (Evans and Wardlaw, 1976). The temporal advantages of some intercropping systems in light interception are therefore also apparent in yield production.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental Site/Soil Type and Geology

The experiments were done as supportive research to Ph.D research by Oluwasemire (Stigler *et al.*, 1995) in the content of the project Traditional Techniques of Microclimate Improvement, in which collaborate the Ahmadu Bello University (Geography Department), the Institute for Agricultural Research (Department of Soil Science, ABU) and Wageningen Agricultural University (Department of Meteorology), The Netherlands.

The experiments were located at the International Institute of Tropical Agriculture research farm at Minjibir, 40 km NW of Kano (latitude 12° 11' N and longitude 08° 43' E; 500 m asl) which falls under the sudan savanna zone. Kano has a monomodal rainfall pattern with an average rainfall of 690 mm/year. The soil type, classified as a Typic Ustipsamment (Institute for Agricultural Research, 1987) is well-drained, shallow (<1 m) and immature with evidence of little profile differentiation. Formed mainly from unconsolidated sands, it is characterized by critically low organic matter, low CEC and low available phosphorus. The sandy nature of the soil is attributed to the granitic and gneissic origin of the soil parent material.

3.2 Crop Varieties Planted

Except for the introduction of the improved grain cowpea (IT86D-719) in the 1995 trial, all the crop varieties for 1994 trial were repeated in 1995. For the millet, only the local variety (Ex Bornu) was used. Sorghum had two varieties - the local variety (Gaya early) and the improved variety (ICSV-400). Dan-Illa was the only local variety of cowpea used in the trials. It is a spreading cowpea with high fodder characteristics. Three improved varieties of cowpea were used-IT86D-719, IT89KD-374 and IT88D-867-11. Bred by IITA, they have high grain production characteristic as compared to Dan-Illa.

3.3 Experimental Treatment

The treatments include two prominent intercrops of cowpea with millet and/or sorghum, their sole crops, and at two fertility levels. The specific 13 treatments for 1994 trial are listed below:

- millet/cowpea + organic manure only,
- millet/cowpea + inorganic fertilizer + organic manure,
- millet/sorghum/cowpea + organic manure + inorganic fertilizer,
- millet/sorghum/cowpea + organic manure only,
- sole millet + organic manure only,
- sole millet + organic manure + inorganic fertilizer,
- sole sorghum (Gaya Early) + organic manure only,
- sole sorghum (Gaya Early) + organic manure + inorganic fertilizer,

sole sorghum (ICVS-400) + organic manure + inorganic fertilizer,

sole sorghum (ICVS-400) + organic manure only,

sole cowpea (Dan-Illa) + organic manure only,

sole cowpea (IT89KD-374) + organic manure only and

sole cowpea (IT88D-867-11 + organic manure only.

However in 1995, IT86D-719 variety of cowpea was added to give a total of 14 treatment for 1995.

3.4 Experimental design/Replication

The experimental design used was a two factor experiment in a randomized complete block design (RCB). The two factors were two levels of fertility - organic manure only (cow dung) and organic manure + inorganic fertilizer (NPK) and crop varieties. In the 1994 trial, the intercrops had 4 replications while the sole crops had 2 replications. In 1995, the sole crops were replicated 3 times and the intercrops maintained at 4 replications.

3.5 Seedbed Preparation

For both trials, a total of 0.6ha of plot was harrowed and ridged. Organic manure (cow dung) was harrowed into the plot. Harrowing and ridging were done using the tractor. Ridging was done in the E-W direction with an inter-row distance of 0.75m maintained between ridges.

3.6 Time of Planting

In the 1994 trial, millet was first planted on the 18th of June. Due to lack of sufficient rain, millet was replanted on the 23rd of June. Sorghum was planted on the 30th of June, while cowpea fodder (local cowpea) and cowpea grain (improved cowpea) were planted on the 7th of July. Planting was done in the N-S direction. In the 1995 trial, millet was planted on the 13th of June, followed by sorghum two days later. Cowpea was planted two weeks after millet on the 27th of June, when the rains were relatively established. For all the treatments, millet and sorghum were thinned to 2 plants per stand two weeks after planting while sorghum was maintained at 4 plants per stand. The planting pattern is depicted in Figure 1. During both years of the study, in the millet/cowpea intercrop combinations, cowpea was planted within rows of millet and at 2m apart giving a plant population for each variety of 6667 plants/ha or a total plant population of 13333 plants/ha for the two cowpea varieties used in the intercrop. In the same millet/cowpea intercrop combinations, millet was planted at 2 m apart and with 2 plants/stand to give a plant population of 13333 plant/ha. In the millet sorghum/cowpea arrangements, sorghum replaced alternate rows of millet to give a plant population with 2 plants per stand of 13333 plants/ha. Except for sole crop arrangements of Dan-Illa and IT89KD-374, that were planted at 0.75m apart (due to their profuse branching habit), other sole crops were planted at 0.5m apart. Sole cowpea Dan-Illa and IT89KD-374 planted at 0.75m apart gave

a planting population with 2 plants/stand of 35555 plants/ha. Other sole cowpea varieties planted at 0.5m apart and with 2 plants/stand gave a planting population of 53333 plants/ha. For both trial, sole millet was planted at 0.5m apart and with 2 plants/stand to give a planting population of 53333 plants/ha. The planting population for sole sorghum planted at 0.5m apart and with 2 plants/stand was 53333 plants/ha in 1994 trial. In 1995, sole sorghum was planted at 0.5m apart and with 4 plants/stand to give a population of 106666 plants/ha. Planting arrangement is depicted in Figure 1.

3.7 Soil Measurements

Pre-planting and post harvest soil samples were collected for the two seasons (Tables 1a, 1b and 2). Particle soil analysis was carried out by the hydrometer method. Soil pH was determined in 1:2.5 soil:water suspension with a glass electrode pH meter. Organic carbon was determined by the wet-oxidation method of Walkley Black. Exchangeable bases were displaced with 1N NH₄OAc buffered at pH 7.0. P and Na in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrophotometry. Available P was determined by the Bray-1 method. Total N was determined by macro-Kjeldahl procedure described by Bremner (1965). Cu, Mg, Zn and Fe were extracted with 0.1N HCl and determined on the atomic absorption spectrophotometer.

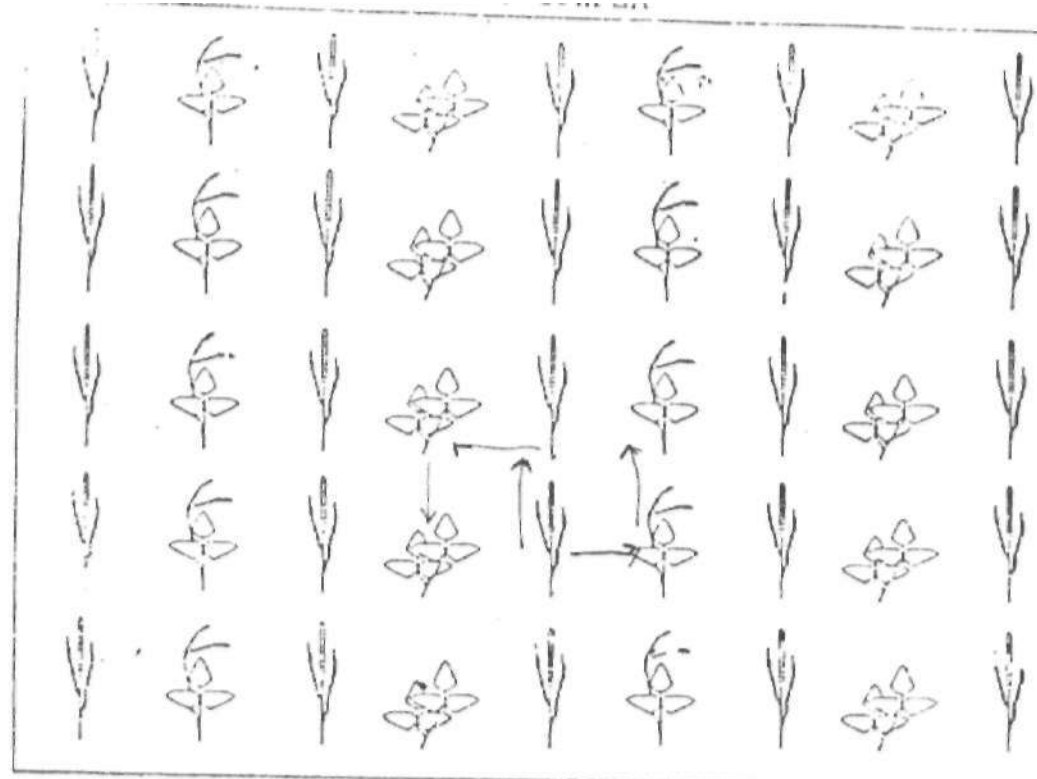
Table 1(a): Pre-planting soil analysis

Particle size Analysis				Exchangeable cations (cmol(+)kg)						Micronutrients							
% Sand	% Silt	% Clay		Ca	Mg	K	Na	Mn		Cu	Zn	OMn	pH H ₂ O	Or.C	Kjel N	C/N	B _{av} -1
										----->	mg/kg	----->	0.1	g/kg	g/kg	Ratio	mg/Kg
86	8	7		1.35	0.52	0.14	1.42	0.06		0.5	1.9	27.6	7.0	2.2	0.34	6.5	14.7
86	8	7		1.23	0.44	0.12	0.34	0.05		0.3	1.6	21.8	6.9	3.1	0.29	11.0	18.7
83	6	7		1.23	0.56	0.16	0.33	0.05		0.3	0.8	25.4	7.0	2.4	0.28	8.6	16.3
83	8	5		1.10	0.50	0.18	0.35	0.04		0.4	0.4	21.8	6.8	2.8	0.28	10.0	15.1
83	8	5		1.30	0.62	0.18	0.32	0.05		0.5	1.4	24.7	6.7	2.8	0.27	10.0	19.7
83	8	5		1.91	0.62	0.14	0.33	0.05		0.4	1.7	18.6	6.7	2.5	0.33	7.6	17.5
83	6	7		2.23	0.89	0.15	0.30	0.05		0.2	1.0	19.3	7.2	3.1	0.31	10.0	14.1
86	10	5		1.24	0.49	0.28	0.40	0.06		0.4	1.1	30.2	7.3	3.8	0.39	9.7	12.9
86	8	7		10.96	2.79	0.19	0.34	0.04		0.3	0.3	22.5	6.6	2.9	0.28	10.0	10.7

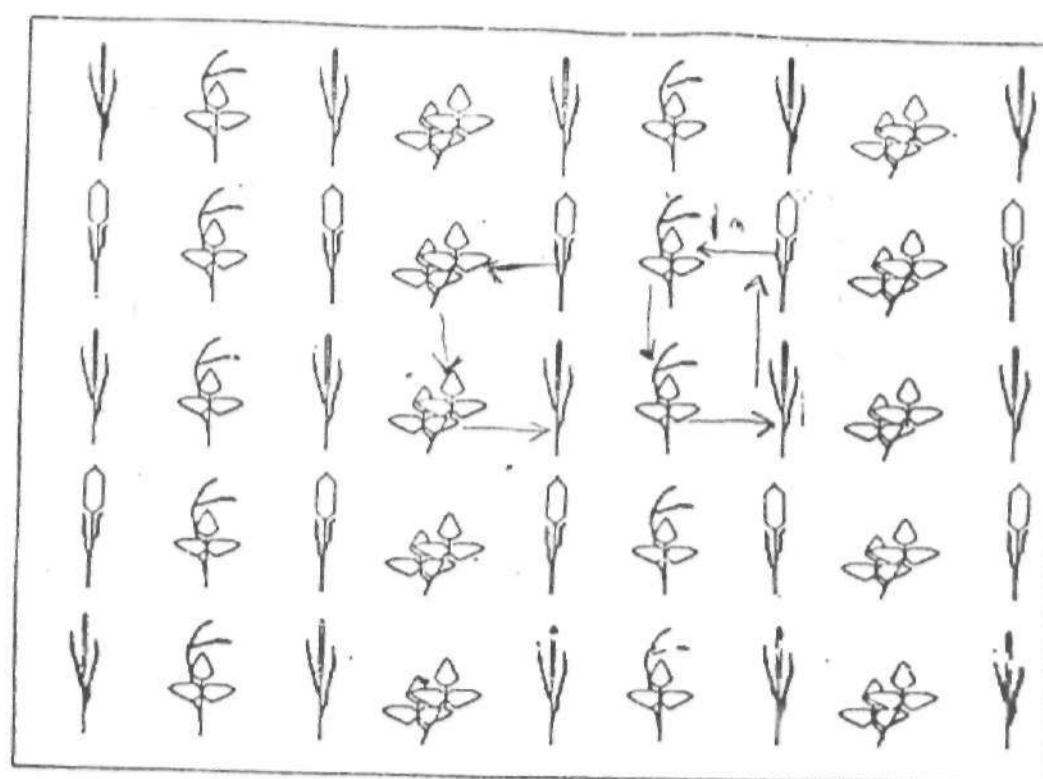
Table 1(b); Organic manure (cow dung) analysis.

P-Bray-1 mg/kg	Kjel-N g/kg	Exchangeable cations				Micronutrients		
		Ca	Mg	Na	K	Cu	Zn	Mn
		<-----cmol(+)/kg----->				<-----mg/kg----->		
162.7	3.92	13.4	6.2	10.3	12.9	13.3	93.9	93.9
163.2	4.01	13.3	6.3	12.3	13.7	22.6	96.9	96.9

Particle size Analysis (Corrected to 20 C)										PH 1:2.5		EXCHANGEABLE BASES FM (Mg/100g soil)		EXCHANGEABLE BASES FM (Mg/100g soil)					
NOT NC	CLAY	SILT	SAND	TEXTURAL CLASS	H2O	CaCl2	OC	TN	AvailP	Ca	Mg	K	Na	C-EC	Ca	Mg	K	Na	C-EC
100	100	100	80	Sandy loam	6.2	6	0.12	0.056	10.75	2.3	0.53	0.34	0.15	5.4	0.53	0.34	0.15	5.4	0.53
100	100	100	80	Sandy loam	6	5.6	0.06	0.070	10.2	1.96	0.57	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	82	loamy sand	5.8	5.7	0.02	0.036	12.34	1.96	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	80	loamy sand	5.7	5.6	0.02	0.042	14.34	1.92	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	84	loamy sand	6.4	5.6	0.02	0.042	10.75	1.7	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	82	loamy sand	6.4	5.6	0.02	0.036	8.06	1.54	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.5	5.5	0.02	0.042	14.78	1.35	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.5	5.5	0.02	0.042	12.34	1.5	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	84	loamy sand	5.4	5.4	0.02	0.036	14.34	1.5	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.4	5.4	0.02	0.036	18.42	1.3	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	84	loamy sand	5.7	5.7	0.02	0.028	12.54	1.32	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.4	5.1	0.02	0.028	17.52	1.32	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.1	4.8	0.02	0.028	14.44	1.36	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	88	loamy sand	5.5	5.4	0.02	0.042	14.34	1.3	0.48	0.24	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	88	Sand	5.7	5.5	0.03	0.056	32.26	1.8	0.67	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	Sand	5.1	5.1	0.03	0.042	18.82	2.3	0.63	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	5.3	5.1	0.03	0.056	25.09	1.4	0.38	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	6	5.9	0.08	0.014	12.54	1.9	0.47	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	84	loamy sand	6	5.7	0.02	0.028	8.06	1.88	0.48	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	84	loamy sand	6.4	5.7	0.02	0.042	10.75	1.76	0.48	0.28	0.15	4.9	0.58	0.35	0.15	5.4	0.58
100	100	100	86	loamy sand	6.4	5.7	0.02	0.042	27.78	2.1	0.83	0.35	0.37	6.4	0.83	0.35	0.37	6.4	0.83
100	100	100	86	loamy sand	6	5.4	0.06	0.070	43.01	2.9	0.6	0.35	0.37	5.1	0.83	0.35	0.37	5.1	0.83
100	100	100	90	Sand	6.1	5.8	0.03	0.042	19.71	1.76	0.41	0.25	0.35	5.1	0.83	0.35	0.37	5.1	0.83
100	100	100	88	loamy sand	6.4	5.8	0.02	0.035	14.34	1.48	0.41	0.25	0.35	5.1	0.83	0.35	0.37	5.1	0.83
100	100	100	84	loamy sand	6.9	5.6	0.03	0.042	17.02	1.78	0.46	0.22	0.28	6.1	0.83	0.35	0.37	5.1	0.83



millet sorghum cowpea



0.75m

legend

0 1 2 m



millet



grain type cowpea



sorghum



fodder type cowpea

3.8 Radiation Measurement

Light transmitted through the canopy was measured using a Model SF-80 Decagon sunfleck ceptometer. This model has 80 light sensors placed at one-centimeter intervals along a line probe. When the probe is inserted horizontally into the canopy, a microprocessor scans the 80 sensors. An average reading of all the sensors (in micromols per square meter and per second) is displayed and can be stored in the in-built memory.

Sunflecks are the fully bright areas under the canopy where direct beam solar radiation penetrates without attenuation by the canopy. The fraction of the ground covered by sunflecks (sometimes called the canopy gap fraction) is a useful measurement for determining canopy cover. Light readings were measured by inserting the ceptometer probe below the crop canopy but above the weeds. This gave actual light transmitted by the part of the canopy above the weeds and hence potentially intercepted mainly by weeds. Reference readings were simultaneously taken outside and above the crop canopies. The ratio of the two readings gave the percentage light transmission at the level of measurement. Recording measurements in percentage was considered better than using absolute intensities, because the latter would be affected by variations in cloudiness at different periods of measurement.

Light readings were done in the centre of each plot marked as the final harvest area. In the millet/cowpea intercrop for 1994 experiment, actual light interception for

millet-millet (M-M) arrangements was recorded by inserting the ceptometer probe below the canopy of two immediate millet stands within the same ridge (on ridge = OR). Thereafter, reference readings were taken above the overall crop canopy. The same methodology was employed between the ridges (BR) for the millet-cowpea improved variety (M-CG) and millet-cowpea local variety (M-CL) as shown in Figure 1 for 1994 experiment. However, for 1995 experiments, light readings taken between two adjacent improved cowpea varieties (CG-CG) on the same ridge and two adjacent local cowpea varieties (CL-CL) lying on the same ridge were incorporated for the millet/cowpea intercrop as indicated in Figure 1.

In the millet/sorghum/cowpea for both experiments, light readings were taken by inserting the ceptometer probe between two adjacent stands of millet-sorghum (M-S), sorghum-improved cowpea (S-CG), improved cowpea-improved cowpea (CG-CG), improved cowpea-millet (CG-M), sorghum-local cowpea (S-CL), local cowpea - local cowpea (CL-CL) and local cowpea-millet (CL-M) see Figure 1 under millet/sorghum/cowpea arrangements. In each reading, reference readings were simultaneously taken outside the crop canopies where there were no shadows.

For the sole crops, the ceptometer was inserted below the canopies of two adjacent crops on the same ridge (OR) and also below the canopies of two opposite crops between two ridges (BR). Reference readings were also taken outside the canopies.

3.9 Soil Temperature Measurements

Soil temperature within the different treatments was measured using platinum resistance sensors buried within 7.5cm soil depth. These sensors were connected to a Campbell 21 micrologger (located outside the plot) to give temperature readings at every 30 seconds that could be averaged over larger periods. The sensors were buried in horizontal direction as burying the sensors in a vertical direction would give a conduction along a temperature gradient thus giving incorrect readings.

In the 1994 experiment, eight soil temperature sensors were used. The sensors were not positioned with respect to a specific plant but were placed anywhere within the chosen canopies. Thus soil temperature sensors were placed in:

- sole sorghum (Gaya early) OM + IF;
- millet/cowpea intercrop OM + IF;
- millet/sorghum/cowpea (OM);
- millet/sorghum/cowpea (OM + IF);
- sole millet (OM);
- sole cowpea;
- sole millet (OM + IF); and
- millet/cowpea (OM) canopies.

However, for 1995 experiment, ten sensors were used. Placement of the sensors were done with respect to plants. Thus, the sensors were inserted under:

- millet in millet/cowpea intercrop (OM + IF);

- improved cowpea (IT89KD-374) in millet/cowpea intercrop (OM + IF);
- local cowpea (Dan-Illa) in millet/cowpea intercrop (OM + IF);
- sorghum (Gaya early) in millet/sorghum/cowpea intercrop (OM + IF);
- Sorghum (Gaya early) in millet/sorghum/cowpea (OM);
- millet in millet/cowpea intercrop (OM);
- sole millet (OM + IF);
- sole sorghum (Gaya early)(OM + IF);
- sole cowpea (Dan-Illa); and
- control.

The control sensor was placed outside the experimental plot and kept vegetation free throughout the experiment. Results are shown in Figures 2 to 7, and 14 and 15.

3.10 Canopy Temperature Measurements

Canopy temperature was measured with an Everest Interscience Model .120 hand-held infrared thermometer (Everest Interscience, Inc., Tustin, CA). The spectral band pass of the instrument was 8 to 14 μm with a resolution of 0.1°C and a field of view of 2°. The instrument was placed 1m directly overhead and at about 60° angle to the horizontal and 30° to the vertical degrees angle to the top of the canopy. The average of the two readings gave an idea of the temperature of the upper layer of the canopy as viewed by the instrument. Measurements were usually done under fully blue skies.

3.11 Weed Inventory

Weed inventories included identifying the weed types and taking their shoot biomass at different stages of crop growth. Weed samples were collected from a quadrant of 1m x 1m in two randomly chosen locations per plot. Phytosociological observations on weeds were recorded to detect and compare variation and changes in weed community as affected by the treatments. A quantitative measure of biomass as well as percentage frequency of occurrence were recorded. Percent frequency of occurrence was determined through numerical estimates of the ratio of individual weed species to the total population of weeds present in the quadrant. Percent frequency, percent weight contribution of individual weed to total weed biomass (shoot biomass) were used in detecting the trends of weed infestation in the various treatments. After identification, the samples were oven-dried at 60C for 76h and weighed to determine the shoot biomass.

3.12 Meteorological Data

Data from the meteorological station situated at about 200m from the experimental site were recorded as shown in Appendices A and B for 1994 and 1995 cropping seasons respectively.

CHAPTER 4

RESULTS

In Minjibir in particular and in the sudan savanna of Nigeria in general, 1994 cropping season was characterised by late, inadequate and erratic rainfall pattern. Long intervening dry spells were common during the cropping season. Expectedly, this affected germination, seedling growth and vigour; and crops, particularly millet and sorghum had to be replanted. In 1995, the rains were stable and more in line with expectations. Rainfall pattern for 1994 and 1995 trials are as shown in Figure 2.

4.1 Weed Biomass

The dry-matter yields of weeds (weed biomass) for the various cropping systems are presented in Table 3a. In 1994 experiment (Table 3a), weed dry-matter was statistically significantly higher under sole cowpea Dan-Illa on Julian Day (JD) 244 (for part of the treatments) and 274 (70 and 100 days after sowing (DAS) of millet respectively). On JD 213 (40 DAS of millet), the weed dry matter was statistically not significantly different among the treatments. However, sole cowpea Dan-Illa still maintained the highest dry weed weight.

