THE EFFECT OF PLANT DENSITY ON THE MICROCLIMATE OF SUNFLOWER (*Helianthus annus l.*) CROP IN A MEDIUM POTENTIAL, SEMI-HUMID AREA IN KENYA

MWANGI JULIUS K.

A THESIS SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN METEOROLOGY IN THE UNIVERSITY OF NAIROBI

OCTOBER 2000

DECLARATION

THIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY

JULIUS K. MWANGI
SIGNATURE.....
DATE 4-10-2000

THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH OUR APPROVAL AS UNIVERSITY SUPERVISORS

DR. F. K. KARANJA
SIGNATURE.....
DATE 4-10-2000

DR. S.B.B OTENGI
SIGNATURE.....
DATE 11-10-2000

CHAPTER THREE

LIST OF FIGURES

FIGURE

LIST OF PLATES

LIST OF TABLES

TABLE

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL	MEANING
PAR	Photosynthetically active radiation
DAS	Days after planting
a.m.s.l.	Above mean sea level
D.F.	Degrees of freedom
S.O.S	Sum of Squares
*	Significant at 1% level
**	Significant at 1% and 5% levels
ns	Not significant

LIST OF APPENDICES

Appendix

ABSTRACT

The relationship between soil factors (soil moisture, soil temperature and soil nutrients), plant factors (stomatal conductance, leaf temperature, leaf area index (LAI) and photosynthetic rate) and environmental factors (diffuse and global irradiance) was studied in a sunflower field. The sunflower was planted at four density plots with plot 1 having a higher than normal and plots 3 and 4 having a lower than normal plant densities. Plot 2 had normal plant density and acted as control. Measurements of global and diffuse irradiance, photosynthetic rate, photosynthetically active radiation (PAR), stomatal conductance and leaf temperature were made in the upper and lower strata of sunflower canopy. Soil moisture was measured weekly at 30cm, 40cm, 60cm and 100cm while soil temperature was measured once a week at 5cm, 10cm and 20cm depths. Measurements were done at three stages of crop growth. These were the vegetative, reproductive and maturity stages.

The experimental site was located at the University of Nairobi, Kabete Field Station. The field station is about 1800 metres A.S.L. and about 10 km north of Nairobi. It is located at at 1° 15'N, 36° 44'E. The station experiences two rainy seasons, with the main rainy season being March-May (long rains) and October-November (short rains).

The land was prepared for planting and subdivided into four equal plots of 9m by 6m. The plots were 1m apart up the slope and 2m apart across the slope (cf. fig. 3). The land was planted with sunflower seeds (Hybrid 8998) on 1-4-97. No fertiliser was applied to the plots. Weeding was done twice during the experimental season; on 24-4-97 and on 26-5-97.

Leaf temperature, stomatal conductance, PAR and photosynthetic rate measurements were done using an Infrared Gas Analyser (IRGA). These were done for three days during each of the three phenological stages of sunflower growth. Daily duration period of measurements was from 800-1700 hours local

time. The global and diffuse irradiance were measured at the same time as the physiological parameters using Kipp solarimeters.

Results showed that leaf temperature increased from morning hours to afternoon hours before decreasing slowly as sunset approached. Photosynthetic rate and PAR were highest in late morning and early afternoon hours. Stomatal conductance was highest in early morning and late afternoon hours. The average soil temperature was higher at 5cm depth than at 10cm and 20cm depths. However, in early morning hours, soil temperature at 5cm was lower than at the other two depths. Global and diffuse irradiance in the upper strata of canopy were independent of plant density. In the lower strata of canopy, the global and diffuse irradiances decreased with increasing plant density. The irradiances were also greater during the vegetative stage than during the reproductive and maturity stages.

Results of yield assessment (above ground dry matter) and economic yield showed that plot 1 gave the highest yield for total above ground dry matter per plot followed by the control (plot 2). Plots 3 and 4 recorded the lowest values both on the above ground dry matter and economic yield per plot.

The plant physiological parameters did not reveal much about the effects of planting density, as evidenced by the results of the analysis of variance. However, the diurnal patterns presented for the various parameters shed some light on the differences as manifested by the plant density. These differences were mostly pronounced on irradiance (global and diffuse) below the sunflower canopy. The irradiance decreased with increasing plant density. Soil temperature at all depths also decreased with increasing plant density.

ACKNOWLEDGEMENT

I would wish to express my sincere thanks and gratitude to my supervisors Dr. F.K. Karanja and Dr. S.S.B. Oteng'i for their guidance and constructive criticism during the compilation of this work.

Special thanks go to the Department of crop science, University of Nairobi through whose generosity I was able to obtain an experimental plot for this study. Specifically, I wish to thank Mr. Raphael Musyoki of the above Department for his skillful guidance in the use and repair of the various instruments employed in this study.

Words of thanks and appreciation are also due to Mr. Muchemi and his staff in the instruments section at the Meteorological Department, Dagoretti Corner, for providing some of the instruments employed in this study. The generosity of Prof. Kinyamario of the Department of Botany, University of Nairobi in availing the instruments for my use is also acknowledged.

To my father, Mr. Samuel Mwangi, and my mother, Alice W. Mwangi, I wish to express my sincere appreciation for their patience, understanding and encouragement during the course of this work. The same goes to my wife, brothers and sisters for bearing with my absence during the study.

This work would not have been successfully completed without the financial assistance. To this end, I sincerely thank The German Academic Programme (DAAD), through the Board of Postgraduate Studies, University of Nairobi, and the Department of Meteorology, for offering me a scholarship and availing research funds to complete this work. Special thanks are also due to those whose names are not mentioned here but who assisted me in one way or another to make this work a success.

Lastly and most of all, I would like to thank the Almighty God for His love and kindness to me and giving me sufficient grace and knowledge even to be able to reach this level in my studies. Let all the glory and honour be unto Him.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Kenya is very much dependent on agriculture for its economy and as a source of livelihood for its ever increasing population. The agricultural production largely depends on the soil moisture status, cultural practices, soil fertility, solar radiation etc. The microclimate of a crop is determined by;

(a) the distribution of incident global radiation which in turn is determined by the plant geometry, the soil fertility, structure and plant density.
(b) the distribution of soil and air temperature which is a manifestation of ;
(i)the distribution of wind within and above the crop canopy.
(ii)the soil moisture status and its availability for evaporation and transpiration.

This study was conducted to study the effect of plant density on the microclimate of sunflower in the Kabete area of Kenya. Soil, plant and environmental (meteorological) factors are considered in this study.

Sunflower is an established oil-seed crop in temperate zones especially in Eastern Europe and South America (Grandy, 1977). The development of sunflower with high oil content and other hybrids, coupled with the high content of polyunsaturated fatty acids in sunflower oil have led to marked increases in production and consumption in world trade. Sunflower has risen from fourth place in 1960, to second place as a world source of vegetable oil (Grandy,1977).

Sunflower production is spreading into subtropical and tropical regions (Amable, 1980). However, the leading producers in tropical Africa are located in the East African highlands where the tropical climate is moderated by altitude (Amable, 1980).

In this study the parameters measured were; soil temperature and soil moisture to explain the soil factors which affect crop yield; the leaf temperature,

stomatal conductance, Photosynthetically Active Radiation (PAR), photosynthetic rate and global and diffuse irradiance.

1.2: PLANT WATER STATUS AND MICROCLIMATE

Simply defined, plant water status is the amount of water available in a plant under given weather conditions manifested in a number of measurable parameters. Plant water status depends both on environmental and plant factors, especially on the immediate microclimate within the canopy.

1.3: OBJECTIVES OF THE STUDY

The overall objective of this study was to assess the effect of plant density on the microclimate of sunflower (*Helianthus annus l.*) crop. To achieve this, measurement of microclimatic factors were done on plant, air and soil factors. This study had the following specific objectives;

(a) to investigate the effect of plant density on the diurnal variation of stomatal conductance, leaf temperature, PAR and photosynthetic rate during crop growth. We also measured radiation, Leaf Area Index (LAI), temperature and soil moisture during the growing period of the crop,

(b) to investigate the effect of the systems in (a) on the variation of the soil temperature in space and time,

(c) to investigate the effect of the systems in (a) on the vertical profile of soil moisture,

(d) to investigate the effect of the systems in (a) on crop yield, and

(e) to study the effect of sunflower plant density on the distribution of irradiance (both direct and diffuse) below and above the crop canopy.

CHAPTER TWO

LITERATURE REVIEW

2.1: SUNFLOWER (*Helianthus annus l.*)

In Kenya, sunflower is grown by large-scale farmers in Trans-Nzoia District and by small-scale farmers in Western Province, notably in Kakamega and Bungoma Districts. It is also grown on limited extent in Coast Province (Acland,1971). Sunflower is mainly grown as an oil crop. The oil content of the seed is 25-50% depending on the variety. Other uses are; as food for caged birds, as a cattle feed and ensiling the young plants or ploughing in as a green manure (Acland, 1971). Sunflower is an annual crop which grows to height of between 0.6 and 4.5 m, depending on the variety. It is highly drought resistant, probably because of its deep tap root system. It grows well in areas which receive an annual rainfall of at least 750 mm. For best yields, it requires an adequate rainfall during the 3 or 4 weeks that coincide with flowering. Plants flower 3-4 months after planting and take a total of 3.5-6 months to mature, depending on the crop variety. There should be dry weather during ripening, otherwise heads rot. Sunflower can be grown from sea level up to 2600 m. Any soil that will produce a good crop of maize is suitable for sunflower (Acland,1971).

Khalifa (1980) looked at some factors influencing the development of sunflower under dryland-farming systems in Sudan. He examined the effect of cultivars and cultural practices on growth and grain yield of sunflower. He found that wider spacing was associated with thicker stems and larger heads both for rainfed and under supplementary irrigation. On the evidence he obtained, 45cm intra-row spacing was recommended for rainfed planting and 30cm intra-row spacing for irrigated production of sunflower.

Although moisture is a limiting factor for crop production in arid and semi-arid tropics, economic production of sunflower in this region is feasible (Amable, 1980). Investigations on cultural practices of sunflower including sowing dates, spacing, plant population density and cultivars are scarce in the tropics.

Salih (1958), Monti (1973) and Vijayalakshmi et al. (1975) observed a small increase of grain size with wider spacing. They found that optimum range of plant population is between 32,000 to 42,000 plants per hectare. These populations can be achieved by spacings of 0.75 m x 0.4 m and 0.75 m x 0.3 m respectively.

Khalifa (1980) found that there was a small increase in oil content with wider spacing in sunflower. However, Pacucci and Martignano (1975) and Zubrinski and Zimmerman (1974) reported no effect of planting density on oil content.

Weiss (1964) found that a local variety of sunflower white 655 was mostly grown in western Kenya. He found that planting from mid-May to mid-June and a population of 10,000 plants per acre gave the highest seed yields.

Hashim and Schneiter (1982) researched on the performance of semi-dwarf and conventional height sunflower at five plant populations. They determined the total water use (TWU), water use efficiency (WUE), harvest index (HI), stalk diameter, plant height and leaf number of both plant types over a three year period (1982-84). They found that all hybrids used had similar TWU, WUE, HI and stalk diameter. They concluded that reductions of plant height do not affect internode number, TWU and HI. Other agronomic traits as a response to plant population were similar for both plant types, and observed differences were often due to genotype origin than to plant type. Increased plant population reduced HI, grain yield per plant and stalk diameter. Increased plant population increased plant height of all hybrids.

2.2RADIATION AND CROPS

Crops use Photosynthetically Active Radiation (PAR) in the electromagnetic spectral range of 0.41-0.71 μm. Diurnal changes of solar radiation dictate the diurnal course of photosynthesis, respiration and transpiration. The vertical gradient of radiant flux in a canopy is a measure of the absorption of

energy by foliage at different heights. The distribution of radiation within a plant community is the most important single element of microclimate.

Early ecological studies of radiation climate were mainly descriptive and were limited in scope by rather primitive instrumentation. A quantitative approach to the subject was initiated by Monsi and Saeki (1953) and by Kasanga and Monsi (1954) whose models of light distribution in plant canopies were a basis for many subsequent studies, both experimental and theoretical. More elaborate models have been developed recently (an indication that it is easier to investigate light distribution in a controlled environment than in the field).

In addition to the primary function of radiation in providing energy for photosynthesis, other less familiar aspects of radiation distribution may influence the pattern of growth and development in a field crop. As sunlight filters through leaves, radiation in the "red" region of the spectrum (0.66 mm) is strongly absorbed, but the absorption is small in the "far-red" (0.73 mm). In a dense crop, the ratio of the relative intensity of the far-red to the red radiation increases rapidly between the top of the canopy and the soil surface.

Another important aspect of radiation in crops is the vertical gradient of long wave radiation on clear nights. Upper leaves loose radiation more rapidly, cool faster and collect more dew than lower leaves (Monsi,1954). The number of hours for which leaves are wet may determine their susceptibility to attack by fungal diseases that need a film of water to germinate spores (Monsi et al.,1954). The net flux of radiation at any level in a crop determines the energy available for the transfer of sensible and latent heat. Measurements of the net radiation gradient are fundamental to the analysis of microclimate (Cowan, 1968) and are needed to estimate how the turbulent exchange coefficient increases with height (Lemon, 1967).

2.3 STOMATAL CONDUCTANCE AND MICROCLIMATE

2.3.1 INFLUENCE OF ENVIRONMENTAL VARIABLES ON STOMATALCONDUCTANCE

Studies under controlled environmental conditions reveal that stomatal conductance varies considerably according to leaf-air differences in quantum flux density, carbon dioxide concentration, temperature, soil water status and atmospheric pollutants. Tropospheric ozone (Rich and Turner, 1972; Unsworth and Black, 1981), sulphur dioxide (Unsworth and Black, 1981) and some atmospheric pollutants influence stomatal conductance, usually by closing stomata, but sometimes by opening them up.

2.3.2.1 QUANTUM FLUX DENSITY

The response of the stomata to quantum flux density varies with species (Korner et al.,1979). Stomatal conductance usually increases hyperbolically with increasing quatum flux density. This leads to marked decreases in conductance at the beginning and end of each day, and in lower leaves within the canopy (Turner, 1974).

Stomata also respond to a step change in light arising from, for example, a cloud passing over the sun. The time taken for closure depends on the species and varies from a few seconds in maize to 40 minutes in yellow poplar (*Liriodendron tulipifera*) (Woods and Turner, 1971). Woods and Turner (1971) found that opening was always faster than closing in four woodland species, and the time to open and close is longer when the change in quantum flux density is small or when the period in low light was long (Pearcy et al., 1985). Thus it is difficult to measure the stomatal conductance in fluctuating light or partly cloudy days.

CARBON DIOXIDE

Increasing carbon dioxide concentration within a leaf above ambient levels decreases stomatal conductance, whereas decreasing the concentration below

ambient levels increases stomatal conductance (Cowan, 1977). This provides a mechanism for stomatal function. In the field, the level of carbon dioxide can decrease in dense rapidly photosynthesizing communities, thereby inducing stomata to open. Additionally, the gradually increasing partial pressure of carbon dioxide in the atmosphere will also cause the stomatal conductance to decrease (Kanemasu, 1975).

2.3.2.2 TEMPERATURE

Stomatal conductance usually shows an increase with air temperature to a maximum value and then a decrease at high temperatures, as shown by cotton and Sitka Spruce (Raschke,1970; Sharpe, 1973; Nelson and Jarvis, 1975). The optimum varies with the species, with temperate species having lower temperature optima than tropical or sub-tropical species. The temperature optima can be increased by growth at high temperature and vice versa (Nelson and Jarvis,1975), and by the process of acclimatization (Kramer, 1980). However, the decrease at high temperature probably results from leaf water deficits or large leaf- to-air water vapour concentration differences generated at high temperature (Nelson and Jarvis, 1975). When water deficits and stomatal closure due to low humidities are avoided, stomata can continue to open at temperatures as high as 50°C, as observed by Kuppers (1988).

Low soil temperatures also decrease stomatal conductance since they reduce the permeability of root membranes thereby influencing water uptake. This, in turn, induces a water deficit in the leaves that causes the reduction in stomatal conductance (Turner and Jarvis, 1975). The soil temperature at which stomatal conductance decreases and stomata close depends on species and whether the plants have been hardened prior to exposure to such extreme temperatures (Turner and Jarvis, 1975), and the evaporative conditions (i.e. the temperature and vapour pressure deficit) to which the plants are exposed when the soil temperatures are low. One of the consequences of exposure to low soil

temperatures is that stomatal conductance may take some days to recover, or may never recover, to the values occuring before exposure (Turner and Jarvis, 1975). It is, therefore, important to know something about the previous environmental history before interpreting or using a particular value of stomatal conductance.

2.3.2.3 LEAF-AIR WATER VAPOUR CONCENTRATION GRADIENT

For most species, stomatal conductance decreases as the atmospheric relative humidity decreases, i.e. as the leaf-air water vapour concentration gradient increases. In a study to show the response of leaf-air water vapour concentration difference in nine herbaceous and woody species, Turner et al. (1984) concluded that the increased leaf-air water vapour concentration difference resulted in direct decrease in stomatal conductance in addition to any decrease induced by the lowering of the leaf water potential. It is, therefore, important to recognise the influence of decreasing or increasing atmospheric humidity on stomatal conductance when using values from literature.

Idso et al (1988) and Idso (1990) have concluded that the reference of stomata to ambient atmospheric humidity is rarely observed in crops and pastures in the field owing to the uncoupling of short closed canopies from the air above them (Jarvis and McNaughton, 1985). Both Idso (1990) and Monteith (1990) highlighted the need for using representative values of atmospheric humidity or vapour pressure deficit for the whole canopy when calculating the impact of ambient humidity or canopy transpiration.

2.3.2.4 SOIL WATER STATUS

Stomatal conductance increases as the soil becomes wet. In many species, closure only begins when approximately one-half to two-thirds of the extractable water in the soil has been utilised (Turner, 1986b). However, in more sensitive species stomatal conductance decreases at high extractable water contents, i.e. with little soil water depletion. Soil water status influences stomatal conductance

either through its influence on leaf water potential or by changes in the level of photo-hormones produced by the roots in response to soil dehydration (Turner,1986b).

2.3.3 INFLUENCE OF PLANT VARIABLES ON STOMATAL CONDUCTANCE

2.3.3.1 LEAF AGE

The conductance of very young leaves of deciduous trees or annual crop plants is often considerably lower at high quantum flux densities than in older leaves; conductance then decreases again as leaves senesce. Turner (1974) and Turner and Heichel (1977), for example, found that in the young and senescing leaves stomatal conductance is less responsive to quantum flux density than in fully expanded green leaves, being higher in the dark and lower in full sunlight.

2.3.3.2 LEAF WATER STATUS

Stomatal conductance is also influenced by leaf hydration. Initially, it was considered that stomata closed at a critical leaf water potential (Turner,1974). Subsequent studies have shown that the response of stomata to leaf water potential depends on the species under consideration, the rate of stress development and the adaptation of the plants to the deficit (Turner, 1986 a,b).

Stomata open and close in response to changes in guard cell/ subsidiary cell turgor pressures (Aylor et al, 1973). This led to stomatal conductance being related to leaf turgor pressure (Turner, 1974). However, Turner (1975), Jones and Rawson (1979) and Henson et al (1986a) did not find any unique correlation between stomatal conductance and bulk leaf turgor pressure. A possible explanation for this is that bulk leaf turgors are usually calculated by difference from measured values of water potential and osmotic pressure. Alternatively, bulk leaf turgor may not be related to that in the epidermis, particularly if the hydraulic connection between the mesophyll and the epidermis is poor (Beadle et al., 1978;

Schackel and Brinckman, 1985). However, recent evidence suggests that changes in the phytohormone level in the leaf epidermis, as a result of dehydration, can induce stomatal closure.

At slow rates of water stress development, stomatal conductance in most species decreases almost linearly with decrease in leaf water potential, whereas a threshold response is observed at rapid rates of stress development (Turner, 1986a). Moreover, with slow rates of stress development the plant has an opportunity to adapt to the stress by active accumulation of solutes in the leaves (Turner, 1986a). This adjustment results in stomatal closure occurring at lower water potentials than in rapidly stressed plants (Turner and Jones, 1980; Ludlow et al., 1985). Nevertheless, in some species such as lupin, stomata appear to close at a critical leaf water potential even when slowly stressed in the field (Turner and Henson, 1989), whereas in other species there was no unique relationship between stomatal conductance and leaf water potential (Gollan et al., 1985; Turner et al, 1985). This very variable set of responses occurs because leaf water potential is not the controlling variable for stomatal conductance in relation to plant hydration.

2.3.3.3 LEAF TEMPERATURE

Whereas transpiration is an active response to climatic factors, leaf temperature is a passive outcome of the heat and mass exchanges (Thom, 1975; Bot, 1983) Leaf temperature directly affects plant metabolic activities and consequently production, and also influences energy management and pest/ disease control. In modern green houses, for example, leaf temperature is one of the most important controlled parameters (Bailey, 1985; Challa et al., 1988).

Various attempts have been made to define specific physiological characteristics that are indicative of drought and heat resistance. Among these are, low stomatal conductance (Sullivan, 1979), low leaf transpiration per unit area (Wilson, 1975) and leaf water potential (Turner, 1974). Other researchers (Idso et al., 1977; Idso,1982) have shown that the difference in leaf-air temperature can be

used to assess the water status of plants and hence serve as an operational practical guide in irrigation scheduling. Ehler (1973) also concluded that the differential between leaf and air temperature could be used to assess water status of plants. He stated that the long-term measurements of leaf temperature provide an indirect indication of stomatal behaviour. However, Idso (1982) cited Gardner (1979) and Walker (1980) who reported that the foliage-air temperature differential alone was not sufficient to assess the water status of plants due to the complexities induced by significant microclimatic variations. Studies by Jackson et al. (1979) and Idso et al. (1977) indicate that wheat is not stressed for water unless leaf temperature exceeds air temperature. Leaves of moisture stressed plants have been found to be warmer than those of non-stressed plants. This is because transpiration is less and hence less cooling effect. Temperature differences between stressed and non-stressed leaves reported for various crops range from +2°C to +8°C (Miller, 1923; Eaton, 1979; Millar et al, 1971; Ehler et al., 1978). Wiegand and Namken (1966) found that the difference in temperature between stressed and non-stressed cotton (*Gossypium hirsutum L.*) leaves ranged from +2.5°C to +4.5°C when solar radiation flux was 200 Wm^{-2} and 1100Wm^{-2} respectively.

Turner (1963) suggested that the temperature difference between stressed and non-stressed potato (Solanum tuberosum L.) leaves gives a qualitative indication of difference in transpiration. He concluded that with a better understanding of heat and vapour transfer process at the plant surface, leaf temperature measurements may provide quantitative data on plant water status. Ehler et al. (1978) demonstrated that canopy temperature in wheat increased as plant water potential decreased. Differences in canopy temperature between stressed and non-stressed plants were shown to be reliable indicators of plant water status.

Aston and Van Bavel (1972) and Nixon et al. (1972) suggested that a large variability in canopy temperature should signal the onset of water deficits due to the inhomogeneous soil moisture retention properties in large fields. The

soil dried were attributed primarily to lower amounts of evaporative cooling as the stomata closed in response to a decrease in leaf turgor. Dale (1961) found that cotton stomata exhibited progressively more day time stomatal closure when the leaf turgidity fell below 85%.

2.4 INFLUENCE OF THE MICROCLIMATE ON THE PHOTOSYNTHETIC RATE

For most environments, plant productivity is determined at least in part by the rate of net photosynthesis, and is, therefore, subject to environmental constraints. The efficiency with which CO_2 is fixed in the presence of light and the rate of CO_2 released through respiration determine the net photosynthetic rate. Carbon dioxide evolution in the light has been estimated to be 25-75% of the net photosynthetic rate (Zelitch, 1975), and thus photosynthetic rate should show sensitivity to changes in light. In an attempt to show how the physical environment controls photosynthetic rate it is necessary to take into account the response of both the resistance to CO_2 and light.

2.4.1 INFLUENCE OF ENVIRONMENTAL VARIABLES ON PHOTOSYNTHETIC RATE

2.4.1.1 LIGHT

Light provides the energy needed in the photosynthetic reaction. Various species of plants differ greatly with respect to their carbon dioxide fixation rates. Leaves of C_4 species (e.g. maize, sorghum, sugar cane) show a virtually linear increase in carbon dioxide uptake rate with increasing level of irradiance at high light saturation level (Moss, 1965). Leaves of C_3 species (e.g. soyabeans, sugar beets) are less productive and may become light saturated at levels of irradiance as low as one-fourth of the full sunlight of the mid-latitudes (Moss, 1965). Some woody species and shade plants are light saturated at even lower irradiance. Leaves of shade and woody species are light saturated at about 660 umol $m^{-2}s$ 1 of

incandescent light. The orchard grass group appears light saturated at about 1310 μmol m^{-2}, while maize leaves are still unsaturated even at 2650 $\mu molm^{-2} s^{-1}$.

2.4.1.2 WATER

Water is an essential component in the photosynthetic reaction. Shortages of soil moisture or extreme dryness of the atmosphere creates a water stress that affects the efficiency of the photosynthetic reaction in the plant. This is through; (a) affecting the levels of metabolic intermediates (b) inhibiting the photosynthetic electron transport system (c)causing stomatal closure and (d) altering rates of transpiration (Boyer, 1970).

Water availability directly influences photosynthesis through the impact on stomatal aperture. As stomates close in response to stress, resistance to the diffusion of carbon dioxide into leaves increases. Moss (1965) speculated on the influence of soil moisture stress and atmospheric evaporative demand on photosynthesis at varying levels of irradiance. With increasing soil moisture stress (increasing dryness), the optimum photosynthetic rate is reached at lower irradiance. When soil moisture stress is low and with little atmospheric demand, photosynthesis continues to rise even at high irradiance. High atmospheric stress and, in particular, extreme atmospheric stress reduces photosynthesis, probably because rapid evaporation reduces turgor in the guard cells causing stomates to close (Moss, 1965).

2.4.1.3 TEMPERATURE

The photosynthetic reaction is not strongly affected by ambient temperature in the normal range of plants adaptation. Temperature does affect photosynthetic performance, but the effects may vary according to prior acclimatization to hot or cold conditions. In a number of desert species, response to temperature are correlated with changes in the concentration of certain enzymes, especially RUP_2

carboxylase (Bjorkman, 1981). Respiration is controlled quite directly by ambient temperature.

Under higher temperatures, the C4 plants have a generally greater photosynthetic potential. Through controlled environmental studies, Moss (1965) has shown that maize assimilates carbon dioxide more effectively as temperatures increase from 10 ^{0}C to 30 ^{0}C. An optimum temperature exists between 30 ^{0}C and 35 ^{0}C, however.

Sugar production in sugar beets, on the other hand, is benefited by a decrease in temperature in the range of 15-29 ^{0}C (Thomas and Hill, 1949). Baldochii et al. (1981) in a field study with alfafa found the flux from air to crop to decrease with increasing temperature in the range 23-32 ^{0}C. In the field, this effect may be due, not only to the direct influence of temperature on photosynthesis and crop respiration, but also to an increase in root respiration that would cause a greater release of Co_2 from below. Such an increased release might diminish the need for Co_2 from the air above.

2.4.1.4 CARBON DIOXIDE CONCENTRATION

Increasing the ambient concentration of carbon dioxide generally increases its fixation. Studies on the influence of CO_2 concentration on photosynthetic rates of maize and sugar beets show a linear increase in the photosynthetic rate with increasing carbon dioxide concentration in the range 220-400 ppm (Moss, 1965; Gaastra, 1959). In the case of C_3 species, the increase in ambient CO_2 concentration may also act to supress photorespiration since that process proceeds at a rate that depends on competition between the oxygen molecules and carbon dioxide molecules for enzymatic sites (Chollet, 1977; Ehleringer and Bjorkman, 1977). Hence, the influence of CO_2 concentration on the photosynthetic rate of C_4 species is smaller than for C_3 species.

2.4.1.5 WIND AND TURBULENCE

Wind and turbulence are among the environmental factors that influence photosynthesis. The supply of carbon dioxide to levels at which it has been depleted by the actively photosynthesizing plant should generally be adequate whenever there is effective turbulent mixing (Baldochi, 1981). In a study to investigate the interacting effects of windiness and irradiance on the flux of CO_2 to an alfafa crop, Baldochi et al. (1981) demonstrated that photosynthetic rate responded to an increase in the flux density of net radiation. However, the rates at any irradiance level increases with increasing windiness. This effect may be due to distortion of the canopy shade by the wind, thus facilitating the penetration of radiation to the lower, light-unsaturated leaves (Baldochi et al., 1981).

2.5 SOIL TEMPERATURE IN SOILS WITH VEGETATION

Soil temperature variations is the most important manifestation of the solar energy reaching the earth's surface, part of which is absorbed and converted into heat in the atmosphere and soil while the remainder is reflected back (Milthorpe and Moorby, 1974). The amount absorbed is influenced by the colour of the soil, since dark coloured soils absorb the most radiation , thus they are the warmest.

The soil surface, therefore, experiences larger fluxes of incoming radiation and re-radiation than deeper layers. The temperature of the soil surface largely depends on these fluxes and hence exhibits the greatest variation (Milthorpe and Moorby, 1974). The surface soil temperature is also influenced by degree of cloudness (Milthorpe and Moorby, 1974). The diurnal and annual (or seasonal) temperature waves, which are approximately sinusoidal, observed at the surface proceed downwards by heat conduction but with rapid reduction of amplitude and progressive increase of time-lag relative to the surface waves (Milthorpe and Moorby, 1974). On surfaces with vegetation, the fluctuations in temperature of the soil surface and deeper layers are much less than with bare soils. This is because much of the heat exchange occurs at the leaf rather than at the soil surface

(Milthorpe and Moorby, 1974). Cooper (1973) experimenting with maize observed that at 7.5 cm depth, as the leaf area index increased, the diurnal variation of soil temperature became smaller.

Cooper (1973) reported that when maize was planted at different times during the same season, later planted maize suffered from a comparatively lower soil temperature at each stage of growth and resulted in lower dry matter per plant at fourteen days of emergence. Cooper (1976) showed that enhanced soil temperature (by polythene mulching) increased the grain yield as long as the apical meristem was below the ground level but thereafter had little beneficial effect. In another time of planting experiment the grain yield of maize (planted eight times between 8- 4-1976 and 9-6-1976) declined with time of planting; this was accompanied by a drop in soil temperature.

