ASSESSMENT OF COMPETITION FOR WATER BETWEEN *Cassia siamea* Lam. AND *Zea mays* L. USING VARIOUS PARAMETERS, IN ALLEY CROPPING UNDER SEMI-ARID CONDITIONS IN MACHAKOS DISTRICT, KENYA.

BY

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Plant Physiology and Biochemistry (Botany) in the University of Nairobi.

1991

DECLARATION

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

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DEDICATION

To my parents, Philemon C. Netondo

and

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LIST OF SYMBOLS AND ABBREVIATIONS

AF	Agroforestry
BMR	Border maize row
$^{\circ}C$	Degree celsius
^{14}C	Radioactive carbon-14
CO_2	Carbon dioxide
cm	centimeters
DARP	Dryland Agroforestry Research Project
DAS	Days After Sowing
df	degrees of freedom
FAO	Food and Agriculture Organization
FNSP	Food and Nutrition Studies Program
g	Gram(s)
hrs	hours
ICRAF	International Council for Research in Agroforestry
IRGA	Infrared Gas Analyser
KEFRI	Kenya Forestry Research Institute
LSD	Least Significant Difference
m	Metres
mm	millimeters
MMR	Middle maize row
$mmol\ m^{-2}s^{-1}$	Millimoles per metre squared per second
MPa	Megapascals
NAF	Non-agroforestry
NDFRS	National Dryland Farming Research Station

ns	not statistically significant
P	Probability
pH	negative logarithm of hydrogen ion concetration
S.E.	Standard error
$s.cm^{-1}$	Seconds per centimeter
var.	variety
*	Statistically significant at $P < 0.05$
**	Statistically significant at $p < 0.01$

ACKNOWLEDGEMENT

I am specially indebted to my supervisors; Dr. J.C. Onyango, Dr. J.N. Macharia and Prof. C.J. Stigter (TTMI-project) for their able and valuable guidance, suggestions, constructive criticisms and encouragement. More thanks are conveyed to Dr. C.L. Coulson for his important ideas and close supervision until he left the Botany Department in August, 1990.

I thank Prof. J.O. Kokwaro, as the Chairman of Botany Department, University of Nairobi, for allowing me to have access to all the necessary facilities useful to this work.

The present study was made possible due to the scholarship awarded to me by the Board of Postgraduate studies (BPS), University of Nairobi. The financial support enabled me to carry out the research work and write up the thesis. The contribution from the TTMI-project, core financed by the Netherlands government, is acknowledged.

I am also grateful to Mr. David N. Mungai, of the Geography Department, University of Nairobi, who, as a TTMI-project Ph.D. student working at the site where this study was done, was a source of inspiration providing valuable advise and ideas. He

also played an important role in encouraging me to know the use of microcomputers. More thanks go to Mr. Raphael J.K. Musyoki, a technician in Crop Science Department, University of Nairobi. He was very helpful in the repair and maintenance of the equipment used in this study.

I extend my acknowledgement to the Director of the Kenya Forestry Research Institute (KEFRI) for having kindly provided the experimental site at the Dryland Agroforestry Research Project (DARP) in Machakos for this study to be carried out. The corporation extended to me by the entire workforce of the institute was also highly appreciated.

I also acknowledge Dr. M.R. Rao together with other staff members of ICRAF for offering me accomodation at their Machakos field station guest house. I also appreciated the kind offer to use various facilities related to this study.

To all my family members and friends, I extend my sincere thanks for their encouragement throughout the study period.

ABSTRACT

A study was carried out in Machakos district, Kenya, to investigate the competition for soil moisture in an alley cropping agroforestry system. The effects on soil moisture and crop yields of Agroforestry (AF) and Non-agroforestry (NAF) systems was evaluated in two growing seasons (Experiment 1 and 2). The AF system involved alleys of a perennial shrub, *Cassia siamea* Lam. and between them a crop *Zea mays* L. var. Katumani composite B. The AF system plots were mulched with leaves and twigs lopped from the Cassia hedgerows just before planting. The NAF plots were not mulched.

Below ground interaction was determined by measurement of soil moisture using the gravimetric method. The soil was sampled using an auger, at four points of 45cm interval from the hedgerow and three depths for every point, respectively.

Measurements of stomatal resistance, transpiration rates and leaf-air temperature difference were used as above ground indicators of competition for soil moisture, and therefore water stress. These were measured every one or two weeks.

The influence of distance from *Cassia* hedgerows on soil moisture did not prove significant for the

first five measurements of experiment 1 and for the entire set of measurements of experimend 2, for all depths. There was no interaction between AF system and distance or depth.

Stomatal resistance of the middle maize row (MMR) was not significantly different from that of the border maize row (BMR) in the AF system for both experiment 1 and 2, respectively. Stomatal resistances of the AF system maize plants were generally lower and in some cases also statistically significantly different from those of the NAF system maize plants for both experiments.

Transpiration rates of maize within the AF system showed statistically insignificant variation between the MMR and the BMR. AF system maize plants showed generally higher transpiration rates than the NAF maize plants, which were again in some cases even statistically significantly different.

Leaf-air temperature differences of the MMR were not significantly different from the BMR in the AF system for both experiments. Appreciable differences were also not detected between AF and NAF systems for both experiments.

Maize yield was not suppressed by proximity to the *Cassia* hedgerows. On the contrary, the grain and cob weights of the BMR were on the average significantly higher than those of the MMR for both

experiment 1 and 2 probably due to a combination of factors such as soil temperature variation and differences in root overlapping. Maize in the AF system performed better than in the NAF system for both experiment 1 and 2, due to various improved conditions.

The study showed that competition for soil moisture between *Cassia* and maize was not significant. This will have been due to the above average rainfall recorded during the experimentation period.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

A rapid population increase in any country presents many problems to the government. One of the problems is increased population pressure on the high potential cultivable land, leading to their subdivision into small holder farms. This is now very common in many parts of Kenya. An alternative solution to this problem has been migration to the fragile marginal and semi-arid areas. These areas are estimated to cover approximately 80% of the entire land area of Kenya (FNSP, 1988). The arid lands have low carrying capacity, since rainfall is extremely variable and unpredictable. Soils are in most cases not well developed to sustainably support even a medium agricultural productivity.

The new inhabitants and those who change from traditional pastoral systems to sedentary farming in the semi-arid areas put a lot of demand on the ecosystem. Trees and shrubs are cut down to give room for continuous cultivation. Trees form the main source of fuel, and materials for furniture, building, fencing and utensils for the expanding rural population. With permanent settlement, most of these areas are hardly left fallow in order to recover through the natural regenerative processes. Owing to their limiting costs, minimum efforts are made to replace the lost nutrients through application of mineral or organic fertilizers. This over-exploitation of the major land resource by man has led to degradation and infertility of semi-arid and arid lands, ultimately resulting in soil erosion by water and wind.

In the past, research has tended to cover in general the more favourable agro-ecological zones and in most countries, development plans rarely focus specifically on the problems of the marginal areas (FAO, 1988). Therefore, more emphasis is now needed on this problem, especially for sustainable food production using recommended technologies. In the semi-arid areas, the goals and approaches of raising productivity should consider the technical, economical, environmental and social aspects of any system introduced. The aim should be focused towards optimum sustainable productivity under conditions of low external input and at the same time maintaining or restoring a balanced ecosystem.

What is required to reduce the problems of the rural communities is introduction of integrated land use systems, such as agroforestry. Agroforestry is just a new name of an age-old practice where forestry, agriculture and/or pastoralism are practised in combination (Huxley, 1989; Jama *et al.*, 1989). The potential benefits of agroforestry in humid and subhumid tropical areas are that, the same land produces food, fuelwood and fodder. This practice is also saving labour and time. The fertility of the farmland is sustained or even improved since some woody perennials have a better ability of nutrient recovery from lower soil layers than annual crops because of their root structure, which exploits a larger volume of soil by growing very deep (Huxley, 1989).

Agroforestry gets various trials in many parts of Kenya and elsewhere in the world. In Kenya, many agroforestry trials and research methodologies are being carried out by various governmental and non-governmental institutions in the semi-arid areas. The Dryland Agroforestry Research Project (DARP), under the umbrella of the Kenya Forestry Research Institute (KEFRI), has been carrying out research in Machakos district since 1983 (Arap Sang *et al.*, 1985), based on on-station and on-farm trials. These studies are aimed at developing agroforestry technologies for semi-arid areas of Kenya and other East African countries (Arap Sang *et al.*, 1985). Alley cropping or hedgerow intercropping is among the agroforestry technologies reported to have great potential in humid and subhumid tropics (Ssekabembe, 1985). Alley cropping is an agroforestry system whereby food crops are grown in alleys formed by hedgerows of leguminous shrubs or trees. During the growing season, the hedgerows are cut back and kept pruned to reduce competition with the annual crop (Kang *et al.*, 1981; Ssekabembe, 1985; Kang *et al.*, 1989; Singh *et al.*, 1989). The prunings are used as mulch on the soil or incorporated into the soil to improve the growing conditions of the annual crop. Essentially, alley cropping was developed to allow higher intensity of land use while maintaining the basic merits of shifting cultivation. It incorporates improved management, combining cropping and fallow phases (Kang *et al.*, 1989).

The potential of alley cropping in semi-arid areas of Kenya is quite diverse. The system may improve performance of crops by improving and maintaining the chemical, physical and biological conditions of the soil when the prunings are added into or on the soil as mulch. The trees or shrubs are a potential source of fuelwood and fodder. The system may also help in reducing soil erosion, which is a common phenomenon in the semi-arid areas (Young, 1987). Most of these benefits have already been demonstrated in humid and subhumid tropical conditions (Yamoah *et al.*, 1986a).

The success of alley cropping systems will in most cases depend on the choice of suitable tree species.

The tree species selected should offer a diversity of benefits and show compatibility with the crop. Increasing attention is now being paid to *Cassia siamea* Lam. as one of the trees to meet the requirements expected of an agroforestry species for alley cropping in semi-arid regions. The plant has been described as having characteristics of growing well in semi-arid and arid areas with different soil types, is fast growing and yields good amounts of mulch (Nair *et al*., 1984). The main benefits of *Cassia* as a multipurpose agroforestry species are: fuelwood, source of organic manure and soil conservation (Nair *et al*., 1984; Jama *et al*., 1989). Not enough is known about its rooting patterns (Mungai, in prep.).

An agroforestry system like alley cropping comprises two or more plant species of agricultural and forestry importance growing together whose resource requirements may be quite variable. The compatibility of growing the perennial tree with the annual crop therefore needs to be ascertained, since major resources like light (above ground), nutrients and water (below ground), will have to be shared. A situation of competition should be minimized when the resources are in limited supply and one plant species requires more of the resources than the other(s) (Caldwell, 1986). The below ground competition can be manifested in the growth and ultimate yield of the crop. It is, however, difficult to observe the actual interaction and understand the mechanism by which growth and yield are affected. Consequently, considerable information has been obtained implicating below ground competition, especially for water and nutrients, to be the basis of yield reduction.

At the DARP site on-station trials, it was generally observed that during the developmental phase, when the *Cassia* hedgerows were establishing, the maize rows adjacent to the hedgerows performed better than the maize rows in the middle of the alleys in terms of dry weights of stovers, cobs and grains. Mungai (in prep) has suggested soil temperatures as a possible factor involved, but fertilizers used and soil conditions which changed the establishment of the trees are most likely to be involved. This was different from the last season of that establishment phase, when the maize rows in the middle of the alleys performed better (Arap Sang and Hoekstra, 1986). These new negative observations on the maize rows adjacent to the hedgerows were thought to result from competition for soil moisture between the well developed *Cassia* hedgerows and the maize crop. During the operational phase, when the lopping was done, the negative impact of the hedgerows was again realised on the same parameters (Arap Sang and Hoekstra, 1987) and was also thought to be due to competition for soil moisture. Similar effects have been observed under subhumid conditions in Nigeria (Yamoah *et al*., 1986a) and were again thought to be associated with competition for soil moisture. However, reintepretation and new data by Mungai (in prep.) showed the opposite difference, the middle maize rows perfoming worse than the rows adjacent to the cassia.

However, below optimal rainfall, maize under an agroforestry system is likely to suffer from water deficit due to competition for soil moisture and this effect will be more severe the drier the conditions. The plants closest to the hedgerows may undergo more severe water deficits, as some of the previous results have indicated. This needed to be further investigated.

The present study therefore aimed at investigating soil moisture competition between *Cassia siamea* Lam. and *Zea mays* L. (var. Katumani composite B), in the DARP alley cropping trials in Machakos district. The specific objectives of this study were as given below:

(i) to establish the presence of soil moisture gradients within the alleys of the *Cassia*/Maize agroforestry (AF) system and compare this with the soil moisture in the non-agroforestry (NAF) system;

(ii) to investigate the response of stomatal resistance, transpiration rates and leaf/air temperature difference separately of the maize plants bordering the *Cassia* hedgerows, those in the middle of the alleys in the AF system and those in the NAF system;

(iii) to find the influence of meteorological parameters on objectives (i) and (ii);

(iv) to evaluate and compare crop yields of maize from the rows bordering the *Cassia* hedgerows and those in the middle of the alleys of the AF system, and compare the yields between the AF and NAF system and,

(v) to relate the findings of this study with the findings of a simultaneous study of the rooting pattern made in the same plot (Umaya, 1991) with a view of assessing the possibility of competition for soil moisture between the two components of the alley cropping system.

1.2 Literature review

1.2.1 Root interaction and competition for soil moisture

Competition for soil moisture and nutrients may be expected among the physiologically active roots of the interacting plant species. Therefore, knowledge of root distribution, both spatially and temporally, is extremely important. Such knowledge is useful in evaluating the moisture uptake with depth and distance and hence the degree of competition to be expected (Leyton, 1983).

In a situation of potential competition for soil moisture and nutrients between various plant species, the genetic characteristics, soil and climatic factors play an important role (Huck, 1983; Leyton, 1983). According to Gregory (1986), in various soil types rooting depth of many plants is restricted mainly to the volume of soil which is frequently wetted. This was previously realised by Prajapati *et al.* (1971), who found *Prosopis* roots to be confined to the top 20cm of the soil, which had a high chance of getting wet even when only small showers of rain were received. The quantity of active roots plays an important role in competition. A plant with a massive root system may be more effective in depleting soil resources in a localized zone than a neighbouring one that has less roots, since the roots occupy a great volume of the soil (Caldwell, 1986).

A desirable characteristic in agroforestry systems such as alley cropping is that roots of perennial shrubs or trees do not greatly overlap with those of annual crops. This has generally been believed to be true, since trees are usually assumed to be deep rooting, while annual crops are often shallow rooting (Berendse, 1979; Connor, 1983; Buck, 1986; Jonsson *et al.*, 1988). Buck (1986) categorized plants into three groups, with woody perennials tending to be deeper rooting than non-woody perennials and the annual crops having the shallowest root system. However, for plants growing under xeric conditions, the roots occupy only the surface layers of the soil (Prajapati *et al.*,1971; Kummerow, 1980).

Studies of root distribution have been done under various climatic conditions. Recently, Jonsson *et al.* (1988) studied the vertical distribution of fine roots (less than 2.0mm in diameter) of *Cassia siamea*, *Eucalyptus tereticornis*, *E. camaldulensis*, *Leucaena leucocephala* and *Prosopis juliflora* as well as those of maize grown in close proximity. These authors found most fine roots of the tree species occupying a similar depth range as that of maize roots. *Cassia* and *Leucaena* had more root mass than maize in the first 60 cm of the soil depth. Kang *et al.* (1981) on the other hand only found small amounts of *Leucaena* roots in the surface soil, beyond a distance of 1.0m from the hedgerows. *Leucaena* was therefore described as having a deep rooting habit, reducing the chances of competition for moisture and nutrients with maize plants. In a semi-arid environment, Singh *et al.* (1989) found *Leucaena* roots to be more densely concentrated above 1.0m soil depth for three distances from the hedgerows of 0.5m, 1.5m, and 3m respectively.