In the 1995 experiment, the dry weed yields on JD 182 (18 DAS of millet) were not statistically significantly different. On JD 213 (47 DAS of sorghum) and JD 244 (77 DAS of sorghum), sole sorghum ICVS-400 with organic manure treatment consistently showed statistically significantly higher weed dry matter (Table 3b).

1994/95 and 10 yr mean rainfall (Kano)

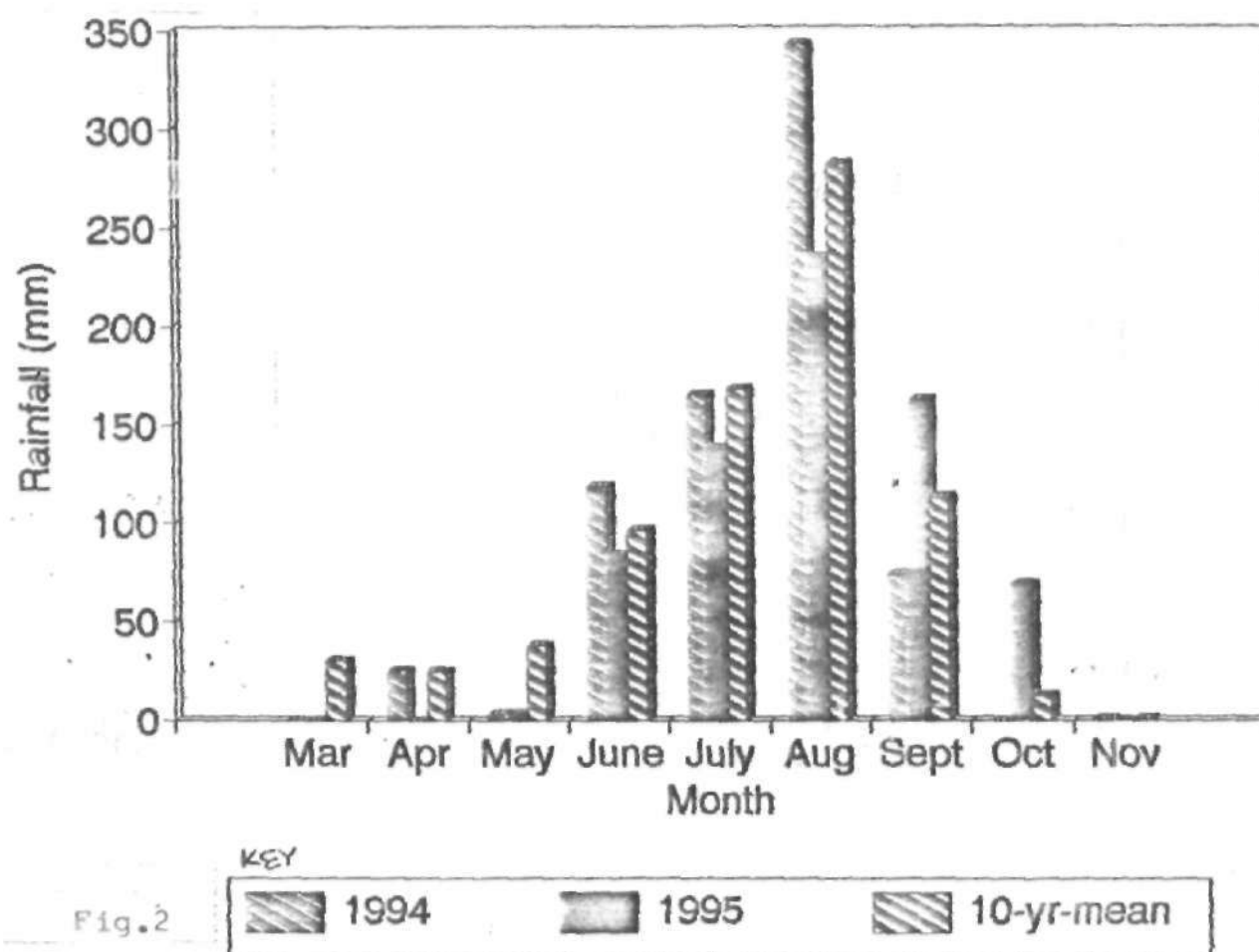


Table 3a: Effect of cropping systems on weed biomass

Cropping system	Weed Biomass (g/m ²)		
	Dates in Julian Day		
	1994		
	213	244	274
M/C OM + IF	21.35	11.69bc*	33.58bc
M/C	12	13.16bc	29.80bc
M/S/C OM + IF	20.95	9.92c	30.87bc
M/S/C OM	3.1	9.71c	31.88bc
Sole millet OM + IF	28.5	8.31c	17.94c
Sole millet OM	25.8	11.04bc	28.86bc
Sole sorghum G.E. OM + IF	21.55	15.63bc	16.7c
Sole sorghum G.E. OM	13.20	22.32ab	7.94d
Sole sorghum ICVS-400 OM + IF	28.45	26.11ab	28.36bc
Sole sorghum ICVS-400 OM	25.40	20.65ab	34.83bc
Sole cowpea - Dan-illa	42.95	39.88a	98.07a
Sole cowpea - 374	35.65	21.27ab	42.33bc
Sole cowpea - 867-11	17.35	13.25bc	55.5b
Sole cowpea - 719	-	-	-

*Only figures followed by different letters in the same column for each experiment differed statistically significantly at 5% probability (DMRT).

M/C = Millet/Cowpea intercrop.
M/S/C = Millet/Sorghum/Cowpea intercrops
OM = Organic Manure
IF = Estimated inorganic fertilizer
GE = Gaya early
Sole Cow = Sole cowpea
Sole Sorg. = Sole Sorghum

Table 3b: Effect of cropping systems on weed biomass

Cropping system	Weed Biomass (g/m ²)		
	Dates in Julian Day		
	1995		
	182	213	244
M/C OM + IF	12.85	43.72b	6.33bc
M/C OM	13.41	8.33cd	4.93bc
M/S/C OM + IF	7.17	29.04bcd	4.25bc
M/S/C OM	27.04	38bc	4.1bc
Sole Millet OM + IF	12.14	12.12bcd	6.68bc
Sole Millet OM	26.26	14.98bcd	6.6bc
Sole Sorghum G.E. OM + IF	5.35	21.18bcd	10.96bc
Sole Sorghum G.E. OM	14.63	20.46bcd	6.95bc
Sole Sorghum ICVS-400 OM + IF	7.93	15.28bcd	14.9bc
Sole Sorghum ICVS-400 OM	10.28	88.15a	32.93a
Sole Cowpea Dan-illa	4.85	13.17bcd	8.03bc
Sole Cowpea - 374	4.1	5.88cd	2.3c
Sole Cowpea 867-11	11.9	2.24d	18.03bc
Sole Cowpea - 719	4.94	26.37bcd	20ab

* Only figures followed by different letters in the same column for each experiment differed statistically significantly at 5% probability (DMRT).

M/C = Millet/Cowpea intercrop.
M/S/C = Millet/Sorghum/Cowpea intercrops
OM = Organic Manure
IF = Estimated inorganic fertilizer
GE = Gaya early
Sole Cow = Sole cowpea
Sole Sorg. = Sole Sorghum

The increase in weed dry matter for sole cowpea Dan-Illa in the 1994 experiment was obviously due to the intervening dry spell occasioned by the erratic rainfall pattern observed for 1994 cropping season. Dan-Illa being a local variety of cowpea could not exhibit its characteristic branching habit to cover the ground in an environment of soil moisture stress (due to the dry spell), especially as it was planted at a greater spacing (0.75m x 0.75m) than other sole crops planted at 0.5m x 0.75m. Because of this, there was more light penetration down the canopy to enhance weed propagation for sole cowpea Dan-Illa treatment for the 1995 season, there was no intervening dry spell as the rainfall pattern was well established throughout the season. Cowpea Dan-Illa had enough moisture to exhibit its branching characteristics and so produced enough canopy cover to suppress weeds. However sole sorghum ICSV 400 with organic matter treatment was poorly established thus providing downward light attenuation for weed propagation.

4.2 Weed Frequency

Sequence of weed incidence and frequency of their occurrence changed as the season progressed. In both years of cropping, *Digitaria horizontalis* Wild, *Cyperus esculentus* L. and *Commelina benghalensis* L. were the major monocotyledonous weeds that showed dominance. *Acanthospermum hispidum* DC, *Spermaoce verticillata* L., *Oldenlandia corymbosa* L. and *Ipomoea eriopcarp* R. Br. were the few dicotyledonous weeds of relative dominance compared to the

grasses. In 1994 experiment, *Cyperus esculentus* L. showed higher frequency at second sampling (67 DAS of millet), followed by *Spermacoce verticillata* L. as shown in Table 4a. As the season progressed, there were changes in dominance as *Spermacoce verticillata* L. exhibited higher frequency than *Cyperus esculentus* L. (Table 4b). Changes in weed flora were also observed as shown in Table 4a and 4b. It was particularly noticed that *Hyptis lancocelata* Poir, *Cassia mimosoides* L., *Euphorbia hyssopifolia* L., *Ipomoea Involucrata* P. Beauv. and *Sida acuta* Burm. f. were absent in the second weed sampling (the active cropping season) but present in the third sampling which was done at the later part of the cropping season. Readings for the first weed sampling could not be taken due to logistic problems.

The absence of *Hyptis Lancocetata* poir, *Cassia mimosoides* L., *Euphorbia gtssioufikua* L., *Ipomea Involucrata* P. Beauv. and *Sida acuta* Burm. f. in the second weed sampling for 1994 and their subsequent presence in the third sampling as indicated in Tables 4a and 4b suggests that these weeds thrive better under lower shade. Third weed sampling for 1994 was done when all of the millet and $\frac{1}{2}$ of the cowpea varieties were experiencing senescence. The setting in of senescence with attendant reduction in crop leaf area resulted in reduced canopy cover. Light was able to penetrate down the canopy for the propagation of these weeds.

On the other hand, *Mariscus alternifolius*, *Eleusine indica* Gaertn., *Cynodon dactylon*, *crotalaria macrocalyx* and *Platostoma africanum* were present during the second weed

Table 4(a): Percent relative incidence of weeds and their sequence of frequency on JD 244 1994 2nd Weed sampling)

		WEED TYPE																				
Cropping system		1 st	2	3	4	5	6	7	8	9	10	11	12	13	14	15-18	19	20-21	22	23	24-30	31
M/C OM + IF*		30.11	2.84	1.70	1.14	7.39						5.68		51.14	0	0	0	0	0	0	0	0
M/C OM		43.34	15.67	2.28	6.76		5.0	0.67	0.3	1.68	1.93		0.3	20.19								3.65
M/S/C OM + IF		38.87	4.98	24.98	0.6		0.73	3.15	0.42	0.36		1.8	2.05	18.75					0.18			
M/S/C OM		2.02	13.57	18.04				6.05	2.03			0.56		57.56								0.19
SM OM		11.59	0.29		4.49	0.23		0.53			13.96			29.58				0.23				1.75
SM OM + IF		21.64	2.05	0.56	7.84		1.49	13.44			1.31		11.53	38.37				5.72				
SS GE OM + IF		18.58	0.84	14.90				1.10	1.41		1.10			5.72	50.85				1.07			
SS GE OM		12.82	2.13	8.59	6.92			0.15				2.66		65.68				0.40				
SS ICVS 400 OM + IF		0.80	0.21				2.15	4.83	0.74		0.64	9.16	0.92	2.23	79.06							0.44
SS ICVS 400 OM		3.92	5.05	40.81	11.74	0.22	0.88					2.86	2.21	31.89								
SC Dan-lla		0.37		10.27				3.96	1.04			18.14			65.72							
SC - 374		2.16	5.95							2.05		4.72			84.80							
SC 867-11		8.76			0.62			1.77				1.54	16.26	65.96				0.62				3.41
Total		103.9	114.6	58.7	109.4	24.91	12.21	38.56	8.61	2.71	4.73	30.77	15.37	69.98	627.7				8.04	0.13		9.44
*M/C =	Millet-cowpea intercrop																					
OM =	Organic manure																					
IF =	Estimated inorganic fertilizer (NPK)																					
M/S/C =	Millet-Sorghum-Cowpea intercrop																					
SM =	Sole Millet																					
								</														

Table 4(b): Percent relative incidence of weeds and their sequence of frequency on JD 274 1994 3rd weed sampling)

Cropping system	Weed Type																					
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20-21	22	22-27	28	
M/C OM+IF ¹	43.01	3.48	24.16	0.34	0.77	1.0				21.24	1.55	0.344	0.6	1.83	0.77			0.67		0.34		
M/C OM	29.19	10.47	3.33	0.77		0.35				43.76			9.52	0.47	2.17							
M/S/C OM+IF	13.27	0.65	18.87	1.47						38.45	12.22	2.12	6.22	0.17	6.43					0.17		
M/S/C OM	26.03	1.797	37.39			0.60	3.0			28.19			3.03									
SM OM	33.35	0.24	7.50	0.47						33.81	1.87	0.24	0.24		2.34							
SM OM+IF	45.72		16.09	1.14						14.80	12.24	0.597	5.92	1.98		0.25						
SS GE OM+IF	38.42		37.09	0.28	0.56					21.41	1.13		0.28		9.36				0.85			
SS GE OM	65.73		5.85	0.44		2.12			0.30	16.34												
SS 1CVS 400 OM+IF	49.40		12.02	2.21	1.84	1.00				22.86	10.69											
SS 1CVS400 OM	48.71		10.38	3.79		9.03				16.28	9.799	0.58	1.46									
SC D. ILLA	5.15	0.98	31.01		0.80	2.71				59.37												
SC 374	45.5	1.52	10.34	0.98	0.46	12.11				27.59		1.52										
SC 867-11	11.30	1.27	30.14	0.16	1.05	3.09				46.35		0.64							6.01			
Total	492.5	10.23	323.4	16.08	7.4	35.42			0.65	390.5	49.5	5.8	36.83	4.15	17.72			1.77		0.51		

kg/ha

1 <i>Illina Squarulata</i> Thunb. ex Vahl	9 <i>Cassia Cistifolia</i>	11 <i>Euphorbia hirsuta</i> Linn.	25 <i>E. tirucula</i> Hochst. ex Steud
2 <i>Spermacoce verticillata</i> Linn	10 <i>Morinda citrifolia</i>	18 <i>Ipomoea involucrata</i> P. Beauv.	26 <i>Cenchrus biflorus</i> Roxb.
3 <i>Commelina benghalensis</i> L.	11 <i>Cynodon dactylon</i> (Linn.) Pers.	19 <i>Sida acuta</i> Burm. f.	27 <i>Ipomoea yessoensis</i>
4 <i>Digitaria horizontalis</i> Willd	12 <i>Crotalaria sacrocalyx</i>	20 <i>Nepenthes olaracea</i>	28 <i>Melastoma scandens</i>
5 <i>Eleusine indica</i> Gaertn.	13 <i>Platostema africanum</i>	21 <i>Amaranthus spinosus</i>	29 <i>Brachiaria distachya</i> (Desf.) Trin. ex Steud
6 <i>Ipomoea eriocephala</i> R. Br.	14 <i>Cyperus esculentus</i> Linn.	22 <i>Heliotropium indicum</i>	30 <i>Brachiaria lata</i> (Schumacher) C.E. Hubbard
7 <i>Acrostospermum hispidum</i>	15 <i>Elymus lanceolatus</i> Poir	23 <i>Portulaca oleracea</i>	31 <i>Chloris plicata</i> Schumacher
8 <i>Oenanthia coriacea</i> Linn	16 <i>Cassia ramosissima</i> Linn.	24 <i>Decyloctenium aegyptium</i> (Linn.) P. Beauv	

sampling although with lower frequencies; they were however completely absent during the third sampling. Conversely, the presence of *Eleusine indica* Gaertn., *Cynodon dactylon*, *Crotalaria macrocalyx* and *Platostoma africanum* in the second weed sampling for the same year (1994) and their absence in the third weed sampling indicates that these weeds are shade loving and that they could thrive under relatively humid conditions. They however exhibited lower frequencies of occurrence. As indicated in section 4.2, for both trials, second weed sampling was done when the crop were in their respective active growth stages. The luxuriant crop growth, high shading effect and increased humidity within the canopy undoubtedly modified the understorey microclimate in favour of shade loving weeds.

Results of 1995 experiment also followed the same trend as that of 1994 except that in 1995 experiment, *Maricus alternifolius*, *Cynodon dactylon*, *Crotalaria macrocalyx* and *platostoma africanum* were completely absent throughout the season as shown in Tables 5a - 5c.

In the 1994 experiment, *Cyperus esculentus* L. (14), *Spermacoce verticillata* L. (2) and *Digitaria horizontalis* Wild (4) were the three most dominant weeds. Fourteen (14) showed the highest dominance with a total frequency of occurrence of 627.66%, followed by 2 with total frequency of occurrence of 114.63% in first sampling. For second sampling, the reverse was the case. Weed 2 had the highest occurrence of 492.48%, followed by weed 14 with occurrence of 390.45%.

Table 5(a): Percent relative incidence of weeds and their sequence of frequency on JD 182 18 (DAS) 1995 1st Weed sampling)

Cropping system	Weed Type																						
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20	21	22	23		
M/C OM+IP ^{a1}	3.13	1.59	80.71	0	5.55	1.78	0.44	1.53	0.55	0	1.13	1.45	0.11	0	0	0	0.11	1.91	0	0			
M/C OM	2.51	4.97	72.17				1.93	0.47	4.23		2.54	2.97				5.06		0.99	0.75	1.26			
M/S/C OM+IF	0.64	1.99	75.42		0.99		5.72	5.06	0.16			1.90	8.02	0.16					0.16				
M/S/C OM	0.65	3.637	87.72		3.49	0.24	0.94	0.98				0.79	1.76	0.13									
SM OM		0.24	88.92				1.15		0.31			5.96					0.69			2.03			
SM OM+IF	6.66	13.81	81.06		3.51	0.23	3.40		1.56			4.694		1.56			0.52						
SS GE OM+IF	5.09	17.46		1.6		7.17	2.29	0.54				6.77					2.24	0.64					
SS GE OM	1.71	5.31	71.86			0.15	2.10					4.89		2.91			2.1	15.23	0.43	0.29			
SS ICSV 400 OM+IF	0.90	3.98	68.46		2.6	7.52	2.08	3.06				4.78	2.91										
SS ICSV 400 OM	0.12	9.79	76.41			1.58	2.12	0.82	3.00			0.439	0.12	1			1.38	4.26					
SC D. IIA	2.88	1.92	70.20				3.81	7.19	3.07	2.59										0.61	1.19		
SC - 374	2.86		68.70																	2.35	1.36		
SC 867-11	2.24	3.46	87.24		0.91	0.91	0.58	0.36				0.46	5.40							0.46			
SC - 719	8.52	61.37		3.18		0.95		0.67				11.25	15.16	0.35					0.63				
Total	37.42	129.5	928.9	4.78	17.05	25.49	28.79	16.56	12.4		3.67	63.71	4.01	6.63	5.06		8.03	23.58	5.4	4.58			

^{a1} Key

1 <i>Illegia Sagamulata</i> Thonn. ex Vahl	9 <i>Cassia Obusifolia</i>	17 <i>Euphorbia hyssoptifolia</i> Linn.	25 <i>E. pennata</i> Hochst. ex Steud
2 <i>Spermacoce verticillata</i> Linn	10 <i>Memomitis charantia</i>	18 <i>Ipomoea involucrata</i> P. Beauv.	26 <i>Cenchrus biflorus</i> Roxb.
3 <i>Commelina benghalensis</i> L.	11 <i>Cynodon dactylon</i> (Linn.) Pers	19 <i>Sida Acuta</i> Burm. f.	27 <i>Ipomoea hyssoptifolia</i>
4 <i>Digitaria horreorialis</i> Willd	12 <i>Oxalaria macrocalyx</i>	20 <i>Nepenthes olivacea</i>	28 <i>Melastoma scandens</i>
5 <i>Eleusine indica</i> Gaertn.	13 <i>Plakotoma africana</i>	21 <i>Amantofus spirobus</i>	29 <i>Eragrostis abovirens</i> (Desf.) Trin. ex Steud
6 <i>Ipomoea eropocarpa</i> R. Br.	14 <i>Oxypus exultans</i> Linn	22 <i>Hesperisium indicum</i>	30 <i>Bractenia laia</i> (Schumacher) C.E. Hubbard
7 <i>Acanthopogon hispidum</i>	15 <i>Hypis lanceolata</i> For	23 <i>Portulaca oleracea</i>	31 <i>Chloris pilosa</i> Schumacher
8 <i>Oclerandia corymbosa</i> Linn	16 <i>Cassia minoroides</i> Linn.	24 <i>Dactyloctenium aegyptium</i> (Linn.) P. Beauv	

Table 5(b): Percent relative incidence of weeds and their sequence of frequency on JD 213 48(DAS) 1995 2nd Weed sampling)

Cropping system	Weed Type																						
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20	21	22	23		
M/C OM+IF ^{a1}	0.46	0.94	85.79		0.11	1.07	0.93	0.91	0.34		5.63	0.11	1.52		1.52	0.68							
M/C OM		1.52	63.89		1.76	1.73	4.37		1.73		22.14				0.86	2.02							
M/S/C OM+IF	1.87		69.21		4.33	0.28	0.44		1.28		11.11				0.46	11.03							
M/S/C OM	0.035	2.50	81.05		6.62						7.26				1.54						0.20		
SM OM			90.18								8.78				0.85								
SM OM+IF			96.99				1.19	0.49			1.35				19.4								
SS GE OM+IF		2.06	57.14				1.91	1.60			15.46			2.45							0.38		
SS GE OM	1.90	1.61	64.73			0.25	1.25	7.32			22.58												
SS IGV'S 400 OM+IF	5.13		47.83			6.56	17.50	0.97			12.11				0.50	3.54							
SS IGV'S 400 OM	0.18	0.83	83.77			0.99	1.46	0.74	0.32	0.36	5.65	1.339	0.36		2.44	4.48							
SC D. ILLA	2.18	0.69	57.47			10.50		6.71			15.36	0.18			8.60	2.35							
SC - 374	1.39		18.17			1.27	4.35	10.49	1.83		51.63						1.85				9.43		
SC 867-11	3.05	2.27	11.66			7.32	11.36	13.70			38.38	0.93											
SC - 719	0.46		28.90			0.8	11.50	0.77			37.94				17.52	1.96							
Total	17.66	12.42	856.78		40.51	53.6	48.53	3.06	3.71		253.4	20.62	4.33		33.4	58.11					10.06		