2.6 SOIL MOISTURE AND THE MICROCLIMATE

It is essential for optimum growth that the soil should remain moist; for the majority of crop species it should neither be too wet nor too dry. The properties of the soil which affect the availability of the soil moisture to plants are as follows;

(a) more infiltration of rain water and less runoff

(b)Soil water retention capacity and water availability to plants

(c) the storage capacity or water holding capacity of the soil within the root zone (this is the amount of water which is held in the soil and does not drain away)

(d) the movement of water within the soil

(e) volume of soil accessible to plant roots.

Variations in soil moisture as influenced by evapotranspiration have been investigated by various workers and attributed to many causes . Kramer (1969) pointed out the difficulty experienced in trying to obtain reliable estimates of soil water content in the entire root zone. He attributed this difficulty to the great vertical and horizontal variability in soil water content in the field. This is partly due to irregularities in root distribution which cause some areas to be depleted of

water sooner than others (Kramer, 1969) and partly due to variations in the physical and chemical characteristics of the soil which influence evapotranspiration or water use efficiency (Turner, 1965; Salter and Goode, 1967; Kramer, 1969; Reuss and Danielson, 1974).

Another factor that influences the rate at which water is depleted from the soil is the height of a crop and leaf area index(LAI). Hudson (1965) reported higher evapotranspirational rates for tall than for short lucerne. Mitchell and Kerr (1974) noticed the same with rye grass and clover. Plant height largely determines the roughness and thus the aerodynamic properties of a crop surface. This may in turn modify the near surface wind regimes and the response of a crop to soil moisture (Lemon et al., 1957; Hudson, 1965; Chang, 1968).

Changes in reflection coefficient of the soil surface will influence the loss of soil moisture by evaporation. Fritchen (1967) for example points out that an increase in soil surface reflection may result in water conservation by reducing the amount of energy absorbed which could be used in evaporation.

Plant density and leaf area index (LAI) affects the loss of soil moisture. Turner (1965) found that plots planted with higher maize densities had a tendency to dry more rapidly than those with lower densities. Blum (1970) and Ritchie and Burnet (1971) experimenting with grain sorghum hybrids and dryland cotton and grain sorghum respectively obtained almost the same results as Turner (1965). Use of higher plant densities and closer row spacing decreases evaporation from the soil thus improving water use efficiency of dryland crops (Ritchie and Burnet, 1971).

Lewis et al. (1974) pointed out that a few investigations have provided quantitative data on the degree of water stress to which their plants were subjected but have sometimes failed to describe the stage of plant development when the stress occurred. Furthermore, estimation of plant water status depends both on the soil water status and those atmospheric factors which affect transpiration.

Sionit (1976) investigated the water status and yield of sunflowers subjected to water stress during four stages of development. He subjected two varieties of sunflower to water stress before head formation, during formation, during flowering and seed development. The leaf water potential of plants subjected to -16 bars returned to normal after flowering, but plants subjected to -23 bars did not return to their pre-stress level and some leaves died. Stress at all stages reduced seed yield.

It is important to mention that plants do not use soil moisture at the same rate throughout their growth period. Glover (1948) and Harold and Dreibelbis (1951) experimenting with maize and sorghum, and wheat respectively reported that these crops used large quantities of water as they approached maturity. Also changes in the soil moisture with depth are not uniform. In the work by Harold and Dreibelbis (1951) most of the soil water changes occurred in the top 18 cm. Turner (1965), using maize at different plant densities found that day to day fluctuations in the soil moisture at 23 cm depth were greater than at 46 cm; however, the general trend of variation over the season was very similar to that at 46 cm from the surface.

CHAPTER THREE

3.1 MATERIALS AND METHODS

3.1.1 Site location and description

The experimental site was on a piece of land belonging to the Faculty of Agriculture of the University of Nairobi at Kabete field station, about 10 km north of Nairobi at 1° 15', 36° 44'E. The site is 1800m a.m.s.l. The station receives rainfall distributed in two seasons, that is, March-June (long rains) and October-November (short rains).

3.1.2 Layout and land preparation

Table 3.1 below gives the summary of the events during the experimental period. Land was prepared for planting and plots demarcated as shown in Figure 3 on 20-3-97. Sunflower seeds (hybrid 8998) were planted around 1-4-97 and germinated on 12-4-97. The emergence was less than 100% since some of the seeds did not germinate. Weeding was done twice during the experiment on 24-4-97 and 26-5-97. No fertiliser was applied to the plots.

The experimental area was subdivided into four equal treatment plots of 9m by 6m each separated by 1m upslope and 2m across the slope. The plots were planted with sunflower at the following four different spacings and densities;

plot 1: spacing 50 cm by 20 cm (100,000 plants per hectare)

plot 2: spacing 75 cm by 30 cm (44,450 plants per hectare)

plot 3: spacing 100 cm by 50 cm (20,000 plants per hectare)

plot 4: spacing 85 cm by 40 cm (29,400 plants per hectare)

Plot 2 had normal planting density and acted as the control.

TABLE 3.1: Events during the experimental period

Date	Event
20-3-97	land preparation
1-4-97	sowing of sunflower seeds
12-4-97	date of germination
24-4-97	first weeding
26-5-97	second and final weeding

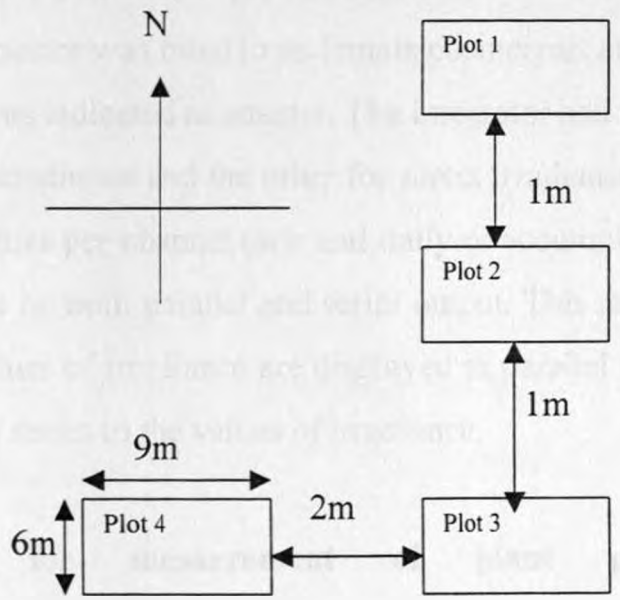


Fig. 3.1: Experimental layout-Kabete

Plots 1,2 and 3 were separated by 1m apart upslope. Plot 4 was separated from plot 3 by 2m across the slope.

3.1.3 INSTRUMENTS USED AND CALIBRATION METHODS

3.1.3.1 Radiation instruments set-up

For irradiance measurements two Kipp solarimeters were used. These were the direct and diffuse solarimeters. The solarimeters had levelling screws on their base. They were then installed in the north-south direction with the diffused solarimeter completely covered from direct sunlight.

When the power supply was switched on, the instrument displayed the solar irradiance (in watts per metre squared) and calculated the irradiation (integral of irradiance) over selectable periods- 10, 30 or 60 minutes. The date and time were also displayed simultaneously.

To connect the solarimeters to a solar integrator CC12, an adapter was used. The solar integrator was then connected to a mains connection through a converter. The power connector (mains connection) was placed in the wall outlets of an Agrometeorological office at the Field station which was 80m from the experimental site. Its connector was fitted to its female counterpart at the rear side of the integrator, which was indicated as adapter. The integrator had two channels (inputs); one for diffuse irradiance and the other for direct irradiance. After each period two irradiation values per channel (sub and daily or accumulating totals) and the time are available on both parallel and serial output. This means that the sub and accumulating values of irradiance are displayed in parallel to each other while time is displayed in series to the values of irradiance.

3.1.3.2 Instruments for measurement of plant physiological parameters

Soil moisture and soil temperature measurements commenced 15 days after sowing (DAS). Global and diffuse irradiance measurements commenced 56 DAS when sunflower canopy was large enough to intercept some solar radiation. Both diffuse and direct measurements of irradiance were taken in the upper and lower strata of the canopy. The measurements of leaf temperature, stomatal conductance, photosynthetic rate and photosynthetically active radiation (PAR) commenced 78 DAS.

3.1.3.3 Principles of infrared gas analysis

Assimilation of CO_2 by plant leaves has been measured using many different techniques, the most common being $14CO_2$-labelling, conductivity and

IR spectroscopy analysis. The latter, infrared gas analysis of CO_2, is the most widespread contemporary method of determining photosynthetic and respiratory CO_2 exchange in plants. Its popularity stems from the reliability, accuracy and simplicity of this technique compared to others. To determine accurately CO_2 exchange for a leaf of about 10 cm^{-2} in an open or semi-closed system the instrument should be capable of resolving a CO_2 mole fraction of 0.1-1.0 μmol mol^{-1} (0.1-1.0 vpm) against normal atmospheric concentration of 340 μmol mol^{-1}.

The air to be measured is drawn into the instrument through a 3 metre -tall roach pole passing it through a pump and made free of CO_2 by soda lime and then passed to the measuring cell. In the absence of CO_2 a maximum signal is obtained by the solid-state detector. After two seconds the flow is switched so that the soda lime column is by-passed and enters the cell without alteration to CO_2 content. Decrease in the detector signal on switching will be directly proportional to the CO_2 content of the air. This way, the IRGA determines the difference in CO_2 concentration in an air stream before and after it has passed over a leaf and calculates stomatal conductances and photosynthetic rates from this principle.

3.1.4 INSTRUMENTAL ANALYSIS AND SAMPLING TECHNIQUES

The data from physical measurements are plagued by uncertainities and errors. An estimate of the magnitude of these errors is of prime importance if experimental results are to have a meaning. Unfortunately, no simple, generally applicable method exist that will provide a measure of the reliability of experimental data with absolute certainity, indeed, the work required in evaluating the quality of data is frequently comparable to the effort that goes into obtaining them. Instrumental analysis, in the face of difficulties in estimation of quality of experimental data, is of prime importance in ensuring that data obtained from experimental measurements are close to being reliable. The analysis involves knowledge of the principles of operation of the various instruments, their calibration procedures, limitations and methods of measurement.

In the broadest sense, an instrument for analysis converts a signal that is usually not directly detectable and understandable by man, to one that is. Thus an instrument can be viewed as a communication device between the system (sample) under study and the scientists. An example of signal used in this case is the Infrared Gas Analyser (IRGA) to measure intensity of infrared radiation. Regardless of its complexity, an instrument generally contains no more than four fundamental components. These components are;
(1) a signal generator which produces analytical signals from the component of the sample ;
(2) an input transducer or detector which converts one type of signal to another (an example is a thermocouple which converts a radiant heat signal into an electrical voltage);
(3) a signal processor which modifies the transduced signal in such a way as to make it more convenient for operation of read-out device and lastly;
(4) an output transducer or read-out which displays the signal output in the form of a metre (or scale), recorder, digital unit or through a data logger.

3.1.5 MEASUREMENTS IN THE FIELD

(a) Irradiance Measurement

A metallic mast of length 4m and diameter 5cm was constructed from cast iron pipes for holding the solarimeters. One centimetre diameter holes were drilled at 5cm intervals on the mast. The mast was made with a supporting base to hold it vertically. A metal ring of 5cm external diameter was made to slide up and down on the mast pipe. The ring was made to rotate freely in the horizontal plane. A 60cm long horizontal bar was connected to vertical bar. This bar had two one centimetre diameter holes drilled at about 20cm and 40cm from the vertical bar. The solarimeters were joined together by a metallic plate which had two 1cm diameter holes. When the solarimeters were placed on top of the horizontal metallic plate, the corresponding holes fitted exactly and two bolts were welded

on top of the holes (20 and 40cm from the vertical bar) for carrying the solarimeters.

Using the holes along the mast, the solarimeters were raised to the desired height above the sunflower canopy and locked in a position using a short piece of metal rod that just fitted into these holes. The irradiance measurements were done above and below the plants canopy. The equipments were transferred from plot to plot after completing measurements in one plot. The order of transfer was from plot 1, plot 2, plot 3 and finally plot 4. This order was adhered to throughout the day. Measurements were confined to the middle of the plots to avoid edge effects. The solarimeters were removed from the mast and kept away when not in use. Measurements were made at hourly intervals from 0800 hours to 1700 hours local time. Measurements were taken for three days in each of the three stages of the crop growth i.e. vegetative, reproductive and maturity stages. These measurements were taken at the same time the plant physiological and other parameters were being taken.

(b) Measurements of PAR, leaf temperature, stomatal conductance and photosynthetic rate

These parameters were measured with a portable IRGA. To take measurements, a stand was selected and an air sampling mast with the pump attached. The tubing was connected to the analyser and leaf chamber in accordance with the principle of an open system. All the connections were checked, the silica gel in the drier and the soda lime in the IRGA. A flow rate which was slightly higher than the sampling rate required by IRGA was set. The leaf chamber was activated and the CO_2 concentration observed was recorded. The relative humidity of the air and PAR were then recorded.

A leaf was inserted into the leaf chamber and CO_2 assimilation in the differential mode measured. When a steady reading was observed (normally after 15-20 seconds), it was recorded and recording of relative humidity, leaf

temperature and quatum flux density in the chamber proceeded immediately. Three leaves (sampling points) were considered both for lower and upper strata of the canopy. An average of five readings of each parameter were done for every leaf per an hour.

(c) Estimation of Leaf area index (LAI)

A small sample of leaves was used to estimate leaf area index. The procedure was to measure the lengths of 3 big and 3 small leaves using a ruler. The length of the leaf was measured from the stalk to the tip of the leaf. The width of the leaf was taken as the average of the widths measured at three positions on the leaf- a few centimetres from the stalk, in the middle of the leaf and a few centimetres from the top of the leaf. These measurements were made 'in site' and therefore the sample leaves were not removed from their respective plants. The total number of leaves of every sunflower plant considered was counted as well as the total number of plants in every plot. The mean length and breadth of the six leaves on the above plants was calculated as well as the mean number of leaves per plant. The total surface area (As) of all the leaves (one side of leaves) on all plants in any plot was obtained from the expression;

$$As = lbnp \quad \text{.....(3.3)}$$

where

l = mean length of the leaf

b = mean breadth of the leaf

n = number of leaves per plant

p = total number of plants per plot

The leaf area index is defined as the total surface area of leaves per unit area of ground. The leaf area index then becomes

LAI = As/s .....(3.4)

where s = area of plot.

(d) Soil temperature measurements

Soil temperature measurements were taken weekly at one hourly intervals starting from 0700 hours to 1800 hours local time. Twelve bent-stem soil thermometers were used for this purpose, three for every plot. These were 5cm, 10cm and 20cm. Each plot was installed with one at the three depths mentioned above. The installation was done at the middle of every plot to avoid edge effects. The measurements were taken on the following dates during the three henological stages;

Table 3.2: Dates of measurement of temperature for the three growth stages

Physiological stage	Dates
Vegetative	14-4-97, 21-4-97, 28-4-97, 5-5-97, 12-5-97, 19-5-97, 1-6-97
Reproductive	9-7-97, 16-6-97, 24-6-97, 1-7-97
Maturity	9-7-97, 16-7-97, 22-7-97, 29-7-97

One of the main difficulties in soil temperature measurements was the placement of thermometers with minimum soil disturbance. Thus the thermometers were installed a week before measurement commenced to allow the soil to stabilise after the installation.

Using a linear graph paper, the probe readings in count ratio versus the volume samples in grams of water per cubic centimetre of soil were plotted. The graph was fitted to a straight line. Two representative points were selected from the straight line and the gradient was calculated, while the intercept on the x-axis was indicated. A general equation of the form;

$$M = A(CR) + B \quad \text{.....(3.4)}$$

was found where

M = grams of water per cubic centimetre of dry soil

A = gradient of the straight line

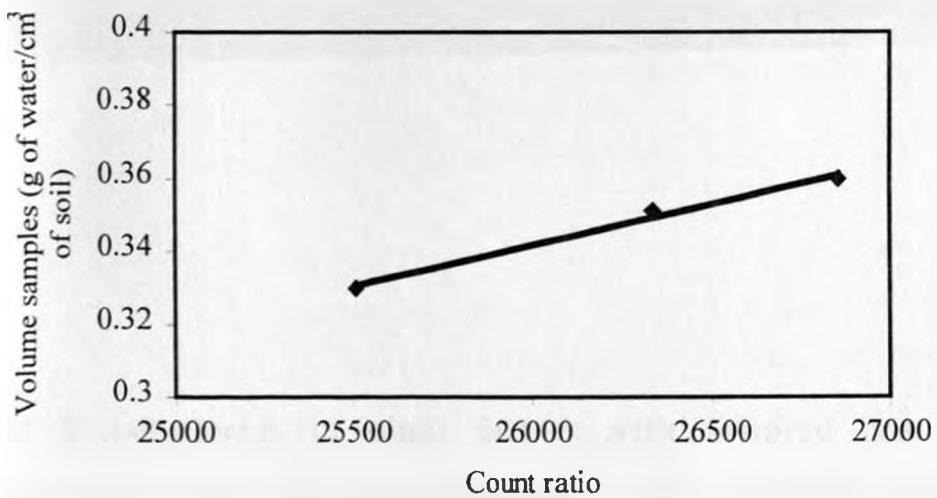


Fig. 3.2. Calibration graph (count ratio versus volume samples)

B= intercept

From equation 3.4 above, the count ratio of the probe were converted to grams of water per cubic centimetre of soil

Plate 1: Measurements of plant factors with Infrared gas analyser (IRGA). Leaves in the lower strata of canopy are being measured in this case (front view)

Plate 2: **Measurements of plant factors with IRGA. Exposed (upper strata of canopy) leaves are being measured in this case (front view)**

Plate 3: **Radiation instruments i.e. mast carrying solarimeters (global and diffuse) and solar integrator CC12 in operational position (front view)**

(f) Accuracy of the Parameters measured

The different parameters measured had the following accuracies (errors);

PARAMETER	ACCURACY (ERROR)
Soil Temperature	±0.3°C
Leaf Temperature	±0.3°C
Stomatal Conductance	±5%
Photosynthetic Rate	±5%
PAR	±5%
Leaf Area Index (LAI)	±0.5
Global Irradiance	±5%
Diffuse Irradiance	±5%

(g) Meteorolgical data

An agrometeorological station situated at about 100 m from the experimental site was used to monitor meteorological parameters. The parameters considered here were rainfall, evaporation, air temperature and radiation.

Table 3.5: Meteorological parameters recorded at the Agrometeorological station at Kabete, Nairobi.

Date	Daily sunshine hours.	daily mean temp. (°C)	daily max. temp. (°C)	Daily min. temp. (°C)	daily mean total rad. $MgJm^{-2}$	daily mean evap. (mm)	daily rain-fall (mm)
05-5-97	3.1	18.0	21.1	14.8	9.91	3.3	12.3
14-5-97	4.7	19.6	22.7	18.5	13.48	2.3	5.8
31-5-97	5.6	16.5	20.9	12.0	11.51	2.9	0.4
20-6-97	0.5	16.6	21.1	12.0	14.38	3.0	0.0
21-6-97	1.3	16.2	19.5	12.8	9.16	2.8	1.3
28-6-97	3.3	17.6	21.5	13.7	10.18	2.6	5.1
09-7-97	6.0	17.1	21.7	12.5	13.74	2.6	0.6
24-7-97	6.4	18.7	25.3	12.0	16.91	5.6	12.1
25-7-97	6.0	17.9	22.5	13.2	15.32	4.0	0.0

Note: The first three days (5th, 14th and 31st of May represent vegetative stage. Reproductive stage is represented by 20th, 21st and 28th of June and ; maturity stage is represented by 9th, 24th and 25th of July.

Table 3.6: Mean monthly meteorological parameters recorded at the Agrometeorological station during the experimental period.

month	monthly mean max. temp. (°C)	monthly mean min. temp. (°C)	monthly mean temp. (°C)	Monthly mean total rad. $MgJm^{-2}$	monthly mean rain-fall (mm)	monthly mean evap. (mm)
March	26.4	14.6	20.5	71.70	29.2	213.2
April	23.3	14.3	18.8	16.00	541.2	125.2
May	21.9	13.5	17.7	15.70	105.8	105.8
June	21.1	12.9	17.0	12.79	23.1	23.1
July	21.2	11.3	16.3	12.32	21.5	21.5

(g) Yield determination (total above ground dry matter)

Determination of yield was done on per total planted area basis. The plant population in all the plots was lower than expected since some of the seeds did not germinate. Since the cause of the missing plants was the natural environmental conditions prevailing at the experimental site, no adjustments were made for missing plants. All the sunflower plants in every plot were cut with a panga at ground level, then cut into smaller pieces and kept in paper bags. These were then put in an oven and dried at 90°C until the plants were completely dry. The dry matter was then weighed and the yield quantified in tonnes per hectare.

To determine the economic yield the sunflower seeds were harvested and then sun-dried. The seeds were weighed and then quantified in tonnes per hectare.

(h) Statistical treatment of the data

(1) Plant physiological data

The plant physiological data of leaf temperature, stomatal conductance and photosynthetic rate were subjected to a one-way analysis of variance (ANOVA). Existence of significant statistical difference was then determined using the F-ratio test (at $p < 0.01$ and $p < 0.05$). The hourly values of the above parameters were also plotted graphically to give the diurnal variation in every plot.

(2) Soil temperature data

Analysis of variance was performed on the soil temperature data to ascertain significant differences between treatments and depths. Graphs of diurnal variation of soil temperature at the three different depths were also plotted for the different plots.

(3) Soil moisture data

Soil moisture data were subjected to a one-way analysis of variance and the F-ratio tests performed for any significant differences between treatments and depths. A graph of soil moisture profile was plotted for the four depths.

(4) Irradiance data

Analysis of variance was performed on irradiance data to ascertain significant differences between treatments both below and above the crop canopy. Graphs of diurnal variation of irradiance were also plotted for the four plots.

(5) Leaf area index (LAI) data

The LAI data was subjected to a one-way analysis of variance and the F-ratio tests performed for any significant differences between treatments. A graph of LAI over the whole growth period was also plotted for the four plots.

(6) Photosynthetically Active Radiation (PAR)

PAR data was subjected to a one-way analysis of variance. Existence of significant differences was then determined using the F-ratio test at 99 % and 95 % confidence limits. Graphs of diurnal variation of PAR were also plotted for the four plots.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SOIL TEMPERATURE

The mean soil temperature values recorded for various growth stages during the experiment are presented tables 4.1a,b,d,e,g and h, appendix 1. Analysis of variance performed for soil temperatures at 5cm, 10cm and 20cm depths showed that there was a significant difference in soil temperatures for the three depths both at 1% and 5% levels (table 4.1 d(i), appendix 1). The soil temperatures were on the average higher in the upper soil strata (5cm depth) in all the plots. This could be attributed to the radiative heating of the uncovered soil surface by the sun. Analysis of variance for soil temperatures at 5cm depth between treatments and the control showed no significant differences (tables 4.1d ii,iii,iv, appendix 1). Plot 4 experienced the highest diurnal average temperature . This could have been partly due to the planting density of the crops and partly due to the plots arrangement i.e. the sun's rays were always directly hitting plot 4 throughout the day. Plot 1 experienced the lowest temperature because the sun's rays were not able to penetrate as easily as in the lower density plots.

For the 10cm depth, the situation was the same as for 5cm depth. Analysis of variance between treatments and the control showed no significant differences (table 4.1d v,vi,vii, appendix 1). Plot 4 experienced the highest diurnal average temperature and plot 1 experienced the lowest temperature.

The situation for the 20cm depth was the same as in the other two depths. Analysis of variance between treatments and the control showed no significant differences (tables 4.1d viii, ix, x, appendix 1).

The diurnal variations of soil temperature at three different depths are shown in Figs. 4.1a,b,c. The pattern at 5cm depth for the four plots (treatments) is

shown in Fig. 4.1a. At this depth plot 4 showed the highest temperature throughout the day and plot 1 showed the lowest. The possible reasons for these observations are explained above. In all the plots the temperatures continue to increase as the day progresses reaching a maximum at 1700 hours local time and then starts to decrease as we approach 1800 hours . The minimum occurred in plot 2 at 0700 hours local time. This is due to radiative heating as the day progresses until sunset and radiative cooling after sunset. From 0700 hours to 1000 hours local time plot 2 experienced the lowest temperature at 5cm depth. After 1000 hours up to 1800 hours, plot 1 experienced the lowest soil temperature. The reason for this could be because plot 1 had the highest plant density and hence higher canopy density which intercepted a greater percentage of the sun's rays than the other plots. For 10cm depth (Fig. 4.1b), the shape of the graphs are the same as for the 5cm depth except for some slight differences, e.g. (a) plot 4 and plot 3 had the same mean soil temperature at 1200, 1300 and 1400 hours; (b) plots 2, 3 and 4 showed an increase in soil temperature even after 1700 hours which was not the case for the 5cm depth. For 20cm depth (Fig. 4.1c), the trend was same as the other two depths. Temperatures at this depth were lower than the 5cm and 10cm throughout the day. There was also an increase of soil temperatures after sunset (1700 hours) in all plots except plot 2. Njihia (1978) found the same observations when investigating on the influence of maize plant density on radiation, soil temperature and soil moisture distribution at Kabete area, Nairobi. He found that at 5 and 10cm depths, the rate of increase of soil temperature with time increased as plant density decreased. Owili (1995), found similar observations on maize in Machakos district in Kenya.

The amplitude of soil temperature decreased with depth for all the plots. This decrease in temperature with depth implies that the temperature gradient is directed downwards into the soil. It is also true that soil temperatures began to rise in the afternoon hours and that the achievement of maximum and minimum temperatures lags as a function of depth (cf: Figs. 4.1 d,e,f,g). From the same

figures we can conclude that the 5cm depth showed the lowest temperature in the early morning hours and the highest temperature in the afternoon hours. This is due to radiative cooling of the soil surface during the night and radiative heating of the surface as the afternoon approaches. However, it should be noted that soil temperature is also affected considerably by such other factors as the sky condition, soil moisture, soil colour, porosity of the soil and surface configuration (Stigter, 1985b).

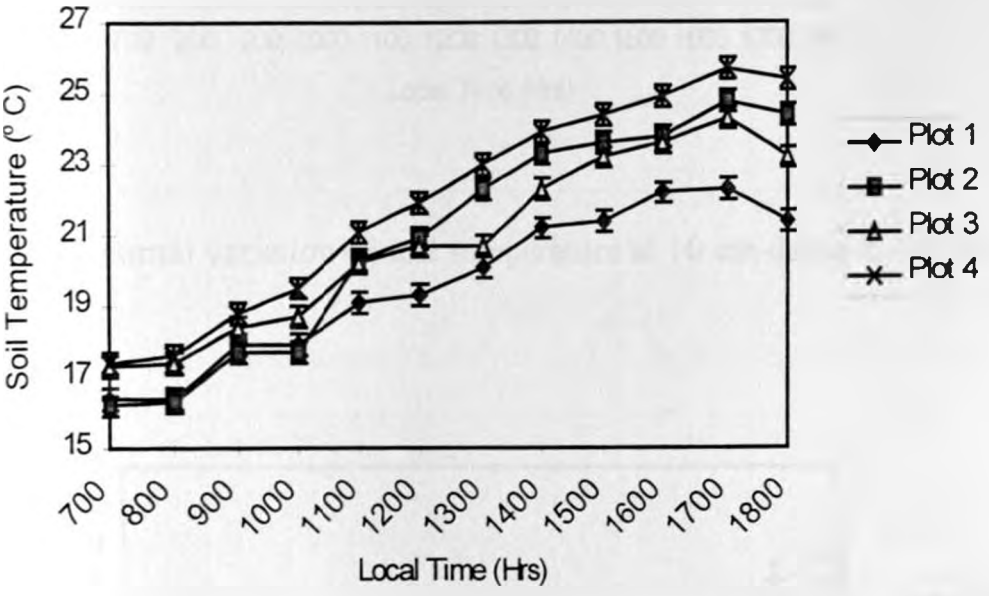


Fig 4.1a: Diurnal variation of soil temperature at 5 cm for the four plots.