The consequence of competition for soil moisture between perennial trees or shrubs and annual crops is a different soil moisture profile and soil moisture gradients horizontally, which suggests the presence of competition. This has been demonstrated for various tree/crop interactions under varying climatic conditions. Recently, Singh *et al.* (1989), used polythene root barriers in a *Leucaena* alley cropping system and showed that the presence of the barrier allowed all distances from the hedge to have uniform moisture, but in their absence more moisture occurred further away from the hedge. More soil moisture was also found in the monoculture plots.

Studies on the effect of *Gravillea robusta* hedgerows on maize under semi-arid conditions of Machakos district, Kenya, clearly showed that the drier soils were adjacent to the hedgerows, while the more moist soils were far away (Huxley *et al.*, 1989). In a more humid environment, soil moisture was found to decrease away from the *Leucaena* hedgerows (Lal, 1989a). It was postulated that the root system of the shrubs did not affect soil moisture in sampled depths, because their active roots were likely to be deeper than those of maize. Therefore, the higher soil moisture content close to the hedgerows was probably due to shading, low evaporation (windbreak effect) and the concentration of water run-off by the hedge barrier.

1.2.2 Crop yield profiles in alley cropping systems

Crop yield profiles in alley cropping system partially reflect soil moisture distribution, especially under competition. A number of crop yield profiles have been described (Prajapati *et al.*, 1971; Yamoah *et al.*, 1986a; Singh *et al.*, 1989). Prajapati *et al.* (1971) showed that the grain and straw weights of *Sorghum vulgare* rose sharply with increase in distance from a *Prosopis* hedge and then levelled off, when root competition by *Prosopis* became practically nil. Singh *et al.* (1989) used a root barrier to eliminate water stress effects of *Leucaena* roots on cowpeas, sorghum and castor oil and this treatment greatly improved the yields, especially for cowpeas and sorghum. The yield of the cowpeas sole crop was higher compared to the crop in the alleys without a root barrier. Yamoah *et al.* (1986a) found yield reduction in cob and grain weights of maize in the rows close to the hedgerows of *Cassia, Gliricidia* and *Flemingia.* The yield reductions were attributed to shading and competition for soil moisture and nutrients. It is noteworthy that the yield reduction, with decrease in distance from the hedgerow, was correlated with a horizontal soil moisture gradient, implying that water stress is one of factors that reduced the yield.

1.2.3 Leaf measurements as water stress indicators

Stomata play an important role since they are the route through which water vapour leaves and carbon dioxide and oxygen required for photosysnthesis and respiration enter into the leaf. The stomata remain open whenever the guard cells have sufficient pressure and so the plant loses water by transpiration. Transpirational water loss continues until a threshold leaf water potential characteristic of the plant, below which the stomata close to reduce further water loss. Closure of the stomata increases the stomatal resistance. Concomitantly, the stomatal closure affects the energy balance of the leaf, since transpirational cooling is reduced. This leads to elevation of leaf temperatures, which may rise above that of air temperature if the water stress becomes more severe (Keener and Kircher, 1983). Therefore, quantification of these plant responses to drought may help in assessing plant water stress. This can also be extended to delimit the effect of water stress on crop plants in an agroforestry system resulting from competition for soil moisture with the perennial plants.

1.2.3.1 Stomatal resistance and water stress

The stomatal apertures are greatly influenced by the plant water potential and under not too extreme evaporation conditions, this directly reflects the soil moisture content. The response of the stomata depends on the turgor relations of the bulk leaf (Raschke, 1975). Therefore, below a certain water potential any change in turgor of the leaf leads to a corresponding change in the stomatal aperture. Water stress makes the turgor potential of guard cells to decrease and this causes narrowing of the stomatal aperture and eventually stomatal closure. Evidences show that normally stomata remain open until a threshold level of leaf water potential is attained, below which they start to close (Kanemasu and Tanner, 1969; Hsiao, 1973; Turner, 1974; Ackerson and Krieg, 1977; Ackerson, 1980; Schulze and Hall, 1981). However, the existence of the threshold leaf water potential may not be universal in all plants, and depends on the plant history (Ackerson, 1980) and interferes with the diurnal opening and closing rythms, with stomata oscillations and with other environmental parameters. The threshold may also not be easy to observe under field conditions, especially when the level of plant water status required for a first stomatal closure to occur is not easily reached (Schulze and Hall, 1981).

Response of stomata to water stress is also age dependent. This has been demonstrated in cotton and sorghum (Ackerson and Krieg, 1977) and in maize (Ackerson and Krieg, 1977; Antonielli *et al.*, 1984). Ackerson and Krieg (1977) showed that during the vegetative phase the stomata of maize, cotton and sorghum were very sensitive to water stress. However, very low resistances were recorded at the reproductive stage, showing that the stomata of these plants became less sensitive with increasing age. Antonielli *et al.* (1984) found a similar behaviour for maize. They found leaf stomatal resistance of maize to increase from ontogeny until maturity, then decrease with senescence, both under sunlight/normal water status of the plant and under low light/water stress conditions.

Sensitivity of stomata to water stress can differ between different plant species and between different varieties of the same plant species. Sanchez-Diaz and Kramer (1971) showed that the stomata of maize close earlier than those of sorghum (*S. vulgare*) when subjected to similar levels of water stress conditions. The minimum values of leaf water potential of maize, sorghum (*S.bicolor* (L.) Moench) and tobacco (*Nicotiana tabacum* L.) for the stomata to respond were found to be -0.8, -2.2 and -1.5 MPa, respectively (Turner, 1974). An experiment by Palta (1984) on six cultivars of cassava showed that the response of leaf diffusive resistance was different among these varieties when subjected to the same level of water stress. The differences were attributed to variations in their adaptations to drought.

The importance of stomatal resistance as an acceptable parameter of detecting water stress in plants is demonstrated by the amount of research work done to compare it with other well established parameters (Clark and Hiler, 1973; Denmead and Millar, 1976; O'Toole and Cruz, 1980; O'Toole *et al.*, 1984; Muchow *et al.*, 1986). Clark and Hiler (1973) used southern peas (*Vigna sinensis* (L.) Endl.) to demonstrate that leaf diffusive resistance is equally important as a plant water stress indicator. It was highly correlated to leaf water potential and air water vapour deficit. Measurements of several water stress indicators; transpiration rate, rate of net photosynthesis, canopy temperature minus air temperature, stomatal resistance, visual leaf rolling score in rice at different leaf water potential showed that they were all sensitive to water stress, except the rate of net photosynthesis (O'Toole *et al.*, 1984). O'Toole and Cruz (1980) had shown earlier that both the leaf diffusive resistance and the degree of leaf rolling were linearly related to leaf water potential in rice.

Denmead and Millar (1976) showed a linkage between leaf water potential, stomatal conductance and transpiration rate in wheat leaves. Leaf stomatal resistance increased when the soil dried up and transpiration rate was restricted. Specific evidences of responses of stomata of maize plants to water stress have been demonstrated (Shimshi, 1963; Raschke and Kuhl, 1969; Raschke, 1970; Lorens *et al.*, 1987b). In each case stomata were found to be highly responsive to water stress.

Stomatal resistance also responds to other environmental factors, like photon flux density, temperature and relative humidity. Denmead and Millar (1976) showed that when water potential is above the critical value, leaf stomatal resistance depends primarily on irradiance. Hence, when water stress develops due to high rates of evaporation, leaf stomatal resistance increases so that the rate of transpiration is limited. This prevents leaf water potentials from falling below their critical value (Denmead and Millar, 1976). Hall *et al.* (1975) found that the stomatal resistance of well watered citrus plants increased when the difference in absolute humidity between the leaf and the air increased.

Response of stomata to changes in vapour pressure deficit has been demonstrated in several plants (Cowan, 1981). Stomata not only close under conditions of large vapour pressure deficits, since these enhance transpiration, but low humidity itself may also cause the stomata to close during the day (Shulze and Hall, 1981). The reaction of the stomata by closing, in order to decrease the rate of transpiration, is termed a feed forward reaction (Cowan, 1981). Low temperatures lead to a decrease in vapour diffusion through stomata and this results in higher values of leaf diffusive resistance.

1.2.3.2 Transpiration rates and water stress.

Leaf stomata play an important role in controlling the rate of transpiration. Their behaviour obviously has a direct influence on transpirational water loss (Hofmann *et al.*, 1984). When the soil water content diminishes, the plant water potential also declines and the plant experiences water deficit. Therefore, the amount of water which is transpired reflects the amount of water in the plant (Rosenthal *et al*, 1987) and the evaporative demands of the atmosphere (Hall and Hoffman, 1976). Variation in crop transpiration reflects the total water supply to the crop from the soil (Fischer, 1980). Measurements of transpiration rates of a crop may, therefore, be useful in showing the extent of water stress and can be used to show the effect of plant competition for water in an agroforestry system.

Transpiration as a plant water stress indicator has been used by several authors (Raschke, 1970; Denmead and Millar, 1976; Ackerson and Krieg, 1977; Ike, 1982; Hofmann *et al.*, 1984; O'Toole *et al.*, 1984; Palta, 1984; Rosenthal *et al.*, 1987; Simmonds and Ong, 1987). Transpiration in maize was found to decrease linearly with increase in water deficit (Raschke, 1970; Ackerson and Krieg, 1977).

1.2.3.3 Leaf/air temperatures differences and water stress

Leaf/air temperature difference measurements can be useful indicators of plant water status since this differential has been shown to be highly correlated with leaf water potential (Ehrler *et al.*, 1978; Idso *et al.*, 1981; O'Toole *et al.*, 1984). Leaves of moisture stressed plants have been found to be warmer than those of non-stressed plants (Gardner *et al.*, 1981).

Leaf temperatures normally reflect the behaviour of the stomata, which control transpiration. Stomatal closure of the sun-lit leaves result in increased leaf temperatures if other relevant factors, like wind speed and vapour pressure remain relatively constant (Ehrler *et al.*, 1978). Clark and Hiler (1973) found the stomatal resistance of peas (*Vigna sinensis* (L.) Endl.) to increase as moisture stress developed. This resulted in an increased leaf temperature. Singh and Kanemasu (1983) also showed that the differences in temperatures of irrigated and non-irrigated pearl millet (*P.americanum* (L.) Leeke) strains were related to the variation in the leaf diffusive resistance. Reduced transpiration in cotton (*G.hirsutum* L.) resulted in a warmer canopy (Hatfield *et al.*, 1987). It was shown that a 10% reduction in evapotranspiration in one canopy led to its temperature being warmer by 1.5%.

Differences in temperatures between stressed and non-stressed plants have been reported in various plant species. Gardner *et al.* (1981) measured leaf and air temperatures for stressed and non-stressed maize plants and showed that the temperatures of sun-lit leaves in severely stressed plants was as much as

4.6°C above air temperature, while the temperature difference for the plants with adequate water supply was found to be either zero or negative. It was concluded that the leaf temperature/air temperature differential is a reasonable indicator of plant water status in maize. Differences obtained by Sandhu and Horton (1978), in spring oats, and Reicosky *et al.* (1980), in soybeans, were linked to differences in transpirational cooling, with more cooling occurring in the non-stressed leaves. Sandhu and Horton (1978) found maximum differences in leaf temperatures between stressed and non-stressed oat plants under maximum solar radiation. The differences increased as solar radiation increased until maximum values of 3 to 4°C were attained and later the differences dropped rapidly when solar radiation decreased. Sandhu and Horton concluded that with proper equipment calibration, there is promise for plant temperature measurements being useful for water deficit identification.

The leaf/air temperature differential also depends on the evaporative demands of the atmosphere. Stevenson and Shaw (1971) employed daily means of the leaf minus air temperature as an index of stress on plants and concluded that on low demand days, there was a negligible effect of either soil moisture or leaf angle on the temperature differences. However, differences were magnified on medium and high demand days. Vapour pressure deficit was found to increase the leaf-air temperature differential because it reduced transpirational cooling, just like reduced relative water content (Carlson *et al.*, 1972).

Following the many findings of the increase in leaf minus air temperatures with increased water stress, it has been suggested that this differential, as well as canopy temperature, could be useful as a criterion for initiating irrigation (Ehrler *et al.*, 1978; Reicosky *et al.*, 1980; Choudhury and Federer, 1984; Hatfield *et al.*, 1987). Similarly, the parameter may be useful in showing water stress arising from competition for water between the perennial tree and the annual crop in an agroforestry system like alley cropping. However, quantification of this parameter like so many others should be used with caution, since some instruments may give unreliable data resulting in wrong conclusions (Coulson *et al.*, 1988).

1.2.4 General considerations of plant water stress with implications on agroforestry

Water stress is a major limiting factor to plant productivity in most agricultural ecosystems. High evaporative demands cause water deficits to plants even when there is sufficient water in the soil (Day, 1981; Schulze and Hall, 1981). Under semi-arid conditions, evapotranspiration rates are extremely high (Day, 1981; Fischer, 1980), and therefore water deficits in plants are very common. Under such conditions, severe soil water deficits are also likely to occur under competitional conditions of agroforestry systems. Therefore, water stress effects that have been studied in individual plants may also be used to explain the yield reductions that are likely to occur in agroforestry systems.

As to yield consequences, water stress studies have concentrated on physiological, biochemical and morphological processes of plant growth, which are very much interrelated. Water stress retards growth the entire plant, leading to low yields. These influences have interested many researchers (Hsiao, 1973; Kumar and Tieszen, 1980).

When soil moisture decreases, leaves experience an increasing degree of water stress. Photosynthesis as a major plant process which contribute to plant growth and productivity may be reduced because of various effects. Stomatal closure restricts the supply of CO_2 to the photosynthetic apparatus in leaves (Boyer, 1969; 1976; Boyer and McPherson, 1975; Kumar and Tieszen, 1980; Palta, 1984; Lawlor and Pock, 1985). Since carbon dioxide contributes about 95% of the dry matter accumulation (Zelitch, 1987) closure of stomata therefore limits photosynthetic activity, thereby influencing total plant dry matter accumulation (Boyer and McPherson, 1975; Lawlor, 1983).

A further reduction of photosynthesis results from non-stomatal factors, which become effective under moderate to severe water stress conditions. These limit photosysnthesis by interfering with the proper functioning of the chloroplasts. Several investigators have used chloroplast tissues (Keck and Boyer, 1974; Boyer, 1976; Fellows and Boyer, 1976; Mohanty and Boyer, 1976; Vapaavuori and Valanne, 1982; Boyer and Younis, 1983; Lawlor, 1983; Valke and Van Poucke, 1983) to elucidate these effects. Damage to the photosynthetic system seriously disrupt metabolism resulting in low crop productivity. Non-stomatal factors that limit photosynthesis of plants under water stress conditions include; inhibition of electron transport (Keck and Boyer, 1974; Lawlor and Pocke, 1985), disruption of the chloroplast membranes and the inactivation of the enzymes involved in photosynthetic carbon fixation, especially ribulose bisphosphate carboxylase (Keck and Boyer, 1974; Lawlor, 1983).

Water stress further restricts photosynthesis by increasing the chances of photoinhibition and reducing quantum efficiency (Lawlor, 1983; Boyer *et al.*, 1987). It is envisaged that the photochemical efficiency of the chloroplasts for carbon dioxide reduction falls, leading to reduced CO_2 assimilation (Boyer *et al.*, 1987). During photoinhibition, the chloroplasts are damaged by excess light when the rate of CO_2 assimilation is reduced, hence the chloroplast pigments undergo photooxidation (Lawlor, 1983; Ludlow and Powles, 1988). Photoinhibition has been demonstrated in chloroplasts of sunflower (*Helianthus annus* L.) and in soybean (*Glycine max* (L.) Merr.) (Mohanty and Boyer, 1976) and in grapevine (*Vitis vinifera* L.) (Downton, 1983) which had been subjected to water stress. Downton (1983) noticed photoinhibition through fluorescence changes. The photosynthetic apparatus also appeared to have been damaged.