^{a1} Key

- | | | | |
|---|---|---|--|
| 1 <i>Illice Sagamula</i> Thonn. ex Vahl | 9 <i>Cassia Obusifolia</i> | 17 <i>Euphorbia hysterocephala</i> Linn. | 25 <i>E. verrucosa</i> Hochst. ex Steud |
| 2 <i>Spermatocoe verticillata</i> Linn | 10 <i>Monardella citrullifolia</i> | 18 <i>Ipomoea involucrata</i> P. Beauv. | 26 <i>Cenchrus biflorus</i> Roeb. |
| 3 <i>Commelina benghalensis</i> L. | 11 <i>Cynodon dactylon</i> (Linn.) Pers | 19 <i>Sida Acuta</i> Burm. f. | 27 <i>Ipomoea hysterocephala</i> |
| 4 <i>Digitaria horizontalis</i> Willd | 12 <i>Oxalis macracalyx</i> | 20 <i>Nepenthes olonacea</i> | 28 <i>Melastoma scandens</i> |
| 5 <i>Elettaria indica</i> Gaertn. | 13 <i>Pluchea officianum</i> | 21 <i>Amaranthus spinosus</i> | 29 <i>Eragrostis alyonensis</i> (Desf.) Trin. ex Steud |
| 6 <i>Ipomoea eriocephala</i> R. Br. | 14 <i>Cyperus eximius</i> Linn. | 22 <i>Holopteryx indicum</i> | 30 <i>Bracharia latic</i> (Schumacher) C.E. Hubbard |
| 7 <i>Acanthospermum hispidum</i> | 15 <i>Hypis lanceolata</i> Pers | 23 <i>Portulaca oleracea</i> | 31 <i>Calanthe pilosa</i> Schumacher |
| 8 <i>Oldenlandia corymbosa</i> Linn | 16 <i>Cassia mimosaoides</i> Linn. | 24 <i>Dactyloctenium aegyptium</i> (Linn.) P. Beauv | |

Table 5(c): Percent relative incidence of weeds and their sequence of frequency on JD 244 78 (DAS) 1995 3rd Weed sampling

Cropping system	Weed Type																						
	1 ^a	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20	21	22	23		
M/C OM+IF ^{a1}	5.56	5.26	40.58				4.17		2.50	7.87	4.12	12.78	11.92	3.94									
M/C OM	0.33	2.94	60.07			4.63	2.15		0.67	24.04	2.83		1.35	0.67	0.33								
M/S/C OM+IF	0.54		46.77			3.41	2.84			38.24	2.43		1.79	3.93									
M/S/C OM	5.78	4.84	36.26			3.23	0.89	0.81		36.16	3.23	1.7	2.55	4.47									
SM OM		1.59	86.04			1.59			9.20	1.58													
SM OM+IF	2.0	1.25	78.61			1.25			7.15	7.08	0.47												
SS GE OM+IF	3.50	0.216	48.10			5.53	5.92		1.22			15.83	10.39	1.14	1.83	6.56							
SS GE OM	6.41	3.21	57.77				1.80			23.49		2.08											
SS ICVS 400 OM+IF	7.62		40.04		2.5	7.58	13.54	0.28		15.83			4.42		2.64							0.53	
SS ICVS 400 OM	3.41	2.89	55.01			4.21	6.14	2.78	0.20	13.51	6.49	1.52	6.7	1.51									
SC D. ILLA			76.99			1.47	10.77	6.71	1.47	7.83	1.47												
SC - 374	2.78		45.76	11.11			3.70			30.33			3.70										
SC 867-11	0.60		65.47			3.58	0.93			15.21	10.06	4.17											
SC - 719	2.79	0.28	28.19			1.48			0.56	51.25	8.11		3.61	2.52						9.22			
Total	41.32	22.48	767.26	19.38	37.96	52.85	6.71	5.54	21.5	272.42	39.21	38.08	40.94	19.74	8.73	6.56	9.22					0.53	

^{a1} Key

- | | | | |
|---|---|---|--|
| 1 <i>Ilirga Squarulata</i> Thoma. ex Vahl | 9 <i>Cassia Obusifolia</i> | 17 <i>Euphorbia hysterocephala</i> Lina. | 25 <i>E. pennula</i> Hochst. ex Steud |
| 2 <i>Spermatocoe verticillata</i> Lina | 10 <i>Memoritis charanta</i> | 18 <i>Ipomoea involucrata</i> P. Beauv. | 26 <i>Cenchrus biflorus</i> Roxb. |
| 3 <i>Commelina benghalensis</i> L. | 11 <i>Oryzoides dactylon</i> (Lour.) Pers | 19 <i>Sida Acuta</i> Burm. f. | 27 <i>Ipomoea hysterocephala</i> |
| 4 <i>Digitalis horreorum</i> Willd | 12 <i>Crotalaria macrocarpa</i> | 20 <i>Nepenthes olivacea</i> | 28 <i>Melastoma candidum</i> |
| 5 <i>Eleusine indica</i> Gaertn. | 13 <i>Paspalum affricanum</i> | 21 <i>Amorpha spinosa</i> | 29 <i>Euphorbia obtusifolia</i> (Desf.) Trin. ex Steud |
| 6 <i>Ipomoea eripocarpa</i> R. Br. | 14 <i>Cyperus exaltatus</i> Lina. | 22 <i>Heptapleuron indicum</i> | 30 <i>Bracharia latia</i> (Schumacher) C.E. Hubbard |
| 7 <i>Acanthospermum hispidum</i> | 15 <i>Hypis lanceolata</i> Poir | 23 <i>Portulaca oleracea</i> | 31 <i>Calotropis pilosa</i> Schumacher |
| 8 <i>Oclerandria corymbosa</i> Lina | 16 <i>Cassia mimosoides</i> Lour. | 24 <i>Dactyloctenium aegyptium</i> (Lour.) P. Beauv | |

In the 1995 experiment, 4 was completely dominating through out the year. This was followed by 3 with frequency of occurrence of 129.53% in the first weed sampling. 14 with frequencies of occurrence of 255.38% and 272.42 was the second dominant weed in both second and third weed sampling (Tables 5b and 5c).

It is interesting to note that in all the weed types that showed dominance in all the sampling dates for the two experiments, sole plot treatments contributed most to the observed dominance. For example, in the 1994 experiment, weed 14 and 2 dominated the 2nd and 3rd weed sampling dates with 627.66% and 492.48% total frequency of occurrence respectively. Out of the total frequency of occurrence of 627.66 for weed 14, 84.80% was contributed by sole cowpea IT89KD-374. This was followed by sole sorghum ICSV-400 with 79.06% (Table 4a). For the dominating weed 2 observed in the 3rd sampling, with a total frequency of occurrence of 492.48%, sole millet (with organic manure only) contributed 53.55%, followed by sole sorghum ICSV-400 (OM + IF) with 49.4% (Table 4b). The same trend was observed for the dominating weed 4 in 1995 experiment. Here, sole millet (OM), sole millet (OM+IF) and sole millet (OM) which showed contributing dominating frequencies of 88.92, 96.99 and 86.04% for 1st, 2nd and 3rd weed sampling respectively Tables 5a, 5b and 5c. This confirms the superiority of intercropping systems to sole cropping systems in weed suppression. The percentage contribution of individual weed

species to total weeds biomass for 1995 experiment are shown in Tables 6a - 6c.

4.3 Canopy Temperature

In the 1994 experiment, sole sorghum ICSV-400 with organic manure treatment showed the highest canopy temperature on JD 237 (54 DAS of sorghum), whereas on JD 267 (90 DAS of millet), sole millet with organic manure treatment had the highest canopy temperature recorded. In the same experiment, millet/cowpea intercrop with organic manure treatment and sole sorghum Gaya Early with organic manure treatment showed minimum canopy temperatures on JD 237 and JD 267 respectively (Table 7).

In the 1995 experiment, highest canopy temperatures were recorded for sole sorghum ICSV-400 OM + IF, sole sorghum ICSV-400 OM and sole sorghum ICSV-400 OM for Julian days 201, 222 and 243 respectively (Table 7). For the same experiment, minimum canopy temperatures were observed in the sole cowpea treatments. Sole cowpea - 719, sole cowpea 867-11 and sole cowpea - 374 showed minimum canopy temperatures for Julian days 201, 222 and 243 respectively.

In both experiments, sole sorghum and sole millet showed the highest canopy temperature values when compared to sole cowpea and the intercrop treatments as shown in Table 7 and for mean values. The higher canopy temperature values recorded for sole sorghum and sole millet treatments compared to sole cowpea and intercrops may be due to the fact that they were more erect and with an instrument of 2 ° angle of

Table 6(a): Percentage contribution of individual weeds species to total weed biomass on JD 182 18(DAS) 1995 1st Weed sampling

Cropping system	Weed Type																								
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17-19	20	21	22	23	24	25				
M/C OM+IF ^{a1}	2.43	4.78	65.66	12.87	5.4	0.40	0.74	1.06	1.56	1.43	1.13	0.047	2.51												
M/C OM	2.29	9.90	50.16	6.05		0.75	1.31	9.26	2.15	4.19		1.498	2.06												
M/S/C OM+IF	0.53	11.76	70.89	0.89		2.25	4.78	0.12	5.08	10.75	0.05	0.73													
M/S/C OM	0.43	9.17	77.28	3.52		0.30	0.53	0.50	0.646	5.06	0.10														
SM OM	0.22	78.33				2.11	0.43	1.74	3.68			0.94							12.65						
SM OM+IF	3.75	16.21	74.53	0.50		0.28	2.77	3.38	0.36		0.04														
SS GE OM+IF	2.56	30.65	47.10	1.38			4.54	3.77	3.50			1.03	0.24												
SS GE OM	0.99	6.23	63.63			0.12	0.33		3.56			1.03	23.98	0.14											
SS 1CVS 400 OM+IF	0.46	7.93	59.51	2.63		1.964	0.69	3.29	4.333	2.32	16.02														
SS 1CVS 400 OM	0.14	14.85	67.31	1.81		0.66	1.81	3.32	0.26	0.05	0.13	7.15	2.53												
SC D, ILLA	1.17	2.22	59.50	8.02		7.52	2.24	7.65				0.48	2.66												
SC - 374	12.31		74.03				6.11		8.99	5.81		1.30	0.70												
SC 867-11	0.13	10.82	80.01	0.57		0.97	0.40	0.70	0.148	2.41		3.87													
SC - 719	9.11	54.49		6.09		1.57		4.44	12.28	8.54	0.15	3.35													
Total	36.28	179.23	867.94	9.09	28.41	22.54	21.18	29.69	33.13	46.75	48.73	18.02	12.43	35.9	8.66	13.35									

^{a1} Key

1 <i>Urtica Sagittalis</i> Thoun. ex Vahl	9 <i>Cassia Obusifolia</i>	17 <i>Euphorbia hystrofolia</i> Linn.	25 <i>E. pennula</i> Hochst. ex Steud
2 <i>Spermatocoe verbicula</i> Linn	10 <i>Momordica charantia</i>	18 <i>Ipomoea batocactis</i> P. Beauv.	26 <i>Cenchrus biflorus</i> Roth.
3 <i>Convolvulus bengalensis</i> L.	11 <i>Oryzaria diachylon</i> (Thunb.) Pers	19 <i>Sida Acuta</i> Burm. f.	27 <i>Ipomoea hystrofolia</i>
4 <i>Digitalis hortensis</i> Willd	12 <i>Oryzaria macrophylla</i>	20 <i>Nepenthes olonacea</i>	28 <i>Melastomum scandens</i>
5 <i>Eleusine indica</i> Gaertn.	13 <i>Pluchea indica</i>	21 <i>Amaranthus spinosus</i>	29 <i>Eragrostis abruviers</i> (Deef.) Trin. ex Steud
6 <i>Ipomoea eriopocarpa</i> R. Br.	14 <i>Cyperus exilis</i> Linn.	22 <i>Holoptropium indicum</i>	30 <i>Brickellia latifolia</i> (Schumacher) C.E. Hubbard
7 <i>Acanthopogon hispidum</i>	15 <i>Hypochaeris lanceolata</i> Poir	23 <i>Portulaca oleracea</i>	31 <i>Calotropis pilosa</i> Schumacher
8 <i>Ocleraria cordata</i> Linn	16 <i>Cassia minoris</i> Linn.	24 <i>Decalocandium aegyptium</i> (Thunb.) P. Beauv	

Table 6(b): Percentage contribution of individual weeds species to total weed biomass on JD 213 48(DAS) 2nd Weed sampling 1995

Cropping system	Weed Type																								
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20-22	23	24	25				
M/C OM+IF ²¹	0.05	0.39	90.11		0.05	1.67	0.41	0.6	0.61		4.52	0.10	0.74		0.26	0.53									
M/C OM		5.50	77.75		3.07	0.78	84.75		2.52		8.98					0.56									
M/S/C OM+IF	1.38		81.43		1.14	0.04	2.58		0.02		1.82					1.0	9.64								
M/S/C OM	0.28	14.34	69.71		11.81						2.52					1.34									
SM OM			96.97								1.85					0.94									
SM OM+IF			98.88		0.70						0.44					24.21									
SS GE OM+IF		0.21	64.20			3.3	0.06				4.68	0.33													
SS GE OM	0.26	4.15	74.62		0.09	0.68	5.14				14.92					10.23									
SS 1CVS 400 OM+IF	1.46		51.0		9.54	26.14	0.55				1.10					2.39	2.64								
SS 1CVS 400 OM	0.01	2.08	80.00		0.37	3.45	0.92	1.90	0.41		8.98	1.09				0.71	0.41								
SC D. ILIA	2.79	0.53	62.40		21.67		0.76				21.24					5.36	2.98								
SC 374	0.43		34.94		2.56	24.86	5.4	2.27			14.40	17.53				2.02									
SC 867-11	1.45	0.31	36.20		18.34	3.4	5.38				22.85					9.27	8.88								
SC 719	0.80		35.52		10.74		11.85	0.31																	
Total	8.91	27.53	953.53		79.38	65.02	117.8	5.08	3.56		109.75	23.03	1.16			20.33	63.04								

Key

- | | | | |
|---|---|---|--|
| 1 <i>Urogon Sagittalis</i> Thonn. ex Vahl | 9 <i>Cassia Obusifolia</i> | 17 <i>Euphorbia hyssofolia</i> Linn. | 25 <i>E. verticillata</i> Hochst. ex Steud |
| 2 <i>Spermatocoe verticillata</i> Linn | 10 <i>Momordica charantia</i> | 18 <i>Ipomoea trilobata</i> P. Beauv. | 26 <i>Cenchrus biflorus</i> Roxb. |
| 3 <i>Commelina benghalensis</i> L. | 11 <i>Cynodon dactylon</i> (Linn.) Pers | 19 <i>Sida Acuta</i> Burm. f. | 27 <i>Ipomoea hyssofolia</i> |
| 4 <i>Digitaria pruriens</i> Willd | 12 <i>Crotalaria macrocarpa</i> | 20 <i>Nepenthes olivacea</i> | 28 <i>Melanthera candens</i> |
| 5 <i>Eleusine indica</i> Gaertn. | 13 <i>Paspalum africanum</i> | 21 <i>Amaranthus spinosus</i> | 29 <i>Eragrostis aegyptiaca</i> (Desf.) Trin. ex Steud |
| 6 <i>Ipomoea trilobata</i> R. Br. | 14 <i>Cyperus exaltatus</i> Linn. | 22 <i>Hibiscus tiliaceus</i> | 30 <i>Brickellia laevis</i> (Schumacher) C.E. Hubbard |
| 7 <i>Acanthopogon nigrum</i> Willd. | 15 <i>Hypochaeris glabra</i> Pers | 23 <i>Portulaca oleracea</i> | 31 <i>Calotropis pilosa</i> Schumacher |
| 8 <i>Oxypetalum corniculatum</i> Linn | 16 <i>Cassia mimosoides</i> Linn. | 24 <i>Dactyloctenium aegyptium</i> (Linn.) P. Beauv | |

Table 6(e): Percentage contribution of individual weeds species to total weed biomass on JD 244 78(DAS) 3rd weed sampling 1995

Cropping system	Weed Type																								
	1 st	2	3	4	5	6	7	8	9	10	11-13	14	15	16	17	18	19	20-22	23	24	25				
M/C OM+IF ^{a1}	4.55	0.75	44.28				3.50		0.75	5.61		2.96	0.78	29.69	7.7	1.88									
M/C OM	0.39	3.33	68.81		0.56		7.86			3.08		9.91	5.31			0.39	0.39								
M/S/C OM+IF	0.47		33.17		2.88		17.37					21.80	12.19			5.56	6.58								
M/S/C OM	3.32	4.814	51.33		0.961		1.28					29.17	0.96	6.25	0.64	1.28									
SM OM			95.78		0.57							3.65													
SM OM+IF	1.16	10.94	84.28		1.25							0.60	1.79												
SS GE OM+IF	1.03	0.17	33.38		1.21		4.11			16.79		2.41	5.84	0.31	0.39	11.38									
SS GE OM	10.05	3.20	63.21	1.83			3.77					16.72			1.24										
SS 1CVS 400 OM+IF	4.08		42.26	8.60	14.04	6.844	0.08					4.69	8.56		2.99		2.75								
SS 1CVS 400 OM	2.56	5.78	38.16		2.14		3.04		11.33	0.85		4.88	4.48	0.72	4.72	1.64									
SC D. ILLA			61.26				23.59		10.92			3.37	0.86												
SC - 374	4.07		36.28	8.77			7.02					33.33					10.53								
SC 867-11	1.26		22.3		1.65		5.56					2.40	61.62												
SC - 719	1.85	1.73	33.84		1.59		1.0			0.34		29.54	32.59	3.78	2.86										
Total	34.79	30.71	748.34	19.2	26.85	84.94		23.0			156.43	134.98	40.75	20.54	22.13	20.25									

^{a1} Key

1 <i>Limbo Sagittalis</i> Thonn. ex Vahl	9 <i>Cassia Obusifolia</i>	17 <i>Euphorbia hystrofolia</i> Linn.	25 <i>E. pennula</i> Hochst. ex Steud
2 <i>Spermatocoe verticillata</i> Linn	10 <i>Momordica charantia</i>	18 <i>Ipomoea involucrata</i> P. Beauv.	26 <i>Cenchrus biflorus</i> Roxb.
3 <i>Commelina benghalensis</i> L.	11 <i>Oenothera dactylon</i> (Linn.) Pers	19 <i>Sida Acuta</i> Burm. f.	27 <i>Ipomoea hystrofolia</i>
4 <i>Digitaria horzonsalis</i> Willd	12 <i>Oxalis macrocarpa</i>	20 <i>Nepenthes olivacea</i>	28 <i>Melastoma scandens</i>
5 <i>Eclipta indica</i> Gaertn.	13 <i>Phaseolus africanus</i>	21 <i>Amorpha fruticosa</i>	29 <i>Eragrostis advenens</i> (Desf.) Trin. ex Steud
6 <i>Ipomoea pes-caprae</i> R. Br.	14 <i>Cyperus eximius</i> Linn.	22 <i>Heliotropium indicum</i>	30 <i>Brickellia laeta</i> (Schumacher) C.E. Hubbard
7 <i>Acorus gramineus</i> Willd.	15 <i>Hypoxis lanceolata</i> For	23 <i>Portulaca oleracea</i>	31 <i>Calotropis plicata</i> Schumacher
8 <i>Oxalanthus corymbosus</i> Linn	16 <i>Cassia minoroides</i> Linn.	24 <i>Dactyloctenium aegyptium</i> (Linn.) P. Beauv	

Table 7: Effect of cropping systems on canopy temperature.

(a)

Cropping system	Temperature in °C Dates in Julian Day (JD)			
	237	Mean	267	Mean
M/C OM + IF	30.0		40.0	
M/C OM	29.7		40.3	
M/S/C OM + IF	31.3		37.0	
M/S/C OM	33.8	31.2	41.6	39.7
Sole millet OM + IF	31.3		44.0	
Sole millet OM	32.2		47.1	
Sole sorghum G.E. OM + IF	33.6		34.2	
Sole sorghum G.E. OM	29.9		33.5	
Sole sorghum ICVS-400 OM + IF	33.0	32.3	42.3	40.0
Sole sorghum ICVS-400 OM	35.1		42.8	
Sole cowpea Dan Illa	32.2		39.5	
Sole cowpea - 374	32.6		38.4	
Sole cowpea 867-11	30.9	31.9	38.0	38.6

(b)

Cropping system	Temperature in °C Dates in Julian Day (JD)					
	201	Mean	222	Mean	243	Mean
M/C OM + IF	30.4		28.8		30.6	
M/C OM	30.3		28.6		31.4	
M/S/C OM + IF	31.1		28.7		30.2	
M/S/C OM	30.6	30.6	28.1	28.6	30.7	30.8
Sole millet OM + IF	30.3		29.6		31.0	
Sole millet OM	30.8		29.6		32.6	
Sole sorghum G.E. OM + IF	31.3		29.4		31.0	
Sole sorghum G.E. OM	32.1		29.5		30.1	
Sole sorghum ICVS-400 OM + IF	32.8		31.4		31.4	30.9
Sole sorghum ICVS-400 OM	32.5	31.4	30.6	29.0	33.0	
Sole cowpea Dan Illa	31.5		27.1		29.1	
Sole cowpea - 374	30.5		27.1		29.1	
Sole cowpea - 867-11	31.5		26.4		30.1	
Sole cowpea 719	30.2	30.9	28.9	27.4	31.3	29.9

vision, the instrument looked deeper down the canopy and so more soil were seen especially for sole sorghum ICVS-400 OM treatment that was poorly established particularly for 1995 season. Sole millet and sole sorghum treatments therefore exhibited poor water relations. On the other hand, high biomass density was observed in sole cowpea treatments. This result in increased water use and hence lower canopy temperatures.

It was also observed that low canopy air temperatures were recorded for the intercrop treatments, and that they were closer to that recorded for sole crop treatments. The low canopy temperatures recorded for intercrops may be due to increased water use efficiency or better water relations within the intercrop treatments. A possible reason for the increased water use efficiency within the intercrop may be due to the windbreak effect when low growing plants such as cowpeas are interplanted with tall plants such as millet and sorghum. This normally leads to an increase in humidity and a reduction in transpiration and therefore low canopy temperatures.

Compared with the air temperature recorded by the nearby weather station, canopy temperature was less by 3.45, 0.79 and 0.06 degree celsius on JD 201, 222 and 234 respectively. This conforms to the physiological status of the crop as plant cover was higher on JD 201. Between JD 222 and 234, there was a reduction in plant cover as plant approached maturity, therefore the canopy temperature for these latter dates approximately approached that of air temperature for 1995 season. Weather data for the sampling dates for 1996 season were not available for comparison.

4.4 Soil Temperature

The 1994 experiment shows that low night and low day soil temperatures were observed for M/S/C OM and sole millet OM + IF; indicating that shading was large throughout these treatments (Figure 3). On the other hand, high day soil temperatures and low night soil temperatures were observed for sole millet OM and sole sorghum Gaya early OM (Figure 3). Because these two treatments were poorly established, solar radiation easily penetrated the canopy during the day while long wave radiation leaves easily at night. For the same year, second soil temperature sampling shows that sole cowpea - 374 showed low night and low day temperatures indicating high biomass density within this treatment (Figure 4). M/S/C OM particularly exhibited low night and high day soil temperatures. This was due to the onset of senescence in millet by the time of second soil temperature sampling and because of the wider spacing in M/S/C treatments, solar radiation easily penetrated the canopy of these treatments.