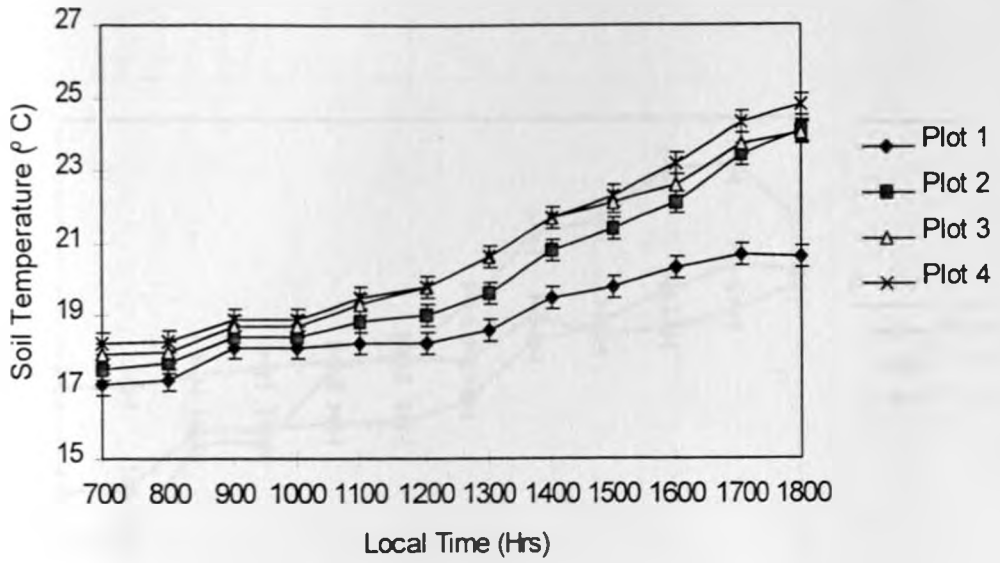


Fig. 4.1b: Diurnal variation of soil temperature at 10 cm depth in the four plots

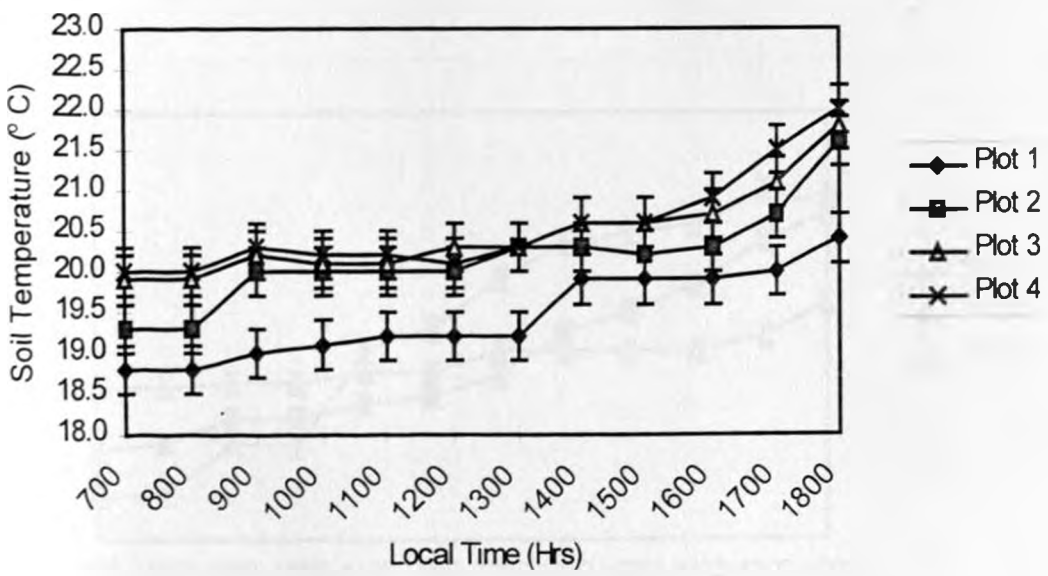


Fig. 4.1c: Diurnal variation of soil temperature at 20 cm depth in the four plots

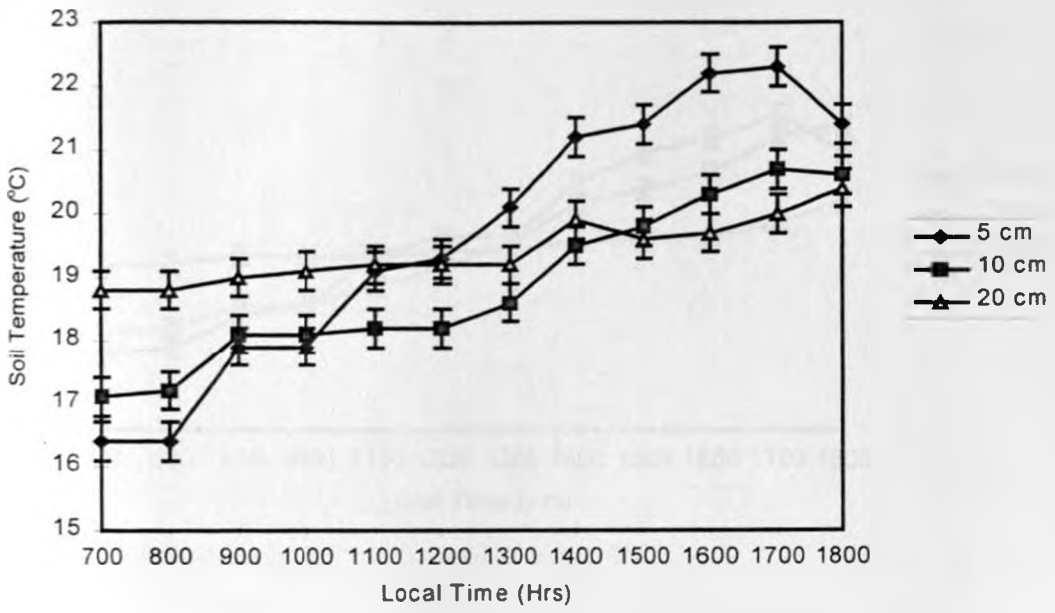


Fig. 4.1d: Diurnal variation of soil temperature in plot 1 at depths 5, 10, and 20 cm.

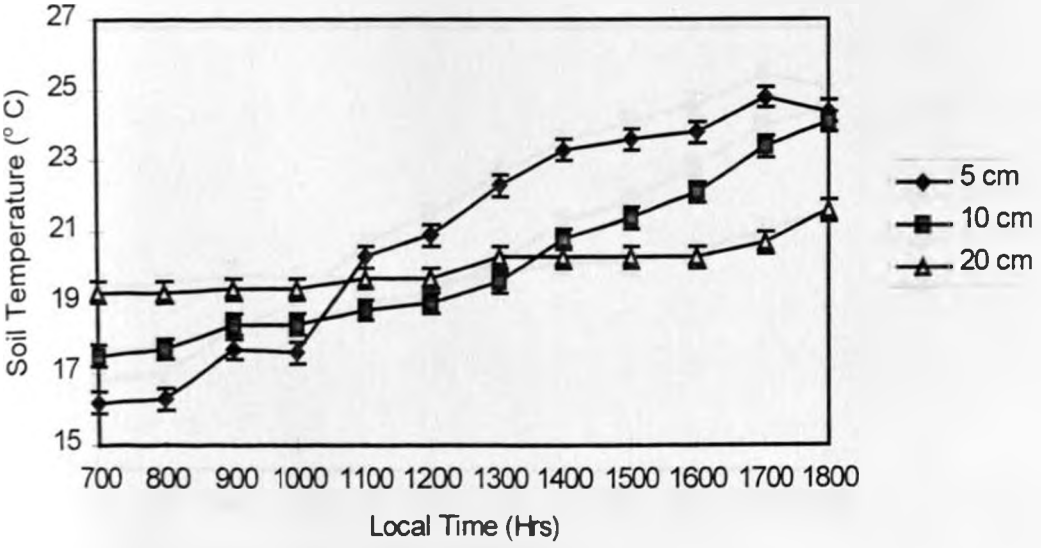


Fig. 4.1e: Diurnal variation of soil temperature in plot 2 at depths 5, 10, and 20 cm.

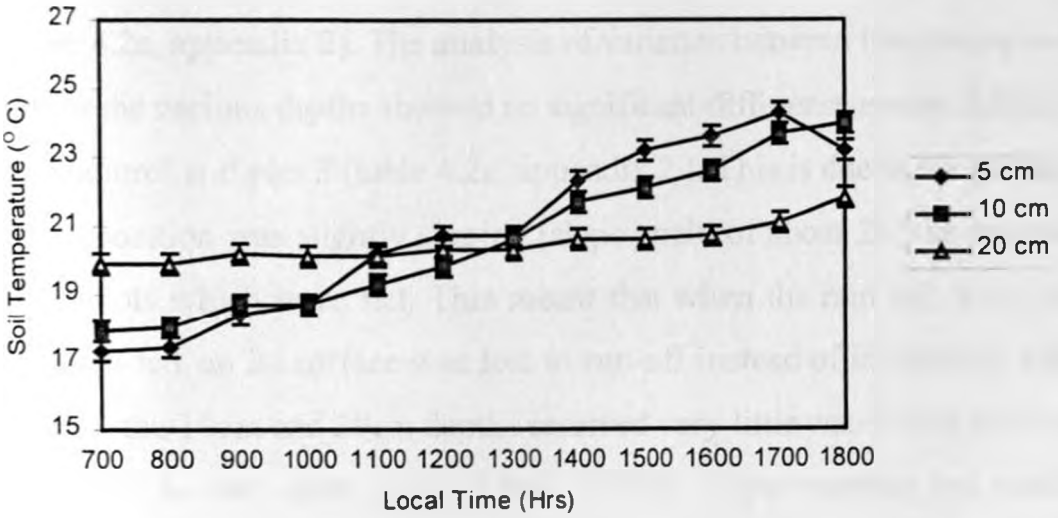


Fig. 4.1f: Diurnal variation of soil temperature in plot 3 at depths 5, 10, and 20 cm.

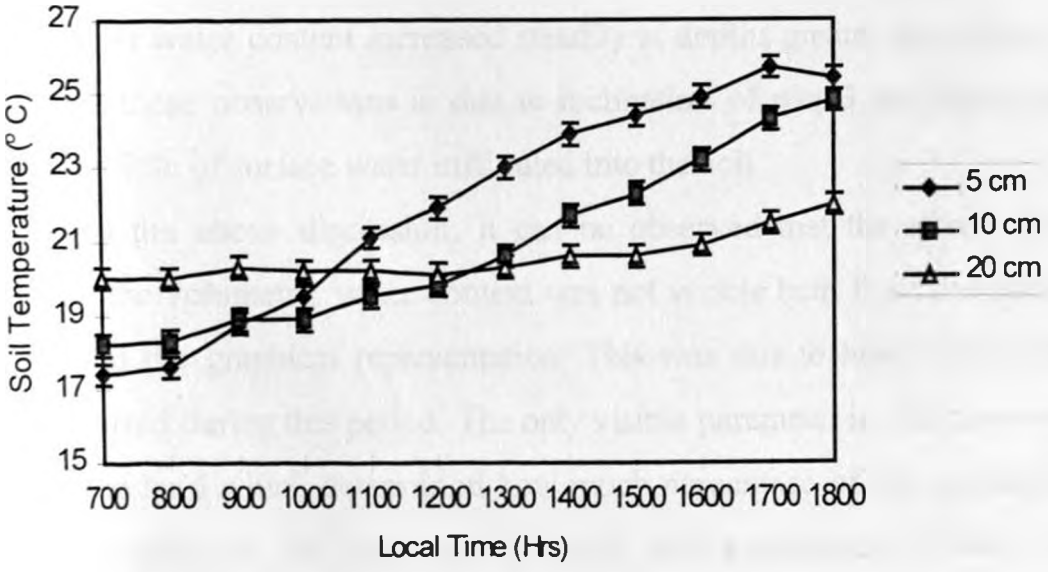


Fig. 4.1g: Diurnal variation of soil temperature in plot 4 at depths 5, 10, and 20 cm.

4.2 SOIL MOISTURE

Analysis of variance performed for soil moisture at four different depths showed no significant statistical difference both at 1% and 5% levels of the F-ratio test (table 4.2a, appendix 2). The analysis of variance between treatments and the control for the various depths showed no significant difference except for the case between control and plot 3 (table 4.2c, appendix 2). This is due to the position of plot 3. Its position was slightly sloping (slope angle of about 25^{o}) as opposed to the other plots which were flat. This meant that when the rain fell, most of the water which fell on its surface was lost as run-off instead of infiltrating into the soil. Hence, the 10cm and 20cm depths received very little water from the surface as compared to the other plots. Owili (1996), experimenting on maize in Machakos district reported a similar observation. This was also reported by Mungai (1991).

From Fig. 4.2, it can be observed that plot 1 experienced the highest volumetric soil water content at 30cm, 40cm and 100cm depths while plot 3 experienced the lowest volumetric at 30cm, 60cm and 100cm depths. For depths lower than 60cm, the differences between plot 3 and 4 ranged between 0-2% .The differences in water content increased steadily at depths greater than 60cm. The reasons for these observations is due to inclination of plot 3 and hence above 60cm, very little of surface water infiltrated into the soil.

From the above discussion, it can be observed that the effect of plant density on the volumetric water content was not visible both from the statistical analysis and the graphical representation. This was due to heavy precipitation which occurred during this period. The only visible parameter in this case was the shape of the land which determined how much percentage of the surface water infiltrated while the rest was lost as runoff and evaporation. Njihia (1978) observed the same behaviour in soil moisture where he found no consistent relationship between soil moisture and plant density.

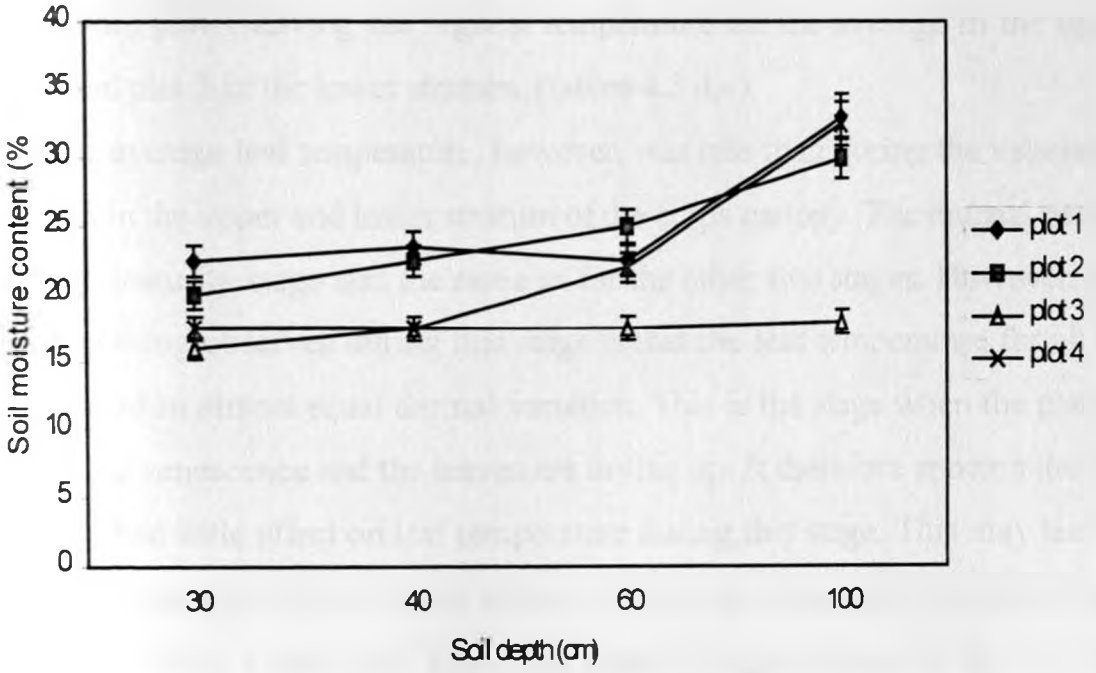


Fig. 4.2 Percentage soil moisture content at different depths.

4.3: LEAF TEMPERATURE

The mean leaf temperature values recorded for various growth stages during the experiment are presented in tables 4.3a,b,d,e, g and h, appendix 3. Analysis of variance to test for significant differences of leaf temperature in the upper and lower strata of the crops canopy between treatments and the control showed that there was no significant differences both at 1% and 5% levels of the F-ratio test (tables 4.3c,f,i, appendix 3).

The diurnal patterns of leaf temperature of the leaves in the upper side of the crop canopy during vegetative stage is shown in Fig. 4.3a. The diurnal trend of leaf temperature during this stage shows a general increase from morning hours to a maximum of 31.3^{O} C at 1300 hours in plot 1 before decreasing gradually as sunset approaches. A similar diurnal pattern is exhibited in the lower strata of the

crops canopy (Fig. 4.3b) where a maximum of 30.6^{0} C was recorded at 1300 hours in plot 2. The diurnal trend was the same during reproductive stage (Figs. 4.3d,e) with plot 1 having the highest temperature on the average in the upper stratum and plot 2 in the lower stratum (tables 4.3 d,e).

The average leaf temperature, however, was less than during the vegetative stage both in the upper and lower stratum of the crops canopy. The diurnal pattern during the maturity stage was the same as for the other two stages. However, one interesting thing observed during this stage is that the leaf temperature for all the plots showed an almost equal diurnal variation. This is the stage when the plant is approaching senescence and the leaves are drying up. It therefore appears that the treatments had little effect on leaf temperature during this stage. This may lead us to conclude that the effect of plant density on the microclimate of sunflower can only be effective during the first two stages of growth as far as the leaf temperature is concerned. The sharp increase in leaf temperature between 1200 hours and 1300 hours could be due to the closure of the stomata (probably due to midday stress). This closure of stomata, coupled with high humidity values, could have resulted in low transpiration rates, hence higher temperatures. When the transpiration rates are higher the leaves tend to be relatively cooler since transpiration has a cooling effect on them. Owili (1996) found a similar observation when experimenting on maize in Machakos District in Kenya.

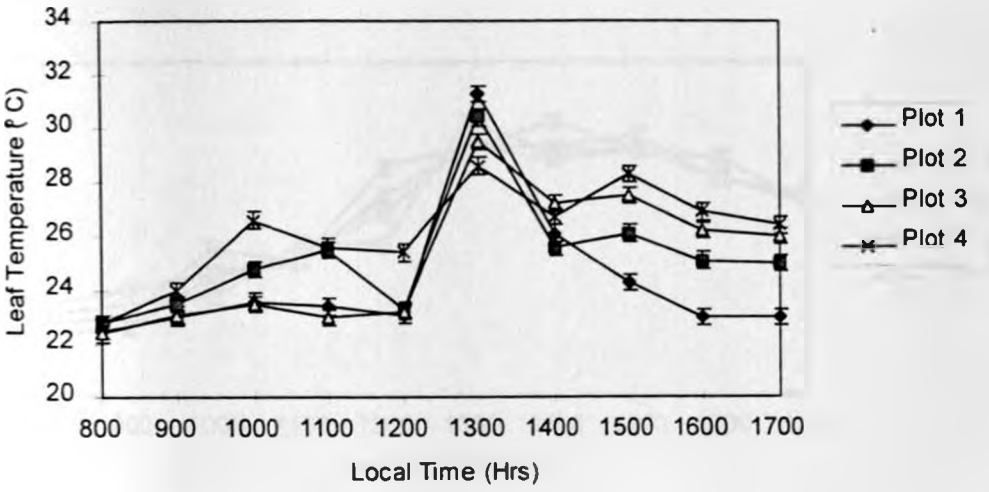


Fig 4.3 a: Diurnal variation of leaf temperature in the upper stratum of the canopy during the vegetative stage

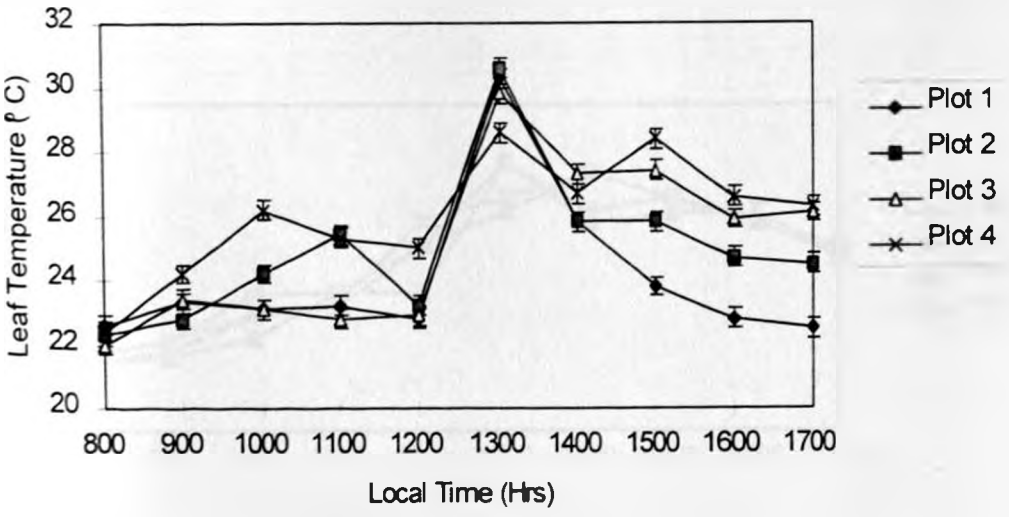


Fig 4.3 b: Diurnal variation of leaf temperature in the lower stratum of the canopy during the vegetative stage

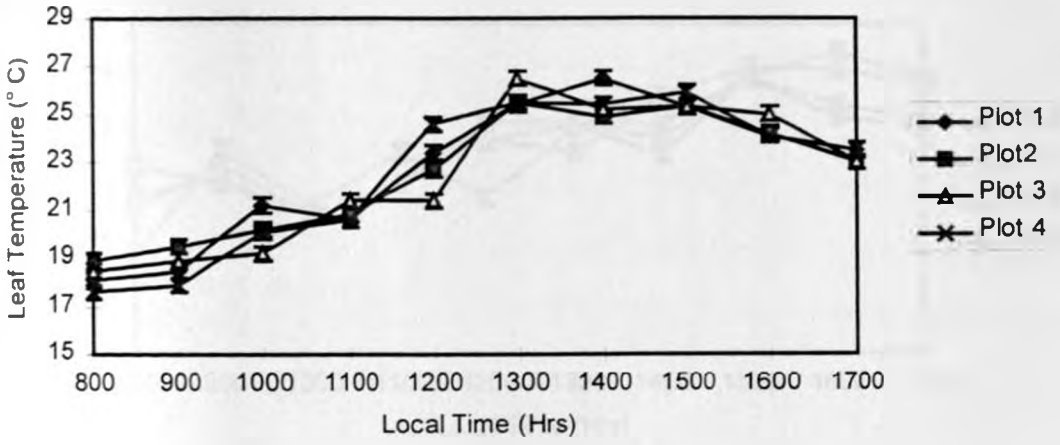


Fig 4.3 c: Diurnal variation of leaf temperature in the upper stratum of the canopy during the reproductive stage

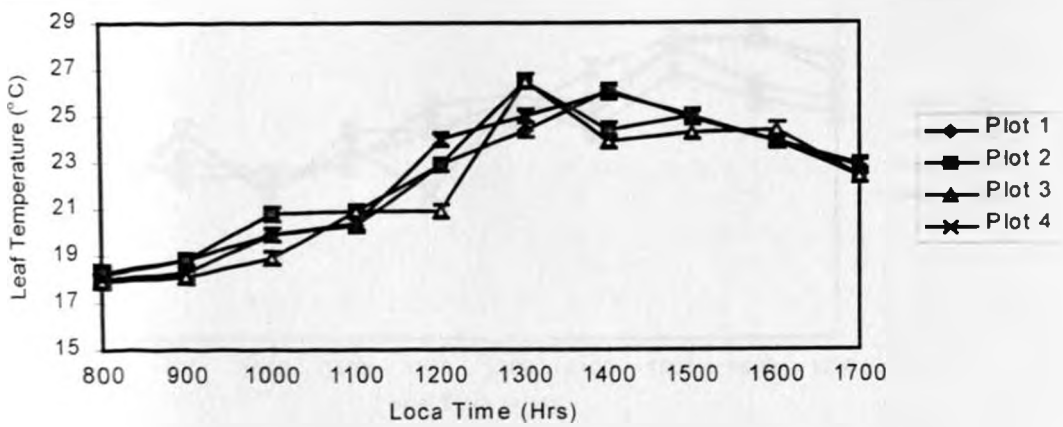


Fig 4.3 d: Diurnal variation of leaf temperature in the lower stratum of the canopy during the reproductive stage

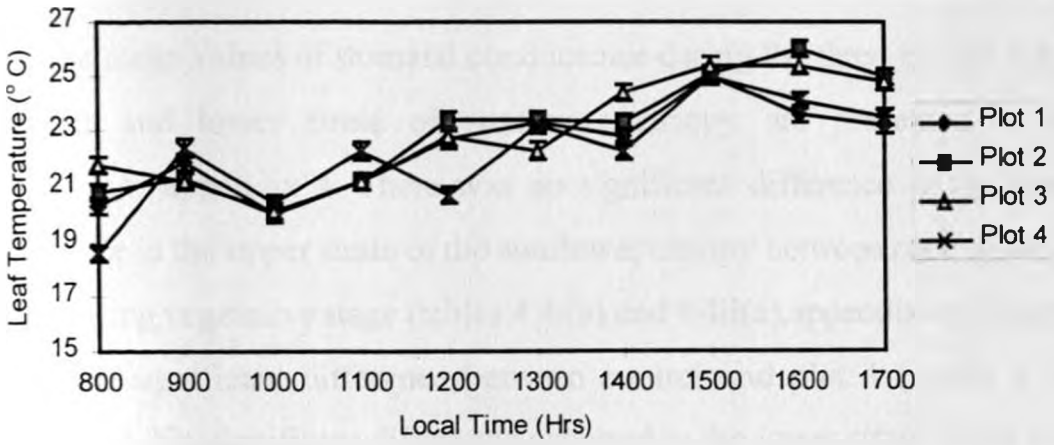


Fig 4.3 e: Diurnal variation of leaf temperature in the upper stratum of the canopy during the maturity stage

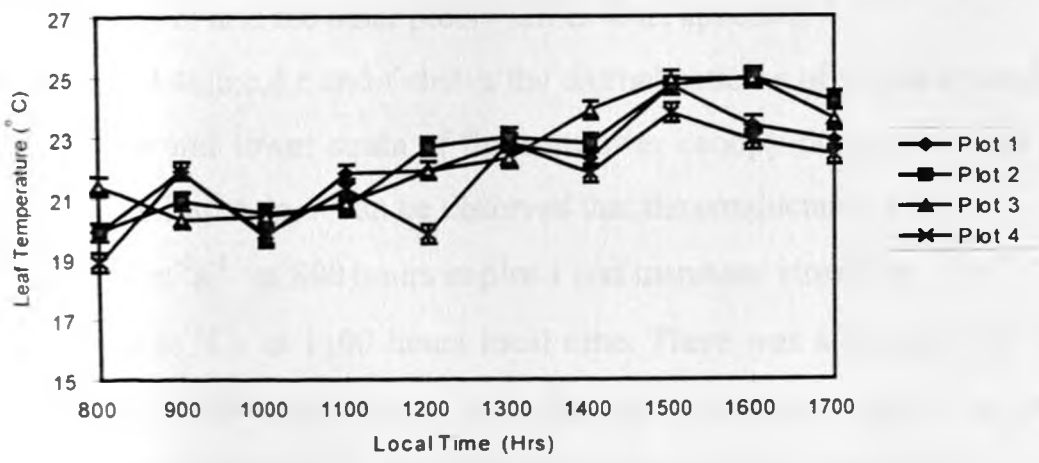


Fig 4.3 f: Diurnal variation of leaf temperature in the lower stratum of the canopy during the maturity stage

4.4: STOMATAL CONDUCTANCE

The mean values of stomatal conductance during the three growth stages in the upper and lower strata of sunflower canopy are presented in tables 4.4a,b,d,e,g,h, appendix 4. There was no significant difference in the stomatal conductance in the upper strata of the sunflower canopy between control and plots 1 and 3 during vegetative stage (tables 4.4i(a) and 4.4ii(a),appendix 4). There was, however, a significant difference between control and plot 4 (table 4.4iii(a), appendix 4). No significant difference occurred in the lower strata of the canopy between control and plots 3 and 4 during this stage (vegetative stage); however, there was a difference between control and plot 1 (table 4.4i(b), appendix 4). This could be attributed to competition for moisture and nutrients since there was more competition in plot 1 due to higher plant density compared with control. During the reproductive and maturity stages, there was no significant difference in stomatal conductance in the upper and lower strata of the sunflower canopy between control and the other plots (tables 4.4c, appendix 4).

Figs. 4.4a,b,c,d,e and f shows the diurnal patterns of stomatal conductance in the upper and lower strata of the sunflower canopy during the three growth stages. From Fig. 4.4a, it can be observed that the conductance was 0.029 μmol $m^{-2}s^{-1}$ at 800 hours in plot 1 and increased slowly to 0.036 μmol $m^{-2}s^{-1}$ at 1100 hours local time. There was a decrease for the next three hours (1200-1400 hours), and then the conductance rose to a maximum value of 0.055 μmol $m^{-2}s^{-1}$ at 1500 hours before finally decreasing to a value of 0.035 μmol $m^{-2}s^{-1}$ at 1700 hours local time. In plot 2, the conductance was 0.027 μmol $m^{-2}s^{-1}$ at 0800 hours, decreasing to 0.003 μmol $m^{-2}s^{-1}$ at 1100 hours local time. From 1200-1500 hours, there was a rise in conductance before decreasing to a 0.031 μmol $m^{-2}s^{-1}$ at 1700 hours. There was a peak at 1500 hours.

In plot 3, the conductance was 0.021 μmol $m^{-2}s^{-1}$ at 0800 hours and decreased gradually to 0.012 μmol $m^{-2}s^{-1}$ at 1100 hours local time. It then rose slowly to 0.031 μmol $m^{-2}s^{-1}$ at 1500 hours before decreasing to 0.024 μmol $m^{-2}s^{-1}$ at 1700 hours local time. There was a dip at 1100 hours. In plot 4, the conductance was 0.019 μmol $m^{-2}s^{-1}$ at 0800 hours. There were decreases from 0800-0900 hours, 1100-1400 hours and 1600-1700 hours local time. Increases occurred between 900-1100 hours and 1400-1600 hours local time. This behaviour in stomatal conductance is due to the presence of clouds which randomly used to appear and cut-off different amounts radiation at different times of the day.

In Fig. 4.4b, it can be observed that there was an increase in stomatal conductance from 0800-0900 hours in plots 1 and 2. An increase is also recorded from 0800-1100 hours at plot 4 while in plot 3 there is a decrease from 800-1200 hours local time. From 1500-1700 hours, there is a decrease in conductance in plots 1 and 2 while in plots 3 and 4 , the decrease occurs from 1600-1700 hours local time. Peaks occur at 0900, 1100 and 1500 hours in plot 1; 900 and 1500 hours in plot 2; 1100 and 1600 hours in plot 4. There were dips at 1100 and 1300 hours in plot 1; 1100 hours in plot 2; 1200 hours in plot 3 and 1400 hours in plot 4. The minimum value was 0.007 μmol $m^{-2}s^{-1}$ at 1100 hours in plot 2 while the maximum value was 0.41 μmol $m^{-2}s^{-1}$ at 1500 hours in plot 1. The explanations for this behaviour is as given above (Fig. a).

Fig. 4.4c shows increases in stomatal conductance from 800-900 hours in plots 1 and 4 and from 0800-1000 hours in plots 2 and 3. A decrease occurs from 1000-1300 hours in plots 1, 3 and 4. There is a gradual increase as we approach sunset (1700 hours local time). The minimum value of stomatal conductance was 0.001 μmol $m^{-2}s^{-1}$ at 1300 hours in plot 3 while the maximum value was 0.059 μmol $m^{-2}s^{-1}$ at 0900 hours local time in plot 1. The reasons are the same as the other two cases given above.

Fig. 4.4d shows an increase in stomatal conductance from 0800-0900 hours in all plots. The conductance then decreases gradually from 1000-1300 hours in plots 1, 2 and 3. It then starts to rise slowly as we approach 1700 hours local time. There were peaks at 0900 hours in plot 1, 0900 and 1400 hours in plot 2, 0900 and 1500 hours in plot 3 and; 0900 and 1300 hours in plot 4. The minimum value of stomatal conductance was 0.003 μmol $m^{-2}s^{-1}$ at 1400 hours in plot 4 while the maximum value was 0.071 μmol $m^{-2}s^{-1}$ at 0900 hours in plot 1. These can be explained in the same way as the other three cases above.

From Fig. 4.4e, a rise in stomatal conductance is recorded from 0800-1000 hours in plots 1, 2 and 3 while in plot 4 there is a decrease from 0800-1100 hours local time. From 1200-1500 hours, the conductance kept on rising and falling depending on the individual plot. From 1600-1700 hours, there was a decline in conductance in all the four plots. Peaks were recorded at 1100 and 1500 hours in plot 1, 1000 and 1500 hours in plot 2, 1000, 1300 and 1600 hours in plot 3 and, 1200 and 1400 hours in plot 4. Dips occurred at 1300 hours in plot 1, 1300 in plot 2 , 1200 and 1500 hours in plot 3 and, 1100 and 1300 hours in plot 4. The minimum stomatal conductance was 0.001 μmol $m^{-2}s^{-1}$ at 1100 hours in plot 1 while the maximum was 0.069 μmol $m^{-2}s^{-1}$ at 1000 hours in plot 2. The explanations are as given above.