Moderate to severe water stress also slows down the rate of cell division, due to reduced turgor, since cell turgidity plays an important role in the process of leaf development (Kirkham *et al.*, 1972; Hsiao, 1973). This results in reduced light interception. Experimental evidences show that water stress limits leaf production and expansion (Denmead and Shaw, 1960; Boyer, 1970; Acevedo *et al.*, 1971; Boyer and McPherson, 1975; Palta, 1984; Sobrado, 1986; Rosenthal *et al.*, 1987). Denmead and Shaw (1960) measured leaf area of water stressed maize plants and found the stressed plants to have less leaf area as compared to the non-stressed plants. The decrease in leaf area was used to explain the observed decline in canopy CO_2 assimilation.

Acevedo *et al.* (1971) found maize leaf expansion to be highly sensitive to reduction in soil water potential. The rate of elongation dropped drastically as water stress increased. Similar effects were earlier observed by Boyer (1970) in maize, soybean and sunflower. Leaf enlargement was found to be sensitive to water stress than photosynthesis. Leaf growth ceased when turgor potential dropped to zero.

The sensitivity of leaf expansion to water stress differs among plant species and among cultivars of the same species. This was demonstrated in six cultivars of maize (Sobrado, 1986). The author also confirmed that leaf expansion in maize is more sensitive to water stress than dry matter accumulation. Leaf growth decreased as osmotic potential dropped and was virtually nil before turgor was fully lost at about -0.2MPa. Osmotic adjustment was also observed in the six maize cultivars, which is advantageous under water stress conditions.

Water stress was observed to delay the rate of leaf production and leaf extension in six cultivars of cassava (*Manihot esculentum* L.) (Palta, 1984). The sensitivity of these parameters was species specific.

Leaf area reduction in crop plants that resulted from water stress brought about by competition for water in an alley cropping agroforestry system was recently demonstrated (Singh *et al.*, 1989). The leaf area index (LAI) of cowpeas and sorghum growing in the alleys of *Leaucaena* hedgerows was less than that of the pure crops. In addition, a polythene barrier put in the soil adjacent to the hedgerows increased the LAI as compared to when the barrier was absent. Therefore, competition for soil moisture produced water deficits to plants in the former treatment and reduced their leaf area.

Water stress reduces leaf surface area by accelerating leaf senescence (Boyer and Mcpherson, 1975; Kao, 1981; Rosenthal *et al.*, 1987). The light harvesting surface area is greatly reduced, leading to limited photosynthesis and hence limited plant productivity. Reduction in leaf surface area by senescence is a response of the plant to minimize the transpirational surface area. Morover, during the reproductive phase, the metabolic changes which occur ensure that carbohydrates and nitrogen compounds are mobilized to the storage organs like grains and fruits at the expense of leaves (Boyer and McPherson, 1975; Rosenthal *et al.*, 1987). Accelerated leaf senescence due to water stress in agroforestry could therefore contribute to reduction in crop yield, since the process limits light interception and nutrients availability in leaves.

Products of photosynthesis eventually move to the various parts of the plant body, especially the harvestable parts. Water stress retards the rate of photosynthate translocation (Brevedan and Hodges, 1973; Hsiao, 1973; Boyer and McPherson, 1975; Westgate and Boyer, 1986). Radioactive ^{14}C experiments have shown that photosynthesis is much more affected than translocation (Brevedan and Hodges, 1973); Jurgens *et al.*, 1978). Jurgens *et al.* (1978) also showed that dry matter accumulation was affected by water stress, since desiccated plants exhibited slower gain in dry weight than the control plants.

The effect of water stress on protein synthesis is well documented (Kramer, 1983). Reduced protein synthesis resulting from water stress affect the nutritional quality of the crop products (Boyer and McPherson, 1975). It has been demonstrated that the protein synthesizing apparatus is interfered with in droughted plants (Hsiao, 1970; Morillar *et al.*, 1973). The activity of the enzyme nitrate reductase is reduced under water stress and since it plays an important role in protein synthesis, protein content of the plant is lowered (Hsiao, 1973; Boyer and McPherson, 1975). Morillar *et al.* (1973) showed that nitrate reductase activity was 60 to 70% at leaf water potential of -0.8MPa, while photosynthesis had dropped by 10 to 20% .

1.2.4.1 Water stress and crop yield

The effect of water stress to crop yield is a complex phenomenon. All the factors responsible for limiting plant growth are involved. A deficiency of water during any growth stage of maize often results in loss of grain yield (Lorens *et al.*, 1987b). The magnitude of the yield reduction depends on the growth stage of the crop at the time of stress, the severity and duration of the stress and the susceptibility of the genotype to the stress (Lorens *et al.*, 1987b). At the vegetative stage, water stress on maize reduces leaf, stem and root expansion and ultimately affects the potential grain yield (Denmead and Shaw, 1960).

The effects of water stress on harvestable yield such as grains or fruits is of much interest. Although water stress can occur at any stage of plant growth, sensitive phase(s) differs between various plants (Hsiao, 1973; Westgate and Boyer, 1986). Stresses that occur during early fruit filling stage are more important than those which occur near fruit maturity, in distribution of assimilates to the sink (Connor, 1983). It has been demonstrated that subsequent grain yield of maize is critically affected by water stress at the anthesis stage (Moss and Downey, 1971; Westgate and Boyer, 1986). Although fertilization takes place, embryo development is suppressed, probably due to lack of nutrients for grain development (Westgate and Boyer, 1986). Jurgens *et al.* (1978) showed that grain components of maize are markedly affected by water stress. It was observed that kernel weight and percentage oil were reduced by desiccation. The grain weight at harvest was more than double for well watered compared to the desiccated plants, indicating that dry matter accumulation was much less for the desiccated plants, although translocation of photosysnthates still continued under water stress conditions.

CHAPTER 2

MATERIALS AND METHODS

2.1 Site description

2.1.1 Location, climate and soils

The alley cropping system was established at the National Dryland Farming Research Station (NDFRS), Katumani, by the Dryland Agroforestry Research Project (DARP) in Machakos district, Kenya, in November 1983. The site is situated about 7 km south of Machakos town (1^{o} 30′ S, 37^{o} 15′ E; 1560m above sea level).

According to Jama *et al.* (1989) the site lies within the subhumid to semi-arid climatic zone with an average annual rainfall of about 700mm, bimodal in nature, and dry periods of about 6 to 7 months in total. The first season rains (so called long rains) are received during the late March to the end of May (average 270mm) and the second season rains (so called short rains) during late October to late December (average 250mm). There is quite some annual variability in the distribution and total amount of rainfall received. The annual average temperature is 19.2^{o}C and potential evapotranspiration rates is approximately 1800mm per year; creating a deficit of about 1100mm per year.

The soils are classified as luvisols, including pisoferic and lithic soil types (FAO, and Kenya soil classification systems, cited by Jama *et al.*, 1989).

These soils are of moderate fertility (1.0 to 1.5% top soil organic carbon; pH, 6.0-6.5) and are porous, friable, moderately leached and highly erodible.

2.1.2 The DARP alley cropping trials experimental layout

The experiment was established as a randomized design. Three treatments were established as agroforestry, 1.0 m and 0.25 m within row spacing of *Cassia*; and the non-agroforestry (sole crop) plots. These are replicated four times in each case. There are four hedgerows per AF plot which are 10m long and the between row spacing of 3.6m.

At the start of every cropping season, the *Cassia* is lopped to a height of 0.5m. Lopping is done separately for each hedgerow. The woody materials are then separated from leaves and twigs. The leaves and twigs are then weighed before being evenly spread in the alleys and ploughed in the soil. Incorporation of mulch is done in such a way that the amount applied correspond to the prunings in each plot. Mulch is not applied in the non-agroforestry plots (controls). Planting is done before the start of the rains. Three rows of maize (*Zea mays* L. cv. Katumani composite B) is grown within each alley of the agroforestry plots and five rows in the non-agroforestry plots at a spacing of 0.9 m (between rows) and 0.3 m (in-rows)

(Fig 2.1). Two seeds are initially sown in each hole and thinning is then done after germination, leaving single plants per hole.

2.2 Experimental programme

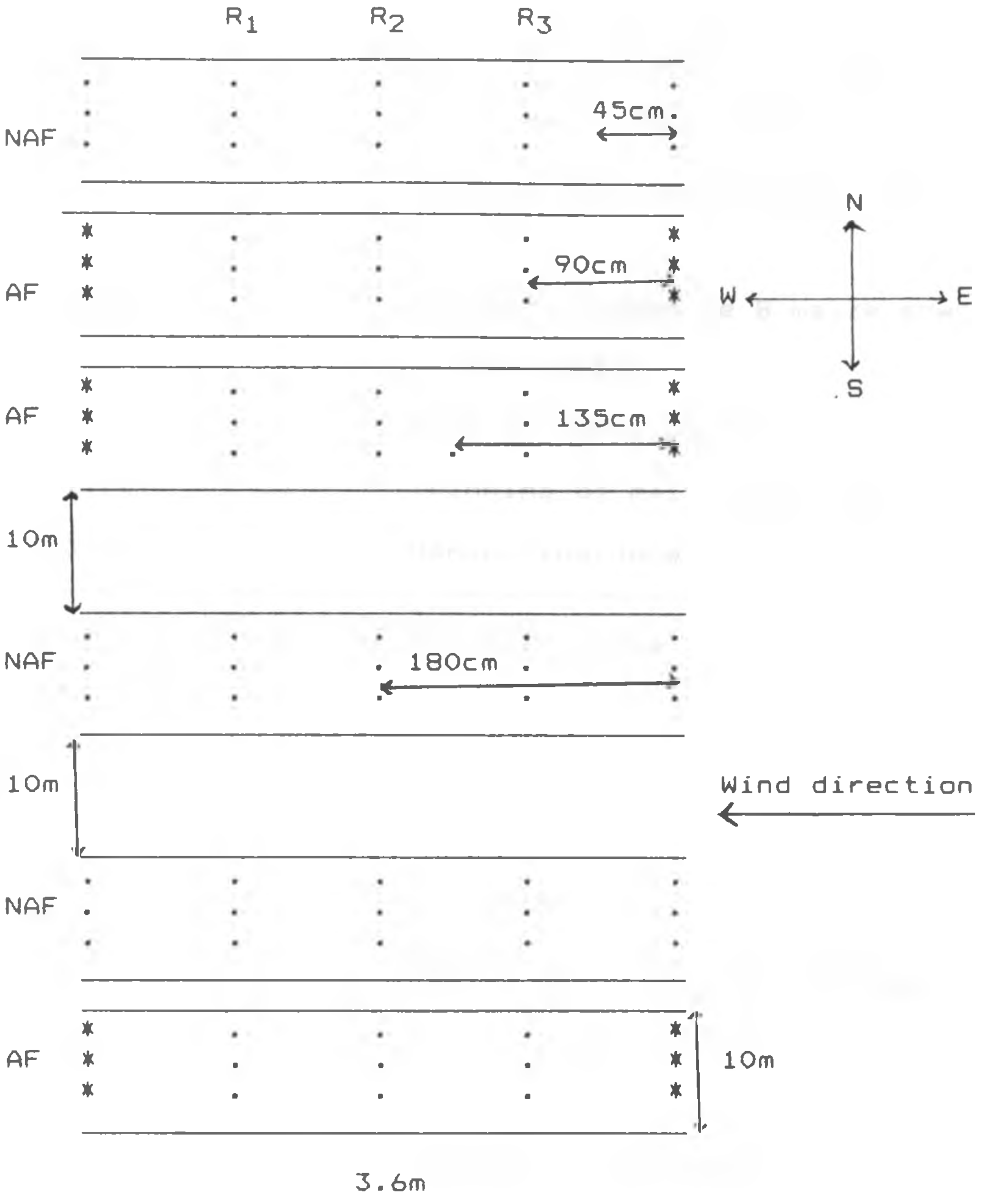
Figure 2.1 shows part of the DARP plot on which the present experiment was carried out. *Cassia* hedgerows with an in-row spacing of 0.25m and forming the middle alley of the AF plots was where all measurements were made. *Cassia* hedgerows in the AF system were replaced by maize rows in the NAF system plots and measurements were carried out within this area as later described. The experiment involved collecting data for two consecutive cropping seasons, the second cropping season of 1989 (experiment 1) and the first cropping season of 1990 (experiment 2). Table 2.1a and 2.1b represent the calendar of agricultural activities.

In both experiments, weeding was frequently done, to keep the experimental plot weed free.

2.2.1 Measurements of soil and plant parameters

2.2.1.1 Measurement of soil moisture

Characterization of soil moisture regimes was made gravimetrically. Cores of soil were removed from the appropriate depths using an auger and immediately weighed to give fresh weight. These were oven-dried



LEGENDS

AF = Agroforestry
NAF = Non-agroforestry
... = Maize rows
*** = *Cassia* hedgerows
R_1-R_3 = maize row number 1 to 3

Figure 2.1. The layout of the experiment at DARP, Machakos.

Date	Event
13/10/89	*Cassia siamea* shrubs planted in November 1983 were lopped, weighed and incorporated into the soil.
31/10/89	Katumani composite B maize sown in all plots.
10/11/89	Date of germination
23/11/89	Thinning of maize seedlings
13/3/90	Harvesting done

Table 2.1a. Calendar of agricultural activities for experiment 1.

Date	Event
15/3/90	*Cassia* was lopped and weighed
16/3/90	Mulch was applied and incorporated into the soil.
17/3/90	Katumani composite B maize sown in all plots.
25/3/90	Date of germination
10/4/90	Thinning of maize seedlings
16/8/90	Harvesting done

Table 2.1b. Calendar of agricultural activities for experiment 2.

at $105^{\circ}C$ for 24 hours to constant dry weight. The loss in weight relative to the oven-dry weight represented the moisture content, which was then expressed as a percentage.

The soil moisture measurements were made at four distances from the the *Cassia* hedgerows on the eastern side of the plot in the middle alleys, for the 15-20 cm, 35-40 cm and 55-60 cm depths. The distances from the *Cassia* hedgerows were 45cm, 90cm, 135cm and 180cm (Fig. 2.1). These represented the positions between *Cassia* hedgerow and maize rows R_3, within R_3, between R_3 and maize row R_2, and within R_2 of the AF system respectively. In the NAF system, soil moisture was estimated as in the alleys of the AF system, with similar depths and distances. A similar method was recently used by Lal (1989a). Soil samples were taken in three replicate points (3 AF and 3 NAF) for each depth, distance and date. Measurements were made after every two weeks, up to the time of physiological maturity of the crop.

2.2.1.2 Measurement of stomatal resistance

Leaf stomatal resistance was measured with a Delta-T Automatic porometer MKII (Delta-T Devices, Cambridge, U.K.). Calibration was made as recommended by Beadle *et al.* (1985). Standard curves were obtained at every period of measurement (at different temperatures) using a perforated plate with known diffusive resistances. These curves were then used in estimating the resistances from the number of counts recorded for every record of measurement.

Measurements were made on the leaves of maize rows R_2 and R_3 (Fig. 2.1) within the middle alleys of the AF system and similar rows in the NAF system. These maize rows are also referred to as middle maize row (MMR) and border maize row (BMR), respectively. Both abaxial (lower) and adaxial (upper) sides of the leaf surfaces were measured and the total leaf stomatal resistance was calculated by assuming that the individual surfaces acted as parallel resistors (Lorens *et al.*, 1987a). Five plants were selected for measurement in each row of maize. Leaves selected for measurement were the top fully expanded ones, which were well exposed.

Stomatal resistance measurements together with those of transpiration and leaf/air temperature differences were carried out at times of direct sunlight or when the sun was diffusely visible, between 9.00 hours and 15.00 hours where possible, three times per day, at 9.00 hours, 12.00 hours and 15.00 hours. Readings were made with an interval of about one or two weeks, depending on the weather conditions.

2.2.1.3 Measurements of transpiration rates

Transpiration rates were measured with a portable

Infrared Gas Analyser (Analytical Development Company Ltd., U.K.) composed of the ADC LCA-2 portable IRGA; The ADC air supply unit; ADC Parkinson Leaf Chamber and the ADC data logger. Calibration of the analyser was frequently done using carbon dioxide gas of known concentration (Long and Hallgren, 1985). All the parameters measured or calculated by the analyser were stored in the data logger and later retrieved into the lotus programme on an IBM computer.

The procedure of measurement was essentially as for the stomatal resistance measurements.