In the 1995 experiment, low night and low day soil temperatures were observed for sole millet OM + IF; whereas low night and high day soil temperatures were observed for M/S/C OM during the first soil temperature sampling (Figure 5). The small soil temperature amplitude observed for sole millet OM + IF was due to the luxuriant plant cover within this treatment. However, in the M/S/C OM treatment, the soil temperature sensor was placed under sorghum (Gaya early), and because of the initial slow growth rate of sorghum (as compared to millet), there was poor canopy cover. This

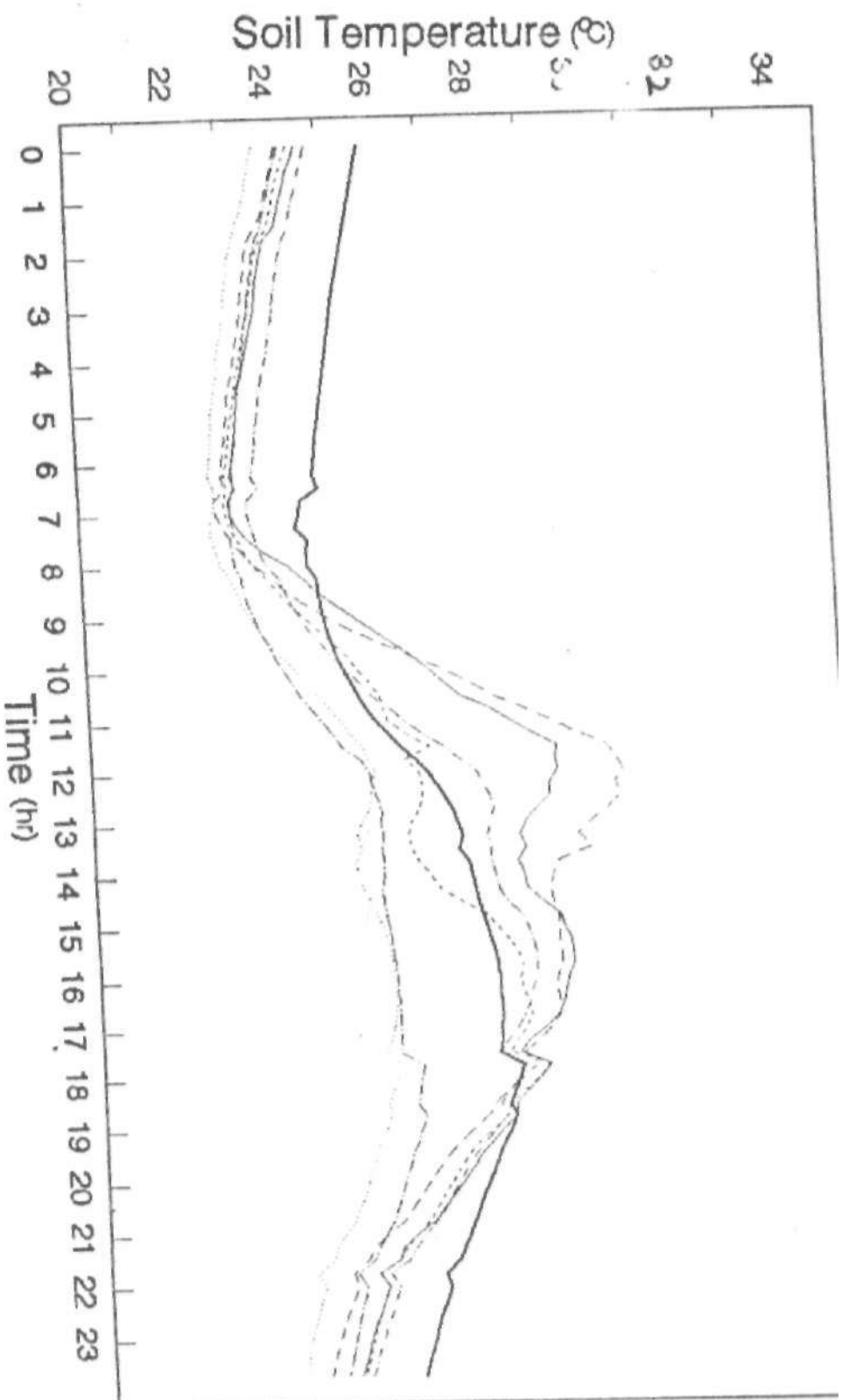
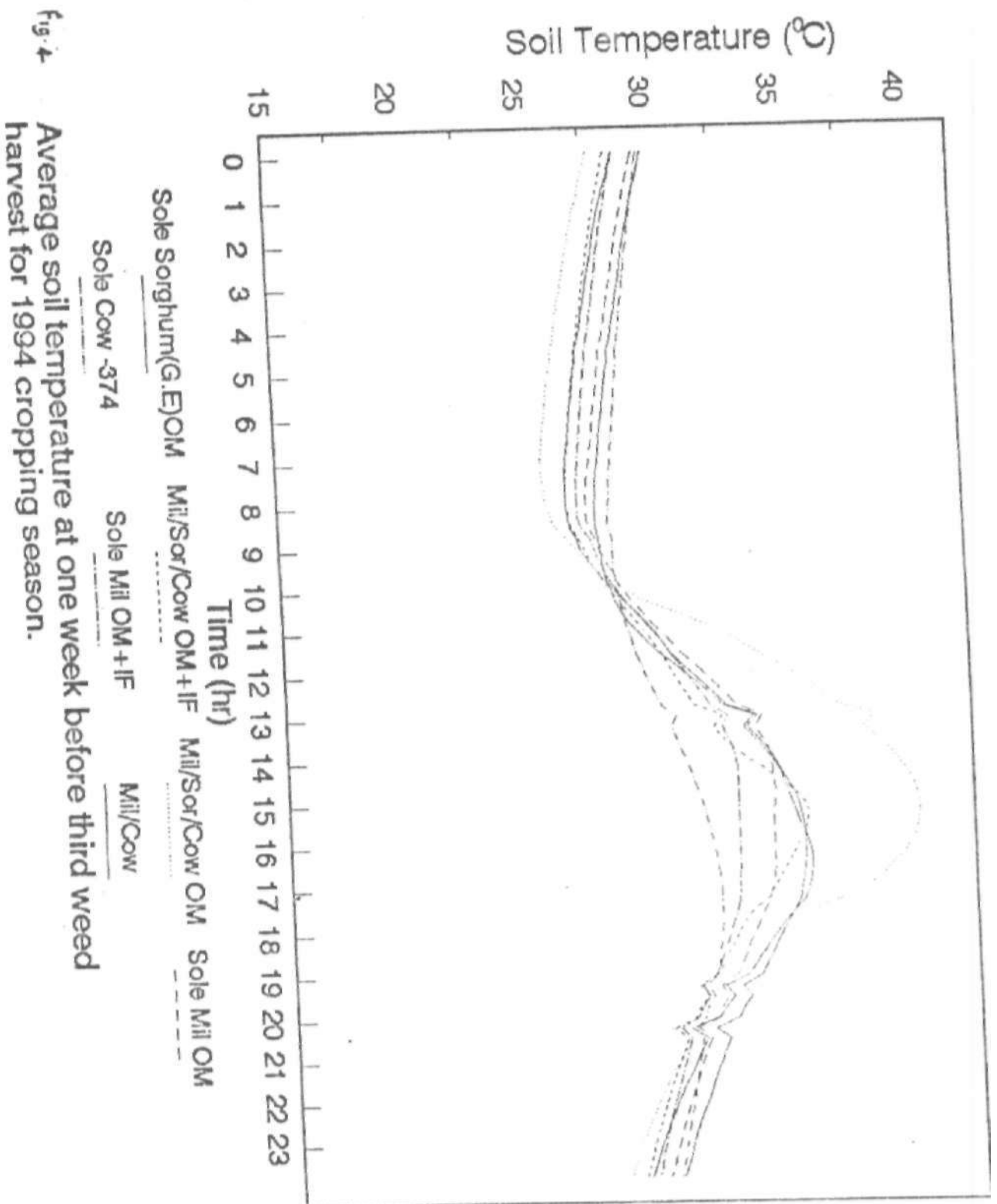
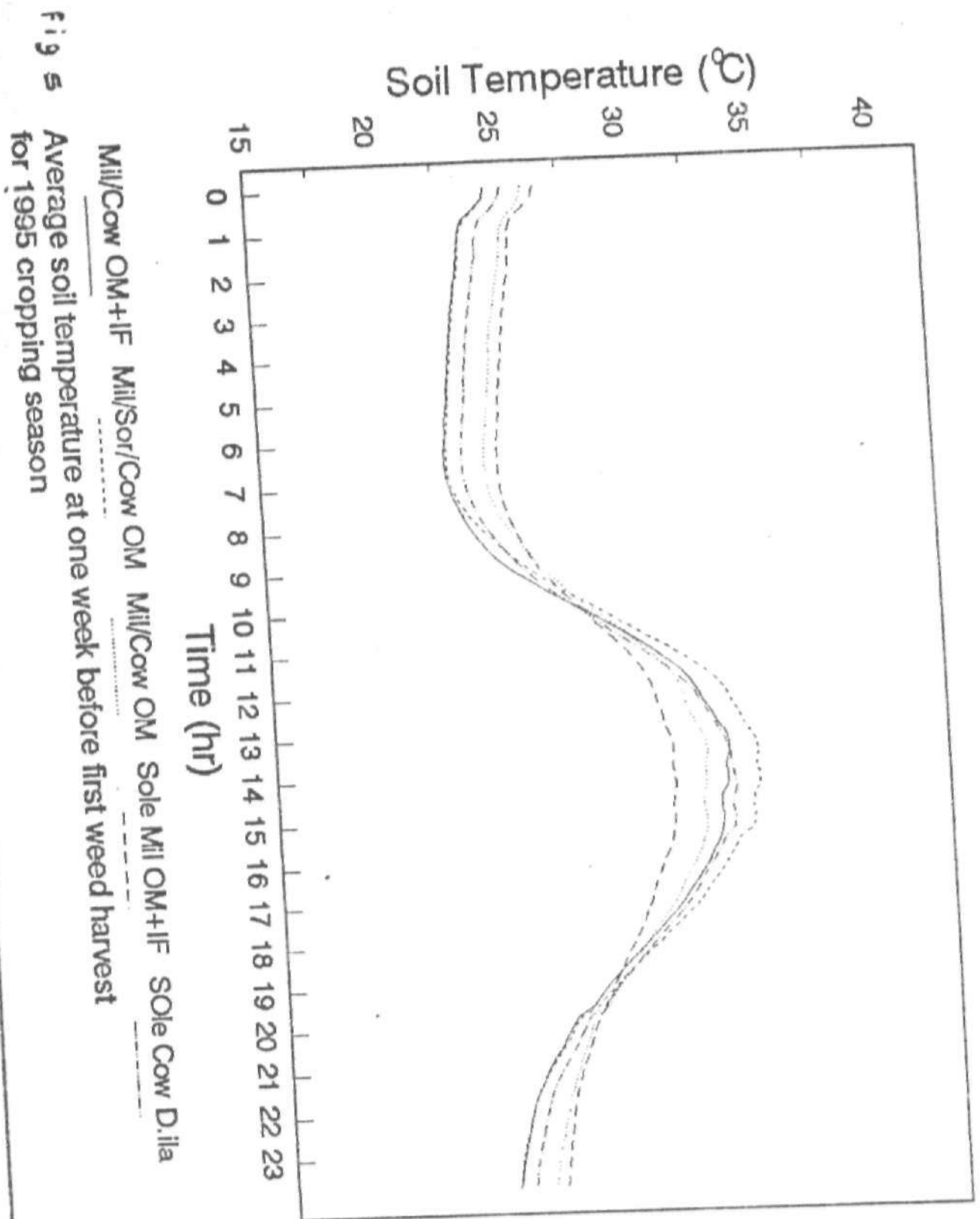


Fig. 2. Average soil temperature at one week before second weed harvest for 1994 cropping season.





facilitated light penetration down the canopy to cause high soil temperature amplitude. As the season progressed, and by the time of second soil temperature sampling, there was an initiation of reproductive primordia in millet. Since this is usually associated with a reduction in total leaf area as assimilates are concentrated in grain filling instead of vegetative growth, all millet associated treatments exhibited higher soil temperature amplitude (when compared with non-millet associated treatments) and this was particularly observed for millet/cowpea OM + IF and millet/cowpea OM treatments (Figure 6). That millet/cowpea treatments showed higher soil temperature amplitude than that of sole millet was due to the fact that the soil temperature sensors were placed under millet in millet/cowpea treatments. Because of the wider planting distance between millet and cowpea in millet/cowpea treatment (1m apart), light penetration was higher in millet/cowpea treatment compared to sole millet (planted at 0.5m apart) during reproductive primordia initiation with its attendant reduction in total leaf area. For the same sampling date, sole cowpea Dan-Illa showed the lowest soil temperature amplitude. This was evidently due to high biomass density that availed in the sole cowpea Dan-Illa treatments. By third soil temperature sampling (just before millet harvest), soil temperature readings for sole millet OM + IF and that of millet/cowpea OM showed higher amplitude, approaching that of the Blank (Figure 7). This was due to senescence occurring in millet. For the same sampling, low soil temperature amplitude was observed for sole cowpea Dan-

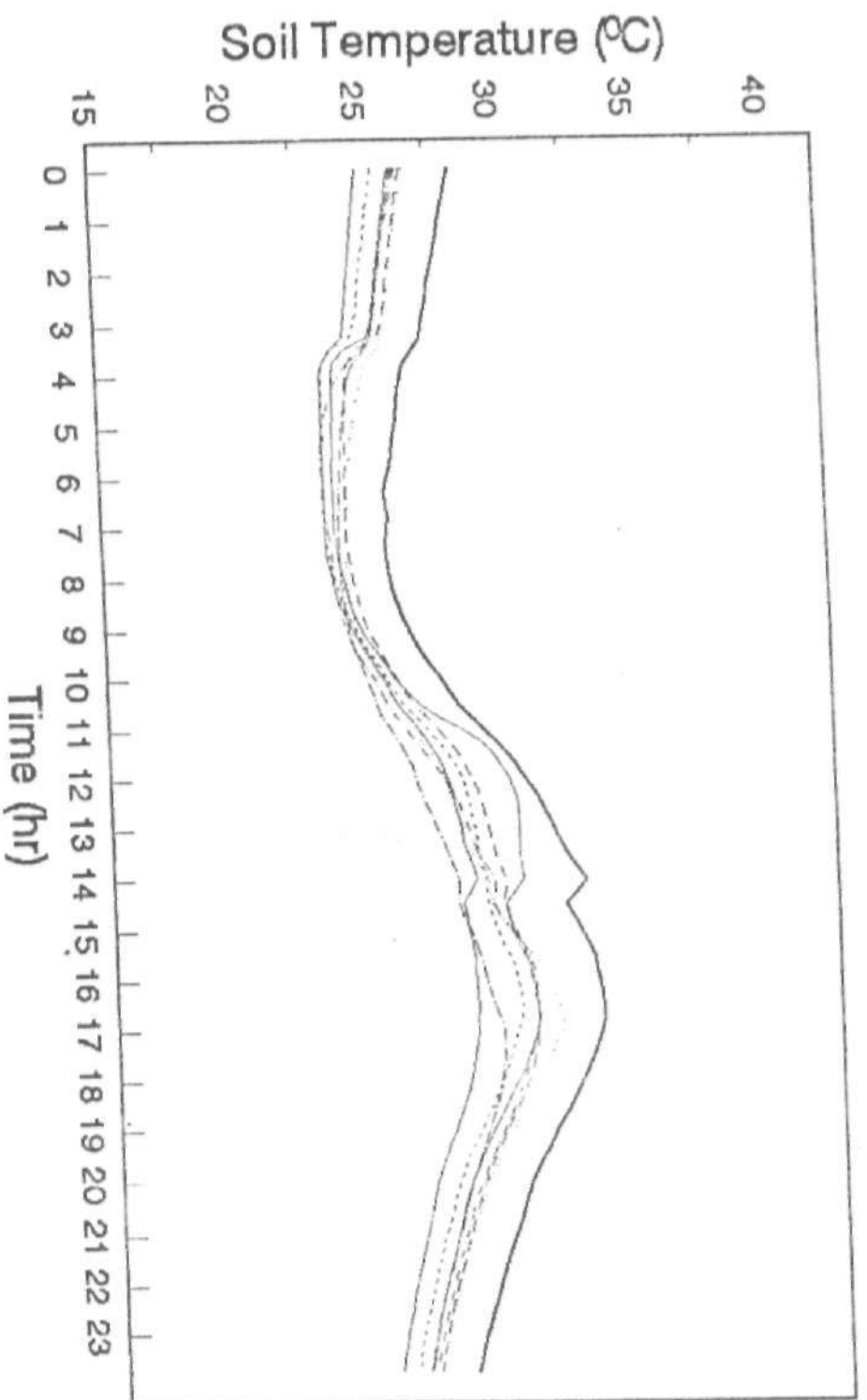


Fig. 6
Average soil temperature at one week before second weed harvest
for 1995 cropping season.

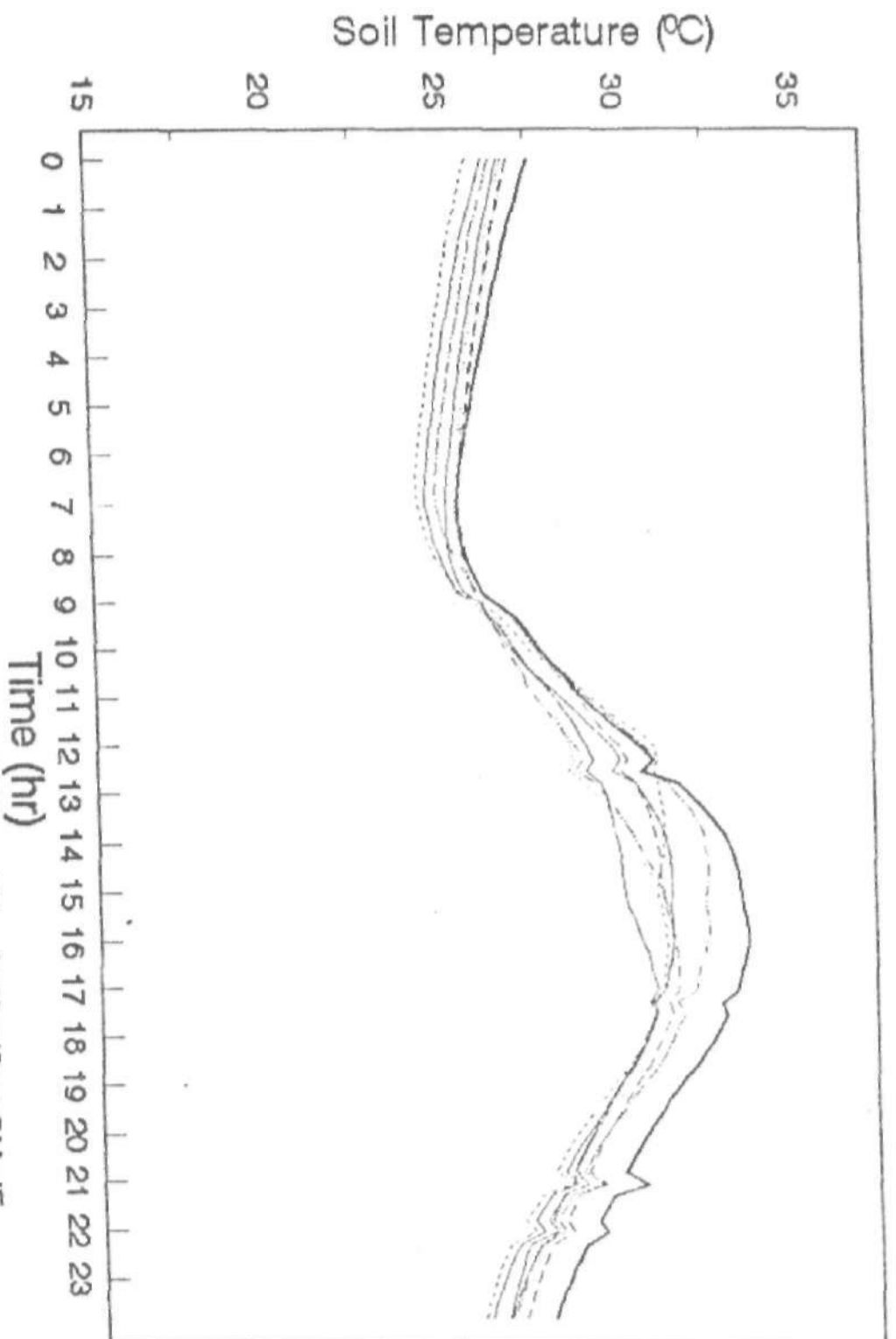


Fig. 7: Average soil temperature at one week before third weed harvest for 1995 cropping season.

Illa treatment because of the high biomass density present in Dan-Illa treatments.

4.5 Light Transmission

Light transmission or transmitted photosynthetically active radiation (LT) is the portion of the incoming solar radiation that is transmitted down the crop canopy. It is eventually the portion of PAR that is available to understory plants after interception by taller plants. LT is effectively the portion of the incoming solar radiation available to emerging weeds. The lower the value, the greater the canopy cover. Values of percentage light transmission with their corresponding crop arrangements are shown in Tables 8a and 8b.