In Fig. 4.4f, there was an increase in conductance from 0800-1000 hours in plots 1 and 4. An increase also occurred between 0800-0900 hours in plots 2 and 3. From 1500- 1700 hours, there was a decrease in conductance in all the plots. Peaks were recorded at 1000, 1300 and 1500 hours in plot 1; 0900, 1100 and 1500 hours in plot 2; 0900, 1300 and 1500 hours in plot 3 and; 1000, 1200 and 1400 hours in plot 4. Dips occurred at 1400 hours in plot 1, 1000 and 1300 hours in plot 2, 1200 and 1400 hours in plot 3 and, 1100 and 1300 hours in plot 4. The explanations are as given above.

From the above discussion, it can be observed that the diurnal trend of stomatal conductance was almost the same for the three stages of sunflower growth, both in the lower and upper strata of sunflower canopy. The trend shows that most of the minimum values occurred in the afternoon hours. It was higher in the morning and late afternoon hours in most cases except during the maturity stage. The mean stomatal conductance was higher during the maturity stage than in the other two (vegetative and reproductive) stages. This is probably because minimum photosynthesis occurs during the maturity stage. The diurnal variations of stomatal conductance observed in this study are comparable to that obtained by Rochette et al (1991) in their study on the estimation of maize canopy resistance.

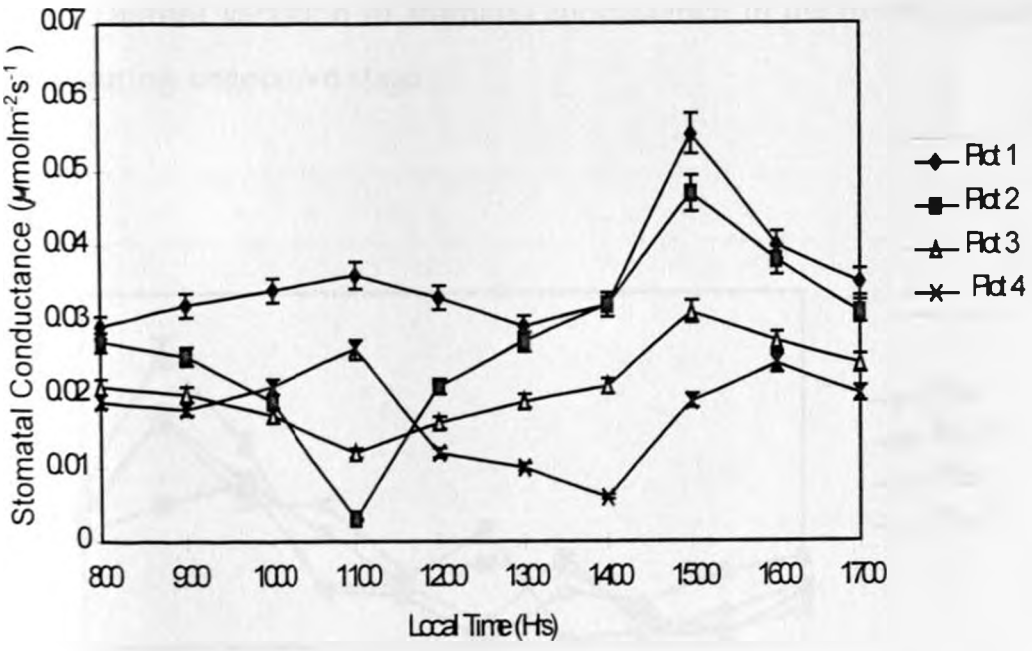


Fig 4.4 a: Diurnal variation of stomatal conductance in the upper stratum of the canopy during vegetative stage

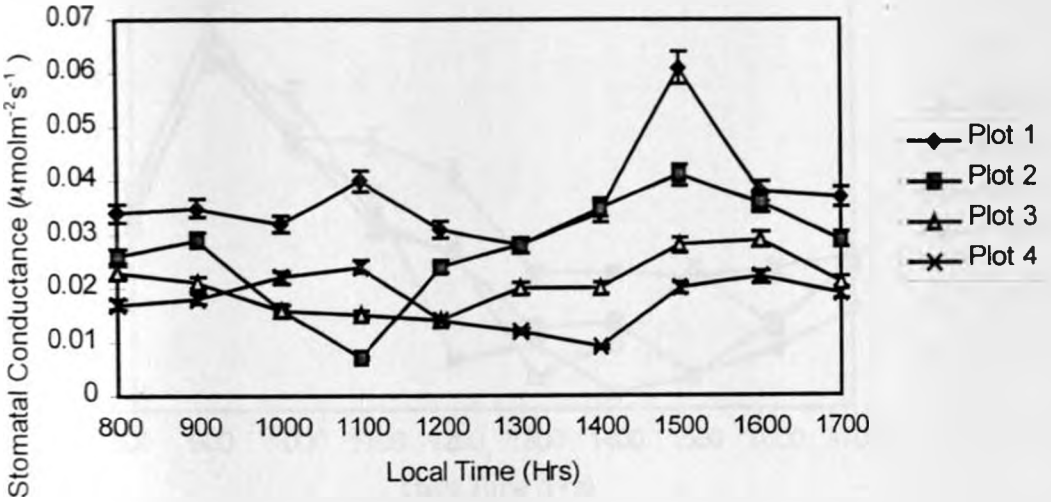


Fig 4.4 b: Diurnal variation of stomatal conductance in the lower stratum of the canopy during vegetative stage

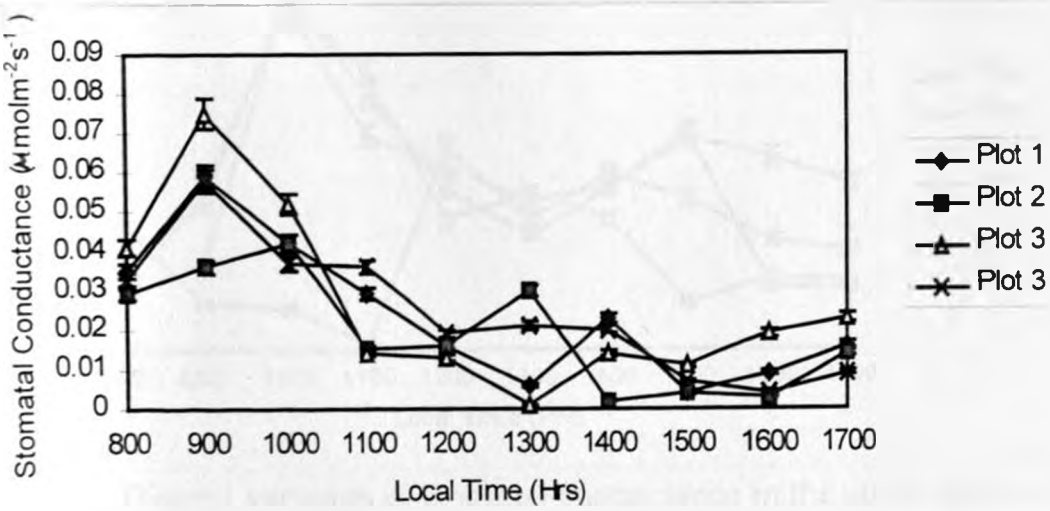


Fig 4.4 c: Diurnal variation of stomatal conductance in the upper stratum of the canopy during reproductive stage

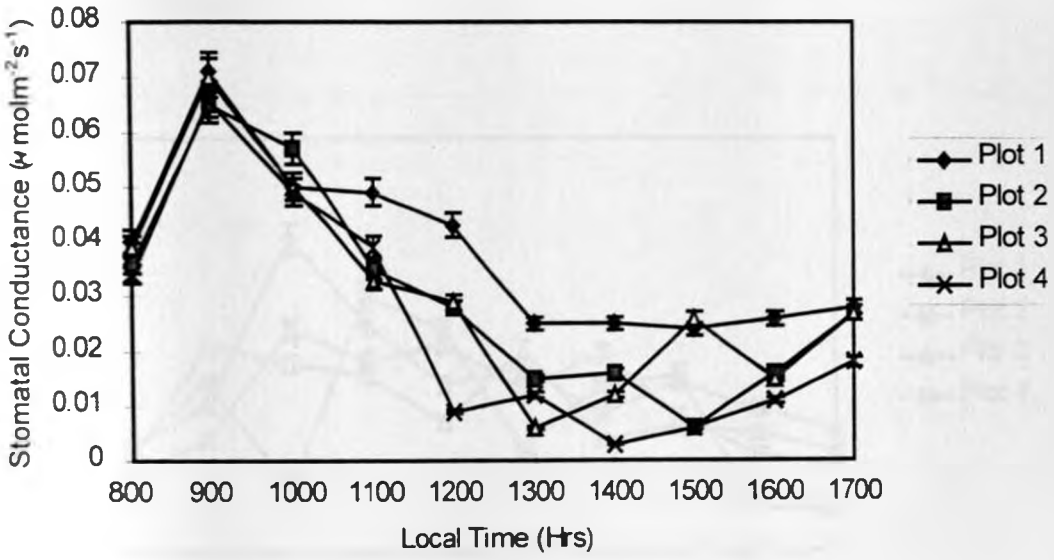


Fig 4.4 d: Diurnal variation of stomatal conductance in the lower stratum of the canopy during reproductive stage

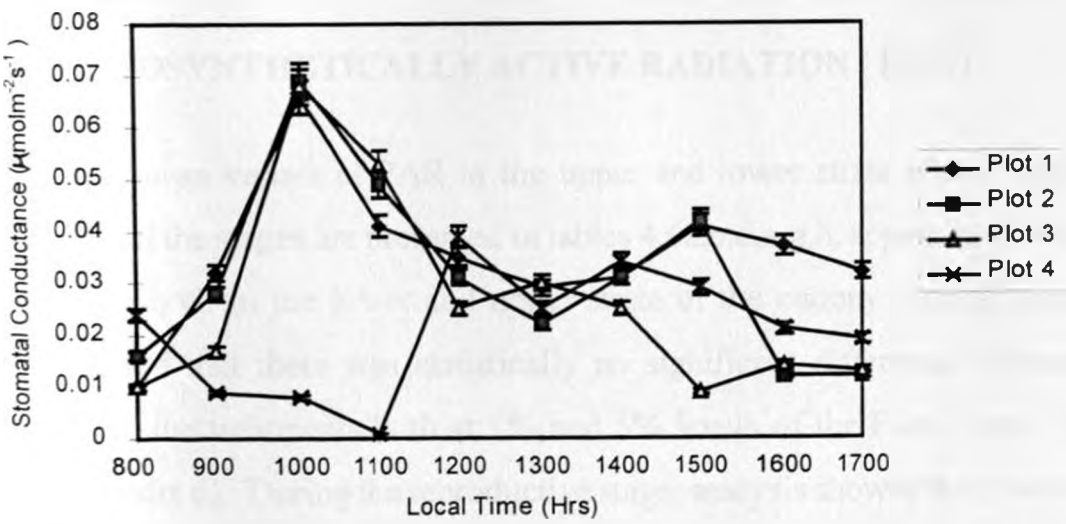


Fig 4.4 e: Diurnal variation of stomatal conductance in the upper stratum of the canopy during maturity stage

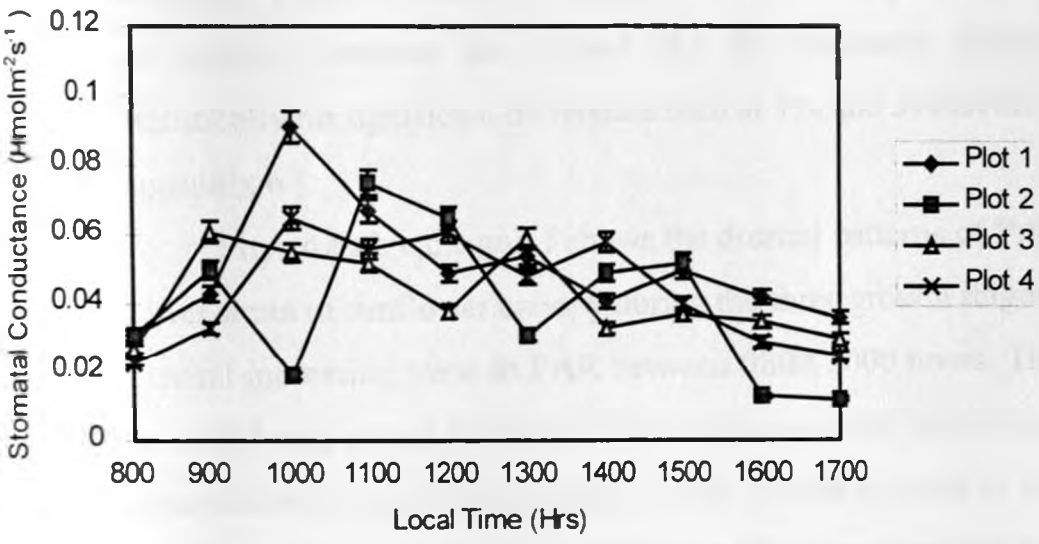


Fig 4.4 f: Diurnal variation of stomatal conductance in the lower stratum of the canopy during maturity stage

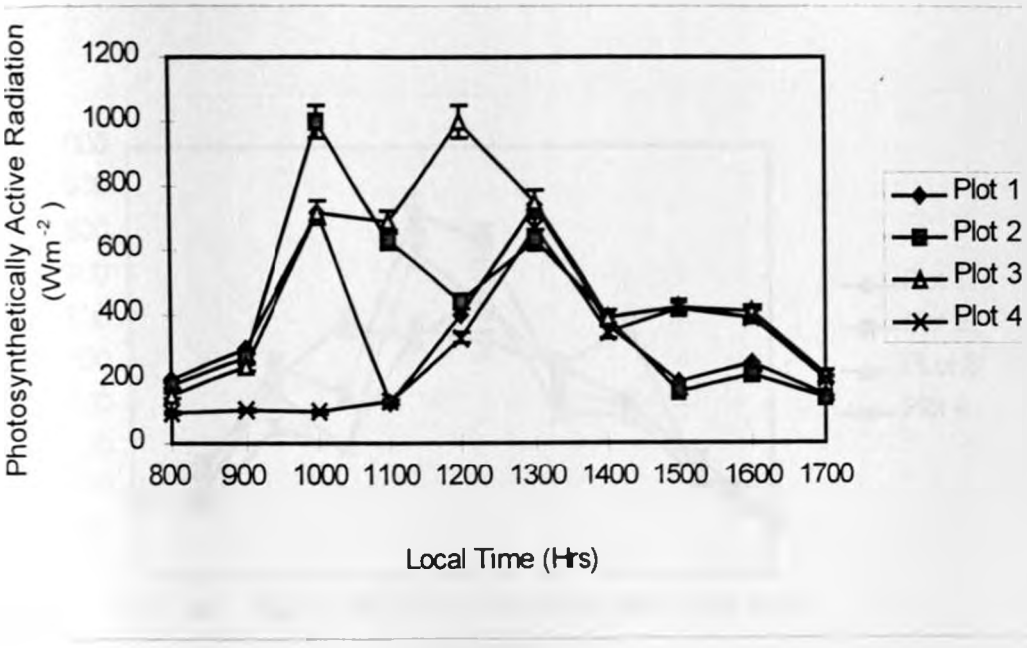
4.5: PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

The mean values of PAR in the upper and lower strata of the sunflower canopy in all the stages are presented in tables 4.6a,b,d,e,g,h, appendix 6. Analysis of variance both in the lower and upper strata of the canopy during vegetative stage showed that there was statistically no significant difference between the control and the treatments both at 1% and 5% levels of the F-ratio test (tables 4.6c, appendix 6). During the reproductive stage, analysis showed that there was a statistically significant difference in the upper strata of the sunflower canopy between control and plot 1 and between control and plot 3 both at 1% and 5% levels (table 4.6f i(a),ii(a), appendix 6), and at 1% level between control and plot 4 (table 4.6f iii(a), appendix 6). During this stage, the rate of photosynthesis is higher since the leaves are broadest and the canopy density is greatest. The difference in canopy density makes the leaves in plots with higher plant density not to receive as much sunlight as those with lower plant density. In the lower

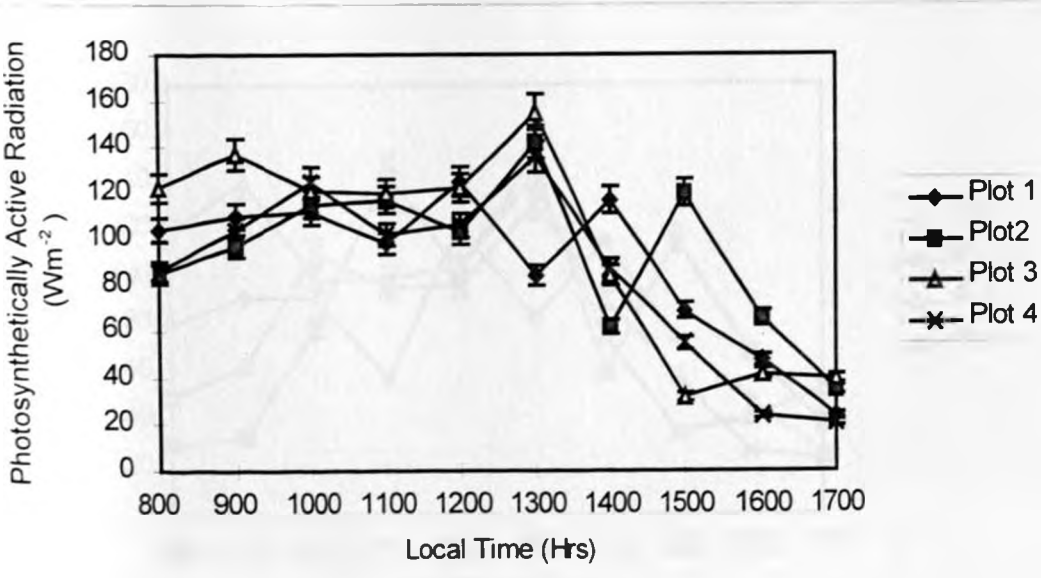
strata of the canopy, analysis showed that there was no statistically significar difference (table 4.6f ib,iib,iiib, appendix 6). During the maturity stage, analys of variance between the control and the treatment showed that there w statistically no significant difference both at 1% and 5% levels (tables 4.6i i,ii,i appendix 6).

Figs. 4.6a,b,c,d,e and f shows the diurnal patterns of PAR in the upper a lower strata of sunflower canopy during the three growth stages. Fig. 4.6a show general increasing trend in PAR between 0800-1000 hours. There was a decre at 1100 hours except for plot 4. This decrease could have been due to the clo since during the growing season, cloudy conditions used to alternate with sur intervals. An increase was recorded from 1200 hours to 1300 hours in all the pl From 1400-1700 hours, there was a gradual decrease in PAR. The minimum P was 95 Wm^{-2} which occurred in plot 4 at 0800 hours while the maximum 1000 Wm^{-2} which occurred in plot 3 at 1200 hours. The highest average PAR recorded in plot 3. In Fig. 4.6b, the trend was the same as that in the upper st of the canopy (Fig. 4.6a). However, the PAR was generally less since some o sun's rays were intercepted by the canopy. The minimum PAR was 21 Wm 1700 hours in plot 4 while the maximum was 155 Wm^{-2} at 1300 hours in pl These behaviours is due to the presence of clouds as earlier indicated which off different amounts of radiation at different times of the day, thus affectin PAR.

During the reproductive stage (Figs. 4.6c and d), the trend was the sar that during the vegetative stage. In Fig. 4.6c, there was an increase from (1000 hours and then a decrease at 1100 hours for plots 1, 2 and 4. Only showed an increase at 1100 hours. From 1200-1300 hours, there was an inc in PAR in all plots. From 1400-1700 hours, there was a gradual decrease of The minimum PAR was 112 Wm^{-2} at 1700 hours in plot 4 while the max was 852 Wm^{-2} at 1200 hours in plot 2. In Fig. 4.6d, the trend was the same of Fig. 4.6b. However, in this stage, the mean PAR was smaller than duri



g 4.5 a: Diurnal variation of photosynthetically active radiation in the upper ratum of the canopy during vegetative stage



ig 4.5 b: Diurnal variation of photosynthetically active radiation in the lower tratum of the canopy during vegetative stage

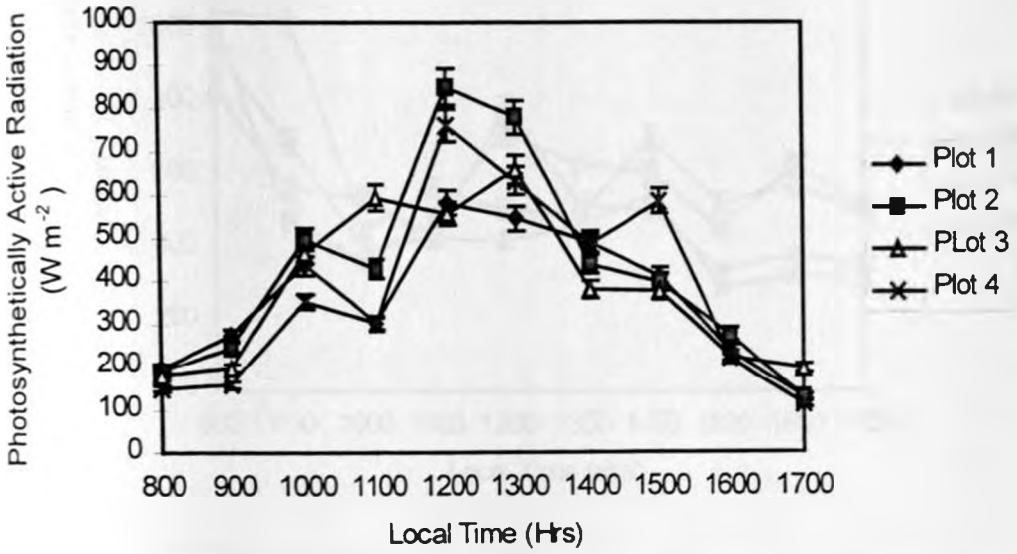


Fig 4.5 c: Diurnal variation of photosynthetically active radiation in the upper stratum of the canopy during reproductive stage

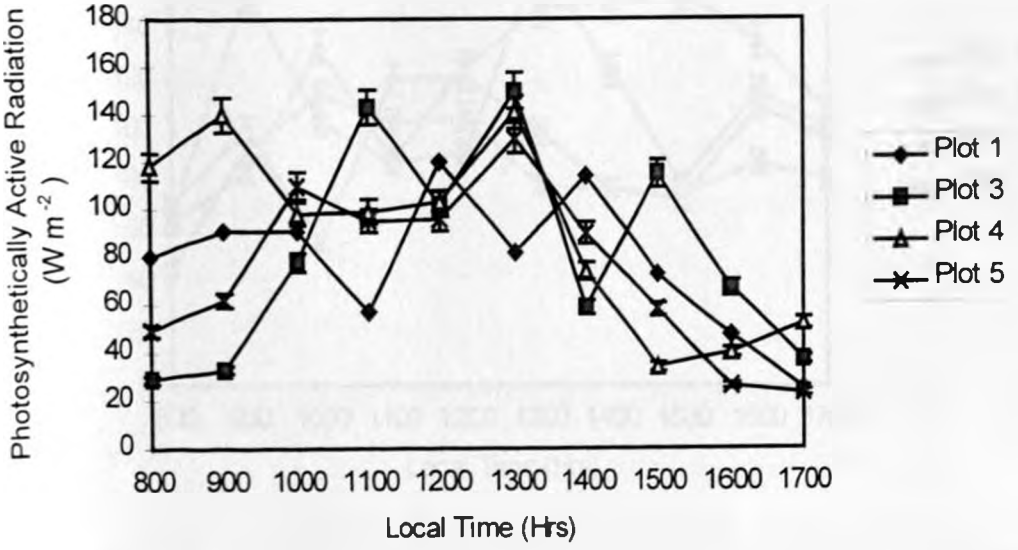


Fig 4.5 d: Diurnal variation of photosynthetically active radiation in the lower stratum of the canopy during reproductive stage

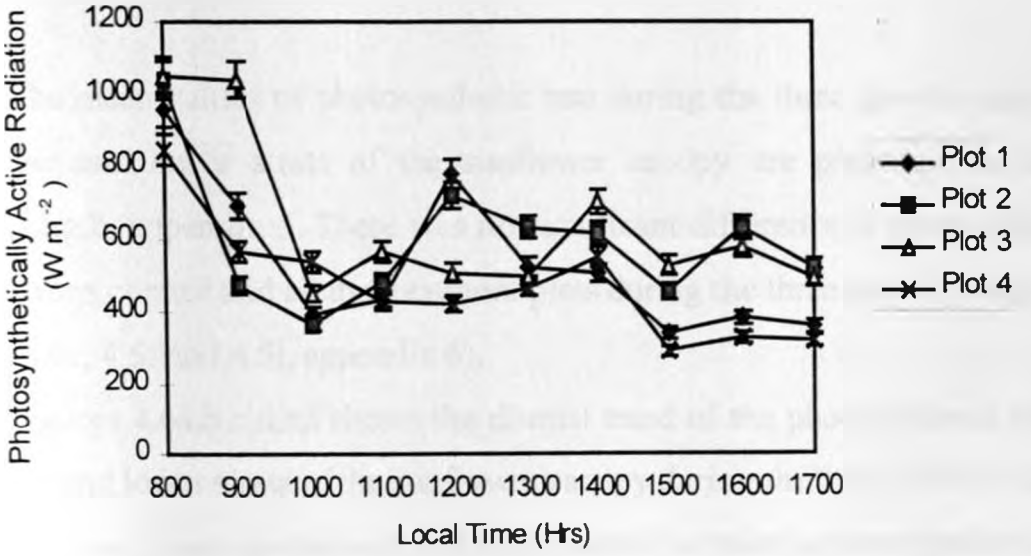


Fig 4.5 e: Diurnal variation of photosynthetically active radiation in the upper stratum of the canopy during maturity stage

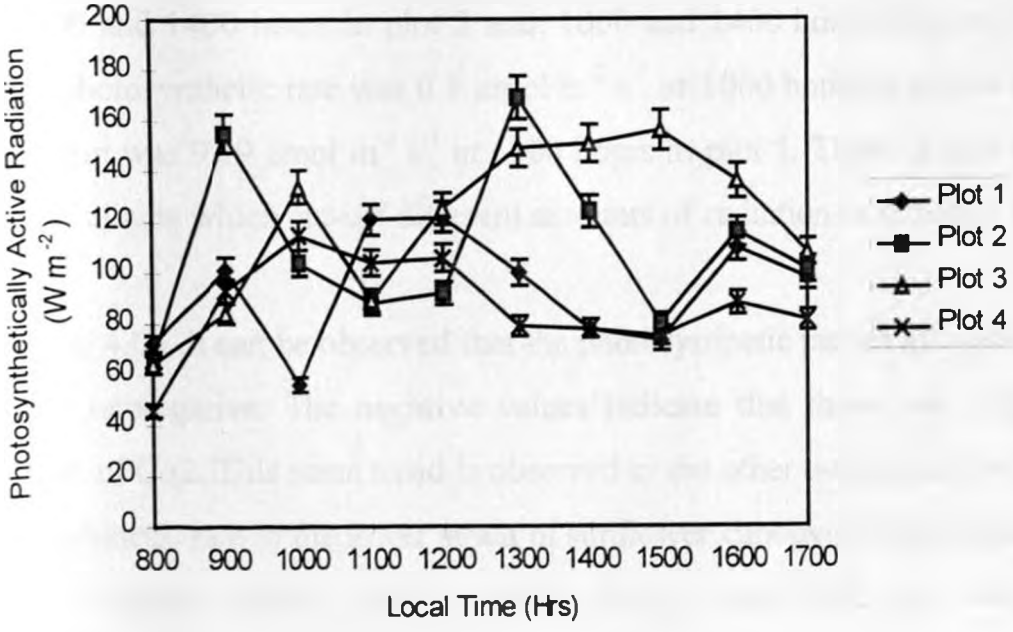


Fig 4.5 f: Diurnal variation of photosynthetically active radiation in the lower stratum of the canopy during maturity stage

4.6 PHOTOSYNTHETIC RATE

The mean values of photosynthetic rate during the three growth stages in the upper and lower strata of the sunflower canopy are presented in tables 4.6a,b,d,e,g,h, appendix 5. There was no significant difference in photosynthetic rate between control and all the treatment plots during the three growth stages (tables 4.6c, 4.5f and 4.5i, appendix 6).

Figures 4.6a,b,c,d,e,f shows the diurnal trend of the photosynthetic rate in the upper and lower strata of the sunflower canopy during the three growth stages. From fig. 4.6a, it can be observed that there was an increase in photosynthetic rate from 0800-1000 hours in plots 1, 2 and 3 while in plot 4 the increase occurred from 0800-0900 hours. There were peaks at 1000, 1300 and 1600 hours in plots 1 and 2; 1000, 1200 and 1500 hours in plot 3 and; 0900, 1300 and 1500 hours in plot 4. Dips occurred at 1100 and 1500 hours in plot 1; 1200 and 1500 hours in plot 2; 1100 and 1400 hours in plot 3 and; 1000 and 1400 hours in plot 4. The minimum photosynthetic rate was 0.1 μmol m^{-2} s^{-1} at 1000 hours in plot 4 while the maximum was 9.19 μmol m^{-2} s^{-1} at 1300 hours in plot 1. These is due to the presence of clouds which cut-off different amounts of radiation at different times of the day.

In fig. 4.6b, it can be observed that the photosynthetic rate in all cases was either zero or negative. The negative values indicate that there was negative assimilation of Co2. This same trend is observed in the other two cases involving the photosynthetic rate in the lower strata of sunflower canopy (cf. figs. 4.6d and 4.6f). The negative values were probably due to low PAR, low stomatal conductance and low irradiances. The low (negligible) stomatal conductance resulted to depletion of intercellular Co_2, hence negative assimilation from the surrounding.