2.2.1.4 Measurements of leaf and air temperatures

A Li-Cor model 1600 steady state porometer (Li-Cor Inc; Lincoln, NE), equipped with a thermistor sensor, was used in measuring leaf temperatures. The thermistor in the leaf chamber was pressed on the upper surface of the leaf for measurement of leaf temperature. Air temperature was measured about 1.0m above the canopy. Both measurements were recorded almost simultaneously. The difference between leaf and air temperature was then calculated.

The sampling criteria was as in the leaf stomatal resistance and transpiration rates. These measurements were done at one or two week(s) intervals depending on weather conditions.

2.2.1.5 Yield data

A routine procedure used in harvesting was followed. The various dates of harvesting are shown in table 2.1a and 2.1b. The crop in experiment 1 was harvested 133DAS while that in experiment 2 was harvested 152DAS. In both experiments the crops were physiologically mature since the maturity time of this maize variety is 100-120 days (Mwenda, 1983). The differences in harvesting time was due to the early on-set of rainfall for the experiment 2 crop which necessited earlier harvesting of experiment 1 crop. A longer dry spell was experienced after maturity of experiment 2 crop, therefore there was no need to hurry the harvesting. Harvesting involved separation of individual plants in each row, R_1, R_2 and R_3 (Fig. 2.1) for each plot. These maize rows are also named relative to the *Cassia* hedge rows as border maize row on western side (BMRW), MMR and border maize row on eastern side (BMRE), respectively. Cobs were removed from the stover and put into paper bags, which had previously been labelled with indications of the plot number, row number and plant number. The harvested maize was further sun-dried before shelling. Separate weights for every plant were determined for the grains and cobs.

2.2.1.6 Meteorological data

The experimental site was close to the International Council for Research in Agroforestry (ICRAF) field station, where an automatic agro-meteorological station is situated. Regular readings are made of air temperatures, soil temperatures, air humidity, wind speed and direction, total radiation flux, net radiation balance, rainfall and evaporation. These are compiled and produced as an ICRAF monthly meteorological bulletin. For the present study, the most relevant parameters were rainfall, evaporation and air temperature.

2.3 Statistical treatment of the data

2.3.1 Soil moisture data

Analyses of variance were performed and F-tests were then used to identify differences between distances from the hedgerows, between depths and between agroforestry and non-agroforestry systems.

2.3.2 Plant physiological data

Plant physiological data of stomatal resistance, transpiration rates and leaf-air temperature differences were analysed by the one-way classification analysis of variance. F-tests ($P \leq 0.01$

and 0.05) were used to ascertain the existence of significant differences between mean values and significantly different means were identified by the use of Least Significant Difference (LSD) test at $P \leq 0.05$.

2.3.3 Yield data

Statistical tests of yield data involved comparing the data of the border maize rows with those of the middle row and comparing the data of the AF system with those of the NAF system. Analysis of variance was performed in each case and interpretation was based on F-values and LSD at $P \leq 0.05$.

CHAPTER 3

RESULTS

3.1 Rainfall, evaporation and temperature

Data for total monthly rainfall and class A pan evaporation are presented in table 3.1a. During the second growing season of 1989 (experiment 1), the total amount of rainfall received was 441mm. The highest amount was received in the month of October (138.3mm) and the least amount was received in January (73.3mm). In the first growing season of 1990 (experiment 2), the total amount of rainfall received in the months of March, April, May and June was 630.1mm. The highest amount fell in the months of March and April and the rainfall diminished to only 9.3mm in the month of June. Appendix 1 shows the distribution of rainfall for every three decades (8, 10 or 11 days) of each month during both experiment 1 and 2. This clearly shows how the rainfall was distributed and this is useful in explaining the profile of soil moisture distribution in the experimental plots temporally.

Total class A pan evaporation for experiment 1 was 674.7mm while that for experiment 2 was 573.8mm. This shows that during experiment 1, total evaporation was higher than precipitation by 233.5mm, while during experiment 2, the total precipitation was higher than

Month	Rainfall (mm)	Class A pan evaporation (mm)
October	138.3	224.7
November	131.3	146.4
December	98.3	140.5
January	73.3	163.1
Total	441.2	674.7
March	245.5	217.5
April	283.5	130.2
May	91.8	124.4
June	9.3	101.7
Total	630.1	573.8

Table 3.1a. Monthly rainfall distribution and class A pan evaporation, from October 1989 to January 1990 and from March to June 1990, at the ICRAF field station, Machakos.

month	Temperature (°C)		
	Maximum	Minimum	Mean
October	26.7	14.3	19.3
November	25.0	15.1	18.9
December	25.4	16.1	19.2
January	25.6	13.6	18.9
February	28.4	14.4	20.4
March	26.1	17.9	19.6
April	25.7	15.4	19.2
May	25.6	14.6	18.8
June	24.1	11.9	16.8

Table 3.1b. Monthly maximum, minimum and average air temperature (°C), from October 1989 to June 1990, at the ICRAF field station, Machakos.

evaporation by 56.3mm. Yields were nevertheless higher in the first experiment. This applies to AF as well as to NAF systems.

Table 3.1b shows the monthly air temperatures recorded at the ICRAF agrometeorological station during the period of both experiments. The mean monthly minimum, mean monthly maximum and monthly averages are shown. It is evident from the table that there was not much fluctuation in monthly mean air temperatures during both experimental periods. The range of the monthly mean temperatures was from 16.8°C to 20.4°C. For the whole period, the maximum monthly average air temperature was 28.4°C recorded in February and the minimum monthly average temperature was 11.9°C recorded in June.

3.2 Soil moisture

Tables 3.2a, 3.2b, 3.2c and 3.2d show the analysis of variance F-ratios of soil moisture data collected in both experiment 1 and 2. A statistical test was initially applied to the data from both the AF and the NAF systems in combination. The results (Table 3.2a, 3.2b) show that there was no significant difference ($P \leq 0.05$) between soil moisture taken from the four positions from the *Cassia* hedgerows, for all the DAS

Source of variation	df	DAS of soil moisture samplings		
		17	31	45
Main effects	6	3.36 **	1.61 ns	2.81 *
system (S)	1	0.67 ns	2.43 ns	7.21 **
Distance (D)	3	0.28 ns	0.67 ns	0.33 ns
Depth (L)	2	9.32 **	2.61 ns	4.15 *
Two- way interactions	11	0.55 ns	0.77 ns	0.29 ns
S x D	3	0.11 ns	0.29 ns	0.12 ns
S x L	2	2.42 ns	2.94 ns	1.12 ns
D x L	6	0.15 ns	0.28 ns	0.08 ns
Three-way interactions	6	0.03 ns	0.19 ns	0.16 ns
S x D x L	6	0.03 ns	0.19 ns	0.16 ns
Explained	6	1.15 ns	0.84 ns	0.91 ns
Residual	48			
Total	71			

Table 3.2a. (Continue).

		58	75	88
Main effects	6	7.97 **	2.20 ns	6.26 **
system (S)	1	4.17 *	1.31 ns	22.27 **
Distance (D)	3	0.17 ns	0.29 ns	0.81 ns
Depth (L)	2	21.58 **	5.52 **	6.42 ns
Two-way interactions	11	0.26 ns	0.19 ns	0.77 ns
S x D	3	0.37 ns	0.06 ns	0.02 ns
S x L	2	0.55 ns	0.82 ns	3.36 ns
D x L	6	0.11 ns	0.04 ns	0.29 ns
Three-way interactions	6	0.11 ns	0.03 ns	0.06 ns
S x D x L	6	0.11 ns	0.03 ns	0.06 ns
Explained	6	2.23 *	0.67 ns	2.02 **
Residual	48			
Total	71			

Table 3.2a. Analysis of variance table of 'F' ratios for soil moisture of Experiment 1.

Source of variation	df	DAS of soil moisture samplings				
		38	55	69	83	97
Main effects	6	3.36 **	0.32 ns	9.22 **	8.31 **	8.94 **
System (S)	1	0.21 ns	0.04 ns	1.54 ns	5.16 **	0.10 ns
Distance (D)	3	0.48 ns	0.17 ns	0.42 ns	0.06 ns	0.22 ns
Depth (L)	2	9.24 **	0.72 ns	26.26 **	22.27 **	26.43 **
Two-way interactions	11	0.18 ns	0.24 ns	0.39 ns	0.49 ns	0.19 ns
S x D	3	0.29 ns	0.03 ns	0.56 ns	0.45 ns	0.30 ns
S x L	2	0.39 ns	0.14 ns	0.52 ns	0.98 ns	0.46 ns
D x L	6	0.06 ns	0.37 ns	0.25 ns	0.34 ns	0.05 ns
Three-way interactions	6	0.04 ns	0.14 ns	0.06 ns	0.20 ns	0.10 ns
S x D x L	6	0.04 ns	0.14 ns	0.06 ns	0.20 ns	0.10 ns
Explained	6	0.97 ns	0.23 ns	2.61 **	2.45 **	2.45 **
Residual	48					
Total	71					

Table 3.2b (cont.)

Table 3.2b. Analysis of variance table of 'F' ratios for soil moisture of experiment 2.

Depth	Source of variation	df	DAS of soil moisture samplings		
			17	31	45
15-20	Distance	3	0.0 ns	0.1 ns	0.1ns
	Error	8			
35-40	Distance	3	0.2 ns	0.5 ns	0.4ns
	Error	8			
55-60	Distance	3	0.4 ns	1.9 ns	1.0ns
	Error	8			

Table 3.2c. (Cont.)

Depth	Source of variation	df	DAS of soil moisture samplings		
			58	75	88
15-20	Distance	3	1.2 ns	0.0 ns	4.2 *
	Error	8			
35-40	Distance	3	2.0 ns	0.4 ns	0.8 ns
	Error	8			
55-60	Distance	3	0.4 ns	0.6 ns	0.9 ns
	Error	8			

Table. 3.2c. One-way analysis of variance table of 'F' ratios of soil moisture in experiment 1 for separate depths in the AF system.

Depths	Source of variation	df	DAS of soil moisture samplings 38	55	69
15-20	Distance	3	1.0 ns	0.2 ns	0.5 ns
	Error	8			
35-40	Distance	3	0.1 ns	0.3 ns	1.1 ns
	Error	8			
55-60	Distance	3	0.2 ns	0.0 ns	1.6 ns
	Error	8			

Table 3.2d (Cont.)

Depth	Source of variation	df	DAS of soil moisture samplings 83	97
15-20	Distance		0.2 ns	0.1 ns
	Error			
35-40	Distance			
	Error		0.6 ns	0.2 ns
55-60	Distance			
	Error		0.0 ns	1.5 ns

table 3.2d One-way analysis of variance table of 'F' ratios of soil moisture in experiment 2 for separate depths in the AF system.

measurements in both experiment 1 and 2, respectively. However, a one-way analysis of variance for the separate depths in the AF system (Tables 3.2c, 3.2d) revealed that there was one significant difference ($P \leq 0.05$) in soil moisture distribution 88DAS for the 15-20cm depth (Table 3.2c), with higher soil moisture occurring away from the hedgerow.

The percentage moisture content of the AF system was significantly different from the NAF 45DAS ($p \leq 0.01$), 58DAS ($P \leq 0.05$) (Experiment 1) and 83DAS ($P \leq 0.01$; Experiment 2). The percentage soil moisture content in the AF system was in all cases higher than in the NAF system except for 88DAS. Soil moisture content increased with depth and the differences proved statistically significant ($P \leq 0.01$; 0.05) for various DAS (Tables 3.2a, 3.2b).

The interactions between the systems and depth, systems and distance; and systems, distance and depth were not statistically significant ($P \leq 0.05$) indicating that all the systems and plots behaved in a similar way.

Figures 3.1a, 3.2a and 3.3a show the soil moisture distribution in the four distances of the middle alley of the AF system 31DAS, 58DAS and 75DAS of experiment 1. Figures 3.1b, 3.2b and 3.3b show the soil moisture distribution in the NAF system taken during the same DAS. These periods coincided with the

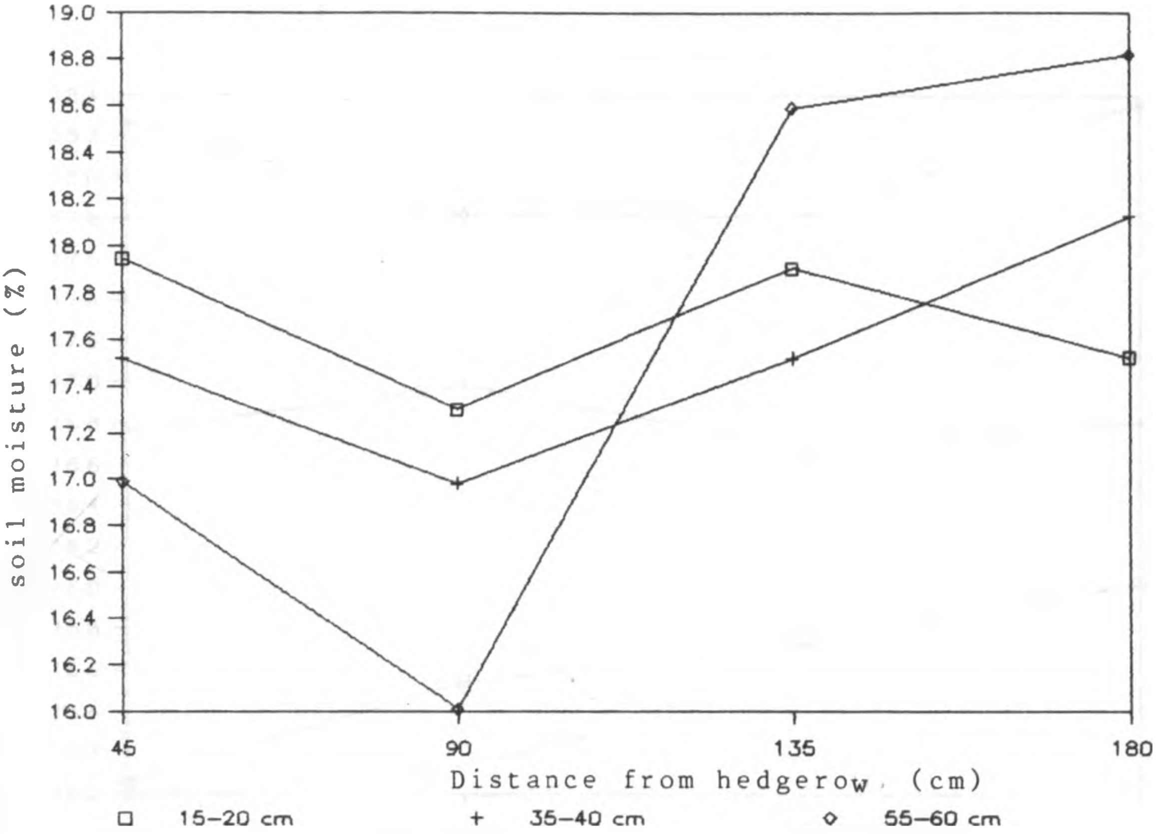


Fig. 3.1a. Soil moisture distribution at four distances and three depths in the AF system 31DAS, pre-flowering stage, during experiment 1.