The 1994 experiment shows that in millet/sorghum/cowpea intercrops, millet-sorghum arrangement consistently exhibited lower % LT. The lowest value of 16% was obtained on JD 223 (49 DAS of millet and 43 DAS of sorghum) for organic manure (OM) plus inorganic fertilizer (IF) treatments. That of OM only was 18% on JD 242 (67 DAS of millet and 61 DAS of sorghum) as shown in Table 8a. Conversely, higher values were exhibited by sorghum(s)-cowpea local (CL) and sorghum-cowpea improved (CG) arrangements for both treatments. S-CL had the highest % LT of 97 on JD 206 (25 DAS of sorghum and 18 DAS of cowpea). This value decreased to 62% on JD 262 (81 DAS of sorghum and 72 DAS of cowpea) because of increased in crop growth vis-a-vis increased shade as the season progressed. Figures 8a and 8b show the % LT within the

Table 8(a): Light transmission within cropping arrangement (1994)

Treatment	Crop Combination	Dates in Julian Days					
		206	220	223	229	242	262
M/S/COM	M-S	81	58	29	46	38	56
	S-CG	80	87	79	94	73	71
	CG-CG	81	94	55	68	56	56
	CG-M	85	85	43	73	46	66
	M-S	65	61	23	*	18	53
	S-CL	97	93	90	78	62	62
	CL-CL	75	69	46	53	46	39
	CL-M	82	75	90	26	78	50
M/S/C OM+IF	M-S	73	53	16	29	24	43
	C-CG	98	87	52	88	79	52
	CG-CG	92	82	65	74	46	51
	CG-M	91	64	46	71	64	51
	M-S	68	66	31	43	28	42
	S-CL	99	*	65	78	54	53
	CL-CL	91	69	36	48	42	41
	CL-M	78	75	52	43	44	42
M/C OM	M-M	61	71	35	28	22	36
	M-CG	83	85	59	47	40	71
	M-CL	91	94	38	62	53	39
							74
M/C OM+IF	M-M	68	50	65	29	14	53
	M-CG	81	90	51	54	64	50
	M-CL	93	87	40		48	47
Sole Cowpea	867-11	OR	95	64	48	65	39
		BR	90	*	66	68	44
							49
	IT89KD-374	OR	90	81		54	62
		BR	95	95		67	41
							56
	DAN ILLAN	OR	93	60	67	67	45
		BR	89	87	58	44	59
							43
Sole Millet	OM	OR	61	48	13	44	28
		BR	50	81	14	31	23
							57
	OM+IF	OR	62	57	19	24	45
		BR	61	64	27	20	59
							52

Table 8(a) contd:

Treatment	Crop Combi-nation	Dates in Julian Days					
		206	220	223	229	242	262
Sole Sorghum O.M	Gaya Early	97	97	81	50	47	28
		93	77	87	64	57	21
	ICVS-400	98	77		90	77	80
		97	94		*	79	84
Sole Sorghum M+F	Gaya Early	92	73	41	85	45	33
		94	94	64	43	37	27
	ICVS-400	94	86	97	94	81	66
		98	87	96	84	58	43

OR = On Ridge

BR = Between Ridge

Key: M-S-C = Millet-sorghum-cowpea intercrop
M-C = Millets-cowpea intercrop
OM = Organic manure (cow dung)
IF = Inorganic fertilizer (NPK)
S-CG = Sorghum-Grain (improved) cowpea arrangement
S-CL = Sorghum-local cowpea arrangement

Table 8(b): Light transmission within cropping arrangement (1995)

Treatment	Crop	Dates in Julian Days				
		194	209	222	235	249
M-S-C OM ONLY	M-S	52	16	19	30	18
	S-CG	18	69	25	54	15
	CG-CG	96	49	5	31	20
	M-CG	54	54	44	27	13
	M-S	6	18	22	5	56
	S-CL	56	55	21	31	54
	CL-CL	94	61	12	43	9
	CL-M	29	52	13	46	45
M-S-C OM+IF	M-S	12	18	30	14	9
	S-CG	56	66	10	42	19
	CG-CG	92	61	9	17	16
	M-CG	16	29	15	29	15
	M-S	17	22	15	14	8
	S-CL	54	49	11	33	16
	CL-CL	74	40	12	36	10
	CL-M	97	48	45	29	5
M-C OM ONLY	M-M	7	11	21	10	40
	M-CG	44	50	97	21	50
	CG-CG	73	52	14	61	37
	M-CL	34	59	22	36	59
	CL-CL	25	40	13	41	22
M-C OM+IF	M-M	7	6	41	15	31
	M-CG	13	37	16	48	40
	CG-CG	78	36	17	37	29
	M-CL	61	25	78	39	24
	CL-CL	97	53	49	48	27
IT88D-867-11 DAN-ILLA	C-CO.R	97			14	14
	C-Cb.R	98			4	24
	C-CO.R	58	30	5	9	20
	C-Cb.R	18	45	32	9	4
IT89KD-374	C-CO.R	64	52	18	14	16
	C-Cb.R	86	35	27	5	11

Table 8(b) contd:

Trt.	Crop	Dates in Julian Days				
		194	209	222	235	249
IT86D-719	C-C.O.R	95	-	-	53	27
OM	C-CB.R	89	-	-	15	56
SM	M-M.O.R	11	23	16	44	50
OM	M-M.B.R	32	20	30	39	50
SM	M-M.O.R	64	23	37	37	85
OM	M-M.B.R	53	52	16	21	58
S-M	M-M.O.R	64	23	37	37	85
OM+IF	M-M.B.R	53	52	16	21	58
SS	S-S OR	51	8	33	20	29
GE.OM	S-S B.R	24	7	28	19	43
GE	OM+IF S-S OR	76	52	-	36	47
	S-S B.R	86	58	-	10	39
ICVS-400						
OM+IF	S-S O.R	51			57	38
	S-S B.R	95			25	35
ICVS-400						
OM	S-S O.R	97			55	24
	S-S B.R	95			31	38

Key: M-S-C = Millet-sorghum-cowpea intercrop
M-C = Millet-cowpea intercrop
OM = Organic manure (cow dung)
IF = Inorganic fertilizer (NPK)
S-CG = Sorghum-Grain (improved) cowpea arrangement
S-CL = Sorghum-local cowpea arrangement
OR = Measurement taken on ridge (within ridge)
BR = Measurement taken between ridge

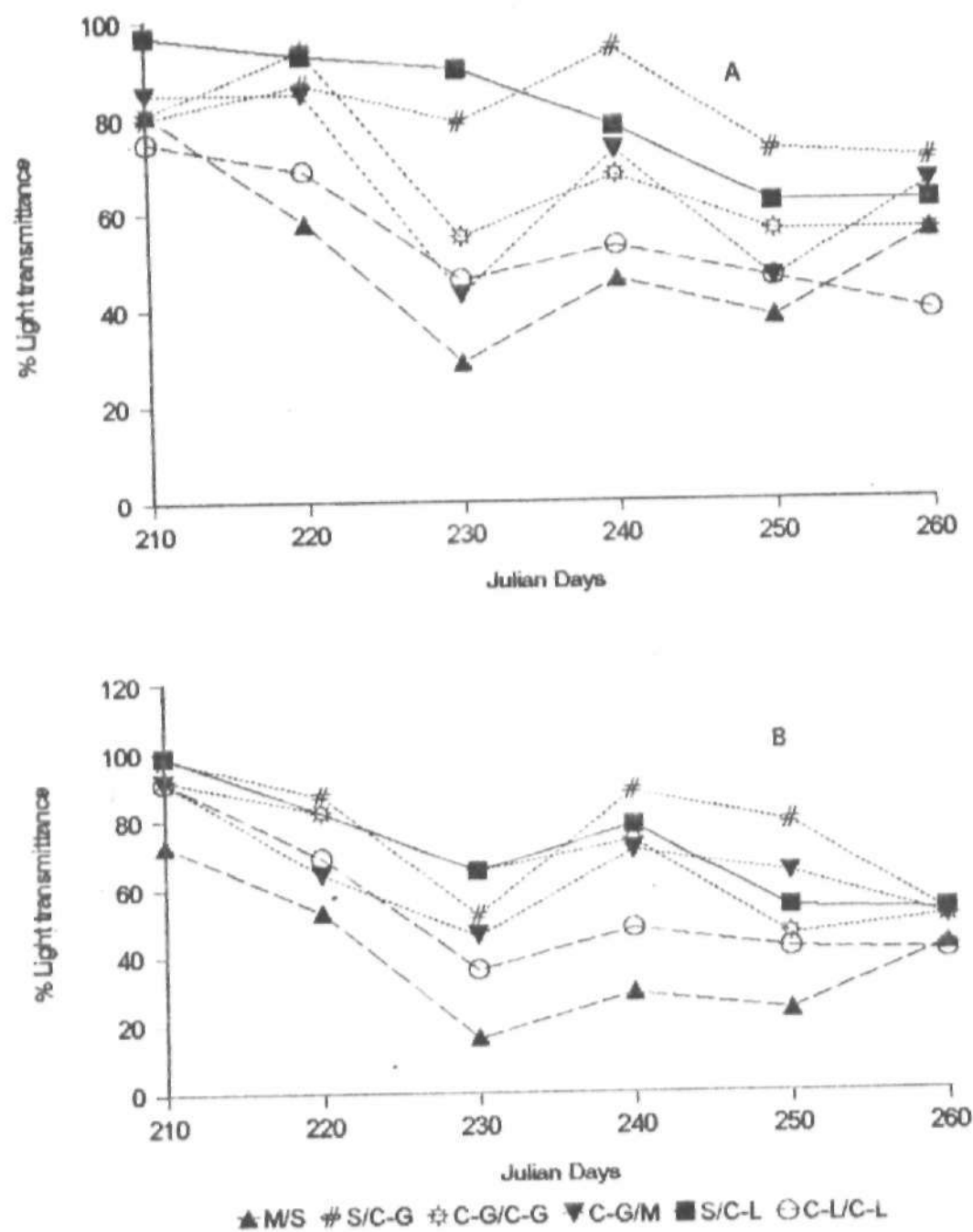


Fig.8: Light transmission within millet/sorghum/cowpea intercrop (a) organic manure application only and (b) organic manure plus inorganic fertilizer (1994).

different cropping arrangements. In millet/sorghum/cowpea OM + IF, S-CG arrangement showed, on the average, higher % LT than the other arrangements as shown in Figure 8b. This was because of the characteristically poor initial establishment of sorghum.

In millet/cowpea intercrops, M-CL and M-CG arrangements showed higher percentage LT in both OM and OM + IF treatments (Figure 9a and 9b). The highest value of 94% was obtained on JD 220 (46 DAS of millet) for M-CL with OM treatment while 85% was obtained for M-CG of the same OM treatment (Figure 9a). However, M-CG showed prominently higher percentage LT value on the average in OM + IF treatments as shown in Figure 9b, suggesting that the addition of inorganic fertilizer caused an increase in the canopy structure of the cowpea (local) component resulting in increased shade. For both OM and OM + IF treatments, M-M arrangements showed lower percentage LT values of 18% for OM, and 14% for OM + IF treatments (Figures 9a and 9b).

In between rows of sole crop treatments, sole sorghum Gaya early (G.E) OM, sole sorghum ICVS-400 OM and sole sorghum ICVS-400 OM + IF showed high percentage LT values. The lowest value of 13% was obtained for sole millet OM while sole millet OM + IF had a percentage LT of 19% (Figure 10). This was because the distance between rows (75 cm) was greater than that within rows (50 cm). Expectedly, due to the difference in spacing, more light penetrated crops in the former arrangement than the latter.

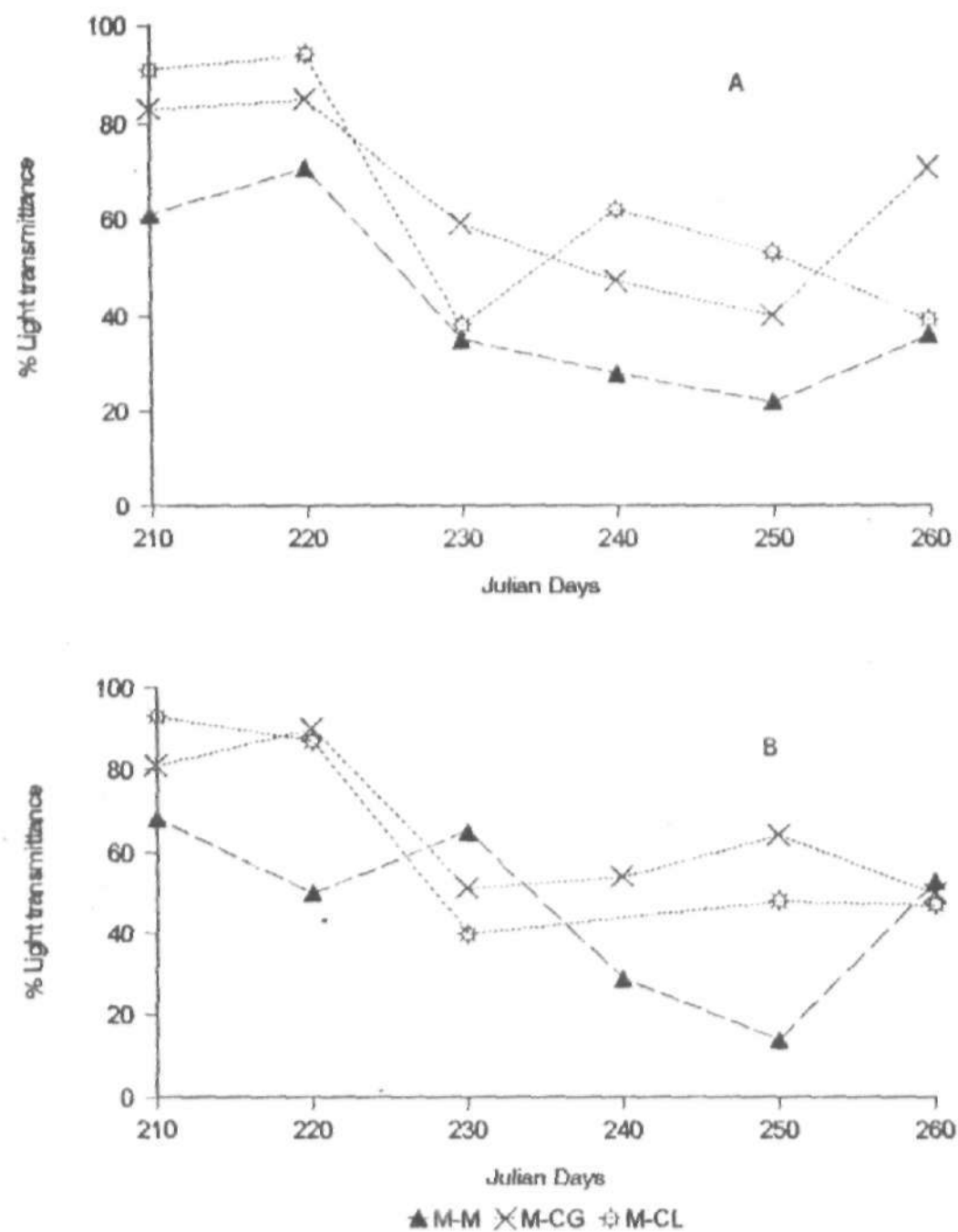


Fig.9: Light transmission within millet/cowpea intercrop (a) organic manure application only and (b) organic manure plus inorganic fertilizer application (1994).

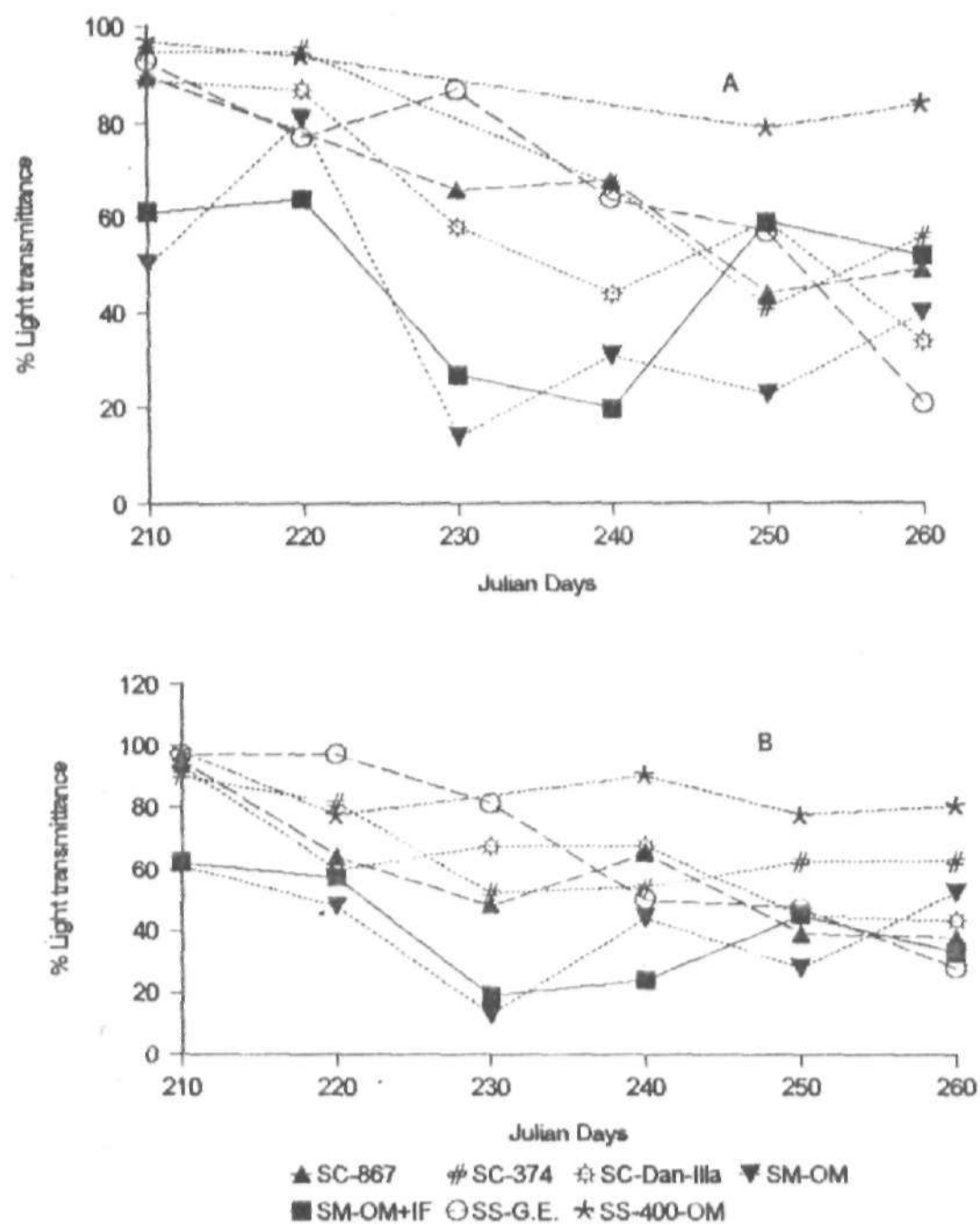


Fig 10: Light transmission in sole crop treatments (a) between rows and (b) within rows (1994).

Percent LT results for 1995 experiment are shown in Table 8b. In this experiment, M-S arrangement had the lowest LT value of 5% on JD 235 (71 DAS of millet) in M/S/C OM treatment. The highest LT of 96% for the same treatment was recorded in CG-CG as against the overall high percentage LT of 97. observed for sole sorghum ICVS-400 OM treatment Table 8b.

The light profiles in the cropping pattern during 1995 trial are depicted in Figures 11a, 11b, 12a, 12b, 13a and 13b. In the 1995 experiment, the different arrangements for millet/sorghum/cowpea at both fertility levels show the same trend except for variations observed for sorghum-cowpea grain, millet-cowpea grain and millet-cowpea local. In millet/sorghum/cowpea with organic manure application only, the light transmitted within millet-cowpea grain (M-CG) arrangement showed a decreasing trend throughout the active crop growth period Figure 11a. This was due to the fast take off/establishment of millet coupled with the smothering effect of the cowpea component. The same trend was also observed in organic manure plus inorganic fertilizer treatment for millet-cowpea local (M-CL) as shown in Figure 11b. Sorghum-cowpea grain arrangements show that light penetration into the canopy was greater initially in organic fertilizer (Figure 11a and 11b). This obviously was due to the application of inorganic fertilizer which provided for a faster crop take off/establishment in OM + IF.

In millet/cowpea intercrops, millet-cowpea grain (M-CG) and millet-cowpea local (M-CL) when compared to other

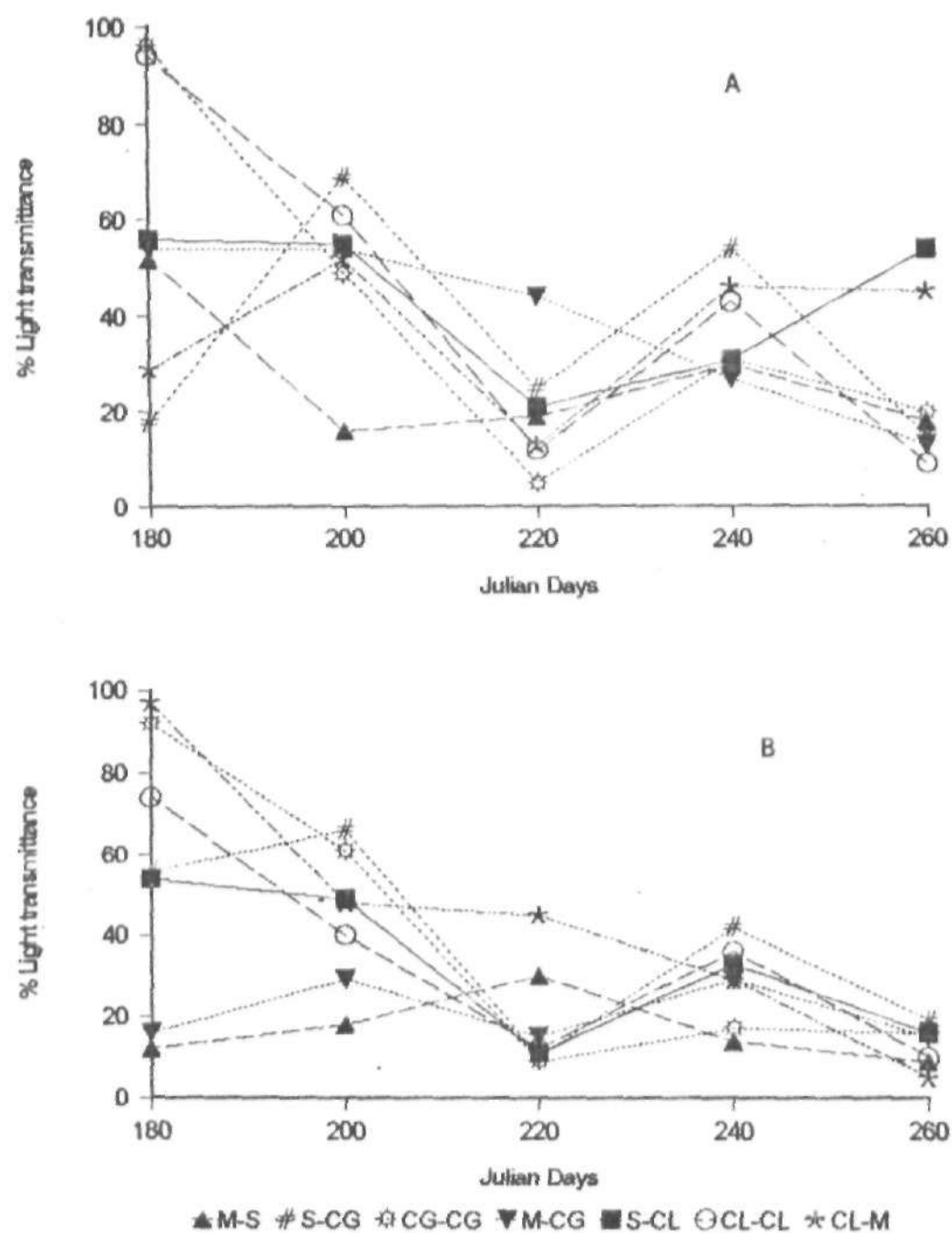


Fig 11: Light transmission within millet/sorghum/cowpea intercrop (a) organic manure application only and (b) organic manure plus inorganic fertilizer application (1995).