In fig. 4.6c, it can be observed that there was an increase in photosynthetic rate between 0800-1000 hours in plots 1 and 4. In plot 2 the increased occurred

between 0800-1200 hours and between 0800-1300 in plot 3. There were gradual decreases from 1400-1700 hours in plot 1, 1200-1700 hours in plot 2, 1300-1500 hours in plot 3 and 1500-1700 hours in plot 4. Peaks occurred at 1200 and 1400 hours in plot 1, 1000 and 1200 hours in plot 2, 1600 hours in plot 3 and; 1000, 1200 and 1500 hours in plot 4. There were dips at 1100 and 1300 hours in plot 1, 1100 hours in plot 2, 1500 hours in plot 3 and; 1100 and 1400 hours in plot 4. The minimum photosynthetic rate was 0 μmol $m^{-2}s^{-1}$ at 1700 hours in plots 1, 2 and 4 while the maximum was 6.84 μmol $m^{-2}s^{-1}$ at 1400 hours in plot 1. The explanations are as given above (fig. 4.6a).

Fig. 4.6e shows decreases of photosynthetic rate from 0800-1000 hours in plot 2 and 0800-0900 hours in plot 4. There were increases from 0800-0900 in plots 1 and 3. There were peaks at 0900, 1200 and 1400 hours in plot 1; 1300, 1400 and 1600 hours in plot 2; 0900, 1100, 1400 and 1600 hours in plot 3; and 1000, 1200 and 1400 hours in plot 4. Dips occurred at 1000 and 1300 hours in plot 1; 1000 and 1500 hours in plot 2; 1000, 1300 and 1500 hours in plot 3; and, 0900, 1100, 1300 and 1400 hours in plot 4. The minimum photosynthetic rate was 0.98 μmol $m^{-2}s^{-1}$ at 1500 hours in plot 4 while the maximum was 8.44 μmol $m^{-2}s^{-1}$ at 1200 hours in plot 1. The reasons are the same as the two cases above.

From the trends in figs. 4.6a,c and e it can be observed that the photosynthetic rate was generally small in early morning and late afternoon hours. This was probably because during these hours the intensity of radiation was small. Owili (1996), experimenting on maize in Machakos District in Kenya, found similar trends in photosynthetic rate, although he only considered the case of exposed leaves (upper strata of canopy). However, his mean values of photosynthetic rate for each physiological stage were higher than the ones observed in this research.

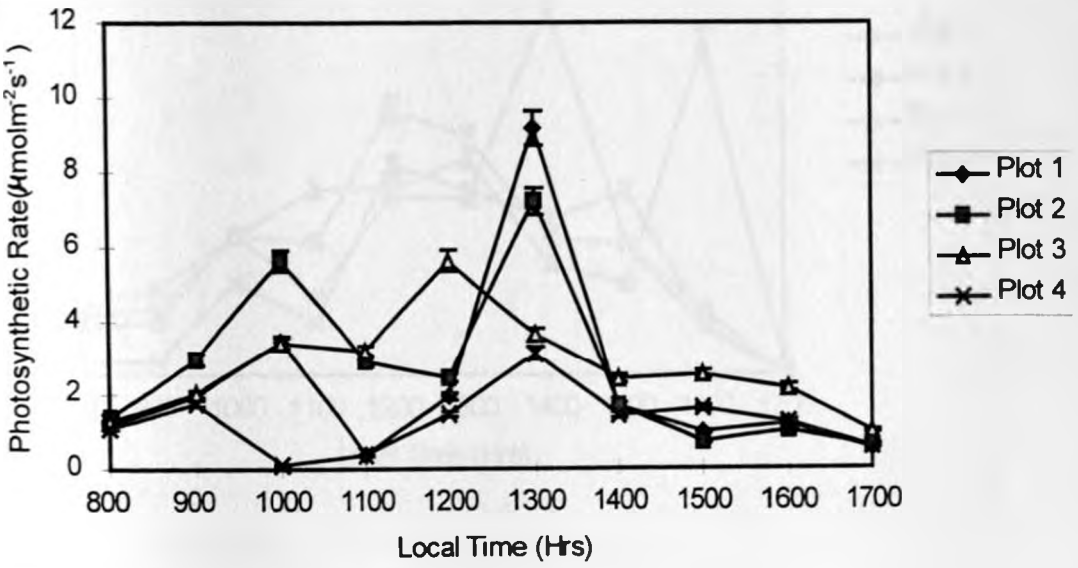


Fig 4.6 a: Diurnal variation of photosynthetic rate in the upper stratum of the canopy during vegetative stage

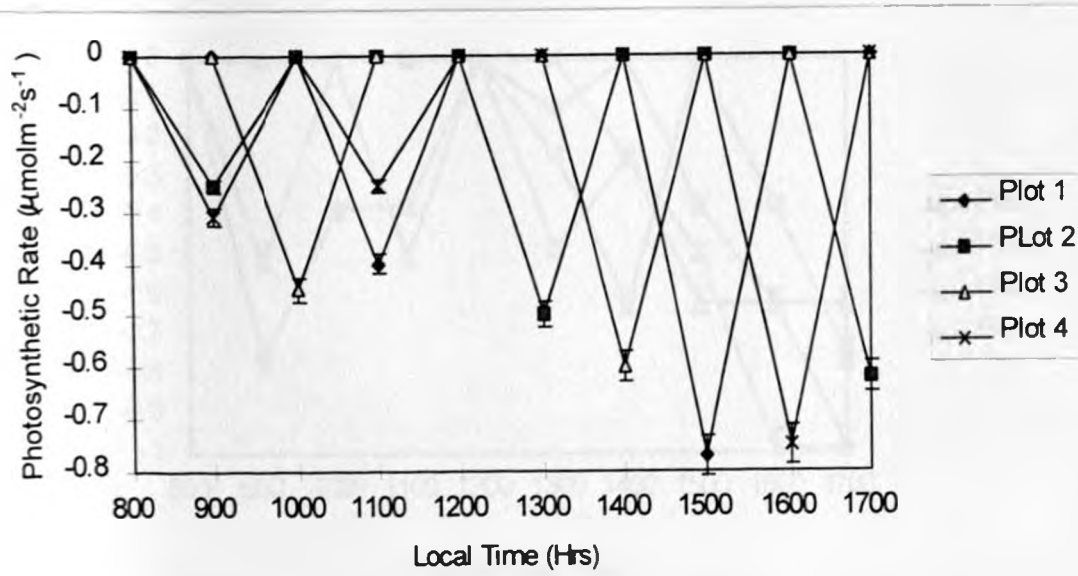


Fig 4.6 b: Diurnal variation of photosynthetic rate in the lower stratum of the canopy during vegetative stage

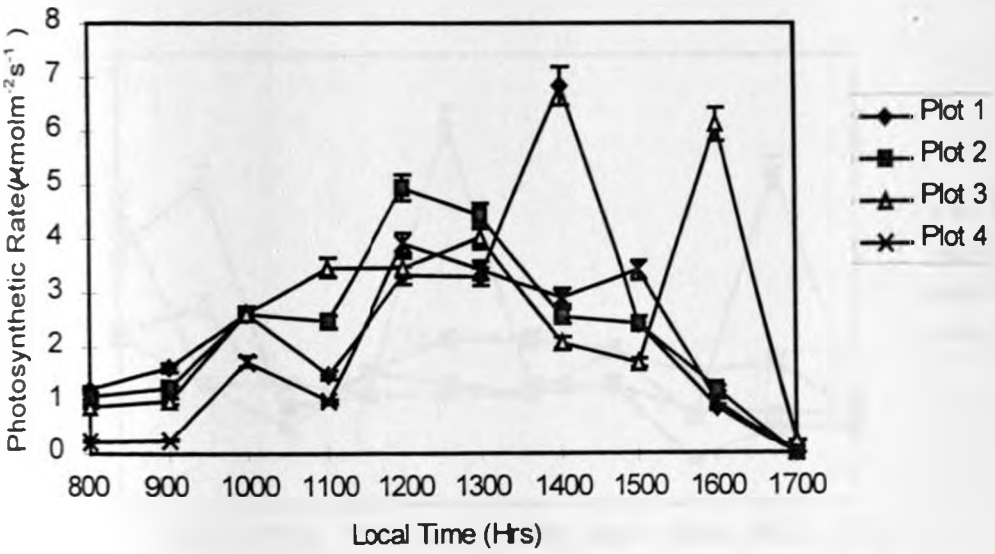


Fig 4.6 c: Diurnal variation of photosynthetic rate in the upper stratum of the canopy during reproductive stage

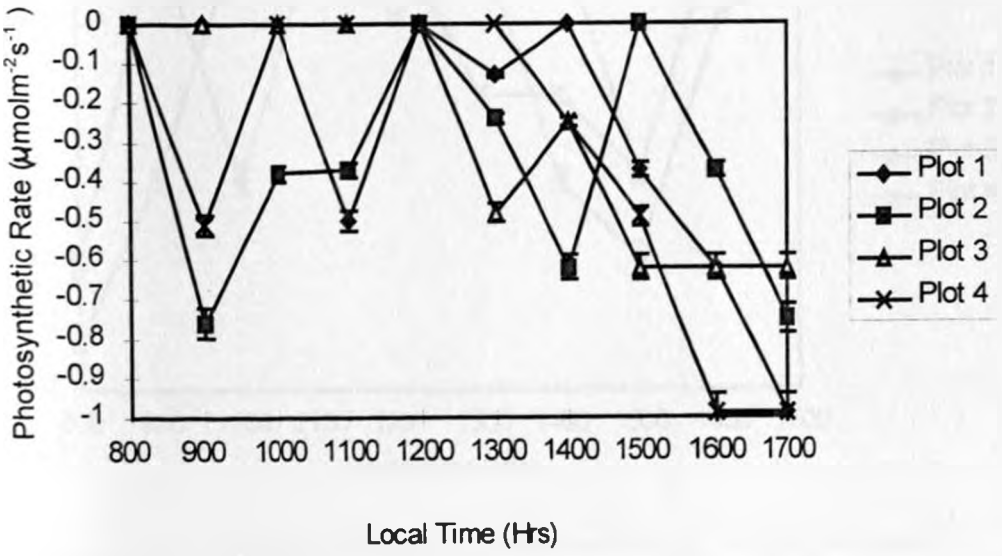


Fig 4.6 d: Diurnal variation of photosynthetic rate in the lower stratum of the canopy during reproductive stage

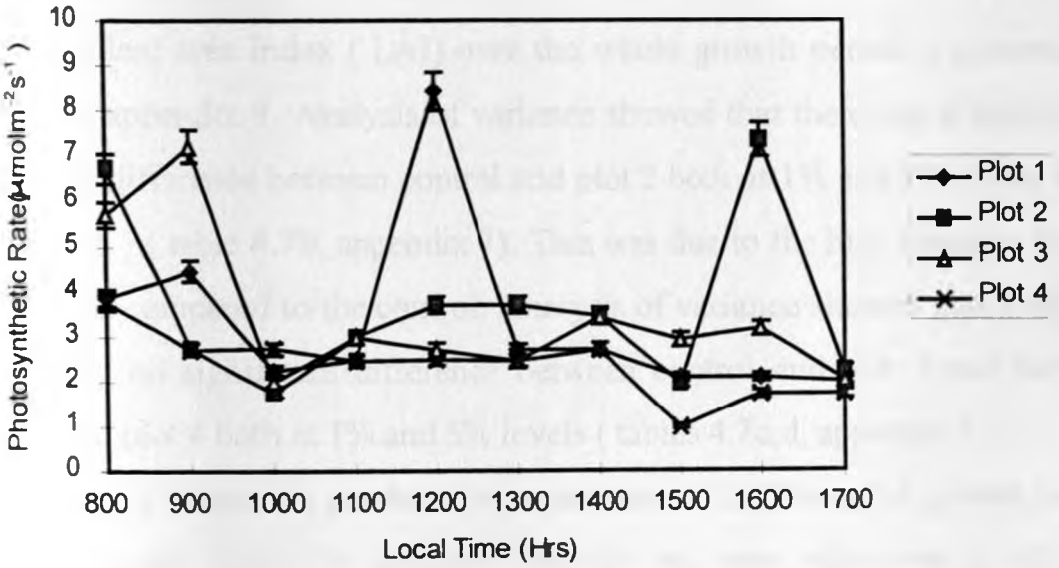


Fig 4.6 e: Diurnal variation of photosynthetic rate in the upper stratum of the canopy during maturity stage

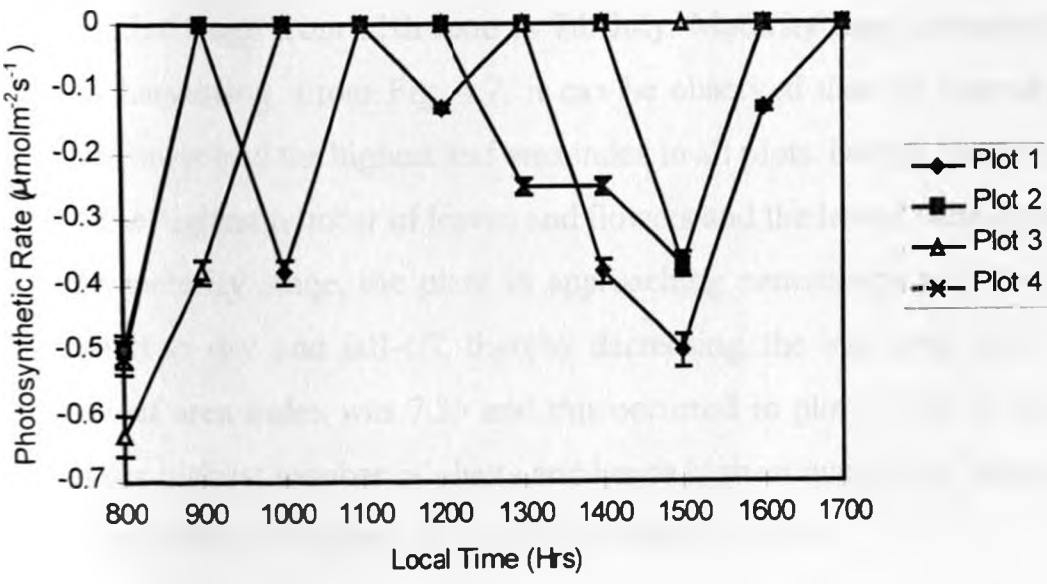


Fig 4.6 f: Diurnal variation of photosynthetic rate in the lower stratum of the canopy during maturity stage

4.7: LEAF AREA INDEX (LAI)

The leaf area index (LAI) over the whole growth period is presented in table 4.7a, appendix 7. Analysis of variance showed that there was a statistically significant difference between control and plot 2 both at 1% and 5% levels of the F-ratio test (table 4.7b, appendix 7). This was due to the high planting density of plot 1 as compared to the control. Analysis of variance showed that there was statistically no significant difference between control and plot 3 and between control and plot 4 both at 1% and 5% levels (tables 4.7c,d, appendix 7).

Fig. 4.7 shows the graphical representation of LAI over the growth period. From the graph, it can be observed that the leaf area index was in all plots minimum when the plants were still young and covered little soil surface. The leaf area index increased to maximum value in the middle of the crop growth when the plant canopy covered completely the soil surface and finally decreased gradually towards maturity. Vegetative stage occurred from planting to 4th June, followed by reproductive stage from 11th June to 7th July. Maturity stage occurred from 7th July to harvesting. From Fig. 4.7, it can be observed that the reproductive stage of sunflower had the highest leaf area index in all plots. During this stage the plants had the highest number of leaves and flowers and the leaves were broadest. During the maturity stage, the plant is approaching senescence and the lower leaves started to dry and fall-off, thereby decreasing the leaf area index. The maximum leaf area index was 7.25 and this occurred in plot 1. This is because plot 1 had the highest number of plants and hence highest number of leaves. The minimum leaf area index was 0.42 and this occurred in plot 4.

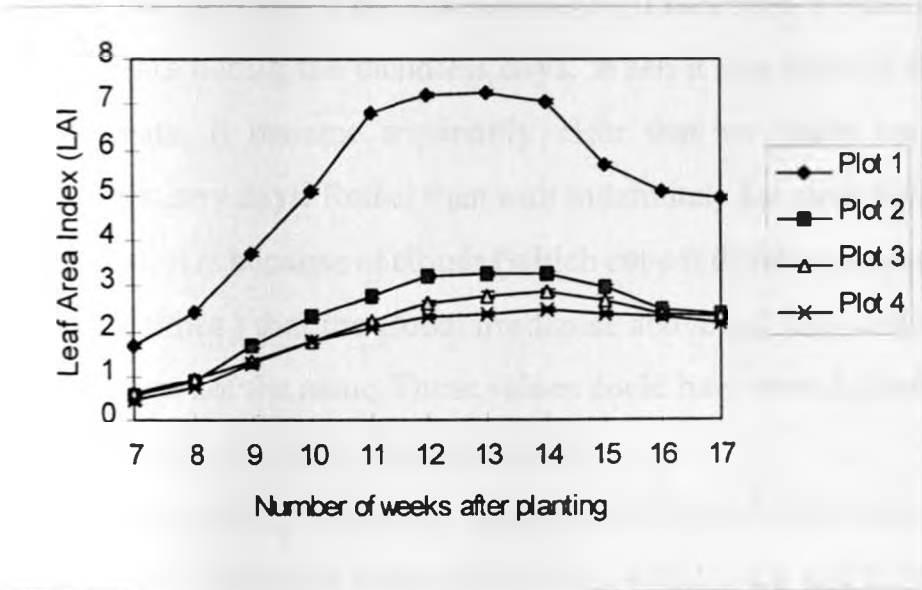


Fig 4.7 Leaf Area Index (LAI) over the growth period of sunflower

4.8: GLOBAL IRRADIANCE

The mean values of global irradiance in the lower and upper strata of the sunflower canopy during the three growth stages are presented in tables 4.8a,b,d,e,g,h, appendix 8. Analysis of variance for global irradiance in the lower and upper strata of sunflower canopy during the vegetative stage showed no statistically significant difference both at 1% and 5% levels (tables 4.8c i(a),i(b),ii(a),ii(b),iii(a),iii(b), appendix 8). During the reproductive stage, analysis in the upper strata of canopy showed no statistically significant difference between control and plots 3 and 4 (tables 4.8f ii(a),iii(a), appendix 8) while a statistically significant difference occurred between control and plot 4 both at 1% and 5% levels (table 4.8f i(a), appendix 8). In the lower strata of the canopy during this stage, no statistically significant difference occurred between control and plots 1 and 3 (tables 4.8f i(b),ii(b), appendix 8) while a difference at 1% level was recorded between control and plot 4 (table 4.8 iii(b), appendix 8). During the maturity stage, analysis of variance showed that there was no statistically

significant difference between control and all the treatment plots (tables 4.8i, appendix 8).

Before the start of the measurements, it had been planned to make all the measurements during the cloudless days. When it was time to begin making the measurements, it became apparently clear that we were not going to have completely sunny days. Rather than wait indefinitely for clear days, measurements commenced. It is because of clouds (which cut-off different amounts of irradiance at different times) that the global irradiance above the four sunflower population densities were not the same. These values could have been higher at some various hours of the day had there been no clouds.

The graphical presentation of global irradiance in the lower and upper strata of sunflower canopy are presented in Figs. 4.8a,b,c,d,e and f. From Fig. 4.8a, it can be observed that the global irradiance started from low values at 0800 hours in all the plots. There was a rise between 0900-1100 hours in plots 1, 3 and 4 and a dip at 1100 for plot 2. A peak occurred in plot 1 at 1200 hours while in plots 2, 3 and 4 there was a decrease. From 1300-1700 hours, there was a gradual decrease of global irradiance. The minimum irradiance was 79 Wm^{-2} at 1700 hours which occurred in plot 2. In the lower strata of the canopy during the vegetative stage (Fig. 4.8b), the trend was the same except that the values were smaller. Low values were recorded at 0800 hours in all the plots increasing gradually upto around 1000 hours for plots 1 and 2. There was a dip at 1000 hours for plots 3 and 4. From 1400-1700 hours, there was a gradual decrease in irradiance for plots 1, 2 and 3. In plot 4, there was a peak at 1600 hours. The minimum was 95 Wm^{-2} at 1700 hours in plot 3 while the maximum was 401 Wm^{-2} at 1300 hours in plot 2. The explanations are as indicated above.

Fig. 4.8c shows the trend of global irradiance in the upper strata of the canopy during the reproductive stage. The trend shows that an increase occurred from 0800-1000 hours for plots 1, 2 and 3 while a peak was recorded for plot 4 at 0900 hours. An increase occurred for plot 2 between 1100-1300 hours and for plot

3 between 1100-1200 hours. For plot 4 the irradiance was the same at 1100 and 1200 hours. A decrease was recorded for plot 1 and plot 4 between 1500-1700 hours and for plot 3 between 1400-1700 hours. The minimum irradiance was 148 Wm^{-2} at 1700 hours in plot 3 while the maximum was 1947 Wm^{-2} at 0900 hours in plot 4. In fig. 4.8e, there was an increase of global irradiance from 0800 hours to 1100 hours in plots 1 and 2. In plot 3, the increase was from 0800-1000 hours and in plot 4 it was from 0800-0900 hours. A decrease occurred from 1200-1400 hours in plots 1, 2 and 4, and from 1100-1700 hours in plot 3. The minimum irradiance was 50 Wm^{-2} at 1700 hours in plot 3 while the maximum was 381 Wm^{-2} at 1100 hours in plot 4. This is due to the presence of clouds as given above.

In the maturity stage, the trend in the upper strata of the canopy is shown in Fig. 4.8e. The trend shows an increase of irradiance from 0800-1100 hours in plot 2 and from 0800-0900 hours in plots 1, 3 and 4. There was a decrease of irradiance from 1300-1700 hours in plot 1 and 1500-1700 in plots 2, 3 and 4. The minimum irradiance was 215 Wm^{-2} at 1700 hours in plot 4 and the maximum was 1391 Wm^{-2} at 1100 hours in plot 1. The trend in the lower strata of the sunflower canopy during this stage (Fig. 4.8f) shows an increase of irradiance from 0800-1000 hours in plots 1 and 4 and from 0800-0900 hours in plots 2 and 3. There was a decrease from 1300-1700 hours in plot 1, 1200-1700 hours in plot 3 and 1400-1700 hours in plot 4. The minimum irradiance was 34 Wm^{-2} at 1700 hours in plot 4 and the maximum was 288 Wm^{-2} at 1400 hours in plot 4. The reasons are the same as the for the other two cases above.

The irradiance in the lower strata of the canopy was smaller as compared to the one in the upper strata. Also, it can be observed that the mean global irradiance in the lower strata of the canopy was highest during the vegetative stage. This is because during this stage, the leaves were small and few as compared to the reproductive and maturity stages. Njihia (1978), observed similar behaviour on global irradiance on maize at Kabete, Nairobi.

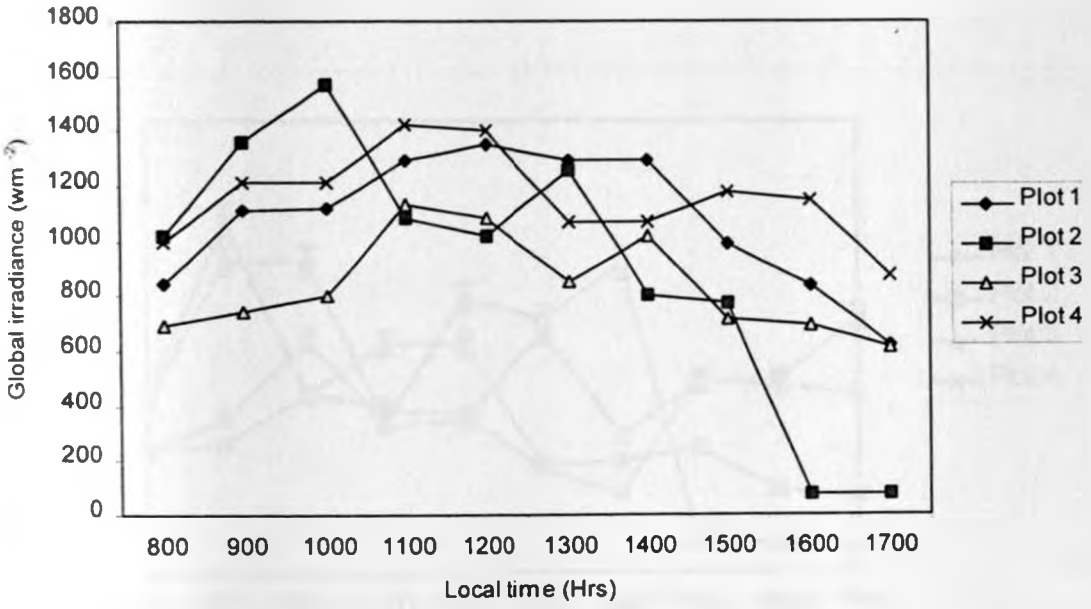


Fig 4.8 a: Diurnal variation of global irradiance in the upper stratum of the canopy during vegetative stage

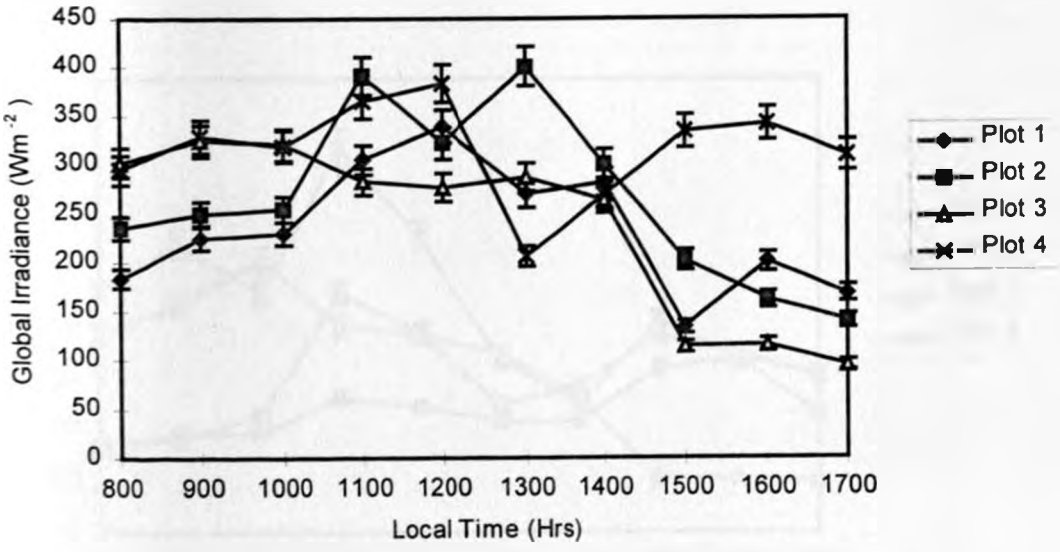


Fig 4.8 b: Diurnal variation of global irradiance in the lower stratum of the canopy during vegetative stage

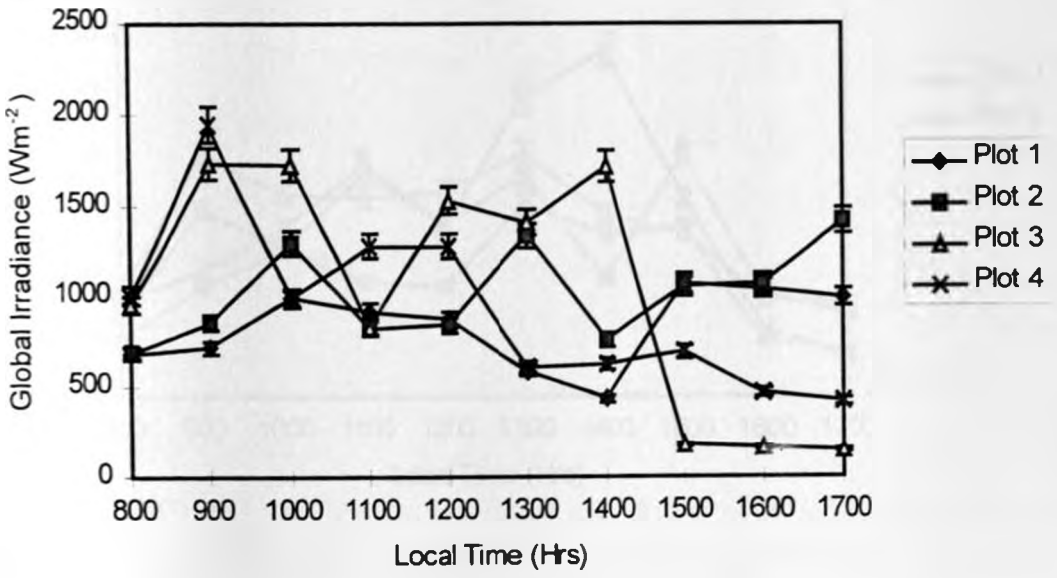


Fig 4.8 c: Diurnal variation of global irradiance in the upper stratum of the canopy during reproductive stage

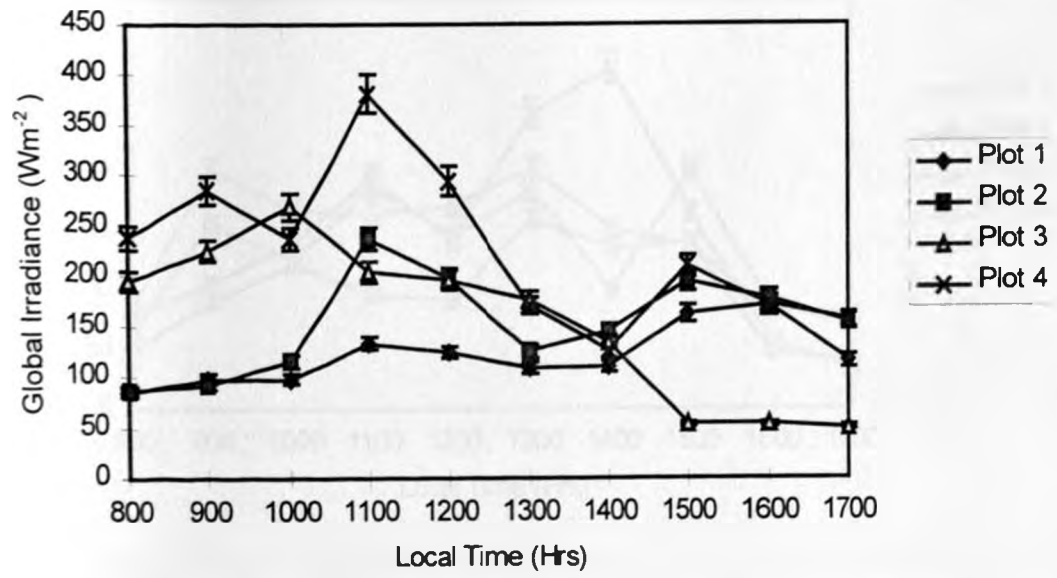


Fig 4.8 d: Diurnal variation of global irradiance in the lower stratum of the canopy during reproductive stage