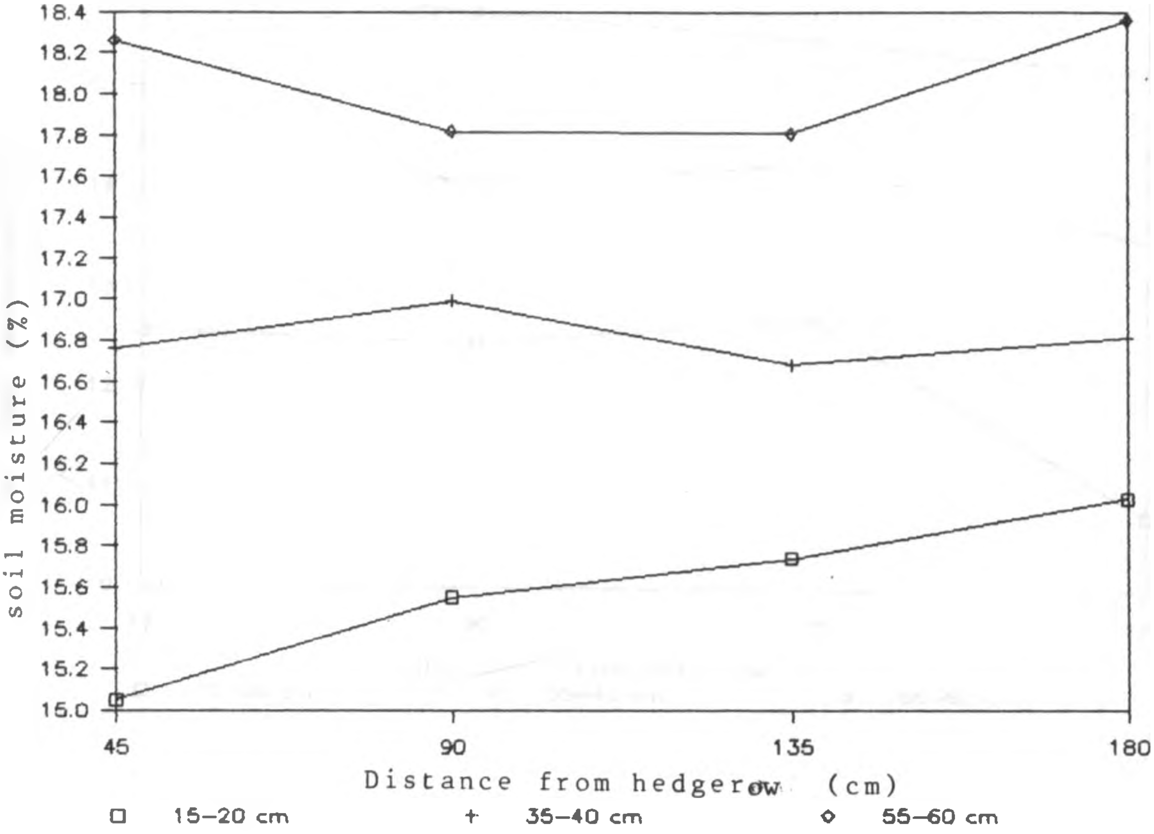


Fig. 3.1b. Soil moisture distribution at four distances and three depths in the NAF system 31DAS, pre-flowering stage, during experiment 1.

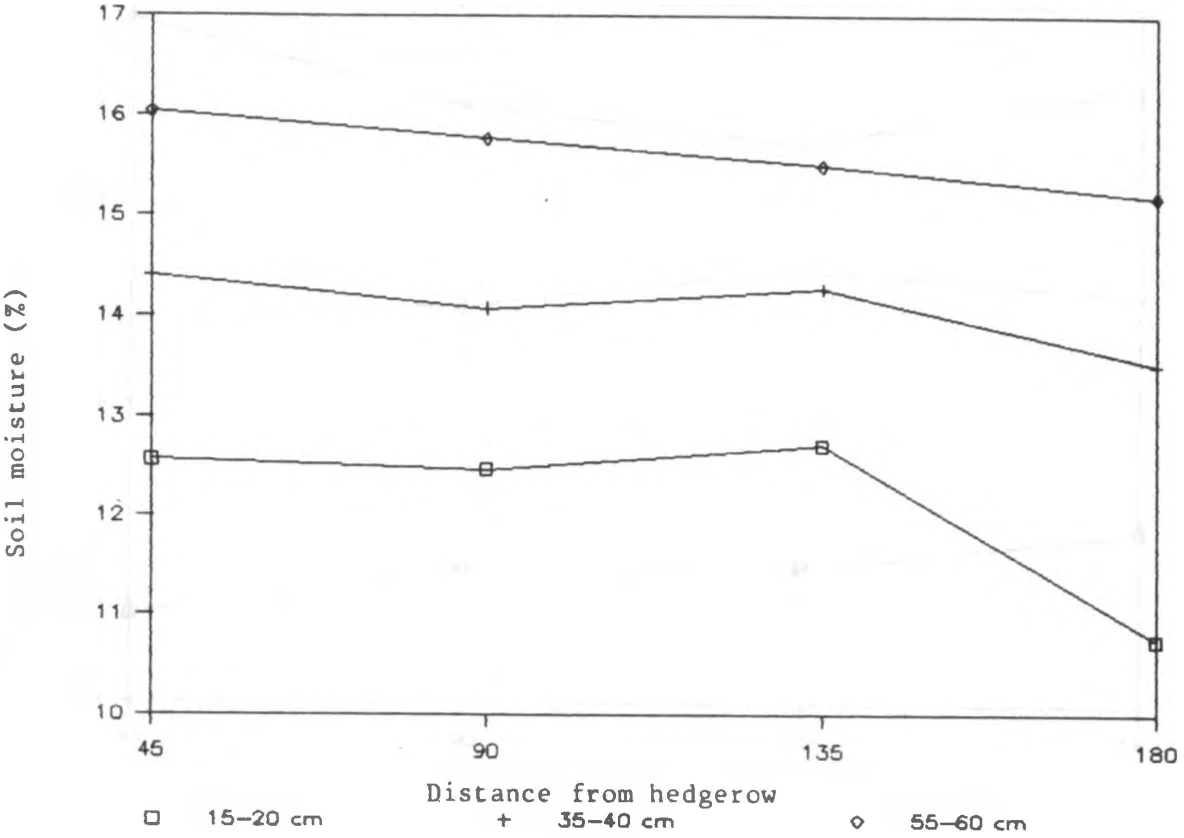


Fig. 3.2a. Soil moisture distribution at four distances and three depths in the AF system 58DAS, flowering stage, during experiment 1.

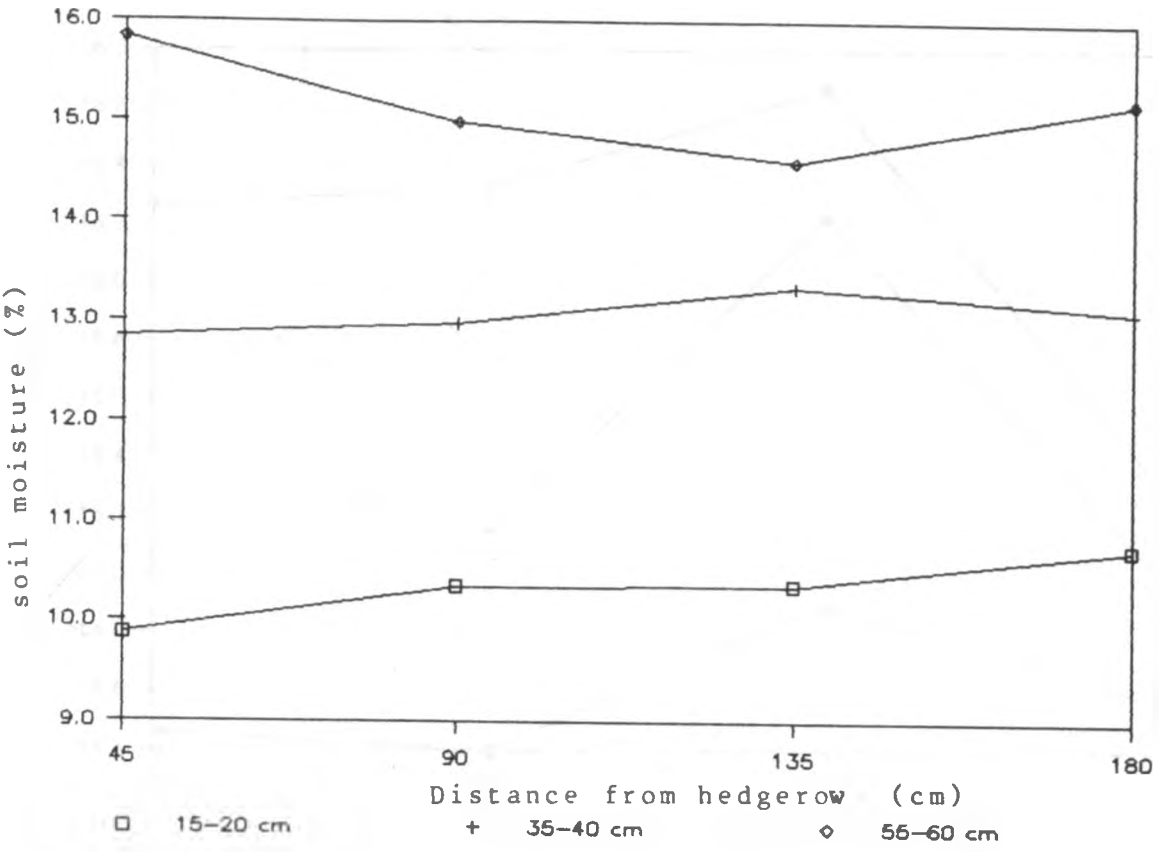


Fig. 3.2b. Soil moisture distribution at four distances and three depths in the NAF system 58DAS, flowering stage, during experiment 1.

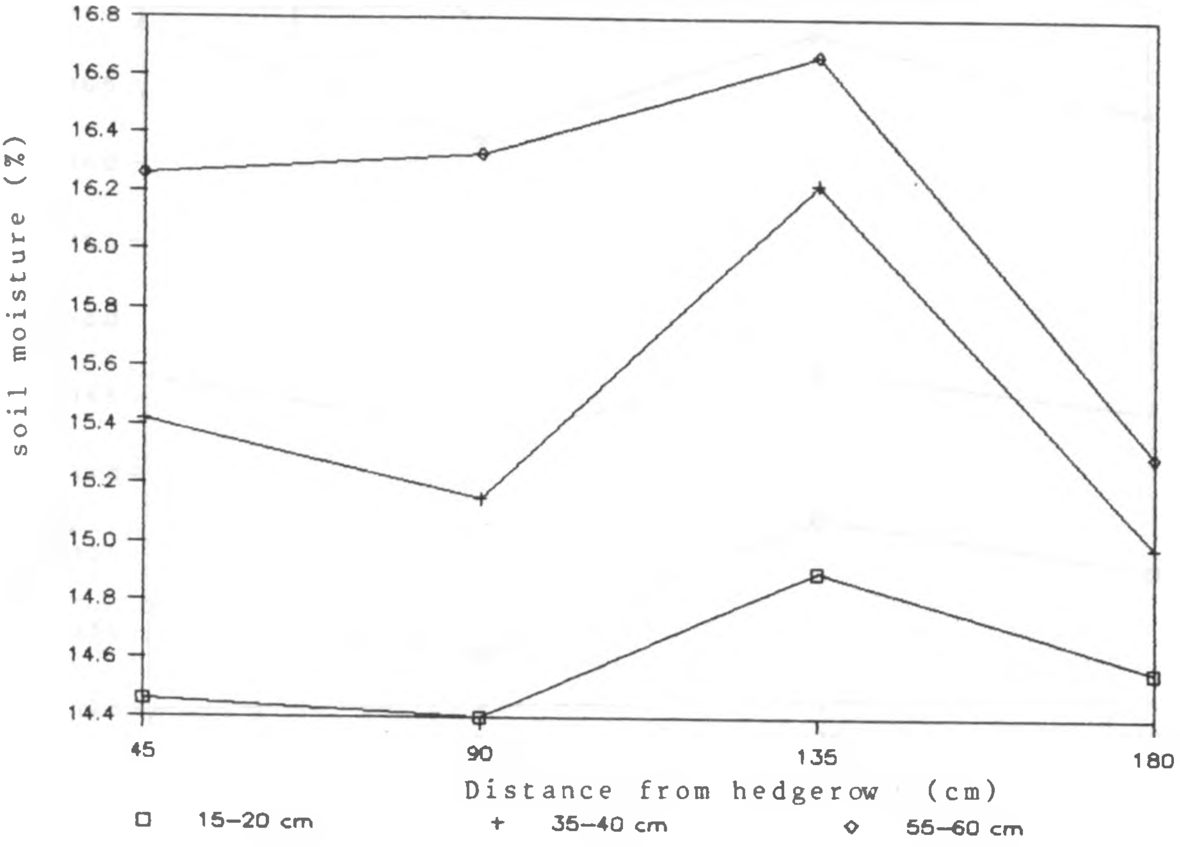


Fig. 3.3a. Soil moisture distribution at four distances and three depths in the AF system 75DAS, post-flowering stage, during experiment 1.

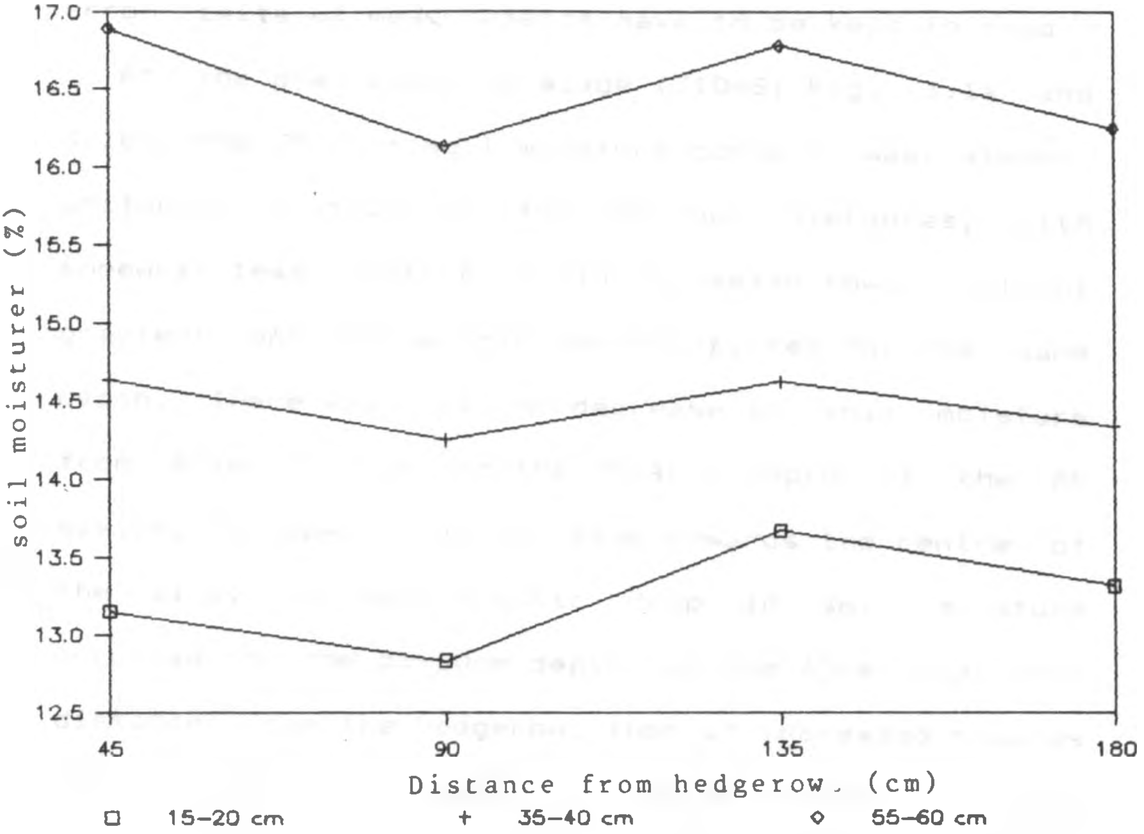


Fig. 3.3b. Soil moisture distribution at four distances and three depths in the NAf system 75DAS, post-flowering stage, during experiment 1.

pre-flowering, flowering and post-flowering stages of the maize growth respectively. In the discussion below, statistical significance of differences and error limits of measurements have to be kept in mind.

At the pre-flowering stage (31DAS; Fig. 3.1a and 3.1b), the 15-20cm soil moisture content was almost uniformly distributed for the four distances, with somewhat less moisture within the maize rows. A slight gradient occurred within the NAF system for the same depth. There was a slight decrease in soil moisture from 45cm to 90cm for the 35-40cm depth of the AF system, followed by an increase towards the centre of the alley. A more drastic drop in soil moisture occurred for the 55-60cm depth at the 45cm and 90cm distances from the hedgerow, then it increased towards the centre of the alley of the AF system. A more uniform distribution of soil moisture was observed for the 35-40 and 55-60cm depths in the NAF system at this pre-flowering stage of growth.