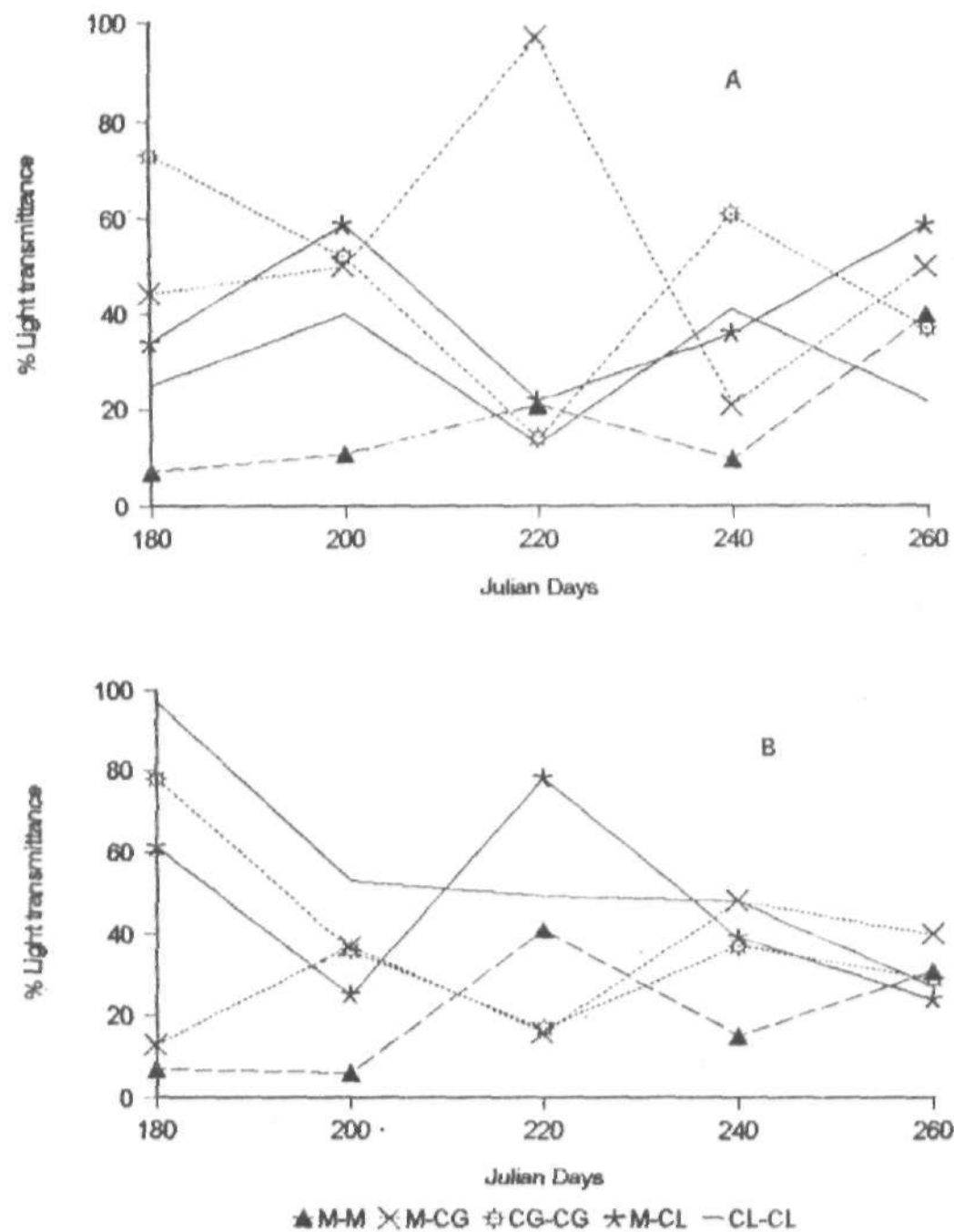


Fig.12: Light transmission within millet/cowpea intercrop (a) organic manure application only and (b) organic manure plus inorganic fertilizer application (1995).

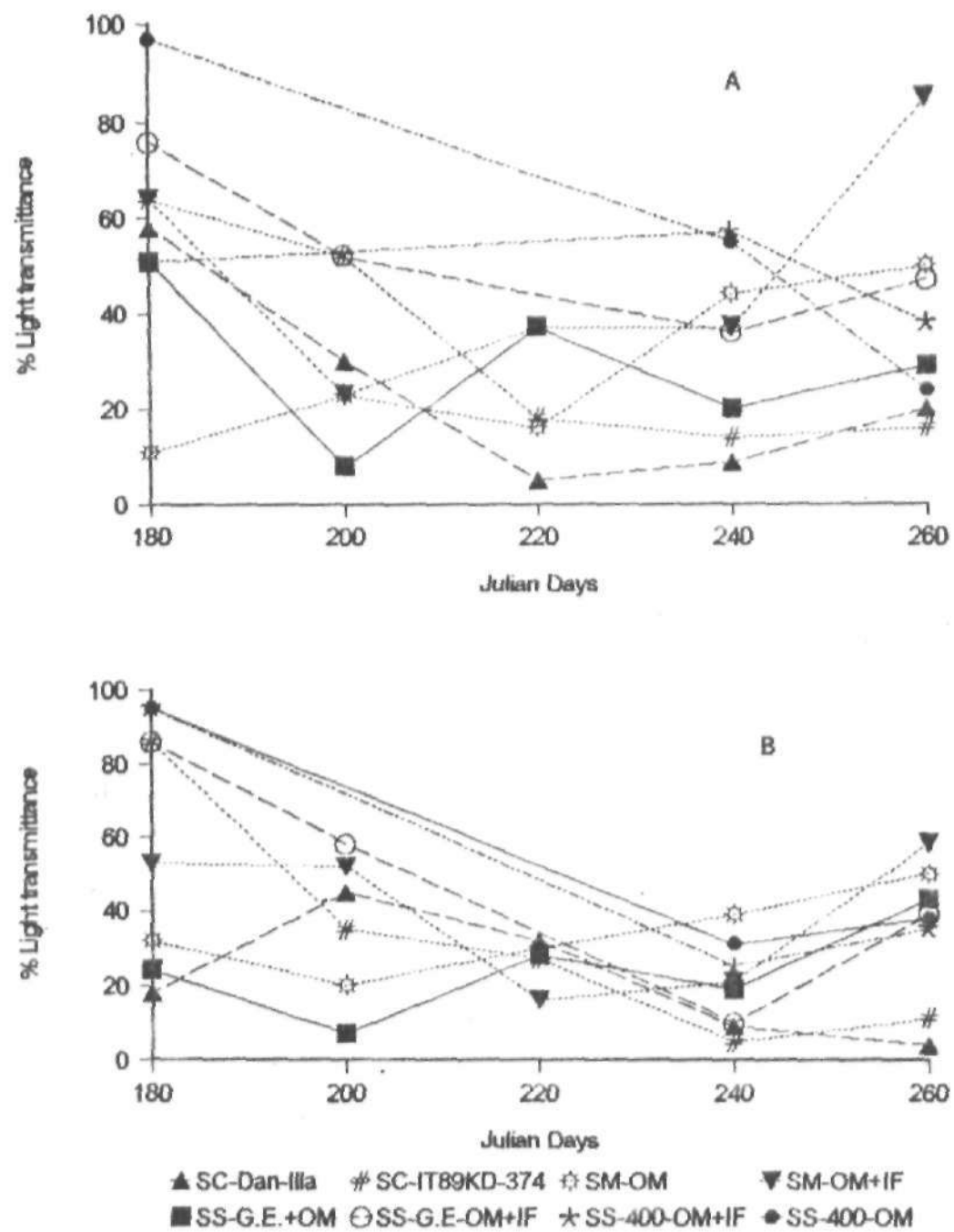


Fig 13: Light transmission in sole crop treatments (a) within rows and (b) between rows (1995).

treatments recorded higher light transmission during the active growth period in OM and + IF treatments respectively as shown in Figures 12a and 12b. It was also noticed that whereas cowpea grain-cowpea grain (CG-CG) arrangement had initial high LT value in OM treatment, and remain higher throughout the year than the corresponding cowpea local-cowpea local (CL-CL) (Figure 12a), in OM + IF CL-CL recorded higher LT values during the same period and remain considerably higher than the correspond CG-CG arrangement. Figure 11 and particularly Figure 12 seem to suggest that cowpea local component in a medium with low nutrient status (as in OM only) utilizes light better than cowpea grain in the same medium; particularly when water is not limiting. Conversely, in a high nutrient soil medium (as in OM + IF), cowpea grain captures and utilizes light better than cowpea local. 1994 light data could not however corroborate this. This perhaps was due to the intervening dry spell observed in the 1994 experiment season.

Light data for 1995 sole crop treatments follow the same trend as that of 1994 with sole sorghum ICSV-400 (OM), sole sorghum ICSV-400 OM + IF and Sole Sorghum Gaya Early OM+IF showing high values (Figures 13a and 13b. As in 1994 experiment, values obtained between rows (0.75m) Figure 13a was higher than that obtained within rows (0.5m) as shown in Figure 13b.

The weed data was taken by randomly throwing the quadrat into the different cropping treatments not minding the crop arrangements within the treatments. The light regime down

the canopy and hence available for weeds was therefore the integral of the shade levels of the different crop arrangements within each canopy. Averages of these values were therefore used to relate the light transmitted down the canopy throughout the season to weed biomass.

A summary of the effects of the different cropping systems on LT is shown in Table 9a and 9b for the 1994 and 1995 experiments respectively. In both experiments, sole sorghum ICVS-400 OM had the highest % LT values of 85 for 1994 and 49 for 1995. This was followed by 82% for sole sorghum ICVS-400 OM + IP in 1994 experiment and 46% by the same crop treatment in 1995 experiment. A cursory inspection of Tables 9a and 9b reveals that higher % LT values were recorded during 1994 experiment than 1995 experiment. This was due to the difference in the degree of cloud cover during the two trials; because 1995 rainfall was evenly distributed more than that of 1994, there was more cloud cover in 1995 than in 1994. As mentioned earlier, the rains during 1994 experiment were erratic with long dry spells during the cropping season. However, during 1995 experiment, rains were well established during the growing period with attendant cloud cover.

4.6 Grain Yield

In 1994 experiment, sole cowpea Dan-Illa recorded the highest grain yield compared to other sole cowpea treatments. In the same experiment, sole sorghum Gaya early, recorded higher grain yield at both organic manure and organic manure

Table 9(a): Effect of cropping systems on light transmission (1994)

Cropping System	Dates in Julian Days						$\bar{x}$
	206	220	223	229	242	262	
M/S/C OM	81	78	57	63	52	57	64
M/S/C OM+IF	86	71	45	59	48	47	59
M/C OM	76	75	40	42	33	55	53
M/C OM+IF	80	68	47	45	35	46	53
SC 867-11	93	64	57	66	42	44	61
SC 374	93	89	78	61	58	55	72
SC D. ILIA	91	73	63	56	52	38	62
SM. OM	56	64	13	38	26	48	41
SM OM+IF	61	61	23	22	52	42	44
SSG.E OM	95	87	84	56	52	25	67
SS ICVS 400 OM	98	85	63	90	78	82	85
SSGE OM+IF	93	84	53	64	41	30	61
SSICVS 400 OM+IF	96	87	97	89	69	54	82

Key: M/S/C = Millet/Sorghum/Cowpea intercrop
M/C = Millet/Cowpea
OM = Organic manure (cow dung)
IF = Inorganic fertilizer (NPK)
SC = Sole cowpea
SSGE = Sole sorghum gaya early
SM = Sole millet

Table 9(b): Effect of cropping systems on light transmission (1995)

Cropping System	Dates in Julian Days					
	194	209	222	235	249	$\bar{x}$
M/S/C OM	51	47	20	33	29	36
M/S/C OM+IF	52	41	19	27	12	30
M/C OM	37	42	33	34	42	38
M/C OM+IF	51	31	40	38	30	38
SC 867-11	98	49	22	9	19	39
SC-374	75	44	18	9	13	32
SC DAN-ILLA	38	37	19	9	12	23
SC-719	92			34	41	46
SM OM	21	21	23	41	50	31
SM OM+IF	59	38	26	29	71	45
SS GE OM	37	7	31	20	36	26
SSICVS 400 M	96			43	31	49
SSGE OM+IF	81	55		21	43	46
SSICVS 400 OM+IF	73			41	36	46

Key: M/S/C = Millet/Sorghum/Cowpea intercrop
M/C = Millet/Cowpea
OM = Organic manure (cow dung)
IF = Inorganic fertilizer (NPK)
SC = Sole cowpea
SSGE = Sole sorghum gaya early
SM = Sole millet

plus inorganic fertilizer treatments as compared to corresponding sole sorghum ICSV-400. For the same year, sole millet with organic manure plus inorganic fertilizer showed higher grain yield than that of sole millet with organic manure only (Table 10a).

In the millet/cowpea intercrop, there was no appreciable difference in the component cowpea yields at both fertilizer levels for 1994 experiment. However, IT89KD-374 cowpea variety showed a slightly higher yield than the corresponding Dan-Illa cowpea variety as shown in Table 10a. In the same millet/ cowpea intercrop, the millet component with organic manure treatment showed higher grain yield than that of organic manure plus inorganic fertilizer. Also in the same year, millet/ sorghum/cowpea with organic manure plus inorganic fertilizer recorded higher yields in all the respective components than the corresponding components than that of organic manure treatment. The only exception was in the yield of the cowpea components in millet/sorghum/cowpea with organic manure. Here, both cowpea IT89KD-374 and Dan-Illa components recorded a grain yield of 70Kg/ha as shown in Table 10a.

Sole plots treatments in 1995 experiment showed that sole cowpea IT89KD-374 and sole sorghum Gaya early recorded higher grain yield than other corresponding varieties as shown in Table 10b. Also in the same year sole millet with organic manure plus inorganic fertilizer recorded higher grain yield than that of organic manure only. In millet/cowpea intercrop for 1995 experiment, cowpea

Table 10: Effects of cropping systems on Grain yield (kg/ha)

(a) 1994 experiment

Cropping System	Cowpea			Millet Ex Bornu	Sorghum Gaya Early	ICVS- 400
	IT89KD- 374	IT88D8 67-11	Dan- illa			
Cowpea	787	696	1238			
Millet OM				2250		
Millet OM+IF				2320		
Sorghum OM					1144	643
Sorghum OM+IF					1454	831
Millet/cowea OM	100		80	1890		
Millet/cowpea OM+IF	110		90	1340		
Millet/sorghum/cowpea OM	70		70	1220	142	
Millet/sorghum/cowpea OM+IF	100		150	1300	208	

(b) 1995 experiment

Cropping System	Cowpea				Millet Ex Bornu	Sorghum Gaya Early	ICVS- 400
	IT89K D-374	IT86D- 719	IT88D- 867-11	Dan- illa			
Cowpea	1767	1544	1645	1652			
Millet OM					2472		
Millet OM+IF					2767		
Sorghum OM						1760	1560
Sorghum OM+IF						1820	1270
Millet/cowea OM	154			173	1935		
Millet/cowpea OM+IF	123			1560	2155		
Millet/sorghum/ cowpea OM	131			212	1452	560	
Millet/sorghum/ cowpea OM+IF	135			153	1141	720	

OM = Organic manure (cow dung), IF = Inorganic fertilizer (NPK).

components associated with millet/cowpea with only organic manure treatment recorded higher yields than the corresponding organic manure plus inorganic fertilizer treatment. However, for both millet/ cowpea organic manure and that of organic manure plus inorganic fertilizer treatments, cowpea variety Dan-Illa recorded higher yields than corresponding IT89KD-374. This was the reverse in 1994 experiment. Also millet component with organic manure plus inorganic fertilizer recorded a higher grain yield of 2155 Kg/ha than the yield of 1935 Kg/ha recorded for organic manure treatment only.

Millet/sorghum/cowpea intercrop for 1995 experiment showed Dan-Illa cowpea component recording higher grain yield than corresponding IT89KD-374 cowpea variety at both fertilizer levels. Also, millet component in millet/sorghum/cowpea with organic manure only recorded higher yield than that with organic manure plus inorganic fertilizer. Sorghum component on the other hand, was higher in millet/sorghum/cowpea with organic manure plus inorganic fertilizer than that of millet/sorghum/cowpea with organic manure only as shown in Table 10b.

CHAPTER 5

DISCUSSION

5.1 Weed Biomass/Frequency

The effects of the different cropping systems on weed biomass is depicted in Figure 14 for 1994 experiment, and Figure 15 for 1995 experiment. In 1994, sole cowpea Dan-Illa recorded the highest weed biomass throughout the 3 sampling dates (Figure 14). A look at the percentage frequency of occurrence (Tables 4a and 4b), show that sole cowpea Dan-Illa was overwhelmingly attacked by *Cyperus esculentus*. This treatment recorded 65.77% frequency of occurrence of *Cyperus esculentus* during the 2nd weeding. During the 3rd weeding, 59.37% frequency of occurrence was recorded and this value was the highest compared to other treatments for the same period. *Cyperus esculentus* was followed by *Cynodon dactylon* and *Digitaria horizontalis* (in order of preponderance) in the 2nd weeding. However, during the 3rd weeding, *Cyperus esculentus* was closely followed by *Digitaria esculentus*; while *Cynodon dactylon* was completely absent. Figure 14, Tables 3a, 3b, 4a and 4b reveal that after sole cowpea Dan-Illa treatment, the second most important weed biomass was observed for sole cowpea IT89KD-374 during the 1st weeding (6 WAS), sole sorghum ICSV-400 OM+IF during the 2nd weeding (10 WAS), and sole cowpea IT88D-867-11 during the 3rd weeding (14 WAS). In all these treatments, *Cyperus esculentus* and *Digitaria horizontalis* were the dominating weeds. One can

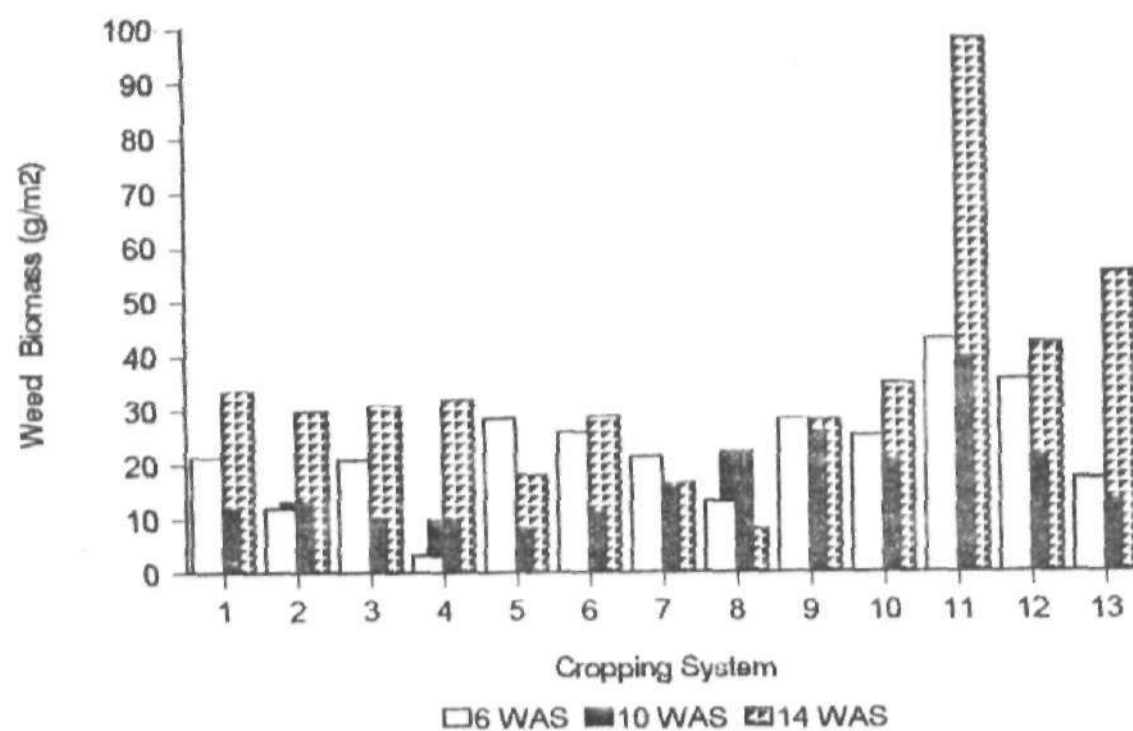


Fig. 14: Effect of cropping system on weed biomass (1994).

KEY:-

- | | |
|-----------------------------------|-----------------------------------|
| 1 = Millet/cowpea (OM+IF) | 8 = Sole sorghum G.E. (OM) |
| 2 = Millet/cowpea (OM) | 9 = Sole sorghum ISVC-400 (OM+IF) |
| 3 = Millet/sorghum/cowpea (OM) | 10 = Sole sorghum ISVC-400 (OM) |
| 4 = Millet/sorghum/cowpea (OM+IF) | 11 = Sole cowpea Dan-Illa |
| 5 = Sole millet (OM+IF) | 12 = Sole cowpea IT89KD-374 |
| 6 = Sole millet (OM) | 13 = Sole cowpea IT88D-86-11 |
| 7 = Sole sorghum G.E. (OM+IF) | |

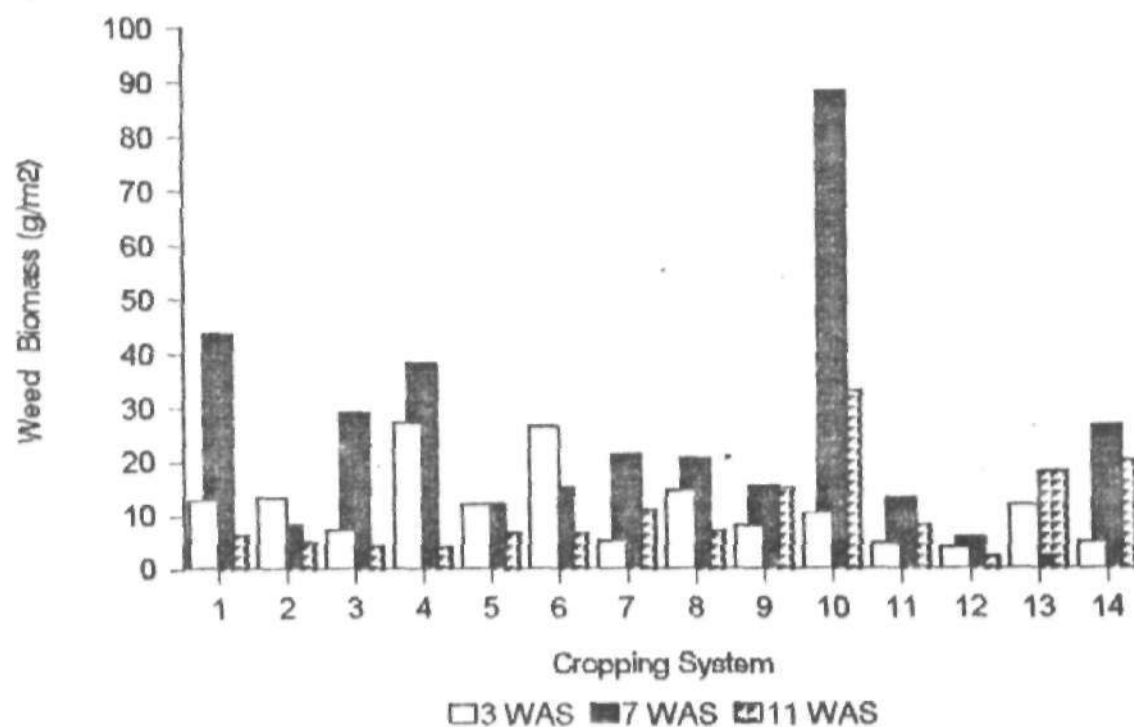


Fig. 15: Effect of cropping system on weed biomass (1995).