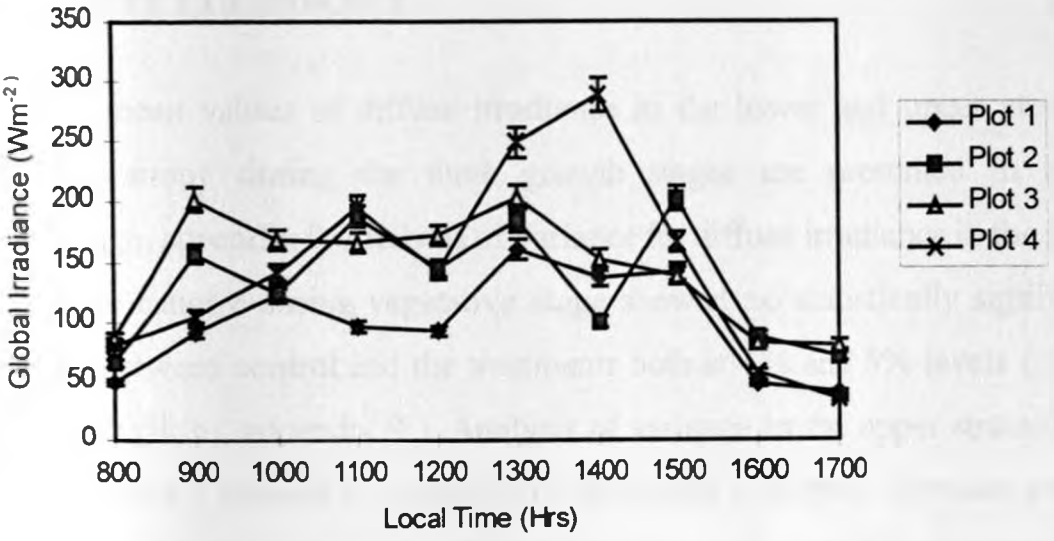


Fig 4.8 e: Diurnal variation of global irradiance in the upper stratum of the canopy during maturity stage

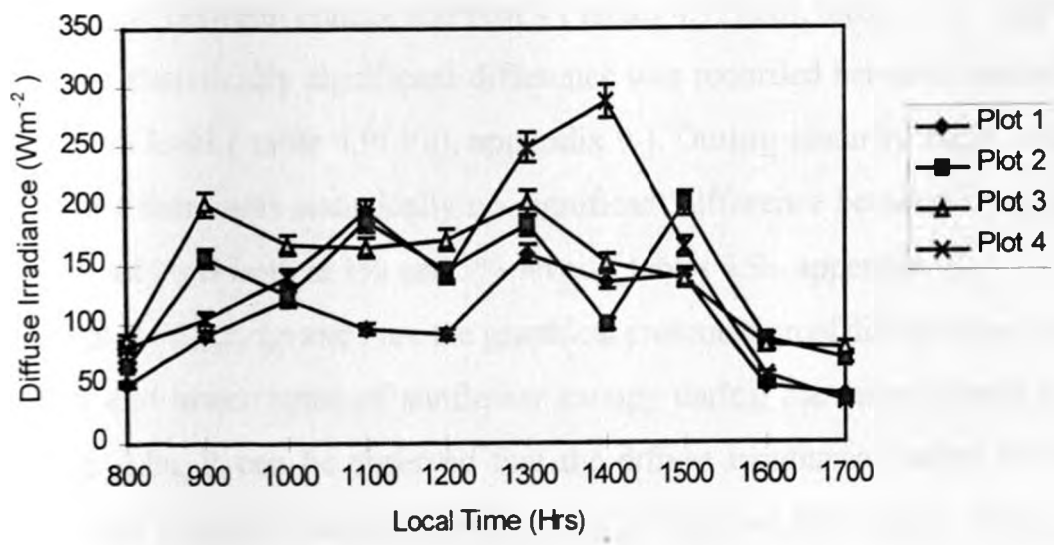


Fig 4.8 f: Diurnal variation of global irradiance in the lower stratum of the canopy during maturity stage

4.9: DIFFUSE IRRADIANCE

The mean values of diffuse irradiance in the lower and upper strata of sunflower canopy during the three growth stages are presented in tables 4.9a,b,,d,e,g,h, appendix 9. Analysis of variance for diffuse irradiance in the lower strata of the canopy during vegetative stage showed no statistically significant difference between control and the treatments both at 1% and 5% levels (tables 4.9c i(b),ii(b),iii(b), appendix 9). Analysis of variance in the upper strata of the sunflower canopy showed no statistically significant difference between control and plot 1 and between control and plot 4 (tables 4.9c i(a),iii(a), appendix 9). However, a statistically significant difference was recorded between control and plot 3 both at 1% and 5% levels (table 4.9c ii(a), appendix 9). During the reproductive stage, there was statistically no significant difference in the upper strata of the canopy (tables 4.9f i(a),ii(a),iii(a), appendix 9). In the lower strata of the sunflower canopy, no significant difference occurred between control and plot 3 and between control and plot 4 (tables 4.9f ii(b), iii(b), appendix 9) while a statistically significant difference was recorded between control and plot 1 at 1% level (table 4.9f i(a), appendix 9). During maturity stage, analysis showed that there was statistically no significant difference between control and the treatment plots both at 1% and 5% levels (tables 4.9i, appendix 9).

Figs. 4.9a,b,c,d,e and f are the graphical presentation of diffuse irradiance in the upper and lower strata of sunflower canopy during the three growth stages. From Fig. 4.9a, it can be observed that the diffuse irradiance started from 415 Wm^{-2} in plot 1 at 0800 hours increasing to 531 Wm^{-2} at 1000 hours. There were dips at 1100, 1300 and 1400 hours and peaks at 1200, 1500 and 1600 hours before finally decreasing to lowest value of 408 Wm at 1700 hours. In plot 2, the irradiance was 395 Wm^{-2} at 0800 hours increasing slowly to 807 Wm^{-2} at 1100 hours. There were dips at 1200 and 1400 hours and peaks at 1300 and 1600 hours

before decreasing to 495 Wm^{-2} at 1700 hours. In plot 3, there was a gradual increase from 0800-1200 hours. There was a dip at 1300 hours and then a decrease from 1400 -1700 hours. Plot 4 shows an increase from 0800-0900 hours and a dip at 1000 and 1200 hours. Peaks occurred at 1000 and 1600 hours. These is due to the presence of clouds which randomly cut-off different amounts of irradiance at different times of the day.

In Fig. 4.9b, an increase occurred from 0800-1200 hours in plot 1. From 1400-1700 hours, a gradual decrease was recorded and a dip occurred at 1300 hours. In plot 2, an increase occurred from 0800-1300 hours and then an decrease for the rest of the day to a minimum value of 195 Wm^{-2} at 1700 hours. In plot 3, an increase was recorded from 0800-0900 hours, then a decrease from 1000 hours to a minimum value 145 Wm^{-2} at 1700 hours. A peak was recorded at 0900 hours. In plot 4, an increase occurred from 0800-0900 hours. Peaks were recorded at 1200 and 1600 hours. There were dips at 1100 and 1300 hours. The minimum value in this plot was 282 Wm^{-2} at 1300 hours. From the figure, the maximum irradiance was 829 Wm^{-2} at 0900 hours in plot 3 while the minimum was 140 Wm^{-2} at 1700 hours in plot 1. The reasons are the same as for Fig. 4.9a.

From Fig. 4.9c, an increase was recorded from a value of 405 Wm^{-2} at 0800 hours to 710 Wm^{-2} at 1200 hours in plot 1 before decreasing to a minimum value of 335 Wm^{-2} at 1700 hours. In plot 2 an increase occurred from 0800-1200 hours. There was a decrease for the rest of the time (1300-1700 hours) . In plot 3, an increase was recorded from 0800-0900 hours. There was a decrease from 1400 hours to a value of 135 Wm at 1700 hours. Peaks were recorded at 0900 and 1200 hours and a dip at 1300 hours. In plot 4, peaks occurred 0900 and 1200 hours . There was a decrease from 1400 hours to a value of 289 Wm^{-2} at 1700 hours in this plot. The explanations are as given above.

Fig. 4.9d shows an increase of irradiance from 0800-1100 hours for plots 1, 2 and 4. In plot 3 , the increase is from 0800-1000 hours. The irradiance decreased gradually from 1400-1700 hours in plots 2, 3, and 4. Peaks were recorded at 0900

and 1500 hours in plot 1; 1100 and 1400 hours in plot 2; 1000 and 1500 hours in plot 3 and; 1100 and 1500 hours in plot 4. The minimum value was 54 Wm^{-2} at 1500 hours in plot 3 while the maximum value was 496 Wm^{-2} at 1100 hours in plot 4. The explanations are as given in the above three cases.

From Fig. 4.9g, the diffuse irradiance started from a minimum at 0800 hours in all the plots, increasing to maximum values at 1400 hours in plot 1 , and 1500 hours in plots 2, 3 and 4. There was a gradual decrease to smaller values at 1700 hours . The minimum value was 75 Wm^{-2} at 1700 hours in plot 2 while the maximum was 581 Wm^{-2} at 1500 hours in plot 4.

Fig. 4.9f shows that the diffuse irradiance increased slowly from 0800-1100 hours in plots 1, 2 and 4 while in plot 3 there was a peak at 0900 hours. There were decreases from 1300-1700 hours in plots 1, 3 and 4. In plot 2, peaks were recorded at 1100, 1300 and 1500 hours. In plot 4, the peak occurred at 1100 hours. These can be explained in the same way as the other trends above.

Also the diffuse irradiance in the lower strata of the canopy was less than the one in the upper strata of canopy. It can also be observed that the mean diffuse irradiance was greatest during the vegetative stage. This is because the interception of irradiance by the canopy is less during this stage because the canopy density is smaller due to smaller and fewer number of leaves. It can be observed from tables 4.9 b, e and g that plot 1 had the lowest diffuse irradiance. Thus, diffuse irradiance in the lower strata of canopy decreased with increasing plant density. Kamande (1982), experimenting on some radiation and temperature aspects of high density plantings of coffee Arabica in Kenya obtained similar trends of irradiance. Hefound less penetration of irradiance in the lower layers in the early morning and late afternoon while in the upper layers, there was more penetration in the afternoon than in the morning hours.

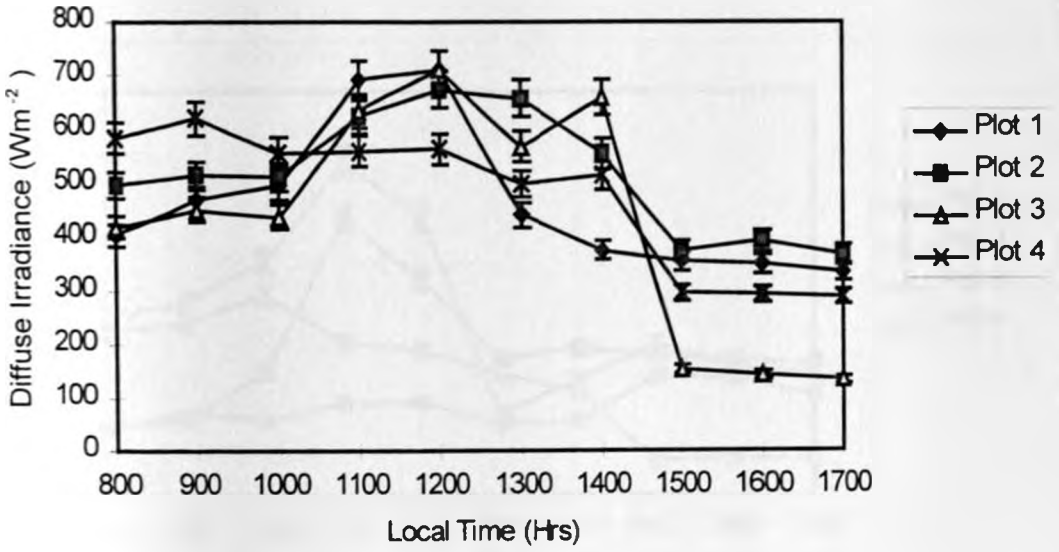


Fig 4.9 a: Diurnal variation of diffuse irradiance in the upper stratum of the canopy during vegetative stage

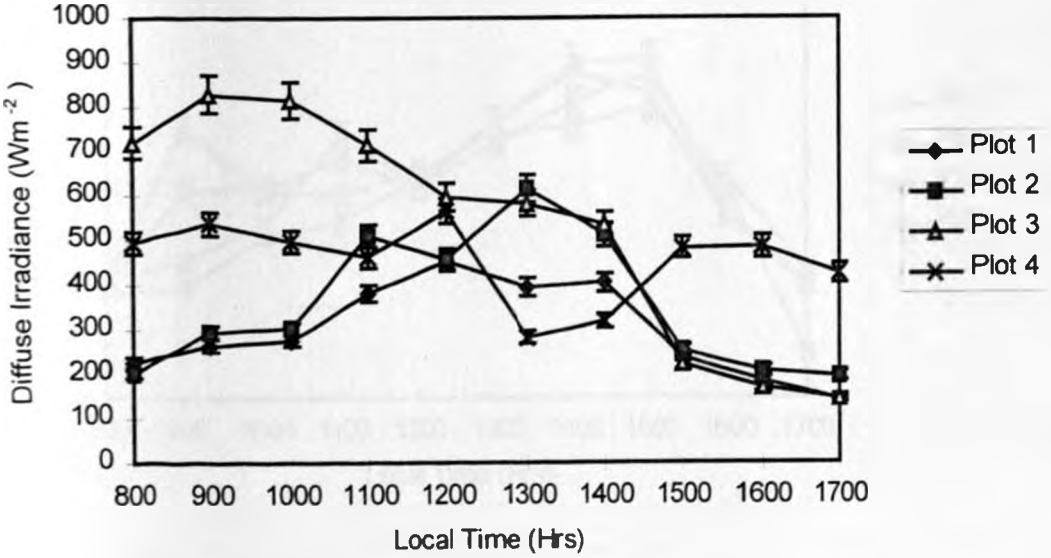


Fig 4.9 b: Diurnal variation of diffuse irradiance in the lower stratum of the canopy during vegetative stage

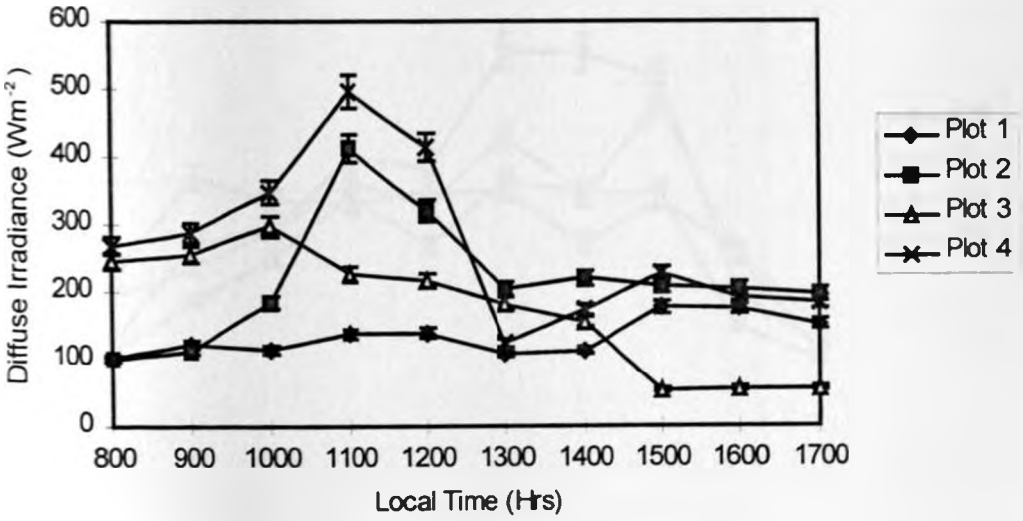


Fig 4.9 c: Diurnal variation of diffuse irradiance in the upper stratum of the canopy during reproductive stage

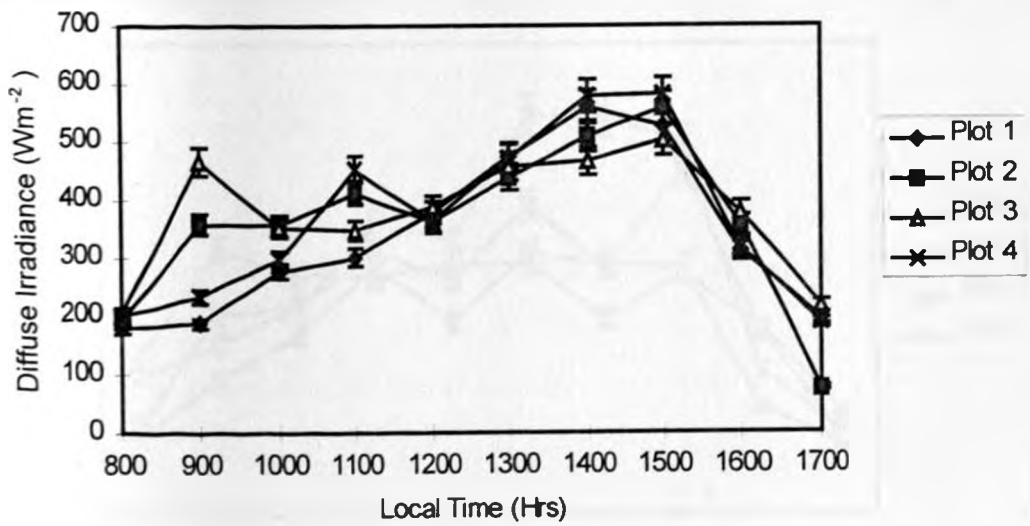


Fig 4.9 d: Diurnal variation of diffuse irradiance in the lower stratum of the canopy during reproductive stage

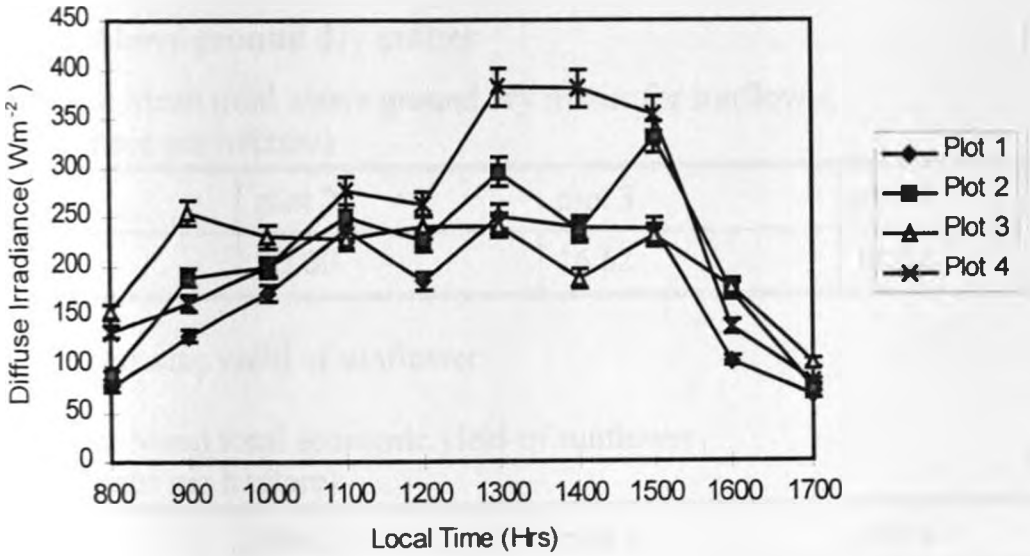


Fig 4.9 e: Diurnal variation of diffuse irradiance in the upper stratum of the canopy during maturity stage

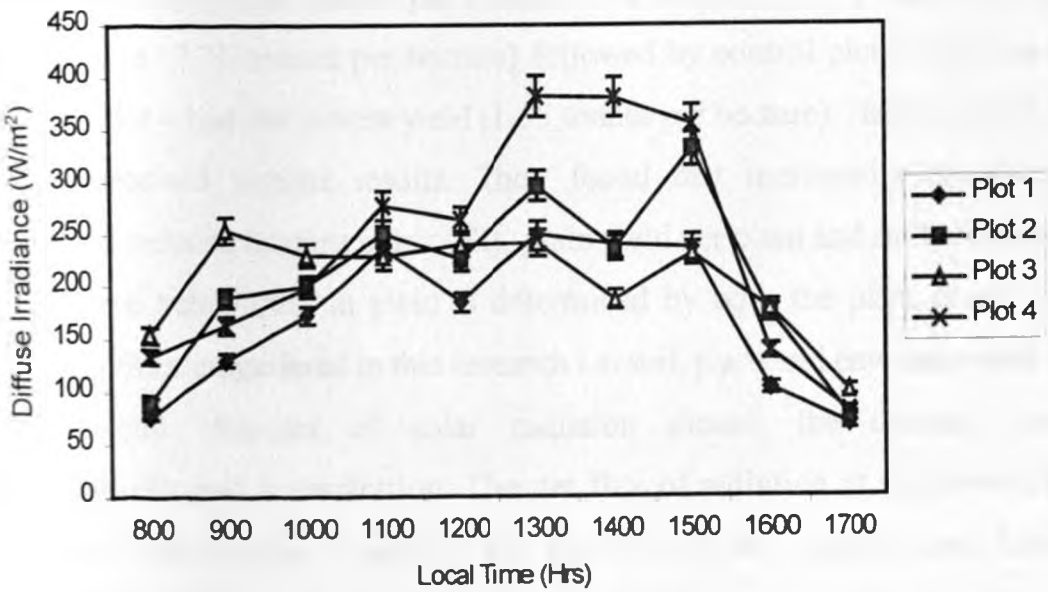


Fig 4.9 f: Diurnal variation of diffuse irradiance in the lower stratum of the canopy during maturity stage

4.10: YIELD ASSESSMENT

4.10 a: Above ground dry matter

Table 4.10a: Mean total above ground dry matter for sunflower (tonnes per hectare)

plot 1	plot 2	plot 3	plot 4
24.93	20.00	16.62	18.62

4.10b: Economic yield of sunflower

Table 4.10b: Mean total economic yield of sunflower (tonnes per hectare)

plot 1	plot 2	plot 3	plot 4
2.71	2.61	1.85	1.55

Plot 1 gave the highest value for the total above ground dry matter (24.93 tonnes per hectare) followed by control plot 2 (20.00 tonnes per hectare). Plot 3 had the lowest value (16.62 tonnes per hectare). For the economic yield, Plot 1 gave the highest yield (2.71 tonnes per hectare) followed by control plot 2 (2.61 tonnes per hectare). Plot 4 had the lowest yield (1.55 tonnes per hectare). Hashim and Schneiter (1982), obtained similar results. They found that increased plant (sunflower) population reduced harvest index (HI), grain yield per plant and stalk diameter.

These behaviours in yield is determined by both the plant density and the other quantities considered in this research i.e. soil, plant and environmental factors.

Diurnal changes of solar radiation dictate the diurnal course of photosynthesis and transpiration. The net flux of radiation at any level in a crop determines the energy available for the transfer of sensible and latent heat (Lemon,1971). Stomatal conductance controls the amount of water lost on the surface of plant leaves through transpiration. Net photosynthesis determines plant productivity and hence the final yield of the crop. Soil temperature is converted

into heat (energy) in the soil. This heat provides the energy to break up the organic matter in the soil and to facilitate the transport mechanism through all the parts of the plant. This organic matter in the soil can only be absorbed by the plant roots in solution form. Soil moisture therefore acts as the solvent to absorb this organic matter.

CHAPTER FIVE

SUMMARY AND CONCLUSION

This study aimed at assessing the effects of plant density on the microclimate of sunflower crop in a medium potential semi-humid area in Kenya. The objective was achieved by measuring both plant and soil parameters in addition to meteorological (environmental) variables. Specifically, the study investigated the effects of plant density on leaf temperature, stomatal conductance, photosynthetic (assimilation) rate, PAR and leaf area index. The soil parameters investigated were moisture and temperature. Meteorological parameters considered were global and diffuse irradiance.

The results showed that the plant density had a profound influence on three of the factors considered i.e. irradiance, soil temperature and leaf area index. As plant density increased, less global irradiance was transmitted in the lower strata of the sunflower canopy. The total irradiance varied independently of plant density in the upper strata of the canopy but in the lower strata it decreased as plant density increased. Diffuse irradiance was not affected by plant density in the upper strata but decreased as plant density increased in the lower strata. The soil warmed up more slowly as plant density increased. At every soil depth, the temperature increased as plant density decreased.

No consistent association of plant density and soil moisture depletion was observed. As reported earlier, the volumetric water content was generally affected by the position and orientation of the specific plot which determined how much percentage of the surface water infiltrated into the soil while the rest was mostly lost as run-off and evaporation.

The plant physiological parameters did not reveal much about the effects of plant density, as evidenced by the result of the analysis of variance. However, the diurnal patterns presented for the various parameters gave some light on the differences as manifested by the plant density. In almost all cases, there were no

significant differences between the treatments and the control for leaf temperature, stomatal conductance, PAR and photosynthetic rate. Photosynthetic rate was generally higher in late morning and early afternoon hours than early morning and late afternoon hours. It was also the case for PAR while the opposite was true for stomatal conductance. The leaf temperature increased from a minimum in early morning hours to a maximum of 27°C at 1300 hours and then started to decrease as irradiance intensity decreased. This maximum value occurred in plot 2.

Quantification of yield was done on total above-ground dry matter. The economic yield was also determined. Plot 1 gave the highest value of the above-ground dry matter (24.93 tonnes per hectare) and economic yield (2.71 tonnes per hectare) followed by plot 2 (20.00 and 2.61 tonnes per hectare respectively). This is due to the high number of plants in plot 1. From these observations, the suitable planting density which can be recommended in this region is the one in plot 1 and 2. This conclusion agrees with Salih (1958), Monti (1973) and Vijayalakshmi et al (1975) observations. They found that optimum sunflower plant population is between 32,000 to 42,000 plants per hectare. These populations can be achieved by spacings of 0.75m x 0.4m and 0.75m x 0.3m respectively.

SUGGESTIONS FOR FUTURE STUDIES AND LIMITATIONS

The relationship between crop growth, yield and weather is not completely understood till today. Some statistical methods are being applied to investigate the correlation between weather elements and crop yields. The results of such investigations give a vague idea of the dependence of crop yields on the weather elements as a number of other factors (agronomic, soil and pathological) act at the same time.

Investigations under controlled conditions are possible only at few places and institutions where facilities are available. Further, the adaptability of results from such controlled laboratories to field conditions will again pose a problem.

Under such circumstances, investigations at the field scale might provide information which, when used in conjunction with those from controlled laboratories, might give a better understanding into the whole problem. Thus, field work is required to supplement the results from controlled laboratories.

In this study, attempts were made to investigate the effect of sunflower plant density on the distribution of irradiance (global and diffuse components), soil temperature, soil moisture, photosynthetically active radiation (PAR), photosynthetic rate, stomatal conductance, leaf temperature and leaf area index (LAI). This investigation was affected in its quality by lack of recording equipments and instruments in sufficient numbers. Thus, more and accurate instruments are needed to come out with more accurate data.

In the present work, data on the final grain yield and a number of yield related components from different plant densities were collected . The irradiance, soil temperature, soil moisture and plant physiological data collected could have given better results if there was more time for data collection. With enough and accurate instruments, more time and enough funds, an investigation of this nature, if conducted in a large field will give a better idea of the relationship between crop growth and yield and factors such as radiation, soil temperature, soil moisture, PAR, leaf temperature, photosynthetic rate, stomatal conductance and leaf area index (LAI). More time and funds should be allocated to field work research.

REFERENCES

Acland, J.D. (1971). East African crops, Longman Group Limited, London.

Alvim, P. de T. (1965). A new type of porometer for measuring stomatal opening and its use in irrigation studies. UNESCO Arid Zones Res., 25: 325-329.

Amable, R.A. (1980). An assessment of performance of sunflowers as an oil-seed crop in Ghana. Journal of Agricultural science, Cambridge 94, 319-323.

Anderson, M.C. (1970). Interpreting the fraction of solar radiation available in forest. Agric. Met. 7: 19-28.

Aston, A.R. and Van Bavel, C.H.M. (1972). Soil surface water depletion and leaf temperature. Agron. J. 64: 368-373.

Aylor, D.E., J.Y. Parlange and A.D. Krikorian (1973). Stomatal mechanics. Am. J. Bot. 60: 163-171.

Bailey, B.J.(1985). Microclimate, physical processes and greenhouse technology. Acta Hortic., 174:35-42.

Baldochii, D.D., Verma, S.B. and Rosenberg, N.J. (1981). Environmental effects on the CO2-water flux ratio of alfafa. Agric. Met. 24: 175-184.

Beadle, C.L., M.M. Ludlow and J.L. Honeysett (1985). Water relations. In: J. Coombs, D.O. Hall, S.P. Long and J.M.O. Scurlock (Editors). Techniques in Bioproductivity and photosynthesis. Pergamon Press, London, pp. 50-61.

Beadle, C.L., N.C. Turner and P.G. Jarvis (1978). Critical water potential for stomatal closure in Sitca Spruce. Physiol. plant, 43: 160-165.

Beardsell, M.F., P.G. Jarvis and B. Davidson (1972). A null-balance diffusion porometer suitable for use with leaves of many shapes. J. Appl. Ecol. 9: 677-690.

Berengena, J. (1978). Sunflower response to irrigation under different environmental conditions. HELIA. Information Bulletin of the F.A.O. Research Network on sunflower. 1, 56-58.

Bierhuizen, J.F.(1973). The effect of temperature on plant growth, development and yield. Plant response to climatic factors, pp. 89-97. Edited by R.O. Slatyer, Unesco, Paris, 1973.

Bierhuizen, J.F., R.O. Slatyer and C.W. Rose (1984). A porometer for field and laboratory operation. J. Exp. Bot.,16: 182-191.

Bingham, G.E. and P.I. Coyne (1977). A portable temperature controlled, steady-state porometer for field measurements of transpiration and photosynthesis. Photosynthesis, 11: 148-160.

Bjorkman, O. (1981). The response of photosynthesis to temperature. Plants and their Atmospheric Environment (J.Grace, E.D. Ford and P.G. Jarvis, Eds), Blackwall, Oxford, ch. 16, pp.273-301.

Black, J.N. (1960). The relationship of illumination and global radiation. Trans. R. Soc. Aust. 83: 83-88.

Bleasdale, J.K.A. (1964). Cropping in a weed-free environment. National vegetable research station, Wellesbourne (U.K.), Span 1,33-36.

Boswell, S.B., C.D. McCarty, K.W. Hench and L. N. Lewis (1975). Effects of tree density on the first ten years of growth and production of Washington Naval oranges, J. soc. Hortic. sci., 100 (4). 370-373.