At the flowering stage of experiment 1 (Figs. 3.2a and 3.2b) there was a slight decrease in soil moisture away from the hedgerow at 180cm in the AF system, but in the NAF system the soil moisture distribution was almost uniform. At the post-flowering stage (75DAS; Figs. 3.3a and 3.3b) the soil moisture at all depths was highest at 135cm, between rows. At the two lower depths it was least at 180cm, in between plants. The fluctuation in soil moisture in the NAF system was even more uniform than in the AF, since it slightly dropped within the BMR and MMR (distances 90 and 180cm).

Figures 3.4a, 3.5a and 3.6a show the soil moisture distribution in the alleys of the AF system and Figures 3.4b, 3.5b and 3.6b that in the NAF system for 38DAS, 69DAS and 83DAS obtained in experiment 2. The periods coincided with the pre-flowering, flowering and post-flowering stages of maize growth. At the pre-flowering stage (Figs. 3.4a and 3.4b), the 15-20cm depth showed a rather uniform soil moisture distribution in the AF system for the four distances. There was an increase in soil moisture content away from the hedgerow in the 35-40cm and 55-60cm depths with an exception at 135cm distance of the AF system for this period of plant growth. A gradient occurred in soil moisture content in the NAF system from the direction of the *Cassia* hedgerow in the three depths of 15-20cm, 35-40cm and 55-60cm, respectively. In the last two cases this applies beyond 90cm distance

At the flowering stage (Figs. 3.5a and 3.5b), soil moisture increased towards the *Cassia* hedgerow, with exceptions at 90cm distance for 15-20cm and at 135cm distance for 55-60cm depth. A uniform distribution of soil moisture occurred in the three depths of the NAF

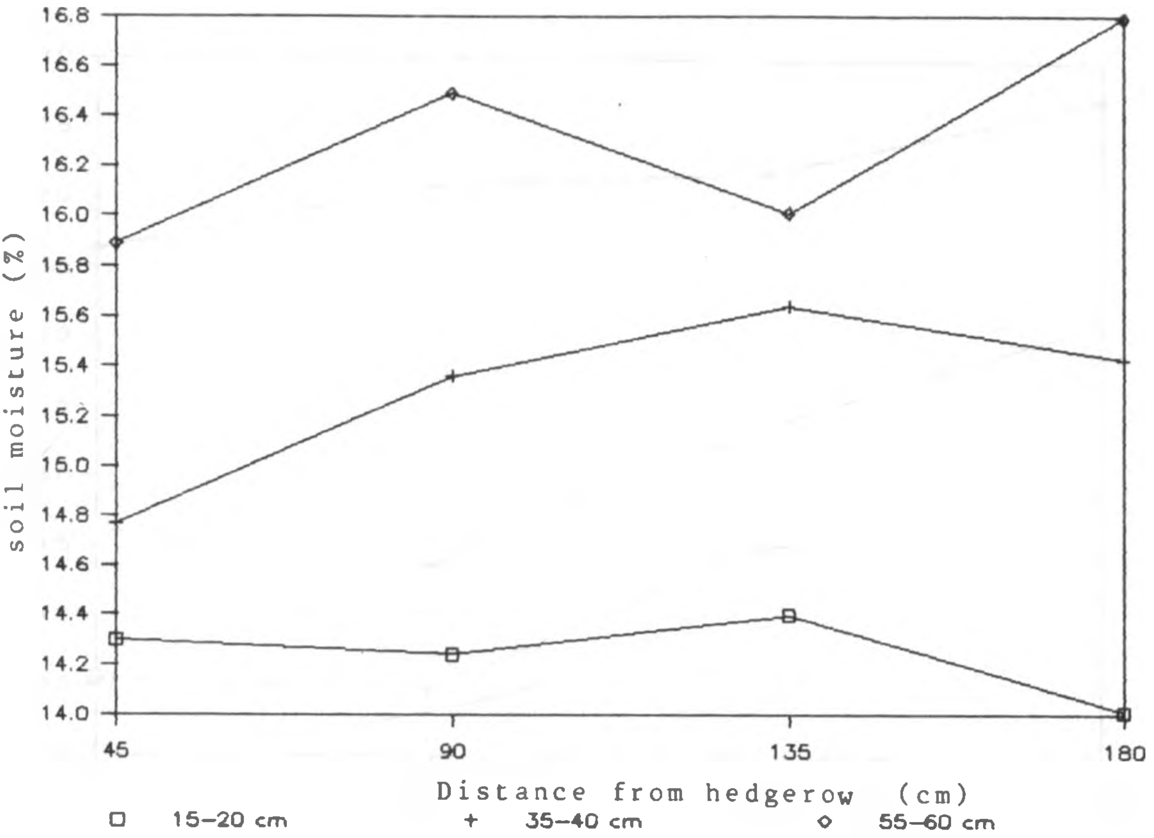


Fig. 3.4a. Soil moisture distribution at four distances and three depths in the AF system 38DAS, pre-flowering stage, during experiment 2.

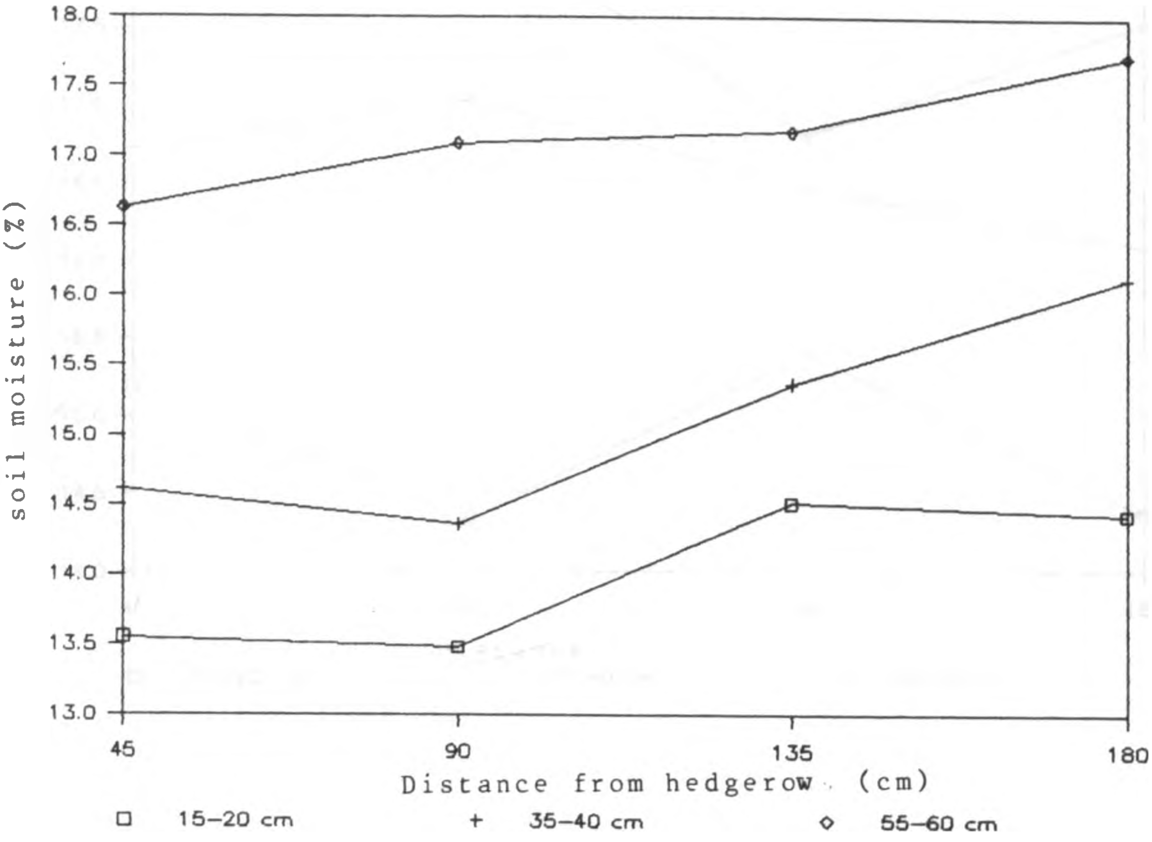


Fig 3.4b. Soil moisture distribution at four distances and three depths in the NAF system 38DAS, pre-flowering stage, during experiment 2.

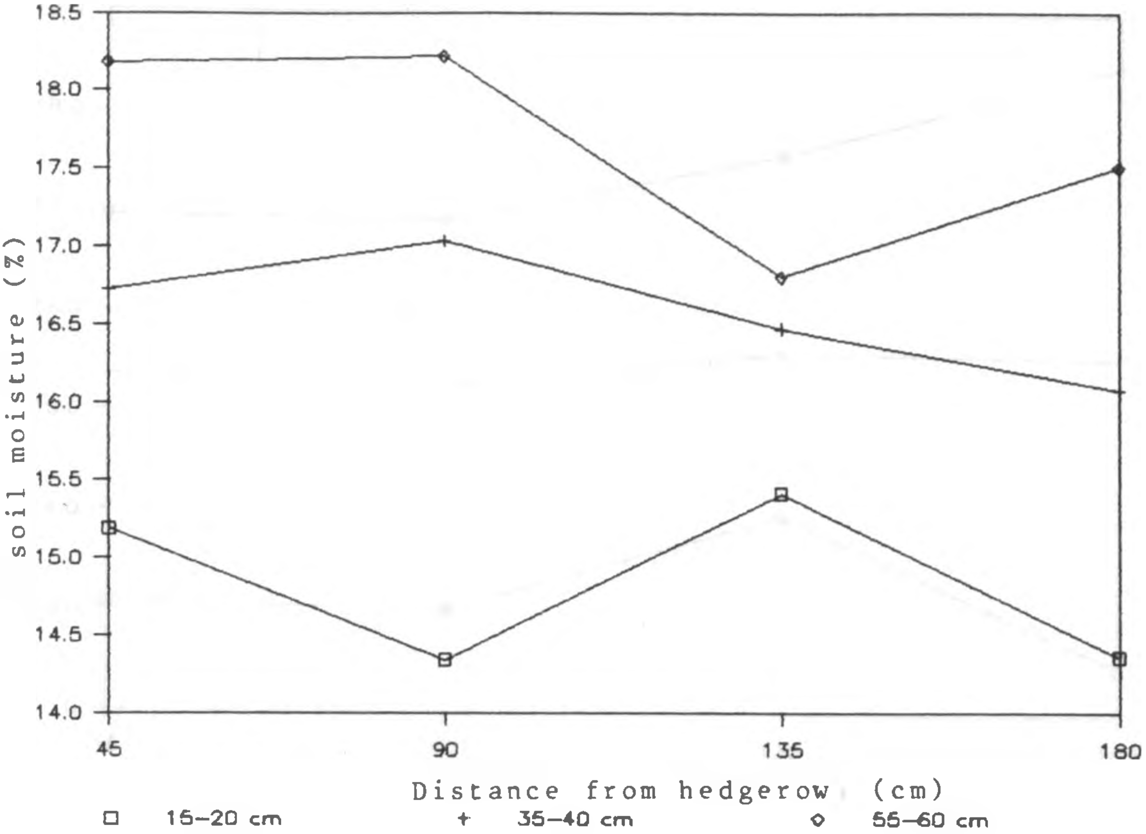


Fig 3.5a. Soil moisture distribution at four distances and three depths in the AF system 69DAS, flowering stage, during experiment 2.

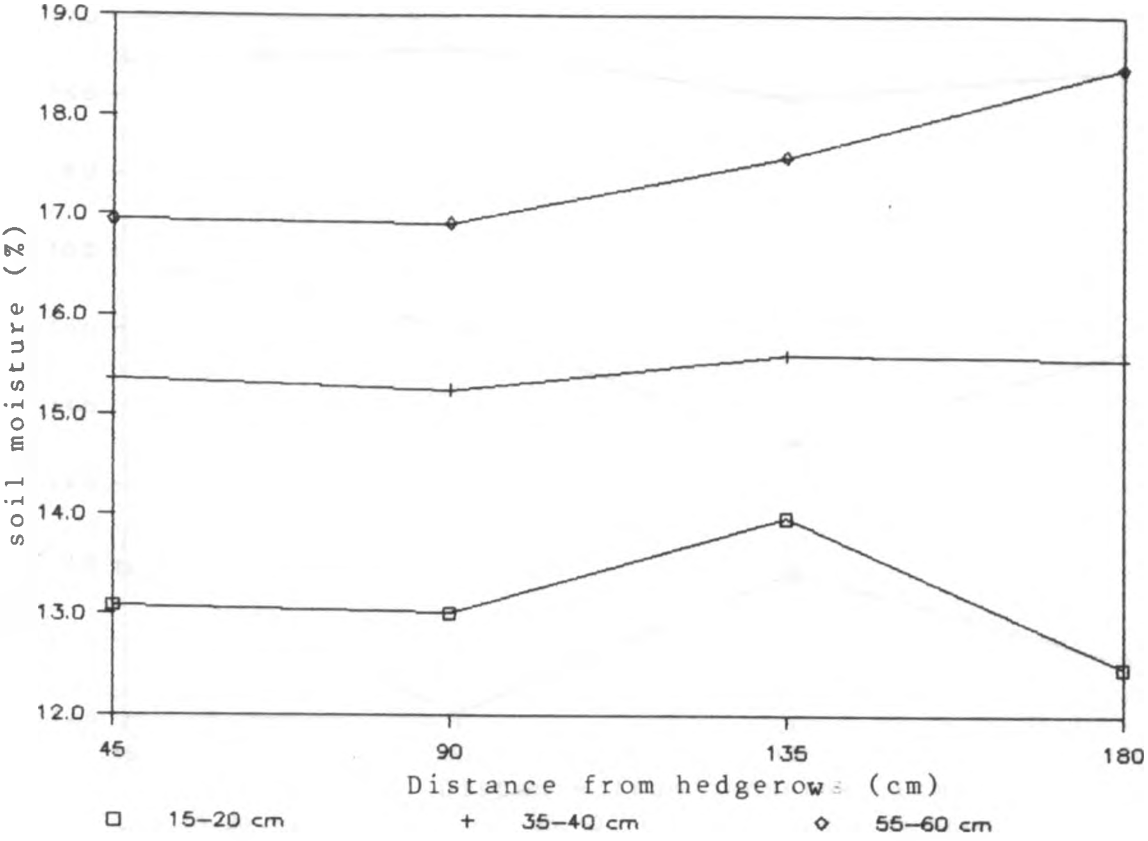


Fig. 3.5b Soil moisture distribution at four distances and three depths in the NAF system 69DAS, flowering stage, during experiment 2.