KEY:-

- | | |
|-----------------------------------|-----------------------------------|
| 1 = Millet/cowpea (OM+IF) | 8 = Sole sorghum G.E. (OM) |
| 2 = Millet/cowpea (OM) | 9 = Sole sorghum ISVC-400 (OM+IF) |
| 3 = Millet/sorghum/cowpea (OM) | 10 = Sole sorghum ISVC-400 (OM) |
| 4 = Millet/sorghum/cowpea (OM+IF) | 11 = Sole cowpea Dan-illa |
| 5 = Sole millet (OM+IF) | 12 = Sole cowpea IT89KD-374 |
| 6 = Sole millet (OM) | 13 = Sole cowpea IT88D-86-11 |
| 7 = Sole sorghum G.E. (OM+IF) | 14 = IT86D-719 |

safely conclude that 1994 weed regime was undoubtedly dictated by *Cyperus esculentus* and *Digitaria horizontalis*.

The dominance of *Cyperus esculentus* and *Cynodon dactylon* in Dan-Illa treatment indicates that these weeds do not like too much radiation. The light regime within sole crop treatments (Figure 10) shows that radiation was highest in sorghum and lowest in millet. That of sole cowpea Dan-Illa, IT88D-867-11 and IT89KD-374 were moderate. Because sole cowpea Dan-Illa had a moderate light regime (Figure 10b), *Cyperus esculentus* and *Cynodon dactylon* found Dan-Illa treatment a better habitat for propagation. It was noted that in sole sorghum ICSV treatment with extreme high light profile, *Cyperus esculentus* was completely absent as shown in Figure 10b and Table 4a. Confirming that *Cyperus esculentus* in particular reacts negatively to very high radiation (Loustalok, 1954; Bell et al., 1962; Magalhaes, 1969; Botha, 1971).

In 1995 experiment the weed biomass for the 1st weeding (6 WAS) were generally low and statistically not significantly different. This was expected as this period marked the onset of the cropping season with the rains yet to be sufficiently established (Figure 15). During the 2nd and 3rd weeding (Figure 15) and Table 3b, sole sorghum ICSV-400 consistently showed higher weed dry weight. This was due to late canopy establishment. As the season progressed, the overall weed dry weight decreased and on 3rd weeding, all the intercropped treatments showed lower weed biomass than sole crops except that of sole cowpea IT89KD-374 (Figure 15).

This was because sole cowpeas IT89KD-374 and Dan-11la were planted at wider spacing (0.75m x 0.75m) compared to other sole crops planted at a spacing of 0.5m x 0.75m. Whereas Dan-11la with its profuse branching characteristic covers the ground quickly, IT89KD-374 does not and so weed took advantage of the wider spacing for propagation. Since the third weeding was done when crops in all the treatments had developed full canopy, decrease in weed biomass in the intercrops relative to sole crops was caused by the shading effect within the intercrops. This confirms the efficiency of intercrops over sole crops in weed suppression (Geertz, 1963; Webster and Wilson, 1966; Walters, 1971; Enyi, 1973; Akobundu, 1980).

As shown in Tables 5a, 5b and 5c, *Digitaria horizontalis* was the dominating weed in terms of frequency of occurrence.

This weed also had the highest percentage contribution to total weed biomass on the different sampling dates as shown in Tables 6a and 6c.

The light profile in 1995 experiment shows that sole sorghum ICSV-400 recorded higher light profile than other sole plots. Since this treatment was dominated by *Digitaria horizontalis*, it stands to reason that this weed can also propagate effectively in high light intensities and are photosynthetically efficient as described by Garner (1962) and Black *et al.* (1969).

5.2 Effect of Intercropping Millet and Cowpea with Sorghum ICSV-400

In the 1994 experiment, intercropping millet (M) and cowpea (C) with Sorghum ICSV-400 OM + IF treatment led to statistically insignificant 26% and 62% less weed on JD 213 (39 DAS of millet) and 244 (70 DAS of millet) respectively than sole sorghum ICSV-400 OM + IF (Table 3). On the other hand, intercropping millet and cowpea with ICSV-400 at OM fertility level led to statistically significant 88% and statistically insignificant 53% less weed on the same dates than the sole sorghum ICSV-400 plots. On the average, intercropping millet and cowpea with sorghum ICSV-400 in 1994 experiment led to 26% (statistically insignificant) less weed weight at the OM + IF fertility level while 45% (statistically insignificant) less weed weight was obtained for the same crop combination at the OM fertility level.

The results for the first weed reading in the 1995 experiment were not statistically significant. Results for JD 213 (49 DAS of millet) and 244 (80 DAS of millet) show that 57% and 88% (both statistically significant) less weed weight respectively were recorded relative to the sole ICSV-400 plots for millet/sorghum/cowpea plots at OM fertility level. For the OM + IF fertility level, 47% (statistically insignificant) more weed weight relative to sole sorghum ICSV-400 plots was recorded on JD 213 in the millet/sorghum/cowpea plots, while 7% (statistically insignificant) less weed weight was recorded for the same plots on JD 244. On the average, results of intercropping

millet and cowpea with sorghum ICSV-400 in 1995 experiment led to statistically insignificant 12% and 47% less weed relative to the sole sorghum ICSV-400 plots at OM + IF and OM fertility levels respectively.

The above results indicate that intercropping millet and cowpea with sorghum ICSV-400 planted in alternate rows could be used in suppressing weeds. If organic manure and inorganic fertilizer are applied, millet and cowpea intercropped with sorghum ICSV-400 suppresses weed by 20% more (statistically insignificant) compared to the sole sorghum ICSV-400 plots, and by 46% more (statistically insignificant) when only organic manure is applied. The differences in weed suppression by millet and cowpea intercropped with sorghum ICSV-400 could be due to the differences in the soil fertility status as 26% additional relative weed weight was due to the application of inorganic fertilizer. The implication of this to a resource-poor farmer is plausible.

5.3 Effects of Intercropping Millet and Cowpea with Sorghum Gaya Early

When compared with sole sorghum (Gaya early) plots, intercropping millet and cowpea with Gaya Early led to 77 and 56% (both statistically significant) less weed weight for OM treatment, and 3 and 37% (both statistically insignificant) less weed weight for OM + IF fertility treatment on JD 213 and 244 respectively in 1994 experiment. However, on JD 274 (120 DAS of millet), comparative 75 and 50% more weed weights were recorded for the OM and OM + IF fertility treatment respectively.

In the 1995 experiment, comparing sole sorghum Gaya early with millet/sorghum/cowpea plots at OM + IF and OM fertility levels, 27% and 46% (both statistically insignificant) more weed weights were respectively recorded for JD 213 (49 DAS of millet). On JD 244 (80 DAS of millet), 61 (statistically significant) and 41% (statistically insignificant) relative weed weight reduction were recorded for the same respective treatments.

From both trials, intercropping Gaya early with millet and cowpea at both OM and OM + IF fertility levels led to fewer reduction in weed weight as compared to higher values obtained for sorghum ICSV-400. Gaya early has a more prolonged slow initial growth than ICSV-400 and so does not produce effective canopy cover to suppress weeds. This shows that sorghum ICSV-400 is a better intercropping component than sorghum Gaya Early for weed suppression in a millet/cowpea cropping system.

5.4 Effects of Intercropping Millet with Cowpea

In 1994 experiment, intercropping millet (Ex Bornu) with cowpea led to 53% and 25% (both statistically insignificant) weed reduction in millet/cowpea at OM and OM + IF fertility levels respectively on JD 213 (39 DAS of millet). On subsequent weed harvests, 6 and 29% more weed weight were recorded on JD 244 (70 DAS of millet) for the respective millet/cowpea with OM and with OM + IF, while 3 and 47% increase weed weights were recorded for the same respective fertility levels on JD 274 (100 DAS of millet). These values

were also statistically insignificant. On the average, statistically insignificant 16% weed weight reduction was observed for millet/cowpea at OM fertility level relative to sole millet plots, while 18% (statistically insignificant) more weed weight was recorded for OM + IF fertility level.

In 1995 experiment, 44% and 25% reduction in weed weight relative to sole millet plots were observed for OM fertility treatment on JD 213 (49 DAS of millet) and 244 (80 DAS of millet) respectively; while for the same dates, 72% (statistically significant) more weed weight and 5% (statistically insignificant) less weed weights were recorded for OM + IF fertility level. In this experiment, and on average for the last two weedings, statistically insignificant weed weight reduction of 35% was recorded for millet/cowpea at OM fertility level while statistically insignificant 34% more weed weight was recorded at OM + IF fertility level.

From both experiments, millet/cowpea plots relative to sole millet plots showed 25% less weed weight at OM fertility level and 25% more weed weight at OM + IF fertility level. These values were all statistically insignificant.

5.5 Light Transmission and Weed Biomass

The differences in mean weed dry matter for the 1995 experiment were statistically significant. Sole sorghum ICSV-400 had the highest two values of percentage LT of 49% for sole sorghum ICSV-400 at OM fertility level, and 46% for the corresponding OM + IF fertility level. Expectedly, sole

sorghum ICSV-400 at OM fertility level with the highest percentage LT, also recorded the highest mean weed dry weight of 440 kg/ha in 1995 experiment (Table 11b). In 1994 experiment, whereas sole sorghum ICSV-400 at OM fertility level had the highest percentage LT of 85, it recorded a mean weed weight of 270 kg/ha (Table 11a). Conversely, sole cowpea Dan-Illa with a percentage LT of 62, recorded the highest mean weed weight of 600 kg/ha. Obviously, the high percentage LT within the sole sorghum ICSV-400 plots was due to its initial slow growth rate.

5.6 Weed Biomass and Crop Yield

In 1994 experiment, sole cowpea Dan-Illa recorded the highest weed biomass. The same treatment also recorded the highest grain yield among the cowpea varieties. This was paradoxical as increase in weed infestation should lead to a decrease in crop yield as weeds compete with the crops for limiting nutrients, water and light. As stated earlier in Chapter 3, 1994 cropping season was characterised by late and erratic rainfall distribution with occasional dry spell. The higher yield of 1238 kg/ha (Table 11a) recorded for sole cowpea Dan-Illa relative to other cowpea varieties was probably due to the fact that Dan-Illa is a local variety and is better adapted to the climatic vagaries associated with its indigenous sudan/sahel zones. That Dan-Illa recorded higher grain yield than other cowpea varieties suggests that it has a higher water use efficiency (WUE) than other cowpea varieties.

The highest light transmission of 85% was recorded in 1994 for sole sorghum ICSV-400 with organic manure treatment. Expectedly, lower yield weight of 643 Kg/ha was also recorded for the same treatment when compared to a yield of 1144 kg/ha recorded for sole sorghum Gaya early of the same organic manure treatment (Table 11a). The decrease in grain yield recorded for ICSV-400 relative to Gaya early could be due to competitive effects of weeds as there was lower shade levels in ICSV-400 treatment than that of Gaya early.

In the 1995 experiment, the highest mean dry weed weight of 438 kg/ha was recorded for sole sorghum ICSV-400 with organic manure treatment. This treatment also recorded a lower yield of 1560 kg/ha compared to 1760 kg/ha recorded for sole sorghum Gaya early of the same organic manure treatment (Table 11b). As in the 1994 experiment, the decrease in yield observed for sorghum ICSV-400 could be attributed to high weed virulence observed for these plots. The wider difference in yield between ICSV-400 and Gaya early for 1994 compared to 1995 experiment was due to intermittent dry spell occasioned by the erratic rainfall pattern that occurred in 1994 cropping season. The local Gaya early was more draught tolerant than the improved ICSV-400. In 1995 however, the rainfall pattern was evenly distributed throughout the season to close up the difference in grain yield between the two sorghum varieties as shown in Table 11b.

CHAPTER 6

SUMMARY AND CONCLUSION

Sole sorghum ICSV-400 with organic manure treatment recorded the highest LT values for both 1994 trials in the sole crop treatments. In the 1995 experiment, this treatment also recorded the highest weed biomass during the 2nd and 3rd weeding. However in 1994, sole cowpea Dan-Illa recorded the highest weed biomass on all the sampling dates.

In millet/cowpea intercrop combinations, millet-millet arrangement showed lower LT values relative to that of millet-cowpea arrangement for both trials.

In millet/sorghum/cowpea intercrop combinations, millet-sorghum arrangement had the lowest LT values during the active growth season than the associated sorghum-cowpea, millet-cowpea and cowpea-cowpea arrangements for both trials.

There was a reduction in weed biomass of the intercrop relative to sole crop plots. In the 1994 trial, all the sole plots of the cowpea varieties used in the intercrops recorded higher weed biomass than the associated intercrop. The same trend was observed (particularly for sole cowpea Dan-Illa in the last weeding) for 1995 trial. This confirms the fact that intercropping suppresses weed more than corresponding sole crop, thereby indicating that shading is a major factor in weed suppression (Baake and Gaessler, 1945; Keely and Thullen, 1978; Patterson, 1979, 1980).

A summary of weed regime in this research shows that sole cowpea Dan-Illa recorded the highest weed biomass in

1994 experiment; while sole sorghum ICSV-400 recorded the highest weed biomass for 1995. From the two experiment, it was realised that the weed flora was dominated by *Digitaria horizontalis* and *Cyperus esculentus*. Understanding the reaction of these two weeds to light is the key to explaining the influence of cropping systems on the weed flora of the study area.

REFERENCES

- Abdul-Wahab, A.S. and E.L. Rice. (1967). Plant inhibition by Johnson grass and its possible significance in old field succession. *Bull. Torrey Bot. Club* 94: 486-497.
- Ahmed, S. and M.R. Rao. (1982). Performance of maize-soybean intercrop combinations in the tropics: Results of a multi-location study. *Field Crops Res.*, 5: 147-161.
- Akobundu, I.O. (1979). Weed control in Nigeria, *PANS*, 25: 287-298.
- Akobundu, I.O. (1980). Economics of weed control in African tropics and subtropics. *Proc. 1980 British Crop Prot. Conf. WEEDS*, Brighton, UK, pp. 911-920.
- Akobundu, I.O. (1981). Weed control in intercropping mixtures. In S.I. Pandey (ed.), *Agronomy Training Manual for Agro-service Agronomists*. IITA/National Accelerated Food Production Project, Lagos, Nigeria, pp. 217-227.
- Akobundu, I.O. (1987). *Weed science in the Tropics*. John Wiley and Sons, New York.
- Allen, Jr., L.H.; T.R. Sinclair; E.R. Lemon (1976). Radiation and microclimate relationship in multiple cropping systems. In: R.I. Papendick, P.A. Sanchez and G.B. Triplett (Editors), *Multiple Cropping*. ASA Spec. Publ. No 27, Madison, WI, pp. 171-200.
- Aldrich, R.J. (1984). *Weed-Crop Ecology: Principles in Weed Management*. Breton Publishers, North Scituate, 465pp.
- Annual Report. 1979/1980. International Crop Research Institute for the semi-arid Tropics (ICRISAT), Patancheru, Andhra, Pradesh, India.
- Ayeni, A.O., W.B. Duke and I.O. Akobundu. 1984. Weed interference in Maize, cowpea and Maize/cowpea intercrop in a subhumid tropical environment 1. Influence of cropping season. *Weed Res.* 24: 269-279.
- Baake, A.L. and W.G. Gaessler. (1945). The effect of reduced light intensity on the aerial and subterranean parts of European bindweed. *Plant physiol.* 20: 246-257.
- Baker, E.F.I. (1981). Population, time and crop mixtures. In: R.W. Willey (Editor), *Proc. Int. Workshop on intercropping*, 10-13 Jan. 1979, Hyderabad. *International Crops Res. Inst. for the Semi-Arid Tropics*, Patancheru, India, pp. 52-60.

- Balasubramanian, V. and G.D. Rao. (1988). Intercropping effects on yield components of dryland sorghum, pigeonpea and mung bean. *Top. Agric. (Trinidad)*, 65: 145-149.
- Bantilan, R.T. and R.R. Harwood. (1973). Weed Management in intensive cropping systems. Saturday seminar paper, 28 July 1973. Los Banos, Laguna, Philippines: International Rice research Institute. 7pp.
- Bell, R.S., W.H. Lachman, E.M. RHAN and R.D. Sweet. (1962). Life history studies as related to weed control in the north East. 1: Nutgrass. *Rhode Island Agric. Exp. Stn. Bull.* 364. 33pp.
- Bendixen, L.E. 1983. Another criterion in defining the world's worst weeds. *proc. 9th Assian Pacific Weed science Conf.*, pp. 176-180.
- Black, C.C. (1971). Ecological implication of dividing plants into groups with distinct photosynthetic production capacities. *Adv. Ecol. Res.* 7: 87-114.
- Black, C.C., T.M. Chen, and R.H. Brown. (1969). Biochemical basis for plant competition. *Weed Sci.* 17: 338-344.
- Blatchley, W.S. (1912). *The Indian Weed Book*. Nature Publishing Company, Indiana polis, Indiana, 191pp.
- Boardman, K. (1977). Comparative Phtosynthesis of sun and shade plants. *Annu. Rev. Plant Physiol.* 28: 355-377.
- Botha, P.J. 1971. Red Nutgrass and its control. *Farming S. Afr.* 47: 53-55.
- Bremmer, J.M. (1965). Total Nitrogen. In: C.A. Black (ed.). *Methods of Soil Analysis. Monograph 9 No.2 Amer. Soc. Agron., Madison; Wisconsin, U.S.A.* pp. 226-234.
- Bristow, K.L. and G.S. Campbell. (1984). On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agric. For Meteorol.*, 31: 159-166.
- Bjorkman, O. and P. Holmgren. (1963). Adatability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats. *Physiol. Plant.* 16: 889-914.
- Burkholder, P.R. 1952. Cooperation and conflict among primitive organisms. *Amer. Sci.*, 40: 601-631.
- Caldwell, M.M. (1987). Plant architecture and resource competition. *Ecol. Studies*, 61: 164-179.

- Carberry, P.S. and R.C. Muchow. (1992). Asimulation model of Kenaf for assisting fibre industry planning in northern Australia. 3. Model description and validation. Aust. J. Agric. Res., 43: 1527-1545.
- Carson, A.G. (1989). Effects of intercropped sorghum and groundnuts on density of *Striga hermonthica* in the Gambia. Trop. Pest Manage., 35: 130-132.
- Cenpukdee, U. and S. Fukai. (1992a). Cassava/legume intercropping with contrasting cassava cultivars. I. Competition between component crops under three intercropping conditions. Field Crops Res., 29: 113-133.
- Cenpukdee, U. and S. Fukai. (1992b). Cassava/legume intercropping with contrasting cassava cultivars 2. Selection criteria for cassava genotypes in intercropping with two contrasting legume crops. Field Crops Res., 29: 135-149.
- Cenpukdee, U. and S. Fukai. (1992c). Agronomic modification of competition between cassava and Pigeonpea in intercropping. Field Crops Res., 30: 131-146.
- Choudhary, A.H., and S.T.O. Lagoke. (1982). Weed control in Groundnut in Northern Guinea and Sudan Savanna zones of Nigeria. Weed Sc. Soc. of Nigeria, 11th Annual Conf., March 1-6, 1982, Programme and Abstract papers, pp. 1-2.
- Chui, J.A.N. and R.M. Shibles. (1984). Influence of spatial arrangements of maize on performance of an associated soybean intercrop. Field Crop Res. 8: 187-198.
- Cooper, C.S. (1966). Responde of birds foot frefoll and alfalfa to various levels of shade. Crop sci. 6: 63-66.
- Cooper, C.S. and M. Qualls. (1967). Morphology and chlorophyll contents of the shade and sun leaves of two legumes. Crop Sci. 7. 672-673.
- Crookston, R.K., K.J. Treharne, P. Ludford, and J.L. Ozbun. (1975). Effects of light interception during growth on the leaf anatomy, photosynthesis and the enzyme activity of beans. Crop Sci. 15: 412-416.
- Davies, J.H.C.; L. van Beuningen; M.V. Ortis and C. Pino. (1984). Effects of growth habit on beans on tolerance to competition from maize when intercropped. Crop Sci., 24: 751-755.
- Day, B.E. (1978). The status and future of chemical weed control. pp 203-213 in Pest Control Strategies, eds. E.H. Smith and D. Pimenter. New York: Academic Press.

- De, R. (1974). Prospects for Crop intensification and diversification in rainfed areas in south east Asia.
- FAD/UNDP International Expert consultation on the rise of Improved Technology for food Production in rainfed areas of Tropical Asia, 1-7 December, 1974, Khon Kean, Thailand.
- Decandolle, M.A. (1932). *Physiologie vegetale*. Vol. 111. Bechet jeune Lib. Fac. Med., Paris. 1474pp.
- Donald, C.M. (1963). Competition among Crop and Pasture plants. *Adv. Agron.*, 15: 1-118.
- Duncan, W.G. (1971). Leaf angles, Leaf area and canopy photosynthesis. *Crop Sci.*, 11: 482-485.
- Enyi, B.A.C. (1973). Effects of Intercropping of maize or sorghum with cowpeas, pigeonpeas or beans. *Exp. Agric.* 9: 83-90.
- Enyinnia, T. (1982). An asset in the control of cassava Mealybug and green spider mite. *Weed Sci. Soc. of Nigeria*, 11th Annual Conf. March 1-6, 1992, Programme and Abstract papers, pp 22, Agricultural complex, Ahmadu Bwilo University, Zaria.
- Evans, L.T. and I.F. Wardlaw. (1976). Aspects of the comparative physiology of grain yield in cereals. *Adv. Agron.* 28: 301-359.
- Fawusi, M.O.A. (1985). Influence of spatial arrangements on the growth, fruit and grain yields and yield components of intercropped maize and okra (*Abelmoschus esculentus*). *Field Crops Res.*, 11: 345-352.
- Fawusi, M.O.A. and S.B.C. Wanki. (1982). Plant density effects on growth yield, leaf area index, and light transmission on intercropped maize and *Vigna unguiculata* (L.) Walp in Nigeria. *J. Agric. Sci.*, 99: 19-23.
- Fisher, N.M. (1979). Studies in mixed cropping. III. Further results with maize beans mixtures. *Exp. Agric.*, 15: 49-58.
- Fordham, R. (1983). Intercropping - What are the advantages? *Outlook Agric.*, 12: 142-146.
- Francis, C.A. (1989). Biological efficiencies in multiple cropping systems. *Adv. Agron.*, 42: 1-42.
- Fukai, S. and B.R. Trenbath. (1993). Processes determining intercrop productivity and yield of component crops. *Field Crops Res.*, 34: 247-271.