Bot., G.P.A. (1983). Greenhouse climate: from physical processes to a dynamic model. Phd. Thesis, Agricultural University, Wageningen.

Boyer, J.S. (1970). Differing sensitivity of photosynthesis to low leaf water potentials in corn and soyabean. 46: 236-239.

Broughman, R.W. (1958). Interception of light by foliage of pure and mixed stands of pasture plants. Aust. J. Agric. Res., 9:39-52.

Byrne, G.F., C.W. Rose and R.O. Slatyer (1970). An aspirited diffusion porometer. Agric. Met., 7:39-44.

Challa, H., G.P.A. Bot, E.M. Nederhoff and N.Y. Van de Braak (1988). Greenhouse climate control in the nineties. Acta Hortic. 230: 459-470.

Chang, Jen-Hu (1968). Climate and Agriculture. Aldine, Chicago, III. 304 pp.

Chollet, R. (1977). The biochemistry of photorespiration. Trends Biochem. Sci. 2:155-159.

Cooper, P.J.M. (1973). Soil physical conditions under maize. Agroclimatology of highlands of East Africa pp.169-186. Proceedings of the technical conference, Nairobi, October 1973.

.....(1976). Soil physical and physiological studies. Maize Agronomy Research project (O.D.M. scheme No. R.2989). Annual Report, Kitale, Kenya.

Cowan, I.R. (1977). Stomatal behaviour and environment. Adv. Bot. Res. 4, 117-122.

Dale, J.E. (1961). Investigations into the stomatal physiology of upland cotton. I. The effects of hour of day, solar radiation, temperature and leaf water content on stomatal behaviour. Ann. Botany N.S.25: 39-52.

Darwin, F.(1898). Observations on stomata. Philos. Trans. R. soc. ser. B., 190:531-621.

Denmead, O.T. (1966).The energy balance of plant communities. Agric. met. proc. WMO seminar Melbourne, Aust. 1: 71-105.

Duncan, W.G. (1975). Maize crop physiology: 23-50. Edited by L.T. Evans, Cambridge Univ. press.

Eaton, F.M. (1979). Leaf temperature of cotton and relation to transpiration, varietal differences and yields. USDA Tech. Bull. No. 91. 33pp.

Erhler, W.L.(1973). Cotton leaf temperature as related to soil water depletion and meteorological factors. Agro. J. 65: 404-409.

....., S.B. Idso, R.D. Jackson and R.J. Reginato (1978). Diurnal changes in plant water potential and canopy temperatures as affected by drought. Agron. J. 70: 998-1004.

..... and C.H.M. Van Bavel (1967). Sorghum folier responses to changes in soil water content. Agron. J. 59: 243-246.

Ehleringer, J. and O. Bjorkman (1977). Quantum yields for CO2 uptake in C3 and C4 plants. Plant physiology, 59: 86-90.

Evans, L.T. (1973). The effect of light on plant growth, development and yield. Plant response to climatic factors: 21-35. Edited by R.O. Slatyer, UNESCO, Paris.

Fehrmann, W. and N.M. Fisher (1976). Intensive system of industrial fruit production G.D.R., present stage and trends. High density symposium, Long Aston, Great Britain, 1976.

Fristchen, L.J. (1967). Net and solar radiation relations over irrigated field crops. Agric. met. 4: 55-62.

Gaastra, J.R. (1959). Photosynthesis of crop plants as influenced by light, carbon dioxide, temperature and stomatal diffusion resistance. Meded. Landbouwhogeschool (Wageningen, Netherlands) 59: 1-58.

Gaastra, P. (1958). Light energy conversion in field crops in comparison with photosynthetic efficiency under laboratory conditions. Meded. Land Hoogesch, Wageningen, 58(4): 1-12.

Gabrielson, E.K. (1960). Lichtwellenlange and photosynthesis in Ruhland, Encyclopedia of plant physiology, Berlin, vol. v/2: 49-74.

Gardner, W.R. (1960). Dynamic aspects of water availability to plants. Soil sci. 89: 63-73.

Gates, D.M. (1968). Transpiration and leaf temperature. Ann. Rev. plant physiol., 19: 211-238.

Glover, J. (1948). Water demands by maize and sorghum. East African Agric. For. J., 13: 171.

Gollan, T., N.C. Turner and E.D. Schulze (1985). The responses of stomata and leaf gas exchange to vapour pressure deficits and soil water content. III. In the scerophyllous woody species Nerium Oleander. Oecologia (Berlin), 65: 356-362. Griffiths, J.H. and P.G. Jarvis (1981). A null-balance carbon dioxide and water vapour porometer. 32: 1157-1168.

Harold, L.L. and F.R. Dreibelbis (1951). Agricultural hydrology as evaluated by monolith lysimeters. U.S.D.A. Tech. Bull. no. 1050.

Hashim, R.M. and A.A. Schneiter (1982). Semidwarf and conventional height sunflower performance at five plant populations. Agron. J. 80: 821-824.

Henson, I.E., C.R. Jensen and N.C. Turner (1989a). Leaf gas exchange and water relations of lupins and wheat. I. Shoot responses to soil water deficits. Aust. J. Plant physiol. 16: 401-413.

Hsiao, T.C. (1973). Plant responses to water stress. Am. Rev. Plant physiol. 24: 519-570.

Hudson, J.P. (1965). Evaporation from Lucerne under advective conditions in Sudan. I. Factors affecting water losses and their

measurement (not available but reviewed by Chang Jen-Hu in climate and Agriculture). Aldine, Chicago, 1968. III. 304pp.

Hull, J.N. (1954). Spectral distribution of radiation from the sun and sky. Trans. illum. Engng. soc. London, 19: 21-28.

Idso, S.B. (1990). Stomatal responses to humidity as inferred by porometer and infrared thermometry. Agric. For. Meteorol. 49: 169-172.

.....(1982). Non-water stressed baselines. A key to measuring and interpreting plant water stress. Agric. Meteorol. 27: 59-70.

....., S.G. Allen and B.J. Chowdhury (1988). Problems with porometry: Measuring stomatal conductances of potentially transpiring plants. Agric. For. Meteorol. 43: 49-58.

....., R.D. Jackson and R.J. Reginato (1977). Remote sensing of crop yields. Science, 196: 19-25.

Jackson, R.D., R.J. Reginato and S.B. Idso (1979). Wheat canopy temperature; a practical tool for evaluating water requirements. Water Resource Res., 13: 651-656.

Jarvis, P.G., C.W. Rose and J.E. Begg (1967). An experimental and theoretical comparison of viscous and diffusive resistances to gas flow through amphistomatous leaves. Agric. Meteorol. 4: 103-107.

..... and K.G. McNaughton (1985). Stomatal control of transpiration. Adv. Ecol. Res., 15: 1-49.

Jones, M.M. and H.M. Rawson (1979). Influence of rate of development of leaf water deficits upon photosynthesis, leaf conductance, water use efficiency and osmotic potential in sorghum. Physiol. plant. 45: 103-111.

Kamande, F.K.(1982). Some radiation and temperature aspects of high density plantings of coffee Arabica L. in Kenya. Msc Thesis. University of Nairobi.

Kanemasu, E.T. (Ed.)(1975). Measurement of stomatal arpeture and diffusive resistance. Bull. 809, College of Agric. Res. Centure, Washington State University.

....., G.W. Thurtell and C.B. Tanner (1969). The design, calibration and field use of a stomatal diffusion porometer. Plant Physiol. 44: 881-885.

..... and G.F. Arkin (1974). Radiant energy and light environment of crops. Agric. Met. 14: 211-225.

Kasanga, H. and M. Monsi (1954). On the light transmission of leaves. Japan J. Bot. 14: 304-324.

Khalifa, F.M. (1980). Some factors influencing the development of sunflower under dry-farming systems in Sudan. J. Agric. Sci., Camb (1981), 97: 45-53.

Kramer, P.J. (1980). Changing concepts regarding plant water relations. Plant cell Environ., 11: 565-568.

..... (1969). Plant and soil water relationships. New York,

McGraw-Hill, 482pp.

.....(1950). Effects of wilting on the subsequent intake of water by plants. American Journal of Bot., 37: 281-284.

Korner, C.H., J.A. Scheel and H. Baner (1979). Maximum leaf Diffusive conductance in vascular plants. Photosynthetica, 132: 45-82.

Kuppers, M. (1988). Water vapour and carbon dioxide exchange of leaves as affected by different environmental conditions. Acta Hortic., 229: 85-112.

Lemeur, R. (1973). Effects of spatial leaf distribution on penetration and interception of direct radiation. plant response to climatic factors: 349-356. Edited by R.P. Slatyer, UNESCO, Paris, 1973.

Lemon, E.R., A.H. Glasser and L.E. Satterwhite (1957). Some of the aspects of the relationship of soil, plant and meteorological factors to evaporation. Proc. soil sci. soc. America, 21: 464-468 (not available but reviewed by P.G.Slatyer and J.E.Goode in Commonwealth Agric. Bureaux, Farnharm Royal, Bucks, England, 1967).

Lewis, R.B., E.A. Hiler and W.R. Jordan (1974). Susceptibility of grain sorghum to water deficit at three growth stages. Agron. Journal, 66: 589-590.

Loomis, R.S., W.A. Williams and W.G. Duncan (1966). Community architecture and the productivity of terrestrial plant communities, pp. 291-308. In A. San Pietro, F.A. Greer and T.J. Army (editors). Harvesting the sun. Academic press, New York.

Luckwill, L.C. (1968). Intensification of apple and pear production in England. Proceedings of a seminar held in Nairobi, Dec. 1968: 165-167.

Ludlow, M.M., M.J. Fisher and J.R. Wilson (1985). Stomatal adjustments to water deficits in three tropical grasses and a tropical legume grown in controlled conditions in the field. Aust J. Plant Physiol., 12: 131- 149.

Maharani, H. and C.H. Andrews (1986). Correlation of some climatological factors with plant and seed characteristics of sunflowers. Indonesian J. crop sci., 1989, vol. 4, no. 2: 63-75.

Majid, H.R. and A.A. Schneiter (1987). Yield and quantity of semidwarf and standard height sunflower hybrids grown at five plant populations. Agron. J. 79: 681-684.

Meidner, H. (1981). Measurements of stomatal arpeture and responses to stimuli. In: P.G. Jarvis and T.A. Mansfield (Editors), stomatal physiology, Cambridge University press, Cambridge, pp. 33-49.

Millar, A.A., R.E. Jensen, A. Bauer and E.B. Norum (1971). Influence of atmospheric and soil environmental parameters on the diurnal fluctuations of leaf water status of barley. Agric. Met. 8: 93-105.

Miller E.E. (1923). Some observations on the temperature of leaves of crop plants. J. Agric. Res. 26: 15-43.

Miller, J.F. and G.N. Fick (1978). Influence of plant populations on the performance of sunflower hybrids. Can. J. Plant sci. 58: 597-600.

Milthorpe, F.L. and J. Moorby (1974). An introduction to crop physiology. Cambridge University press, 1974, 202 pp.

Mitchell, K.J. and J.R. Kerr (1974). Differences in rate of use of soil water by stand of perennial ryegrass and white clover. Agon. J., 58: 5-8.

Monsi, M. and T. Saeki (1953). The light factor in plant associations and its importance in dry matter production. Japan J. Bot. 14: 22-52.

Monteith, J.L. (1957). Dew. Quart. J.R. Met. soc. 83: 322.

.....(1965). Light distribution and photosynthesis in field crops. Ann. of Bot. (N.S.) 29: no. 113.

.....(1973). Principles of environmental physics. Arnold, Long, 1973, 241 pp.

.....(1979). Soil temperature and crop growth in the tropics, ch. 5.1. In: Soil physical properties and crop production in the tropics. John Wiley and sons, Chichester. 249-269.

.....(1990). Porometry and baseline analysis : the case for compatibility. Agric. For. Met. 49: 155-167.

....., G.S. Campbell and E.A. Potter (1988). Theory and performance of a dynamic diffusion porometer. Agric. For. Met. 44: 27-38.

Monti, M. (1973). Investigations of the cultural technique for sunflower. 2: plant density and spacing. Annali della facorta di Agrania Universita degli studi di perugia 28, 551.

Moon, P.(1940). Proposed solar radiation curves for engineering use. J. Franklin Inst. 230: 583-617.

Moss, D.N. (1965). Capture of radiant energy in Agricultural meteorology (P. E. Waggoner, ed.), ch. 5, met. monogr. 6(28): 90-108. Am. met. soc., Boston.

Mudd, J.B. and T.T. Kozlowski (editors),1975. Responses of plants to air pollution. Academic press, New York.

Nelson, R.E. and P.G. Jarvis (1975). Photosynthesis in Sitka spruce (picea sitchensis (bong.) carr.). 4. Response of stomata to temperature. J. Appl. Ecol. 12: 879-891.

Niilisk, H. (1964). Spectral radiation regime of maize and calculation of photosynthetically Active Radiation (PAR). Report by Inst. Phys. and Astronomy of the Accd. of Estonian, S.S.R. no. 3: 177-191.

Njihia, J.K. (1978). The influence of maize plant density on radiation, soil temperature and soil moisture distribution. Msc Thesis. University of Nairobi.

Nixon, P.R., L. N. Namken and C.L. Wiegand (1972). Spatial and temporal variations of crop canopy temperatures and implications for irrigation scheduling. In: F. Shahrokhi (Ed). Proc. conf. Earth Resources observation and information Analysis system : Remote sensing of Earth Resources , Tulla homa, TN, vol. 21 pp. 643-657.

Owili, J.O. (1995). Assessment of microclimate effects of stover mulch and *Cassia siamea Lam.* hedgerows on plant water status of maize (*Zea mays L.*) in the sei-arid areas of Machakos District, Kenya. Msc Thesis

Owonubi, J.J., E.T. Kanemasu and W.L. Powers (1975). The microclimate of narrow and wide-row sorghum with equal plant densities. Agric. Met., 15: 61-69.

Paccucci, G. and F. Martignano (1975). Effect of sowing density on yield and some bioagronomic characteristics of tall and dwarf sunflower cultivars. Rivista di Agronomia 9: 180-186.

Parkinson, K.J. (1985). Porometry. In: B. Marshall and F.J. Woodland (editors); Instrumentation for environmental physiology. Cambridge University press, Cambridge, pp. 171-191.

Pearcy, R.W., K. OOsteryong and M.W. Calkin (1985). Photosynthetic responses to dynamic light environments by Hawaiian trees-time course of CO2 uptake and carbon gain during sunflecks . Plant physiol. 79: 896-902.

Raschke, K. (1970). Temperature dependence of CO2 assimilation and stomatal arpeture in leaf sections of zea mays. Planta, 91: 336-363.

Rawlings, S.L. and W.H. Wright (1964). Portable leaf porometer. Conn. Agric. Exp. stn. New Haven spec. soils Bull. 20: 1-6.

Reuss, J.O. and R.E. Danielson (1974). Physical and chemical barriers to more efficient water use by crops. Agric. Met., 14: 183-198.

Rich, S. and N.C. Turner (1972). Importance of moisture on stomatal behaviour of plants subjected to ozone. APCA J., 22: 718-721.

Ritchie, J.T. (1974). Atmospheric and soil water influences on the plant water balance. Agric. Met. 14: 183-198.

.....(1977). The contribution of the surface energy balance in climate stress for Agriculture. Presented at Climate-Technology seminar. Oct. 25-26, Columbia, MO, 23 pp.

.....and E. Burnet (1971). Dryland evaporative flux in a subhumid climate, II. plant influences. Agron. J. 63: 56-62.

Roger, W.S. and I. Modlibooska (1950). J. Hort. sci., 26: 47-59.

Rogers, W.S. (1968). Progress of intensification in temperate perennial crops. Proceeds of a seminar held in Nairobi, December, 1968: 165-167.

Ross, Y.U. and T. Nelson (1963). Concerning the theory of the plant cover regime. Report by the Inst. phys. and Astronomy of the Acad. of Estonian S.S.R.

Saeki, T. (1963). Light relations in plant communities. In: L.T. Evans (editor), Environmental control of plant growth. Academic press, New York.

Salih, M.O.M. (1958). Agronomy of oil crops. Annual report of Toti Research Station, Sudan.

Salter, P.J. and J.E. Goode (1967). Crop responses to water at different stages of growth. CommonW. Agric. Bureaux, Farnharm Royal, Bucks, England, 256 pp.

Schulze, E.D., A.E. Hall, O.L. Lange and H. Walz (1982). A portable steady-state porometer for measuring the carbon dioxide and water vapour exchanges of leaves under natural conditions. Oecologia (Berlin), 53: 141-145.

Schackel, K.A. and E. Brinckmann (1985). In situ measurements of epidermall cell turgor, leaf water potential and gas exchange in Tradescantia Virginiana L. plant physiol. 78: 66-70.

Sharpe, P.J.H. (1973). Adaxial and abaxial stomatal resistance of cotton in the field. Agron. J., 65: 570-574.

Sionit, N. (1976). Water status and yield of sunflowers (Helianthus annus) subjected to water stress during four stages of development. Agric. sci., Cambridge 89: 663-666.

Slatyer, R.O. (1967). In situ measurements of stomatal resistance. Aust. J. Instrum. Control., 23: 88-89.

Szeicz, G., J.L. Monteith and J.M. Dos Santos (1964). Tube solarimeters to measure radiation among plants. J. appl. Ecol. 1: 169-174.

Taylor, A.H. and G.P. Kerr (1941). The distribution of energy in the visible spectrum of day light. J. Opt. soc. Am. 1: 3-8.

Thom, A.S. (1976). Momentum, mass and heat exchange of plant communities. In: J.L. Monteith (editor), vegetation and atmosphere. I. Principles. Academic press, New York, NY, pp 59-109.

Thomas, M.D. and G.R. Hill (1949). Photosynthesis under field conditions. Photosynthesis in plants (J. Frank and W.E. Loomis, eds.), plant physiol. monogr. Iowa State Univ. press, Ames, pp. 19-52.

Turner, D.J. (1965). An investigation into the causes of low yield in late planted maize. E.A. Agric. For. J., 31(2): 249-260.

Turner, N.C. (1970). Responses of adaxial and abaxial stomata to light. New phytol., 69: 647-653.

.....(1974). Stomatal response to light and water under field conditions. In: R.L. Bieleski, A.R. Ferguson and M.M. Cresswell (editors), mechanisms of regulation of plant growth. Bull. R. soc. N.Z., 12: 423-432.

.....(1975). Concurrent comparisons of stomatal behaviour, water status and evaporation of maize in soil at high or low water potential. Plant physiol., 55: 932-936.

.....(1979). Differences in response of adaxial and abaxial stomata to environmental variables. In: D.N. Sen (editor), structure, function and ecology of stomata . Bishen Singh Mahendra Pal Singh, Dehra Dun, pp. 229-250.

.....(1986a). Adaptation of water deficits: a changing perspective. Aust. J. plant physiol., 13: 175-190.

.....(1986b). Crop water deficits: a decade of progress. Adv. Agron., 39: 1-51.

..... and G.H. Heichel (1977). Stomatal development and seasonal changes in diffusive resistance of primary and regrowth foliage of red oak (Quercus rubra L.) and red maple (Acer rubrum L.). New phytol., 78: 71-81.

.....and I.E. Henson (1989). Comparative water relations and gas exchange of wheat and lupins in the field. In: K.H. Kreeb, H. Ritcher and T.M. Hinckley (editors), structural and functional responses to environmental stresses: water shortage. SPB Academic publishing, The Hague, pp. 293-304.

.....and P.G. Jarvis (1975). Photosynthesis in sitka spruce (picea sitchensis (bong.) carr.). 4. Responses to soil temperature. J. Appl. ecol., 12: 561-576.

.....and M.M. Jones (1980). Turgor maintenance by osmotic adjustment : a review and evaluation. In: N.C. Turner and P.J. Kramer (editors), adaptation of plants to water and high temperature stress. Wiley, New York, pp. 87-103.

.....and J.Y. Parlange (1970). Analysis of operation and calibration of ventilated diffusion porometer. Plant physiol., 46: 175-177.

....., F.C.C. Pedersen and W.H.Wright (1969). An aspirated diffusion porometer for field use. Conn. Agric. Exp. stn. New Haven spec. soils Bull., 29: 1-14.

....., E.D. schulze and T. Gollan (1984). The responses of stomata and leaf gas exchange to water vapour pressure deficits and soil water content. I: Species comparisons at high soil water contents. Oecologia (Berlin), 63: 338-342.

Unsworth, M.H. and V.J. Black (1981). Stomatal responses to pollutants . In: P.G. Jarvis and T.A. Mansfield (editors), stomatal physiology. Cambridge University press, Cambridge, pp. 187-203.

Van Bavel, C.H.M. (1972). Soil temperature and crop growth. In: D. Hillel (editors). Optimizing the soil physical environment toward greater crop yields. Academic press, New York and London, pp. 173-191.

....., F.S. Nakayama and W.L. Erhler (1965). Measuring transpiration resistance of leaves. Plant physiol., 40: 535-540.

Vijayakshmi, K., W.K. Saghi, W.L. Petton and C.H. Anderson (1975). Effects of plants population and row spacing on sunflower agronomy. Can. J. Plant sci. 55: 491-499.

Waggoner, P.E. (1965). Calibration of a porometer in terms of diffusive resistance. Agric. Met. 2: 317-329.

Walker, G.K. (1980). Relationship between crop temperarures and the growth and yield of kidney beans (phasaeolus vulgaris L.). PhD Thesis, University of California, Davis, C.A. 203 pp.

Wallihan, E.F. (1964). Modification and use of an electric hygrometer for estimating relative stomatal arpetures. Plant physiol., 39: 86-90.

Weiss, E.A. (1964). Sunflower trials in western Kenya. E. African Agric. and Forestry Journal, vol. 31: 405-408.

Wiegand, C.L. and L.N. Namken (1966). Influence of plant moisture stress, solar radiation and air temperatures on cotton leaf temperature. Agron. Journal, 58: 582-586.

Wilson, D. (1975). Leaf growth, stomatal diffusive resistance and photosynthesis during droughting of lelium perenne populations selected for contrasting stomatal length and frequency. Ann. Appl. Bio. 79: 67-82.

Woods, D.B. and N.C. Turner (1971). Stomatal response to changing light by four tree species of varying shade tolerance. New phytol., 70: 77-84.

Zeltich, I. (1975). Improving the efficiency of photosynthesis. Science 188: 626-633.

Zubriski, J.C. and D.C. Zimmerman (1974). Effects of nitrogen, phosphorus and plant density on sunflower. Agron. Journal, 66: 798-801.

APPENDIX

Parameter	Accuracy (Error)
Soil temperature	$\pm$0.3°C
Leaf temperature	$\pm$0.3°C
Stomatal conductance	$\pm$5%
Photosynthetic rate	$\pm$5%
Photosynthetically Active Radiation(PAR)	$\pm$5%
Leaf area index (LAI)	$\pm$0.5
Global irradiance	$\pm$5%
Diffuse irradiance	$\pm$5%

APPENDIX 1: SOIL TEMPERATURE ($T_s \pm 0.3^{o}C$)

Table 4.1a: Mean Soil temperature (^{0}C) at 5cm depth for the four plots

Time(hrs)	plot 1	plot 2	plot 3	plot 4
700	16.4	16.2	17.3	17.4
800	16.4	16.3	17.4	17.6
900	17.9	17.7	18.4	18.8
1000	17.9	17.6	18.7	19.5
1100	19.1	20.3	20.2	21.1
1200	19.3	20.9	20.7	21.9
1300	20.1	22.3	20.7	23.0
1400	21.2	23.3	22.3	23.9
1500	21.4	23.6	23.2	24.4
1600	22.2	23.8	23.6	24.9
1700	22.3	24.8	24.3	25.7
1800	21.4	24.4	23.2	25.4
mean	19.6	20.9	20.8	22.0

Table 4.1b: Mean soil temperature (°C) at 10cm depth for the four plots

Time(hrs)	plot 1	plot 2	plot 3	plot 4
700	17.1	17.5	17.9	18.2
800	17.2	17.7	18.0	18.3
900	18.1	18.4	18.7	18.9
1000	18.1	18.4	18.7	18.9
1100	18.2	18.8	19.3	19.5
1200	18.2	19.0	19.8	19.8
1300	18.6	19.6	20.6	20.6
1400	19.5	20.8	21.7	21.7
1500	19.8	21.4	22.1	22.3
1600	20.3	22.1	22.6	23.2
1700	20.7	23.4	23.7	24.3
1800	20.6	24.1	24.0	24.8
mean	18.9	20.1	20.6	20.9

Table 4.1c: Mean soil temperatures (°C) at 20cm depth for the four plots

Time(hrs)	plot 1	plot 2	plot 3	plot 4
700	18.8	19.3	19.9	20.0
800	18.8	19.3	19.9	20.0
900	19.0	20.0	20.2	20.3
1000	19.1	19.4	20.1	20.0
1100	19.2	19.7	20.1	20.2
1200	19.2	19.7	20.3	20.1
1300	19.2	20.3	20.3	20.3
1400	19.9	20.3	20.6	20.6
1500	19.6	20.3	20.6	20.6
1600	19.7	20.3	20.7	20.9
1700	20.0	20.7	21.1	21.5
1800	20.4	21.6	21.8	22.0
mean	19.4	20.1	20.5	20.5

Table 4.1d: Statistical analysis for soil temperature

(i) Analysis of variance for soil temperature at three different depths (5, 10 and 20cm)

source	S.O.S.	D.F.	mean square	F-ratio
between	819.125	2	412.695	547^{**}
within	6.785	9	0.754	
total	825.910	11		

(ii) Analysis of variance for soil temperature between plot 1 and plot 2 at 5cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	10.402	1	10.402	4.3^{ns}
within	166.067	22	7.549	
total	176.469	23	23	

(iii) Analysis of variance for soil temperature between plot 2 and plot 3 at 5cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	0.326	1	0.326	1.351^{ns}
within	186.587	22	3.936	
total	186.913	23		

(iv) Analysis of variance for soil temperature between plot 2 and plot 4 at 5cm depth

source	S.O.S.	D.F.	mean square	F_ratio
between	6.407	1	6.407	4.78^{ns}
within	217.453	22	9.8842	
total	223.860	23		

(v) Analysis of variance for soil temperature between plot 1 and plot 2 at 10cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	8.640	1	8.640	0.795^{ns}
within	239.000	22	10.864	
total	247.640	23		

(vi) Analysis of variance for soil temperature between plot 2 and plot 3 at 10cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	0.8066	1	0.8066	4.785^{ns}
within	107.1267	22	4.8694	
total	107.9333	23		

(vii) Analysis of variance for soil temperature between plot 2 and plot 4 at 10cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	3.84	1	3.84	6.66^{ns}
within	118.12	22	5.369	
total	121.96	23		

(viii) Analysis of variance for soil temperature between plot 1 and plot 2 at 20cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	1.500	1	1.500	2.86^{ns}
within	11.533	22	0.524	
total	13.033	23		

(ix) Analysis of variance for soil temperature between plot 2 and plot 3 at 20cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	3.0816	1	3.0816	17.72^{**}
within	16.5767	22	0.7535	
total	19.6583	23		

(x) Analysis of variance for soil temperature between plot 2 and plot 4 at 20cm depth

source	S.O.S.	D.F.	mean square	F-ratio
between	2.5349	1	2.5349	4.282^{ns}
within	13.0234	22	0.592	
total	15.5583	23		

APPENDIX 2: SOIL MOISTURE

TABLE 4.2: STATISTICAL ANALYSIS FOR SOIL MOISTURE

(i) Analysis of variance for soil moisture at four different depths

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0084	3	0.0028	6.81^{ns}
within	0.0494	12	0.004	
total	0.0578	15		

(ii) Analysis of variance for soil moisture between plot 1 and plot 2

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0018	1	0.0018	1.048^{ns}
within	0.0101	6	0.0017	
total	0.0119	7		

(iii) Analysis of variance for soil moisture between plot 2 and plot 3

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0195	1	0.0195	12.25^{*}
within	0.0096	6	0.0016	
total	0.0291	7		

(iv) Analysis of variance for soil moisture between plot 2 and plot 4

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0056	1	0.0056	0.465^{ns}
within	0.0135	6	0.0023	
total	0.0191	7		

APPENDIX 3: LEAF TEMPERATURE (T_L±0.3°C)

Table 4.3a: Mean leaf temperature (°C) of the upper strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	22.5	22.8	22.4	22.8
0900	23.0	23.5	23.1	24.0
1000	23.6	24.8	23.5	26.6
1100	23.4	25.5	23.0	25.6
1200	23.1	23.3	23.2	25.4
1300	31.3	30.4	29.5	28.6
1400	26.1	25.6	27.2	26.7
1500	24.3	26.1	27.5	28.3
1600	23.0	25.1	26.2	26.9
1700	23.0	25.0	26.0	26.4
mean	24.3	25.2	25.2	26.1

Table 4.3b: Mean leaf temperature (C) of the lower strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	22.6	22.3	22.0	22.4
0900	23.3	22.8	23.4	24.2
1000	23.1	24.2	23.1	26.2
1100	23.2	25.4	22.8	25.3
1200	22.8	23.2	22.9	25.0
1300	30.3	30.6	29.8	28.6
1400	25.8	25.8	27.3	26.7
1500	23.8	25.8	27.4	28.4
1600	23.8	24.7	25.9	26.6
1700	22.5	24.5	26.1	26.3
mean	24.0	24.9	25.1	26.0

Tables 4.3c: Analysis of variance for leaf temperature during vegetative stage

(i) between plot 1 and plot 2

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	3.872	1	3.872	0.671^{ns}
within	103.85	18	5.7694	
total	107.722	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	4.14	1	4.14	0.737^{ns}
within	101.097	18	5.6165	
total	105.237	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.012	1	0.012	0.0023^{ns}
within	93.953	18	5.2196	
total	93.965	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.098	1	0.098	0.0161^{ns}
within	109.582	18	6.088	
total	109.68	19		

(iii) between plot 2 and plot 4

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	4.232	1	4.232	1.104^{ns}
within	69.03	18	3.835	
total	73.262	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	5.408	1	5.408	1.213^{ns}
within	80.282	18	4.4601	
total	85.690	19		

Table 4.3d: Mean leaf temperature (^{o}C) of the upper strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	18.1	18.9	18.5	17.6
0900	18.5	19.5	18.9	17.9
1000	21.2	20.2	19.2	20.1
1100	20.6	20.8	21.4	20.6
1200	23.4	22.7	21.4	20.6
1300	25.4	25.5	26.5	25.5
1400	26.5	24.9	25.2	25.4
1500	25.3	25.3	25.3	25.9
1600	24.1	24.2	25.0	24.1
1700	23.5	23.0	23.0	23.5
mean	22.7	22.5	22.4	22.5