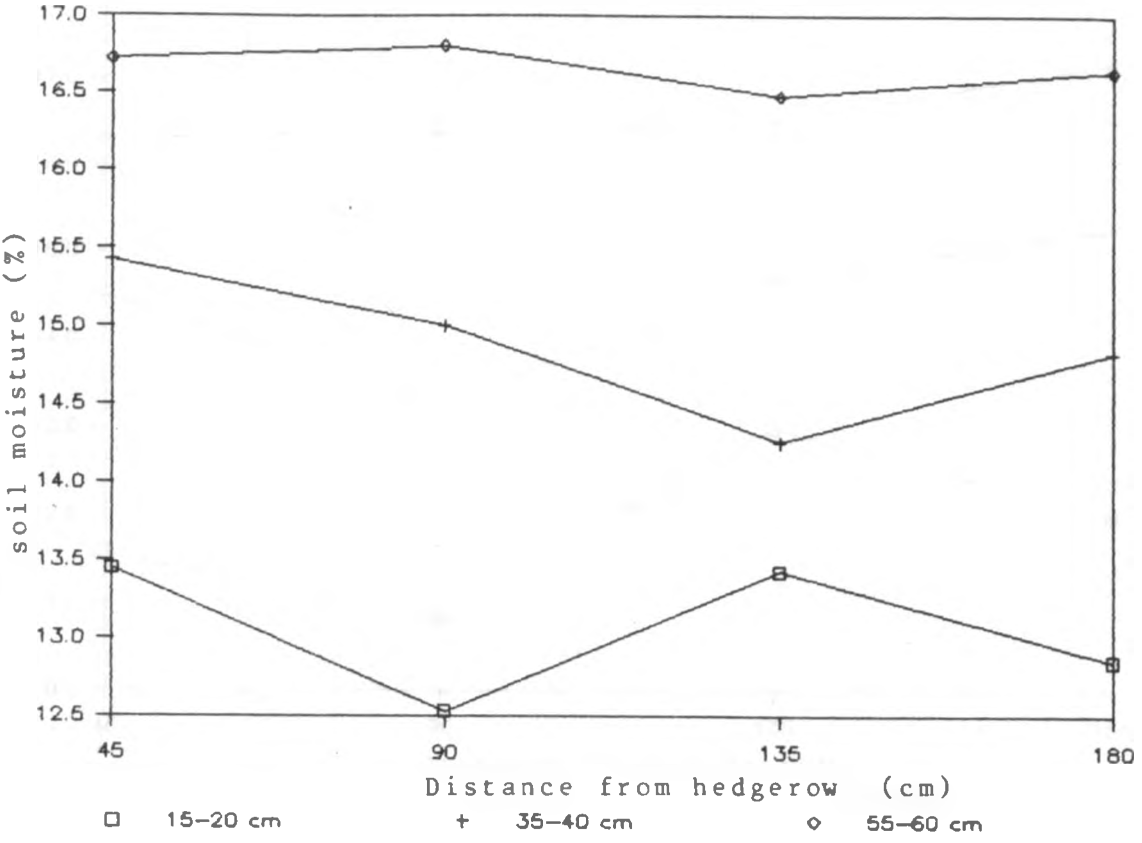


Fig. 3.6a. Soil moisture distribution at four distances and three depths in the AF system 83DAS, post-flowering stage, during experiment 2.

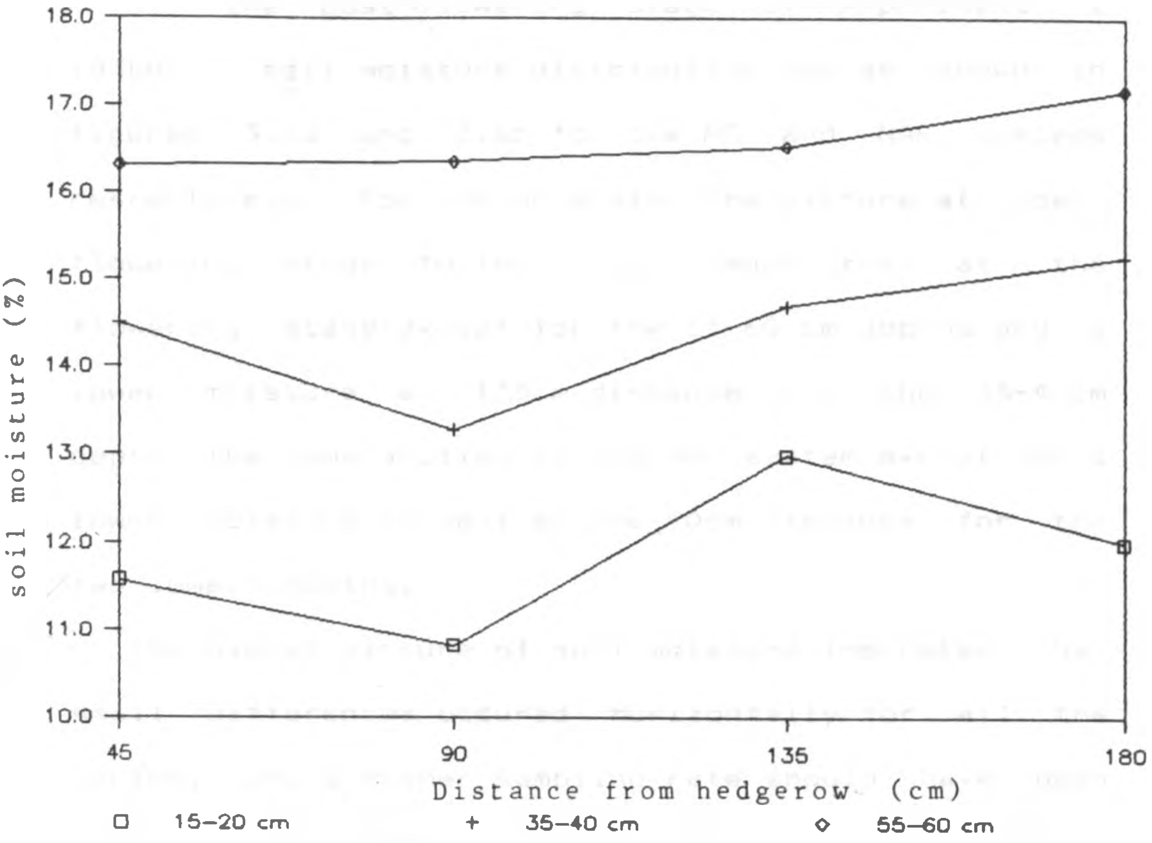


Fig. 3.6b. Soil moisture distribution at four distances and three depths in the NAF system 83DAS, post-flowering stage, during experiment 2.

system, with exceptions of increases at 135cm distance for 15-20cm and 55-60cm depths and at 180cm distance for the lowest depth.

At the post-flowering stage of experiment 2 (83DAS), soil moisture distribution was as shown in figures 3.6a and 3.6b for the AF and NAF systems respectively. For the AF system the picture at post-flowering stage followed very much that at the flowering stage except for the 55-60 cm depths and a lower moisture at 135cm distance for the 35-40cm depth. The same applies to the NAF system except for a lower moisture content at the 90cm distance for the two lowest depths.

The overal picture of soil moisture indicates that small differences occured horizontally for all the depths, and a higher sampling rate should have been applied for more accurate results. This would, however, not have been worth the supplementary efforts needed because of the limited time for the collection of these data and for the other parameters. Vertical differences were more common both in the AF and NAF systems. More soil moisture was also shown to occur in the AF system.

3.3 Leaf stomatal resistance

Variations in the leaf stomatal resistance of the

DAS	Row/system	Time of measurement		
		8.00 hrs.	12.00 hrs.	15.00hrs.
25	MMR(AF)		1.60	1.43
	BMR(AF)		1.45	1.62
	MMR(NAF)		1.65	1.55
	BMR(NAF)		1.66	1.59
	F-ratio		1.3 ns	1.5 ns
46	MMR(AF)	1.18	1.31	
	BMR(AF)	1.18	1.32	
	MMR(NAF)	1.31	1.14	
	BMR(NAF)	1.32	1.30	
	F-ratio	1.1 ns	1.7 ns	
53	MMR(AF)		0.82	
	BMR(AF)		0.82	
	MMR(NAF)		1.07	
	BMR(NAF)		1.05	
	F-ratio		6.6 **	
	LSD, 0.05		0.15	
68	MMR(AF)		0.89	
	BMR(AF)		0.88	
	MMR(NAF)		0.85	
	BMR(NAF)		0.87	
	F-ratio		0.2 ns	
75	MMR(AF)		1.26	1.43
	BMR(AF)		1.25	1.39
	MMR(NAF)		1.32	1.42
	BMR(NAF)		1.33	1.45
	F-ratio		0.8 ns	0.2 ns
89	MMR(AF)		0.81	0.96
	BMR(AF)		0.75	0.90
	MMR(NAF)		0.79	0.85
	BMR(NAF)		0.82	0.89
	F-ratio		1.1 ns	1.6 ns

Table 3.3a. Mean stomatal resistance ($s.cm^{-1}$) of maize for various DAS and times of measurement during experiment 1.

DAS	Row/System	Time of measurement		
		9.00 hrs	12.00 hrs	15.00 hrs
37	MMR(AF)	1.44		1.55
	BMR(AF)	1.58		1.66
	MMR(NAF)	1.93		1.89
	BMR(NAF)	1.97		1.89
	F-ratio	4.8 **		6.0 **
	LSD, 0.05	0.33		1.19
49	MMR(AF)	1.34	1.41	1.94
	BMR(AF)	1.36	1.58	2.06
	MMR(NAF)	1.44	1.51	2.16
	BMR(NAF)	1.31	1.47	2.10
	F-ratio	1.5 ns	1.1 ns	2.0 ns
63	MMR (AF)	1.06	0.92	1.67
	BMR(AF)	1.06	0.97	1.84
	MMR(NAF)	1.08	1.02	1.65
	BMR(NAF)	1.06	0.89	1.74
	F-ratio	0.1 ns	1.2 ns	1.2 ns
77	MMR(AF)		0.96	1.19
	BMR(AF)		1.01	1.32
	MMR(NAF)		0.92	1.26
	BMR(NAF)		0.89	1.34
	F-ratio		1.5 ns	0.7 ns
85	MMR(AF)	1.34	0.85	
	BMR(AF)	1.38	0.86	
	MMR(NAF)	1.44	1.11	
	BMR(NAF)	1.39	1.04	
	F-ratio	0.7 ns	6.3 **	
	LSD, 0.05		0.14	
92	MMR(AF)	1.27	0.99	
	BMR(AF)	1.37	1.04	
	MMR(NAF)	1.45	1.09	
	BMR(NAF)	1.43	1.09	
	F-ratio	3.5*	1.7 ns	
	LSD, 0.05	0.12		

Table 3.3b. Mean stomatal resistance ($s.cm^{-1}$) of maize for various DAS and times of measurement during experiment 2.

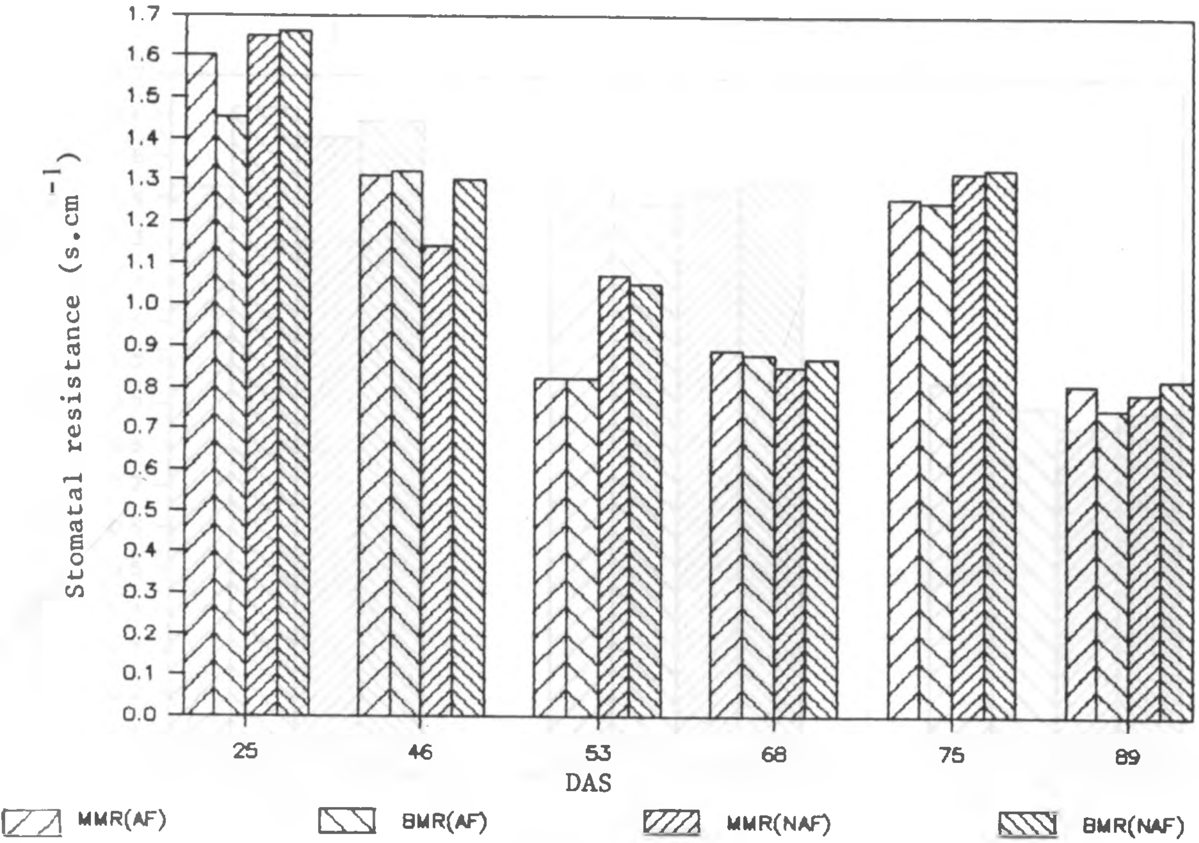


Fig. 3.7a. Variation in the mean stomatal resistance of maize leaves in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 1.

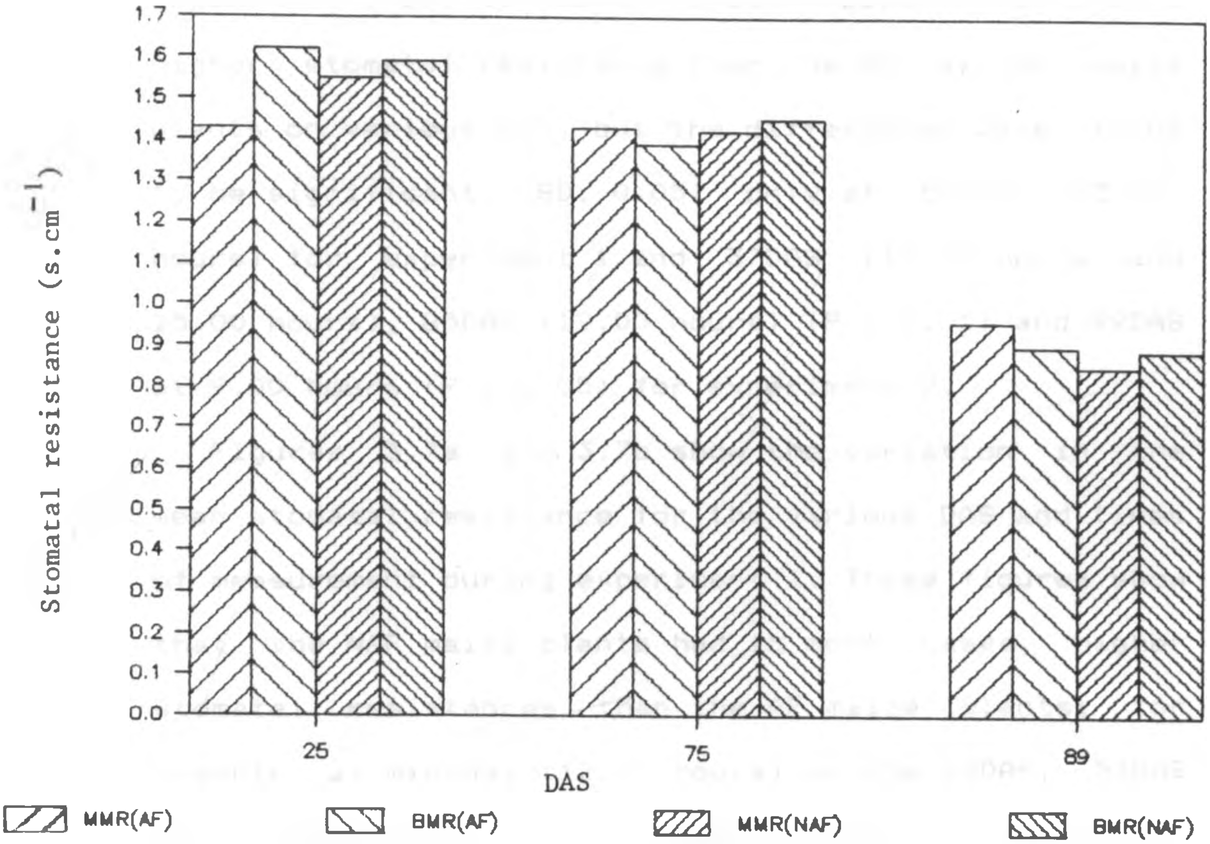


Fig. 3.7b. Variation in the mean stomatal resistance of maize leaves in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 1.

maize plants of MMR and BMR in the AF system were not significantly different ($P \leq 0.05$) for both experiment 1 and 2 (Table 3.3a and 3.3b). Likewise, the stomatal resistance of the corresponding maize rows in the NAF system were not significant ($P \leq 0.05$) for both experiment 1 and 2. The NAF system maize plants showed higher stomatal resistance than the AF system maize plants on various DAS, but the differences were found to be significant (LSD, 0.05) only at 53DAS (12.00 hours) for experiment 1 and 37DAS (12.00 hours and 15.00 hours), 85DAS (12.00 hours) ($P \leq 0.01$) and 92DAS at 9.00 hours ($P \leq 0.05$) for experiment 2.