- Garner, W.W. (1962). Effects of light on plants. A literature review, 1950. U.S. Dep. Agric. Res. Serv., Crop Res.Div.ARS. Gates, D.M. (1980). Biophysical Ecology. Springer-Verlag. New York.
- Geertz, E. 1963. Agricultural Involution. Davies, Caloifornia: Unniversity of California.
- Goldberg, B.; W.H. Klein and R.D. McCartney. (1979). A comparism of some simple model used to predict solar irradiance on a horizontal surface.solar Energy, 23: 81-83.
- Goudraain, J. (1982). Potential production Processes. In: F.W.T. Penning de Vries and H.H. Van Laar (Editors), Simulation of plant growth and crop production. Pudoc. Wageningen, pp. 98-113.
- Graham, P.L.; J.L. Steiner and A.F. Wiese. (1988). Light absorption and competition in mixed Sorghum-pigweed communities. Agron. J. 80: 415-418.
- Grummer, G. (1961). The role of toxic substances in the interrelations between higher plants. symp. Soc. Exp. Biol. 15: 219-228.
- Haizel, K.A. (1972). The canopy relationship of pure and mixed populations of barley, white mustard and wildoats. J. Appl. Ecol., 9: 589-600
- Harland, J.R. and J.M.J. De Wet. (1965). Some thoughts about weeds. Econ. Bot., 19: 16-24.
- Harper, J.L. (1977). Population biology of plants. Academic Press. London.
- Harper, R.M. (1955). Preliminary report on the weeds of Albama. Bull. Geol. Sur. Ala. Univ., Ala., No.53, pp. 275.
- Harris, D.; M. Natarajan; and R.W. Willey. (1987). Physiological basis for yield advantage in a sorghum/groundnut intercrop exposed to drought. I. Dry matter production, yield and light interception. Field Crop Res., 17: 259-272.
- Harwood, R.R. (1974). The application of science and technology to long range solutions: Multicropping Potentials. Paper presented at the Int. Conf. on nutrition and Agricultural and Economic Devt. in the Tropics. 2 6 Dec., 1974, I NCAP, Guatemala.
- Hawkins, A.F. (1982). Light interception, photosynthesis and crop productivity. Outlook Agric., 11: 104-113 .

- Hiebsch, C.K. and R.E. McCollum. (1987). Area X time equivalency ratio: A method for evaluating the productivity of intercrops. *Agron. J.* 79: 15-22.
- Holmes, M.G. and H. Smith (1975). The function of phytochrome in plants growing in the natural environment. *Nature*, 254: 512-514.
- Horowitz, M. and T. Friedman (1971). Biological activity of subterranean residues of *Cynodon dactylon* L., *Sorghum halepense* L., and *Cyperus rotundus* L weed. *Res.* 11: 85-93.
- Hulugalle, N.R. and H.C. Ezumah (1991). Effects of cassava-based cropping system on physico-chemical properties of soil and earthworm casts in a tropical Alfisol. *Agric. Ecosyst. Environ.*, 35: 55-63.
- Ikeorgu, J.E.G., H.C. Ezumah, and T.A.T. Wahua (1989). Productivity species in cassava/maize/okra/egusi melon complex mixtures in Nigeria. *Field Crops Res.*, 21: 1-7.
- Institute for Agricultural Research. (1987). Detailed soil survey of Minjibir Agricultural Research Farm, Kano, Zaria, Nigeria: Ahmadu Bello University Press.
- Keating, B.A.; J.P. Evenson and S. Fukai. (1982). Environmental effects of growth and development of cassava (*Manihot esculenta* Crantz). I. Crop development. *Field Crops Res.*, 5: 271-281.
- Keating, B.A. and P.S. Carberry. (1993). Resource capture and use in intercropping: Solar Radiation. *Field Crop Res.*, 34: 273-301.
- Keely, P.E. and R.J. Thullen. (1978). Light requirement of Yellow nutsedge (*Cyperus esculentus*) and light interception by crops. *Weed Sci.* 26: 10-16.
- Knake, E.L. (1972). Effect of shade on giant foxtail. *Weed Sci.* 20: 588-592.
- Kretchmer, P.J.; J.L. Ozbun; S.L. Kaplan; D.R. Laing and D.H. Wallace. (1977). Red and far-red light effects on climbing in *Phaseolus vulgaris* L. *Crop Sci.*, 17: 797-799.
- Lagoke, S.T.O. and A.H. Choudhary. (1982). Weed control in cotton (*Gossypium hirsutum*) in the Nigerian savanna. *Weed Sci. Soc. of Nigeria*, 11th Ann. Conf. March 1-6, Programme and Abstract Papers, pp. 2-3 Agricultural Complex, Ahmadu Bello University, Zaria.

- Le Tourneau, D., G.D. Failes and H.G. Heggeness. (1956). The effect of aqueous extracts of plant tissue on germination of seeds and growth of seedlings. *Weeds* 4: 363-368.
- Lightfoot, C.W.F. and R.S. Taylor. (1987). Intercropping sorghum with cowpea in dryland farming systems in Botswana. I. Field experiments and relative advantages of intercropping. *Exp. Agric.*, 23: 425-434.
- Lightfoot, C.W.F.; K.B.G. Dear; and R. Mead. (1987). Intercropping sorghum with cowpea in dryland farming systems in Botswana. II. Comparative stability of alternative cropping systems. *Exp. Agric.* 23: 435-442.
- Loomis, R.S. and W.A. Williams. (1963). Maximum crop productivity: an estimate. *Crop Sci.*, 3: 67-72.
- Loustalot, A.J.; T.J. Muzik and H.J. Crzado. (1954). Studies on Nutgrass (*Cyperus rotundus* L) and its control. U.S. Dept. of Agri. Mayaguez, Puerto Rico Bull. No. 52. 30pp.
- Magalhaes, A.C. (1969). Observacoes sobre o efeito da luz no crescimento da tiririca (*Cyperus rotundu* L) (Effects of light on purple nutsedge growth). *Braganta* (Brazil) 26: 131-142.
- May, K.W. (1982). Effects of planting schedule and intercropping on green gram (*Phaseolus aureus*) and bulrush millet (*Pennisetum americanum*) in Tanzania. *Exp. Agric.*, 18: 149-156.
- Midmore, D.J., J. Roca, and D. Berrios. (1988a). Potato (*Solanum spp.*) in the hot tropics. IV. Intercropping with maize and the influence of shade on potato microenvironment and crop growth. *Field Crops Res.*, 18: 141-157.
- Midmore D.J., D. Berrios, and J. Roca. (1988b). Potato (*Solanum spp.*) in the tropics .V. Intercropping with maize and the influence of shade on tuber yields. *Field Crops Res.*, 18: 159-176.
- Molisch, H. (1937). Der Einfluss Einer Pflanze auf die andere-allelopathic. Fischer, Jena; cited by rice, 1974.
- Monteith, J.L. (1973). Principles of Environmental Physics, Edward Arnold (Publishers) Ltd., 25 Hill Street, London.
- Monteith, J.L. (1981). Does light limit crop production? In: C.B. Johnson (Editor), Physiological Processes Limiting Plant Productivity. Butterworths, London, pp. 23-38.

- Moody, K. and S.V.R. Shetty. (1979). Weed management in intercropping systems. Proc. Int. workshop on intercropping, 10-13 Jan., (1979), ICRISAT, Patancheru, Andhra Pradesh, India.
- Moody, K. (1978). Weed control in intercropping in tropical Asia. Paper presented at the International Weed Sci. Conf., 3-7 July, 1978, International Rice Research Institute, Los Banos, Laguna, Philippines.
- Morris, R.A. and D.P. Garrity. (1993). Resource capture and utilization in intercropping: non-nitrogen nutrients. Field Crops Res., 34: 319-334.
- Muller, C.H. (1969). Allelopathy as a factor in ecological process. Vegetatio 18: 348-357.
- Nageswara Rao, R.C.; K.D.R. Wadia; and J.W. Williams. (1990). Intercropping short and long duration groundnut genotypes to increase productivity in the environments prone to end-of season droughts. Exp. Agric., 26: 63-72.
- Natarajan, M and R.W. Willey. (1980a). Sorghum-pigeonpea intercropping and the effects of plant population density. 1. Growth and yield. J. Agric. Sci., Camb., 95: 51-58.
- Natarajan, M. and R.W. Willey. (1980b). Sorghum-pigeonpea intercropping and the effects of plant population density. 2. Resource use. J. Agric. Sci. Camb. 95: 59-65.
- Natarajan, M. and R.W. Willey. (1985). Effects of row arrangement on light interception and yield in sorghum-pigeonpea intercropping. J. Agric. Sci. Camb., 104: 263-270.
- Ndon, B.A. 1982. Chemical Weed control in oil palm (*Elaeis guineensis* Jacq) Nurseries. Weed Sci. Soc. of Nigeria, 11th Annual Conf., 1-6 March, 1982, Programme and Abstract Papers, pp. 13, Ahmadu Bello University, Zaria.
- Norman, D.W. (1973). Crop mixtures under indigenous conditions in northern part of Nigeria. 130-144pp in Factors of Agricultural Growth in west Africa. ed. I.M. Ofori. Inst. of Social Economic Research, Univ. of Ghana.
- Norman, D.W. (1974). Rationalising mixed cropping under indigenous conditions. The example of northern Nigeria. J. Devel. Studies, 11: 3-21.

- Okigbo, B.N. (1981). Evaluation of plant interactions and productivity in complex mixture as a basis for improved cropping systems design. in R.W. Willey (Editor), Proc. Int. Workshop on Intercropping, 10-13 Jan. (1979), Hyderabad. ICRISAT, Patancheru, India, pp. 155-179.
- Olasantan, F.O. (1988a). Intercropping cassava with maize or cowpea under different row arrangements. Field Crops Res., 19: 41-50.
- Olasantan F.O. (1988b). The effects of soil temperature and moisture content on crop growth and yield of intercropping maize with melon. Exp. Agric., 24: 67-74.
- Owonubi, J.J. and E.T. Kanemasu. (1982). Water use efficiency of three heights isolines of sorghum. Can. J. Plant Sci., 62: 35-46.
- Owonubi, J.J. E.T. Kanemasu, and W.L. Powers. (1975). The microclimate of narrow and wide-row sorghum with equal plant densities. Agric. Meteorol. 15: 61-69.
- Patterson, D.T. (1979). The effects of shading on the growth and photosynthetic capacity of itch grass (*Rottboellia exaltata*). Weed Sci. 27: 549-553.
- Patterson, D.T. (1980). Light and temperature adaptation. pp. 205-235 in J.D. Hesketh and J.W. Jones (Editors), Predicting photosynthesis for Ecosystem Models Vol.1, C.R.C. Pres. Inc., Boca Raton, FL.
- Radosevich, S.R.; and J.S. Holt. (1984). Weed Ecology: Implication for vegetation management. Wiley-Interscience, New York, pp. 265.
- Raheja, P.C. (1973). Mixed cropping. ICAR Technical Bull. No. 42. New Delhi, India Council for Agric Res. pp. 40.
- Rao, M.R. and R.W. Willey. (1980). Preliminary studies of intercropping combinations based on pigeonpea or sorghum. Exp. Agric., 16: 29-39.
- Rao, M.R. and R.W. Willey. (1983a). Effects of pigeonpea plant population and row arrangement in sorghum/pigeonpea intercropping. Field Crops Res., 7: 203-212.
- Rao, M.R. and R.W. Willey. (1983b). Effects of genotype in cereal/pigeonpea intercropping on the Alfisols of the Semi-Arid Tropics of India. Exp. Agric., 19: 67-78.
- Rao, M.R. (1986). Cereals in multiple cropping. In: C.A. Francis (Editor), Multiple Cropping Systems. Macmillan, New York. pp. 96-132.

- Reddy, S.N.; E.V.R. Reddy; V.M. Reddy; M.S. Reddy; and P.V. Reddy. (1989). Row arrangement in groundnut/pigeonpea intercropping. *Trop. Agric.* 66: 309-312.
- Rees, D.J. (1986). Crop growth, development and yield in semi-arid conditions in Botswana. II. the effects of intercropping *Sorghum bicolor* with *Vigna unguiculata*. *Exp. Agric.*, 22:169-177.
- Rice E.L. (1965). Inhibition of nitrogen-fixing and nitrifying plants. II. Characterization and identification of inhibitors. *Physoil. Plant.* 18: 255-268.
- Rice, E.L. (1969). Inhibition of nitrogen-fixing and nitrifying bacteria by seed plants. III. Inhibitors from *Euphorbia supina*. *Physiol. Plant* 22: 1175-1183.
- Rice, E.L. (1974). Allelopathy. Academic Press, New York, pp 353.
- Ripley, P.O. (1941). The influence of crops upon those which follow. *Sci. Agric.* 21: 522-583.
- Rhodes, I. and Stern, W.R. (1978). Competition for light. In: J.R. Wilson (Editor), *Plant Relations in Pastures*. CSIRO, Melbourne, pp. 89-175.
- Rose, S.J.; O.C. Burnside; J.E. Specht and B.A. Swisher. (1984). Competition and Allelopathy between soybean and weeds. *Agrn. J.* 1984, 523-528.
- Rosenberg, N.I. (1974). *Microclimate the Biological Environment*, Wiley-Interscience Publication, New York.
- Satorre, E.H. and C.M. Ghera. (1987). Relationship between canopy structure and weed biomass in different winter crops. *Field Crops Res.*, 17: 37-43.
- Shetty, S.V.R. (1978). Weed control in sorghum in the tropics. Presented at the 1st Annual meeting of Weed Sci. Soc. Conf., 11-17 July, 1978, Jakarta, Indonesia.
- Shetty S.V.R. and A.N. Rao. (1979). Weed management studies in sorghum/pigeonpea and pearl millet/groundnut intercrop systems-some observations. *Proc.Int. Workshop on Intercropping*, 10-13 .
- Shetty, S.V.R.; B.A. Krantz and S.R. Obien (1977). Weed research needs of the small scale farmer. Invitational paper presented during the Plenary session of the "weed science conference and workshop in India." January 17-20, Andhra Pradesh Agricultural University, Hyderabad, India. Jan., 1979, ICRISAT, Patancheru, Andhra Pradesh, India.

- Sinclair, T.R. and E.R. Lemon. (1973). The distribution of 660 and 730nm radiation in corn canopies. *Solar Energy* 15:89-97.
- Singh, N.B., P.P. Singh, and K.P.P. Nair. (1986). Effect of legume intercropping on the enrichment of soil nitrogen, bacterial activity and productivity of associated maizecrops. *Exp. Agric.*, 22:339-344.
- Sivakumar, M.V.K., and S.M. Virmani. (1980). Growth and resource use of maize, pigeonpea and maize/pigeonpea intercrop in an operational research water shade. *Exp. Agric.* 16:377-386.
- Sivakumar, M.V.K., and S.M. Virmani. (1984). Crop productivity relation to interception of photo synthetically active radiation. *Agric. for Meteorol.*, 31:131-141.
- Smith, M.E. and C.A. Francis. (1986). Breeding for multiple cropping systems. In: C.A. Francis (Editor), *Multiple Cropping Systems*, New York, pp. 219-249.
- Squire, G.R. (1993). *The Physiology of Tropical Crop Production*. C.A.B. International, Wallingford, UK.
- Ssekabembe, C.K. (1986). The importance of differences in maturity periods and stature in sorghum/finger millet intercrops. *Trop. Agric.* 63: 289-292.
- Steiner, K.G. (1982). *Intercropping in tropical smallholder agriculture with special reference to West Africa*. GTZ No.179, Eschborn Germany. 304pp.
- Stern, W.R. (1993). Nitrogen fixation and transfer in intercropping. *Field Crop Res.*, 34: 335-356.
- Stigter, C.J. and C. H. Baldy. (1993). Manipulation of the Microclimate by intercropping. Making the best services ended. Invited paper for presentation at the Int.Meeting on Ecophysiology in Tropical Intercropping. Guadeloupe, French Antilles, Dec., 1993, INRA, Antilles. Guyane.
- Stoop, W.A. (1986). Agronomic management of cereal/cowpea cropping systems for major toposequence land types in the West African savanna. *Field Crops Res.*, 14:301-319.
- Suryatna, E.S. (1976). Nutrient uptake, insect, disease, labour use, and productivity characteristics of selected traditional intercropping patterns which together affect their continued use by farmers. Ph.D. Thesis, Los Banos college, University of Philippines, Laguna, Philippines.

Sweet, R.D. and P.L. Minotti. (1980). Studies in weed crop competition. In I.O. Akobundu (ed), Weeds and their control in the Humid and subhumid Tropics, pp. 252-263. IITA Proc. Series No.3, Ibadan, Nigeria.

Taria, N.M. and T.A.T. Wahua. (1985). Effects of component populations on yields and land equivalent ratios of intercropped maize and cowpea. Field Crops Res., 12:81-89.

Trenbath, B.R. and J.L. Harper. (1973). Neighbour effects in the genus *Avena*. I. Comparison of crop species. J. Appl. Ecol., 10:379-400.

Trenbath, B.R. (1986). Resource use by intercrops. In: C.A. Francis (Editor), Multiple cropping systems. Macmillan, New York, pp. 57-81.

Tsay, J.S., S. Fukai, and G.L. Wilson. (1985). The response of soybean to cassava intercropping. In S. Shanmugasundaram and E.W. Sulzberger (Editors), Soybean in Tropical and sub-tropical Cropping systems. AVRDC, Tainan, Taiwan, pp.13-24.

Tsay, J.S., S. Fukai, and G.L. Wilson. (1988a). Intercropping cassava with soybean cultivars of varying maturities. Field Crops Res., 19: 211-225.

Tsay, J.S., S. Fukai, and G.L. Wilson. (1988b). Effect of relative sowing time of soybean on growth and yield of cassava in cassava/soybean intercropping. Field Crops Res., 19:227-239.

Tukey, A.B. (1969). Implications of allelopathy in agricultural plant science. Bot. Rev. 35:1-16.

Wallace, J.S.; C.H. Batchelor; D.N. Dabeasing; and G.C. Soopramenien. (1990). The partitioning of light and water in drip irrigated plant cane with a maize intercrop. Agric. Water Manage., 17:407-413.

Walters, R.F. (1971). Shifting cultivation in Latin America. FAO, Forest Devt. Paper 17. FAO, Rome. pp 305.

Wahua, T.A.T. (1984). Rhizosphere bacterial counts for intercropped maize (*Zea mays* L.) cowpea (*Vigna unguiculata* L.) and 'Egusi' melon (*Colosynthis vulgaris* L.). Field Crops Res., 8:371-379.

Warren Wilson, J. (1969). Maximum yield potential. In: Proc. VIIth Colloquium. Int. Potash Inst., Bern, Switzerland, pp 34-56.

- Webb, M.A., Togola and D. Traore. (1994). Effects of Intercropping pearl millet with cowpea on the density of emerged *striga hermonthica* in Mali. Brighton Crop Protection Conf. Weeds.
- Webster, C.C. and P.N. Wilson. (1966). Agriculture in the Tropics. London: Longmans.
- Wien, H.C. and J.B. Smithson. (1981). The evaluation of genotypes for intercropping. In: R.W. Wileey (Editor), Proc. Int. Workshop on Intercropping, 10-13. Jan (1979), Hyderabad. International Crops Res. Inst. for the Semi-arid Tropics, Patancheru, India, pp.105-127.
- Willey, R.W. (1979a). Intercropping - its importance and research needs. Part 1. Competition and yield advantages. Field Crops Abst., 32: 1-10.
- Willey, R.W. (1979b). Intercropping - its importance and research needs. Part 2. Agronomy and research approaches. Field Crops Abst., 32:73-85.
- William, R.D. and G.F. Warren (1979). Competition between purple nutsedge and vegetables. Weed Sci. 23:317-323.
- Zimdahl, R.L. (1980). Weed-crop competition: A Review. IPPC document No. 31-A-80. Int. Plant Protection Centre, Oregon State University, Corvallis, Oregon, U.S.A. pp. 197.

Mijibir Weather Data: 1994 (Appendix A)

Month	Rain fall (mm)	Pot evapo (mm)	Wind speed (km/h)	Solar Radiatn MJ/HR	Temperature(C)		Rel.humidity(%)	
					Max	Min	Max	Min
Jan.	0.0	5.6	1.6	19.6	29.8	12.5	24	10
Feb.	0.0	7.2	1.6	22.7	31.9	14.7	16	10
Mar.	0.0	10.0	1.3	26.3	38.8	18.3	15	7
Apr.	10.4	9.5	2.5	23.1	38.5	24.2	32	8
May	47.7	8.9	2.2	23.4	37.7	25.2	40	8
Jun.	130.1	8.6	3.5	21.1	37.9	25.3	49	16
Jul.	160.5	6.5	3.2	18.2	33.1	22.8	59	24
Aug.	249.9	5.8	2.0	17.2	30.1	21.4	69	35
Sep.	133.3	6.9	1.5	19.3	32.9	22.0	66	26
Oct.	37.9	7.4	1.4	20.1	35.0	21.7	58	19
Nov.	0.0	6.3	2.2	20.2	33.0	14.0	32	18
Dec.	0.0	5.4	2.5	19.8	28.0	11.8	25	19
Total/avg	769.8	7.3	2.1	20.9	33.9	19.5	40	17

Mijibir Weather Data: 1995 (Appendix B)

Month	Rain fall (mm)	Pot evapo (mm)	Wind speed (km/h)	Solar Radiatn MJ/HR	Temperature(C)		Rel.humidity(%)	
					Max	Min	Max	Min
Jan.	0.0	0.0	1.2	0.0	27.6	10.9	20	16
Feb.	0.0	159.4	1.7	24.7	30.7	12.8	22	16
Mar.	0.0	220.3	1.7	26.3	37.6	19.0	24	16
Apr.	7.1	205.9	2.9	22.4	39.7	23.9	24	20
May	25.5	214.7	2.4	23.0	37.8	24.9	64	38
Jun.	125.6	196.5	3.0	23.7	34.4	23.0	67	46
Jul.	99.1	149.8	2.7	19.2	32.8	22.5	63	42
Aug.	146.3	162.9	1.6	18.3	32.1	21.9	72	52
Sep.	156.3	166.9	1.5	19.4	33.2	21.8	69	46
Oct.	0.0	58.9	0.9	21.5	32.8	22.1	45	28
Nov.	0.0	115.3	1.3	22.0	30.8	11.9	20	15
Dec.	0.0	151.5	1.1	21.8	31.6	11.9	18	14
Total/avg	559.9	1801.5	1.8	20.2	18.9	26.1	42	29