Table 4.3e: Mean leaf temperature (°C) of the lower strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	18.2	18.3	17.9	18.0
0900	18.8	18.8	18.1	18.3
1000	19.9	20.8	18.9	19.9
1100	20.3	20.9	20.9	20.4
1200	22.9	22.9	20.9	24.0
1300	24.4	26.5	26.5	25.0
1400	26.1	24.4	23.9	26.0
1500	24.9	25.0	24.3	25.0
1600	23.9	23.9	24.4	23.9
1700	22.8	22.4	22.4	22.9
mean	22.2	22.4	21.8	22.3

Table 4.3f: Analysis of variance for leaf temperature during reproductive stage

(i) Between plot 1 and plot 2

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.128	1	0.128	0.0112^{ns}
within	204.944	18	11.3858	
total	205.072	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.1445	1	0.1445	0.0197^{ns}
within	132.185	18	7.344	
total	132.3295	19		

(ii) Between plot 2 and plot 3

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.018	1	0.018	0.0016^{ns}
within	207.794	18	11.544	
total	207.812	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	1.6245	1	1.6245	0.204^{ns}
Within	143.445	18	7.9692	
total	146.0695	19		

(iii) Between plot 2 and plot 4

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.002	1	0.002	0.00016^{ns}
within	219.397	18	12.1887	
total	219.398	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.012	1	0.012	0.00252^{ns}
within	142.573	18	7.921	
total	142.585	19		

Table 4.3g: Mean leaf temperature (°C) of the upper strata of canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	20.0	20.8	21.8	18.6
0900	21.9	21.3	21.2	22.4
1000	20.0	20.0	20.1	20.4
1100	21.2	21.2	21.2	22.3
1200	22.7	23.4	22.8	20.7
1300	23.3	23.4	22.3	23.2
1400	22.8	23.3	24.4	22.3
1500	25.0	25.1	25.4	25.0
1600	23.6	26.0	25.4	24.1
1700	23.2	25.0	24.8	23.5
mean	22.4	23.0	22.9	22.3

Table 4.3h: Mean leaf tempeature (°C) of the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	19.9	19.9	21.4	18.9
0900	21.9	20.9	20.3	21.9
1000	19.7	20.5	20.4	19.8
1100	21.8	20.7	20.8	21.3
1200	21.9	22.7	21.9	19.8
1300	22.8	23.0	22.3	22.8
1400	22.3	22.8	23.9	21.8
1500	24.7	24.7	24.9	23.8
1600	23.4	25.0	24.9	22.9
1700	22.9	24.2	23.6	22.4
mean	22.1	22.4	22.4	21.5

Table 4.3i: Analysis of variance for leaf temperature during maturity stage

(i) Between plot 1 and plot 2

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	1.512	1	1.512	0.457^{ns}
within	59.525	18	3.307	
total	61.037	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.4805	1	0.4805	0.169^{ns}
within	51.265	18	2.8481	
total	51.7455	19		

(ii) Between plot 2 and plot 3

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	1.458	1	1.458	0.0818^{ns}
within	320.734	18	17.819	
total	322.192	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	17.944	1	17.944	5.424^{*}
within	59.288	18	3.294	
total	77.232	19		

(iii) Between plot 2 and plot 4

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.1125	1	0.1125	0.0063^{ns}
within	319.815	18	17.7675	
total	319.9275	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	4.05	1	4.05	1.36364^{ns}
within	53.448	18	2.97	
total	57.498	19		

APPENDIX 4: STOMATAL CONDUCTANCE (SC±5%)

Table 4.4a: Mean stomatal conductance ($\mu mol\ m^{-2}s^{-1}$) of upper strata of canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.029	0.027	0.021	0.019
0900	0.032	0.025	0.020	0.018
1000	0.034	0.019	0.017	0.021
1100	0.036	0.003	0.012	0.026
1200	0.033	0.021	0.016	0.012
1300	0.029	0.027	0.019	0.010
1400	0.032	0.032	0.021	0.006
1500	0.055	0.047	0.031	0.019
1600	0.040	0.038	0.027	0.024
1700	0.035	0.031	0.024	0.020
mean	0.0355	0.027	0.0208	0.0175

Table 4.4b: Mean stomatal conductance (μmol $m^{-2}s^{-1}$) of the lower strata of canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.034	0.026	0.023	0.017
0900	0.035	0.029	0.021	0.018
1000	0.032	0.016	0.016	0.022
1100	0.040	0.007	0.015	0.034
1200	0.031	0.024	0.014	0.014
1300	0.028	0.027	0.020	0.012
1400	0.034	0.035	0.020	0.009
1500	0.061	0.041	0.028	0.020
1600	0.038	0.036	0.029	0.022
1700	0.037	0.029	0.021	0.019
mean	0.037	0.0271	0.0207	0.0177

Tables 4.4c: Analysis of variance for stomatal conductance during vegetative phase

(i) Between plot 1 and plot 2

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.000361	1	0.000361	3.709^{ns}
within	0.001753	18	0.000097	
total	0.002114	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0004901	1	0.0004901	5.41^{*}
within	0.0016309	18	0.0000906	
total	0.002121	19		

(ii) Between plot 2 and plot 3

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.000196	1	0.000196	2.333^{ns}
within	0.00151	18	0.000084	
total	0.001706	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0002048	1	0.0002048	3.325^{ns}
within	0.001109	18	0.0000616	
total	0.0013138	19		

(iii) Between plot 2 and plot 4

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.000452	1	0.000452	5.077^{*}
within	0.001598	18	0.000089	
total	0.00205	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0000085	1	0.0000085	0.0274^{ns}
within	0.0055825	18	0.0003101	
total	0.005591	19		

Table 4.4d: Mean stomatal conductance (μmol $m^{-2}s^{-1}$) of the upper strata of canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.035	0.029	0.041	0.033
0900	0.059	0.036	0.075	0.058
1000	0.042	0.042	0.052	0.037
1100	0.029	0.015	0.014	0.036
1200	0.016	0.016	0.013	0.019
1300	0.006	0.030	0.001	0.021
1400	0.023	0.002	0.014	0.020
1500	0.004	0.004	0.011	0.007
1600	0.009	0.003	0.019	0.004
1700	0.016	0.014	0.023	0.009
mean	0.024	0.019	0.026	0.024

Table 4.4e: Mean stomatal conductance (μmol $m^{-2}s^{-1}$) of the lower strata of canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.040	0.036	0.039	0.034
0900	0.071	0.065	0.070	0.066
1000	0.050	0.057	0.050	0.049
1100	0.049	0.035	0.033	0.039
1200	0.043	0.028	0.029	0.009
1300	0.025	0.015	0.006	0.012
1400	0.025	0.016	0.012	0.003
1500	0.024	0.006	0.026	0.006
1600	0.026	0.016	0.015	0.011
1700	0.028	0.027	0.027	0.018
mean	0.038	0.030	0.031	0.025

Table 4.4f: Analysis of variance for stomatal conductance during reproductive stage

(i) Between plot 1 and plot 2

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.000115	1	0.000115	0.447^{ns}
within	0.004632	18	0.000257	
total	0.004747	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.00032	1	0.00032	0.95^{ns}
within	0.0060748	18	0.000337	
total	0.0063948	19		

(ii) Between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0002591	1	0.0002591	0.715^{ns}
within	0.0065251	18	0.0003625	
total	0.0067842	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0000018	1	0.0000018	0.00453^{ns}
within	0.00715	18	0.000397	
total	0.0071518	19		

(iii) Between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0001407	1	0.0001407	0.58^{ns}
within	0.0043711	18	0.0002428	
total	0.0045118	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0001458	1	0.0001458	0.247^{ns}
within	0.0106342	18	0.0002428	
total	0.01078	19		

Table 4.4g: Mean stomatal conductance ($\mu mol\ m^{-2}s^{-1}$) of the upper strata of canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.010	0.016	0.010	0.024
0900	0.032	0.028	0.017	0.009
1000	0.066	0.069	0.068	0.008
1100	0.041	0.049	0.053	0.001
1200	0.035	0.031	0.025	0.039
1300	0.029	0.022	0.030	0.025
1400	0.031	0.031	0.025	0.034
1500	0.041	0.042	0.009	0.029
1600	0.037	0.012	0.014	0.021
1700	0.032	0.012	0.013	0.019
mean	0.035	0.031	0.026	0.021

Table 4.4h: Mean stomatal conductance (μmol $m^{-2}s^{-1}$) of the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0.031	0.031	0.027	0.023
0900	0.043	0.050	0.061	0.033
1000	0.091	0.019	0.055	0.065
1100	0.067	0.075	0.052	0.056
1200	0.049	0.065	0.038	0.061
1300	0.054	0.031	0.059	0.048
1400	0.041	0.049	0.033	0.058
1500	0.050	0.052	0.037	0.040
1600	0.042	0.013	0.035	0.029
1700	0.036	0.012	0.030	0.025
mean	0.050	0.040	0.043	0.044

Table 4.4i: Analysis of variance for stomatal conductance during maturity stage

(i) Between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0000882	1	0.0000882	0.3409^{ns}
within	0.004656	18	0.0002587	
total	0.0047442	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0005725	1	0.0005725	1.4732^{ns}
within	0.0070263	18	0.0003903	
total	0.007599	19		

(ii) Between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0001152	1	0.0001152	0.3253^{ns}
within	0.006374	18	0.0003541	
total	0.0064892	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.000045	1	0.000045	0.141^{ns}
within	0.0057442	18	0.000319	
total	0.0057892	19		

(iii) Between plot 2 and plot 4

(a) Upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0005305	1	0.0005305	2.258^{ns}
within	0.0042245	18	0.0002347	
total	0.004755	19		

(b) Lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.0000841	1	0.0000841	0.2315^{ns}
within	0.0065397	18	0.0003633	
total	0.0066238	19		

APPENDIX 5:PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR+5%)

Table 4.5a: Mean PAR (Wm^{-2}) of the upper strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	195	182	150	95
0900	295	269	240	105
1000	720	1000	718	98
1100	129	634	690	130
1200	400	440	1000	328
1300	740	630	749	668
1400	370	392	393	345
1500	190	160	425	416
1600	248	214	409	392
1700	152	140	215	198
Mean	344	406	500	278

Table 4.5b: Mean PAR (Wm^{-2}) of the lower strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	104	85	122	86
0900	110	97	137	104
1000	112	115	121	125
1100	98	117	120	102
1200	125	103	122	106
1300	84	142	155	136
1400	117	62	84	87
1500	69	120	32.4	55
1600	48	65.5	42	24
1700	23.5	35	40	21
Mean	89.1	94.2	97.5	84.6

Table 4.5c: Analysis of variance for PAR during vegetative stage

(i) Between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	19158	1	19158	0.0826^{ns}
Within	4174570	18	231921	
Total	4193728	19		

(b) lower strata of the canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	130.05	1	130.05	0.122^{ns}
Within	19190.25	18	1066.125	
Total	19320.30	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	192.2	1	192.2	0.00126^{ns}
Within	2743633.8	18	152424.0	
Total	2743826.0	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	57.46	1	54.46	0.0378^{ns}
Between	27370.27	18	1520.571	
Total	27427.73	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	261289.8	1	261289.8	1.996^{ns}
Within	2356477.4	18	130915.41	
Total	2617767.2	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	456.02	1	456.02	0.35^{ns}
Within	23450.42	18	1302.801	
Total	23906.44	19		

Table 4.5d: Mean PAR (Wm^{-2}) of the upper strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	196	190	180	149
0900	274	246	196	159
1000	438	498	467	353
1100	302	430	595	303
1200	582	852	557	762
1300	546	782	660	634
1400	491	440	381	487
1500	412	399	376	586
1600	239	277	226	221
1700	129	128	196	112
Mean	361	424	383	377

Table 4.5e: Mean PAR (Wm^{-2}) of the lower strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	80	29	118	49
0900	91	33	140	62
1000	91	78	98	110
1100	57	143	99	95
1200	120	102	103	96
1300	82	150	141	130
1400	114	59	74	90
1500	73	115	34	58
1600	47	67	40	26
1700	25	37	52	23
Mean	78	81	90	74

Table 4.5f: Analysis of variance for PAR during reproductive stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	44741.8	1	44741.8	14.52**
Within	55228.0	18	3068.22	
Total	99969.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	54.45	1	54.45	0.0383^{ns}
Within	25600.50	18	1422.25	
Total	25654.95	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	70686	1	70686	20.338**
Within	62561.5	18	3475.64	
Total	133247.5	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	365.52	1	365.52	0.209ns
Within	31467.22	18	1748.179	
Total	31832.74	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	79002.4	1	79002.4	7.129*
Within	199467.5	18	11081.53	
Total	2798469.9	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	270.12	1	27.12	0.165ns
Within	29491.22	18	1638.4	
Total	29761.24	19		

Table 4.5g: Mean PAR (Wm^{-2}) of the upper strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	959	1039	1050	846
0900	691	474	1040	567
1000	392	364	449	537
1100	432	482	565	427
1200	780	720	507	422
1300	523	632	496	466
1400	506	614	702	549
1500	339	454	526	290
1600	382	631	577	326
1700	358	520	492	318
Mean	536	593	640	475

Table 4.5h: Mean PAR (Wm^{-2}) of the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	72	66	64	46
0900	101	155	84	93
1000	56	104	134	115
1100	121	88	89	104
1200	122	92	125	106
1300	100	169	149	79
1400	78	124	151	78
1500	73	80	156	75
1600	110	116	136	88
1700	98	101	108	81
Mean	93	110	120	86

Table 4.5i: Analysis of variance for PAR during maturity stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	16131.2	1	16131.2	0.408^{ns}
Within	711343.6	18	39519.09	
Total	727474.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	1353.015	1	1353.015	1.745^{ns}
Within	13954.725	18	775.263	
Total	15307.74	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	11233.8	1	11233.8	0.2615^{ns}
Within	773366.4	18	42964.8	
Total	784600.2	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	510.05	1	510.05	0.493^{ns}
Within	18606.90	18	1033.717	
Total	19116.95	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	69856.2	1	69856.2	2.231^{ns}
Within	563717.6	18	31317.44	
Total	633573.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	2656.52	1	2656.52	3.683^{ns}
Within	12982.72	18	721.262	
Total	15639.24	19		

APPENDIX 6: PHOTOSYNTHETIC RATE (PR±5%)

Table 4.6a: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the upper strata of the canopy during vegetative phase

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	1.23	1.41	1.28	1.12
0900	1.98	2.97	2.04	1.79
1000	3.44	5.64	3.41	0.10
1100	0.37	2.93	3.18	0.37
1200	1.97	2.46	5.63	1.47
1300	9.19	7.24	3.63	3.13
1400	1.71	1.71	2.44	1.45
1500	0.98	0.73	2.54	1.62
1600	1.23	1.04	2.18	1.25
1700	0.54	0.62	0.98	0.58
Mean	2.26	2.68	2.73	1.29

Table 4.6b: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the lower strata of the canopy during vegetative phase

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0	0	0	0
0900	0	-0.25	0	-0.31
1000	0	0	-0.45	0
1100	-0.4	0	0	-0.25
1200	0	0	0	0
1300	0	-0.5	0	0
1400	0	0	-0.6	0
1500	-0.77	0	0	0
1600	0	0	0	-0.75
1700	0	-0.62	0	0
Mean	-0.12	-0.14	-0.11	-0.13

Table 4.6c: Analysis of variance for photosynthetic rate during vegetative stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.8446	1	0.8446	0.147^{ns}
Within	103.2123	18	5.734	
Total	104.0569	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.00162	1	0.00162	0.0264^{ns}
Within	1.10586	18	0.06144	
Total	1.10748	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.01568	1	0.01568	0.00478^{ns}
Within	58.98814	18	3.27712	
Total	59.00382	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.0045	1	0.0045	0.0859^{ns}
Within	0.9425	18	0.0524	
Total	0.947	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	9.61885	1	9.61885	3.488^{ns}
Within	49.63901	18	2.75772	
Total	59.25786	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.00008	1	0.00008	0.00139^{ns}
Within	1.03974	18	0.05776	
Total	1.03982	19		

Table 4.6d: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the upper strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	1.21	1.09	0.9	0.22
0900	1.63	1.24	1.0	0.25
1000	2.61	2.62	2.63	1.74
1100	1.49	2.48	3.47	0.99
1200	3.33	4.94	3.47	3.92
1300	3.30	4.42	4.02	3.42
1400	6.84	2.57	2.08	2.93
1500	2.44	2.44	1.71	3.42
1600	0.86	1.22	6.13	0.98
1700	0.00	0.00	0.24	0.00
Mean	2.37	2.30	2.57	1.79

Table 4.6e: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the lower strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	0	0	0	0
0900	0	-0.76	0	-0.51
1000	0	-0.38	0	0
1100	-0.5	-0.37	0	0
1200	0	0	0	0
1300	-0.13	-0.24	-0.48	0
1400	0	-0.62	-0.25	-0.25
1500	-0.37	0	-0.62	-0.49
1600	-0.62	-0.37	-0.62	-0.99
1700	-0.99	-0.75	-0.62	-0.99
Mean	-0.26	-0.35	-0.26	-0.32

Table 4.6f: Analysis of variance for photosynthetic rate during reproductive stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.0238	1	0.0238	0.0081^{ns}
Within	53.12985	18	2.9517	
Total	53.15365	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.03872	1	0.03872	0.373^{ns}
Within	1.86938	18	0.10385	
Total	1.9081	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.34584	1	0.34584	0.1276^{ns}
Within	48.79721	18	2.71096	
Total	49.14305	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.0405	1	0.0405	0.4702^{ns}
Within	1.5503	18	0.08613	
Total	1.59805	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	1.326125	1	1.326125	0.579^{ns}
Within	41.22477	18	2.290265	
Total	42.550895	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.00338	1	0.00338	0.0269^{ns}
Within	2.2619	18	0.12566	
Total	2.26528	19		

Table 4.6g: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the upper strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	3.86	6.72	5.71	3.76
0900	4.47	2.73	7.21	2.72
1000	2.25	1.75	2.00	2.73
1100	2.48	2.99	2.99	2.47
1200	8.44	3.70	2.72	2.49
1300	2.71	3.70	2.47	2.47
1400	2.72	3.46	3.44	2.72
1500	2.09	1.96	2.93	0.98
1600	2.09	7.35	3.18	1.72
1700	1.98	2.25	2.04	1.72
Mean	3.31	3.66	3.47	2.38

Table 4.6h: Mean photosynthetic rate (μmol $m^{-2}s^{-1}$) of the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	-0.50	-0.50	-0.63	-0.51
0900	0.00	0.00	-0.38	0.00
1000	-0.38	0.00	0.00	0.00
1100	0.00	0.00	0.00	0.00
1200	-0.13	0.00	0.00	0.00
1300	0.00	0.00	0.00	-0.25
1400	-0.38	0.00	0.00	-0.25
1500	-0.50	-0.37	0.00	-0.37
1600	-0.13	0.00	0.00	0.00
1700	0.00	0.00	0.00	0.00
Mean	-0.20	-0.09	-0.10	-0.14

Table 4.6i: Analysis of variance for photosynthetic rate during maturity stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.69952	1	0.69952	0.185^{ns}
Within	68.09418	18	3.78301	
Total	68.7137	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.066125	1	0.066125	1.640^{ns}
Within	0.72577	18	0.040321	
Total	0.791895	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	0.128	1	0.128	0.0278^{ns}
Within	82.77778	18	4.59877	
Total	82.90578	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.00098	1	0.00098	0.0235^{ns}
Within	0.7505	18	0.04169	
Total	0.75148	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	4.3338	1	4.3338	1.248^{ns}
Within	62.51455	18	3.47303	
Total	66.84835	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
Between	0.013005	1	0.013005	0.3645^{ns}
Within	0.642277	18	0.035682	
Total	0.655282	19		

APPENDIX 7: LEAF AREA INDEX (LAI±0.5)

Table 4.7a: Leaf Area Index (LAI) over the growth period

week	plot 1	plot 2	plot 3	plot 4
7th	1.70	0.53	0.59	0.42
8th	2.44	0.91	0.93	0.75
9th	3.71	1.68	1.35	1.28
10th	5.07	2.31	1.78	1.78
11th	6.83	2.79	2.24	2.09
12th	7.23	3.20	2.62	2.30
13th	7.25	3.26	2.79	2.39
14th	7.04	3.27	2.84	2.48
15th	5.69	2.97	2.69	2.89
16th	5.09	2.99	2.35	2.34
17th	4.94	2.37	2.34	2.17

Table 4.7 b: Analysis of variance for leaf area index between plot 1 and plot 2

source	S.O.S.	D.F.	mean square	F-ratio
between	44.276	1	44.276	19.41**
within	45.6173	20	2.2809	
total	89.8933	21		

Table 4.7c: Analysis of variance for leaf area index between plot 2 and plot 3

source	S.O.S.	D.F.	mean square	F-ratio
between	0.489	1	0.489	0.657ns
within	14.885	20	0.744	
total	15.374	21		

Table 4.7d: Analysis of variance for leaf area index between plot 2 and plot 4

source	S.O.S.	D.F.	mean square	F-ratio
between	1.331	1	1.331	1.904^{ns}
within	13.989	20	0.699	
total	15.320	21		

APPENDIX 8: GLOBAL IRRADIANE (GI±5%)

Table 4.8a: Mean global irradiance (Wm^{-2}) in the upper strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	845	1020	695	998
0900	1115	1362	746	1212
1000	1124	1572	799	1217
1100	1295	1084	1134	1424
1200	1352	1019	1082	1402
1300	1297	1256	853	1068
1400	1291	801	1016	1069
1500	992	774	713	1176
1600	839	80	693	1151
1700	624	79	615	875
mean	1077	905	835	1059

Table 4.8b: Mean global irradiance (Wm^{-2}) in the lower strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	184	235	302	295
0900	225	250	325	329
1000	230	255	321	319
1100	305	391	283	365
1200	340	322	277	384
1300	270	401	287	207
1400	282	301	264	269
1500	134	203	114	334
1600	201	162	116	342
1700	168	140	95	310
mean	234	266	238	315

Table 4.8c: Analysis of variance for global irradiance during vegetative stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	149127	1	149127	0.969^{ns}
within	2769976	18	153887.6	
total	2919103	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	5152	1	5152	0.858^{ns}
within	108128.9	18	6007.16	
total	113280.9	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	24571	1	24571	0.1754^{ns}
within	2521836	18	140102	
total	2546407	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	3808.8	1	3808.8	0.469^{ns}
within	146094.4	18	8116.36	
total	149903.2	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	323851	1	323851	2.346^{ns}
within	2484836	18	138046	
total	2808687	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	12201.8	1	12201.8	2.362^{ns}
within	92976.4	18	5165.36	
total	105178.2	19		

Table 4.8d: Mean global irradiance (Wm^{-2}) in the upper strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	685	690	958	1005
0900	720	855	1729	1947
1000	992	1295	1722	994
1100	916	822	833	1281
1200	874	845	1532	1281
1300	590	1339	1412	611
1400	436	759	1717	624
1500	1074	1056	182	697
1600	1046	1074	162	467
1700	995	1420	148	420
mean	833	1016	1040	933

Table 4.8e: Mean global irradiance (Wm^{-2}) in the lower strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	85	86	195	238
0900	98	92	225	285
1000	98	115	269	237
1100	133	237	204	381
1200	124	198	196	294
1300	109	125	176	171
1400	110	145	134	125
1500	162	194	53	210
1600	170	178	53	172
1700	115	154	50	156
mean	120	152	156	227

Table 4.8f: Analysis of variance for global irradiance during reproductive stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	166897	1	166897	24.398**
within	123130	18	6840.6	
total	290027	19		

(b) lower strata of canopy

source	S.O.S.	D:F.	mean square	F-ratio
between	5120	1	5120	3.203^{ns}
within	28772.8	18	1598.5	
total	33892.8	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	2881	1	2881	0.0144^{ns}
within	3592895	18	199605.3	
total	3595776	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	48.05	1	48.05	0.011^{ns}
within	78176.9	18	4343.16	
total	78224.9	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	34280	1	34280	0.148^{ns}
within	1476488	18	82027.11	
total	1510768	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	27751.25	1	27751.25	6.61*
within	75571.30	18		
total	103322.55	19		

Table 4.8g: Mean global irradiance (Wm^{-2}) in the upper strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	657	594	727	693
0900	1115	909	1040	1120
1000	1021	1052	649	388
1100	1391	1352	655	1123
1200	1257	1128	1244	1080
1300	1287	1292	1312	1075
1400	1062	614	589	1120
1500	1054	1351	1301	1210
1600	500	508	625	471
1700	226	253	254	215
mean	957	905	840	850

Table 4.8h: Mean global irradiance (Wm^{-2}) in the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	50	66	87	81
0900	91	157	202	105
1000	122	125	168	141
1100	96	188	166	196
1200	92	145	172	142
1300	160	184	203	249
1400	136	100	152	288
1500	141	202	138	166
1600	48	87	82	57
1700	40	70	80	34
mean	98	132	145	146

Figure 4.8i: Analysis of variance for global irradiance during maturity stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	13365	1	13365	0.091^{ns}
within	2653922	18	147440.11	
total	2667287	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	6055.2	1	6055.2	2.809^{ns}
within	38798.8	18	2155.5	
total	44854.0	19		

(ii) between plot 2and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	21583	1	21583	0.152^{ns}
within	2558578	18	142143.22	
total	2580161	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	793.8	1	793.8	0.334^{ns}
within	42799.0	18	2377.7	
total	43592.2	19		

(iii) between plot2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	15568	1	15568	0.107^{ns}
within	2622373	18	145687.4	
total	2637941	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	911.25	1	911.25	0.198^{ns}
within	82915.30	18	4606.41	
total	83826.55	19		

APPENDIX 9: DIFFUSE IRRADIANCE (DI±5%)

Table 4.9a: Mean diffuse irradiance (Wm^{-2}) in the upper strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	415	395	210	502
0900	531	452	265	520
1000	531	666	282	505
1100	441	807	659	515
1200	452	602	697	512
1300	441	616	392	541
1400	418	541	460	552
1500	682	624	228	715
1600	682	695	221	806
1700	408	495	201	788
mean	500	589	362	596

Table 4.9b: Mean diffuse irradiance (Wm^{-2}) in the lower strata of the canopy during vegetative stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	225	200	720	495
0900	264	295	829	537
1000	275	302	815	498
1100	380	509	715	462
1200	453	457	597	565
1300	395	615	582	282
1400	405	511	535	319
1500	239	252	221	482
1600	185	207	169	484
1700	140	195	145	425
mean	296	354	533	455

Table 4.9c: Analysis of variance for diffuse irradiance during vegetative stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	39783.2	1	39783.2	3.058^{ns}
within	234205.0	18	13011.4	
total	273988.2	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	16936.2	1	16936.2	0.970^{ns}
within	314397.0	18	17466.5	
total	331333.2	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	259464.2	1	259464.2	10.426^{**}
within	447962.6	18	24886.81	
total	707426.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	159311.2	1	159311.2	3.427^{ns}
within	836715.7	18	46484.21	
total	996026.9	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	198.4	1	198.4	0.0132^{ns}
within	270950.5	18	15052.81	
total	271148.9	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	50601.8	1	50601.8	3.165^{ns}
within	287815.0	18	15989.72	
total	338416.8	19		

Table 4.9d: Mean diffuse irradiance (Wm^{-2}) in the upper strata of the canopy during reproductive stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	405	498	420	585
0900	471	516	452	621
1000	496	513	439	558
1100	693	623	634	560
1200	710	674	711	564
1300	442	658	568	500
1400	377	556	660	516
1500	356	375	155	297
1600	351	394	143	294
1700	335	368	135	289
mean	464	518	432	478

Table 4.9e: Mean diffuse irradiance (Wm^{-2}) in the lower strata of the canopy during reproductive stage

Time(hrs)	Plot 1	Plot 2	Plot 3	Plot 4
0800	102	101	245	268
0900	122	113	255	288
1000	114	184	297	247
1100	138	413	226	496
1200	139	320	260	414
1300	109	205	182	124
1400	113	220	156	173
1500	177	208	54	226
1600	176	204	56	191
1700	152	196	56	184
mean	134	216	174	271

Table 4.9f: Analysis of variance for diffuse irradiance during reproductive stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	14526.0	1	14526.0	0.928^{ns}
within	281792.9	18	15655.16	
total	296318.9	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	33784.2.	1	33784.2	7.43^{*}
within	81838.0	18	4546.56	
total	115622.2	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	36808.2	1	36808.2	1.197^{ns}
within	553332.6	18	30740.7	
total	590140.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	8862.05	1	8862.05	1.07^{ns}
within	149060.5	18	8281.14	
total	157922.55	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	7644.0	1	7644.0	0.506^{ns}
within	271838.9	18	15102.2	
total	279482.9	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	14960.4	1	14960.4	1.35^{ns}
within	199581.3	18	11087.9	
total	214541.7	19		

Table 4.9g: Mean diffuse irradiance (Wm^{-2}) in the upper strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	178	192	205	199
0900	187	358	467	233
1000	277	356	353	297
1100	301	413	348	453
1200	378	362	387	364
1300	475	439	457	471
1400	559	510	467	578
1500	526	557	502	581
1600	311	356	378	317
1700	195	75	216	187
mean	337	362	378	368

Table 4.9h: Mean diffuse irradiance (Wm^{-2}) in the lower strata of the canopy during maturity stage

Time(hrs)	plot 1	plot 2	plot 3	plot 4
0800	77	90	154	134
0900	130	189	254	163
1000	173	200	230	199
1100	237	251	228	277
1200	185	226	240	263
1300	250	296	241	382
1400	239	236	187	381
1500	237	331	231	355
1600	103	174	178	138
1700	68	75	101	81
mean	170	207	204	237

Table 4.9i: Analysis of variance for diffuse irradiance during maturity stage

(i) between plot 1 and plot 2

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	2668.0	1	2668.0	0.134^{ns}
within	359033.7	18	19946.4	
total	361701.7	19		

(b) lower strata of the canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	6808.05	1	6808.05	1.172^{ns}
within	104524.50	18	5806.92	
total	111332.55	19		

(ii) between plot 2 and plot 3

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	1312.2	1	1312.2	0.086^{ns}
within	275053.6	18	15280.8	
total	276365.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	28.8	1	28.8	0.007^{ns}
within	80228.0	18	4457.11	
total	80256.8	19		

(iii) between plot 2 and plot 4

(a) upper strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	192.2	1	192.2	0.0092^{ns}
within	374323.6	18	20795.0	
total	374515.8	19		

(b) lower strata of canopy

source	S.O.S.	D.F.	mean square	F-ratio
between	4651.25	1	4651.25	0.496^{ns}
within	168635.70	18	9368.65	
total	173286.95	19		