Figures 3.7a and 3.7b show the variation in the mean stomatal resistance for the various DAS and times of measurement during experiment 1. These figures show that the NAF maize plants had in most cases, higher stomatal resistances than the AF maize plants; for example at mid-day (12.00 hours) on the 25DAS, 53DAS and 75DAS. A similar response of stomatal resistance occurred in experiment 2 (Fig. 3.7c-3.7e) on various DAS. The variations between the responses of the MMR and BMR in the AF system were not very distinctive, although the BMR values with few exceptions were always higher in experiment 2 (Fig. 3.7c-3.7e).

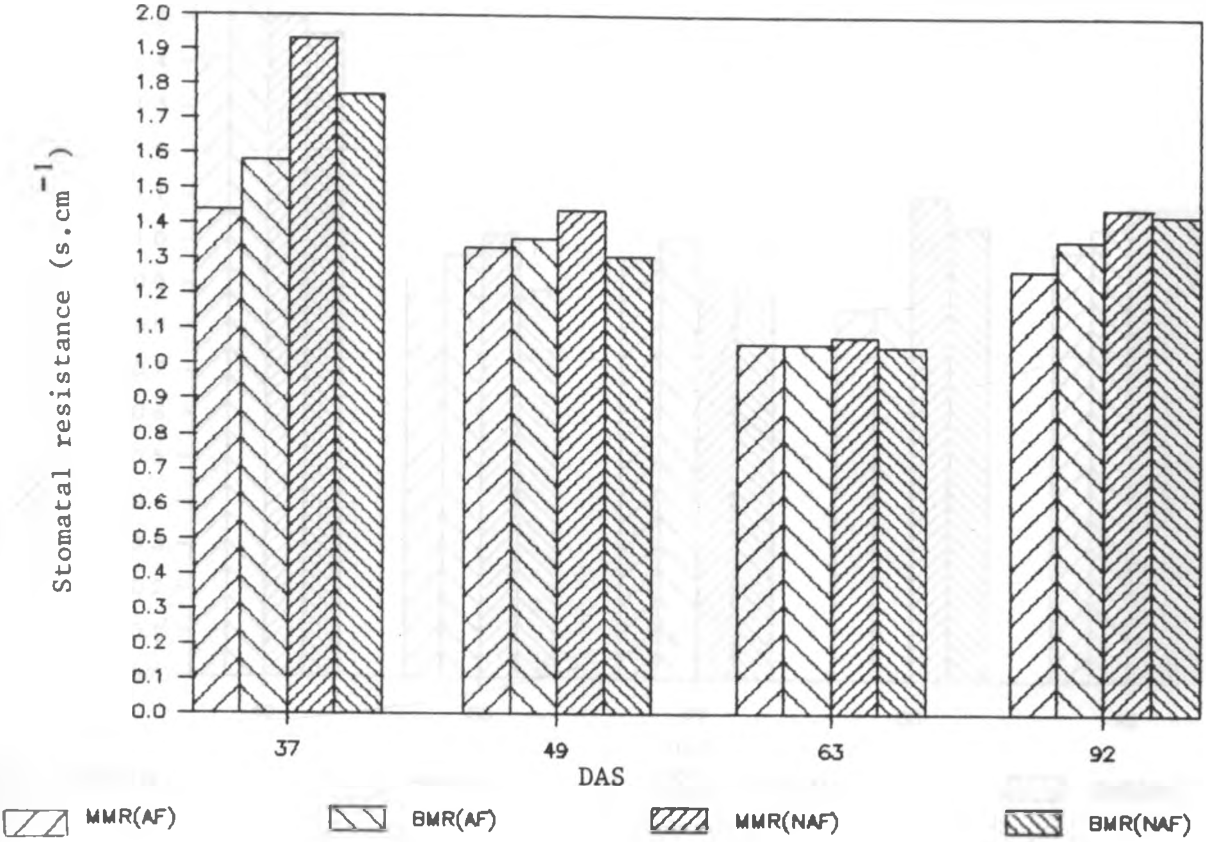


Fig. 3.7c. Variation in the mean stomatal resistance of maize leaves in the MMR and BMR of AF and NAF systems, at 9.00 hours, for various DAS during experiment 2.

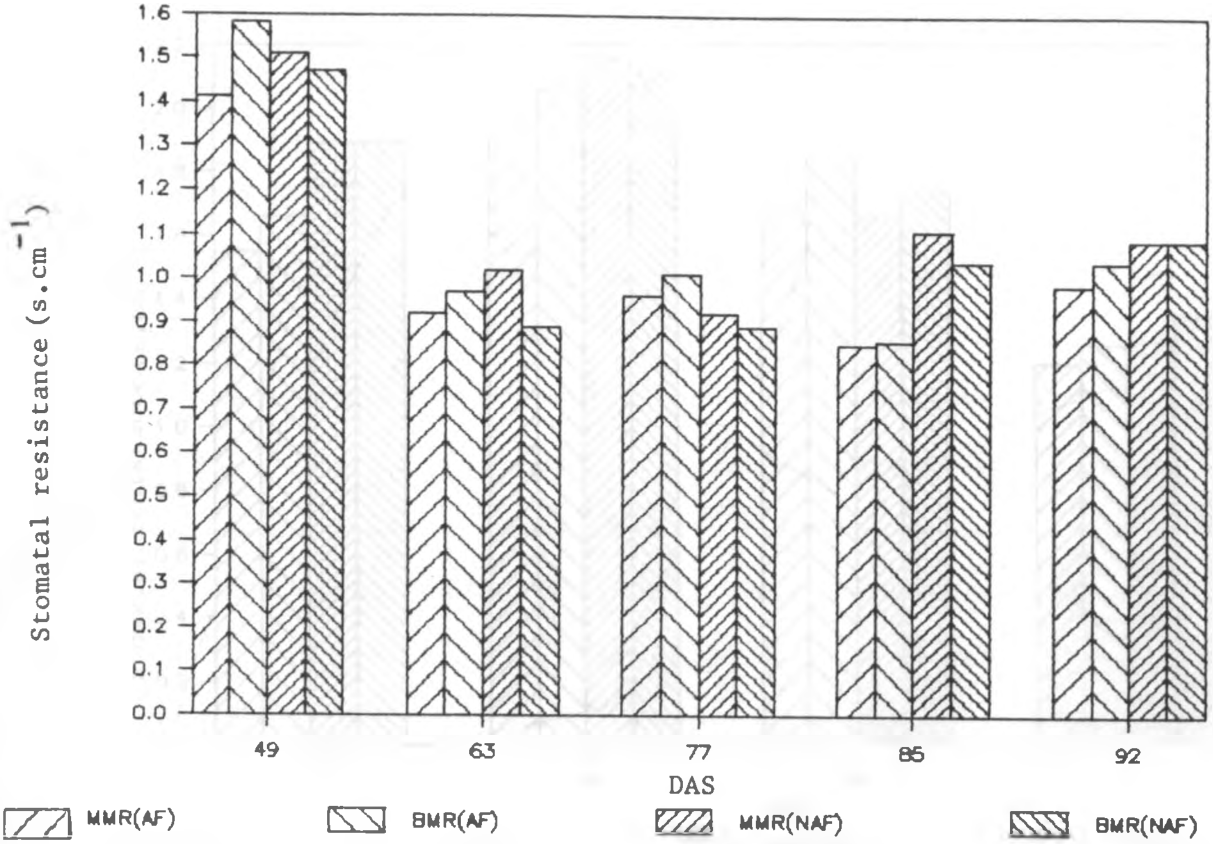


Fig. 3.7d. Variation in the mean stomatal resistance of maize leaves in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 2

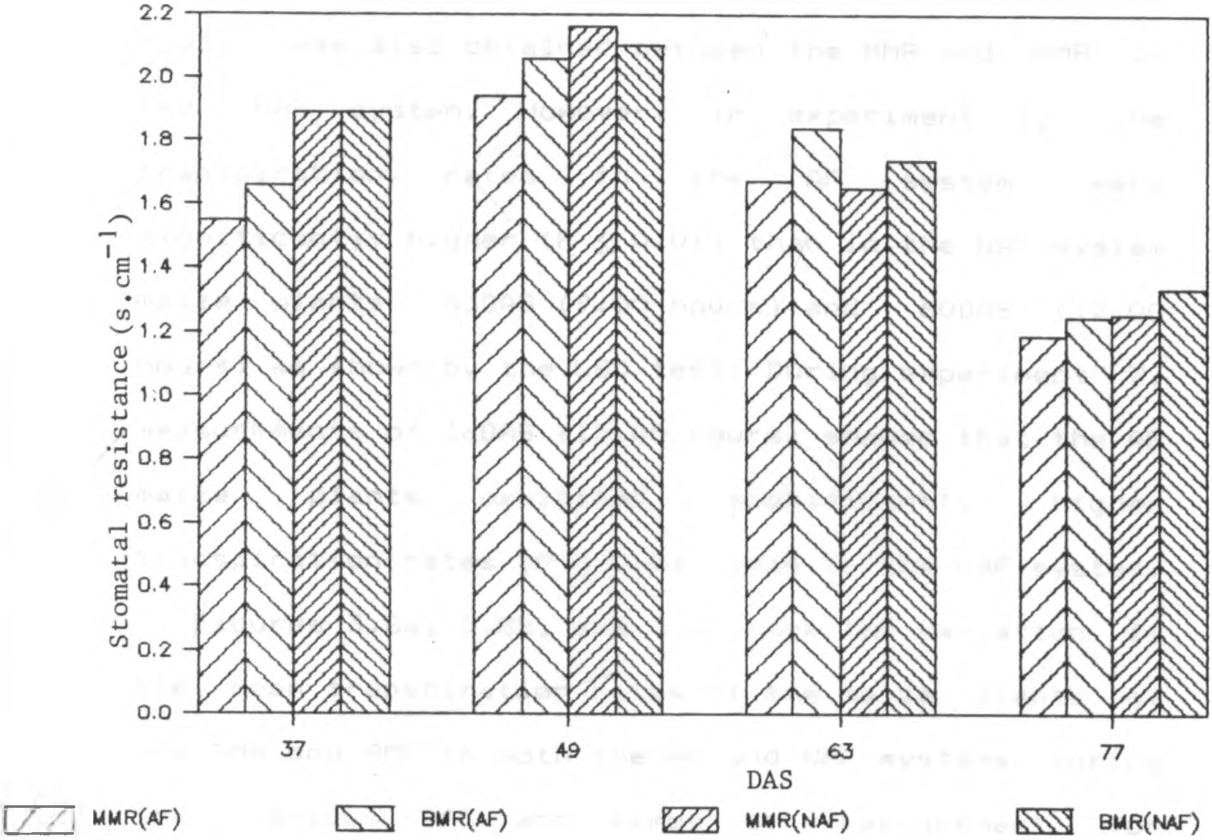


Fig. 3.7e. Variation in the mean stomatal resistance of maize leaves in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 2.

3.4 Transpiration rates

Statistical tests showed no significant difference ($P \leq 0.05$) in the transpiration rates between the MMR and the BMR in the AF system for both experiment 1 and 2 (Table 3.4a, 3.4b). No significant difference ($P \leq 0.05$) was also obtained between the MMR and BMR in the NAF system. However, in experiment 1, the transpiration rates in the AF system were significantly higher ($P \leq 0.01$) than in the NAF system maize plants 53DAS (9.00 hours) and 60DAS (12.00 hours) as shown by the LSD test. During experiment 2, measurements of 36DAS (15.00 hours) showed that the AF maize plants exhibited significantly higher transpiration rates ($P \leq 0.01$) than in the NAF system.

Figures 3.8a, 3.8b, and 3.8c show the variation in the mean transpiration rates of the maize plants of the MMR and BMR in both the AF and NAF systems during the various DAS and times of measurement for experiment 1. Figure 3.8d, 3.8e and 3.8f show the same variation during experiment 2. Higher transpiration rates occurred in the MMR of the AF system compared to those in the BMR, 89DAS (9.00 hours), and 72DAS (12.00 hours) in experiment 1. Similar observations occurred 36DAS, and 91DAS (9.00 hours), 36DAS, 49DAS, and 91DAS (12.00 hours) and 36DAS, 63DAS and 76DAS (15.00 hours) in experiment 2. Transpiration

DAS	Row/system	Time of measurement		
		9.00 hrs.	12.00 hrs	15.00 hrs
22	MMR(AF)		4.25	
	BMR(AF)		4.35	
	MMR(NAF)		3.89	
	BMR(NAF)		3.97	
	F-ratio		1.5 ns	
39	MMR(AF)		5.74	
	BMR(AF)		5.85	
	MMR(NAF)		5.85	
	BMR(NAF)		5.50	
	F-ratio		0.9 ns	
53	MMR(AF)	5.15		
	BMR(AF)	5.19		
	MMR(NAF)	4.81		
	BMR(NAF)	4.95		
	F-ratio	6.3 **		
	LSD, 0.05	0.19		
60	MMR(AF)		6.03	5.63
	BMR(AF)		6.15	5.93
	MMR(NAF)		5.30	5.65
	BMR(NAF)		5.15	5.27
	F-ratio		7.9 **	1.7 ns
	LSD, 0.05		0.50	
72	MMR(AF)		6.54	4.93
	BMR(AF)		6.49	5.13
	MMR(NAF)		5.96	5.22
	BMR(NAF)		5.93	4.95
	F-ratio		2.3 ns	0.6 ns
89	MMR(AF)	5.05		5.01
	BMR(AF)	4.94		5.19
	MMR(NAF)	5.41		5.53
	BMR(NAF)	5.33		5.55
	F-ratio	1.4 ns		1.5 ns

Table 3.4a. Mean transpiration rates (mmol $m^{-2}s^{-1}$) for various DAS and times of measurement during experiment 1.

DAS	Row/system	Time of measurement		
		9.00 hrs	12.00 hrs	15.00 hrs
	MMR(AF)	4.99	6.34	5.68
	BMR(AF)	4.59	6.09	5.43
	MMR(NAF)	4.79	5.81	5.23
36	BMR(NAF)	5.11	6.20	5.11
	F-ratio	2.6 ns	1.1 ns	4.3 **
	LSD, 0.05			0.33
	MMR(AF)	5.33	6.08	5.16
	BMR(AF)	5.33	6.07	5.31
	MMR(NAF)	5.31	5.79	5.25
49	BMR(NAF)	5.30	5.89	5.39
	F-ratio	0.0 ns	0.8 ns	0.5 ns
	MMR(AF)	4.54	5.91	5.24
	BMR(AF)	4.61	5.93	5.12
	MMR(NAF)	4.77	5.54	4.96
63	BMR(NAF)	4.96	5.71	5.09
	F-ratio	1.3 ns	1.8 ns	0.5 ns
	MMR(AF)		4.18	3.81
	BMR(AF)		4.30	3.73
	MMR(NAF)		4.35	3.87
76	BMR(NAF)		4.45	3.74
	F-ratio		1.2 ns	0.6 ns
	MMR(AF)	3.48	3.95	4.87
	BMR(AF)	3.13	3.82	4.87
	MMR(NAF)	3.29	3.92	5.01
91	BMR(NAF)	3.31	4.08	4.92
	F-ratio	0.7 ns	0.7 ns	0.2 ns

Table 3.4b. Mean transpiration rates (mmol $m^{-2}s^{-1}$) for various DAS and times of measurement during experiment 2.

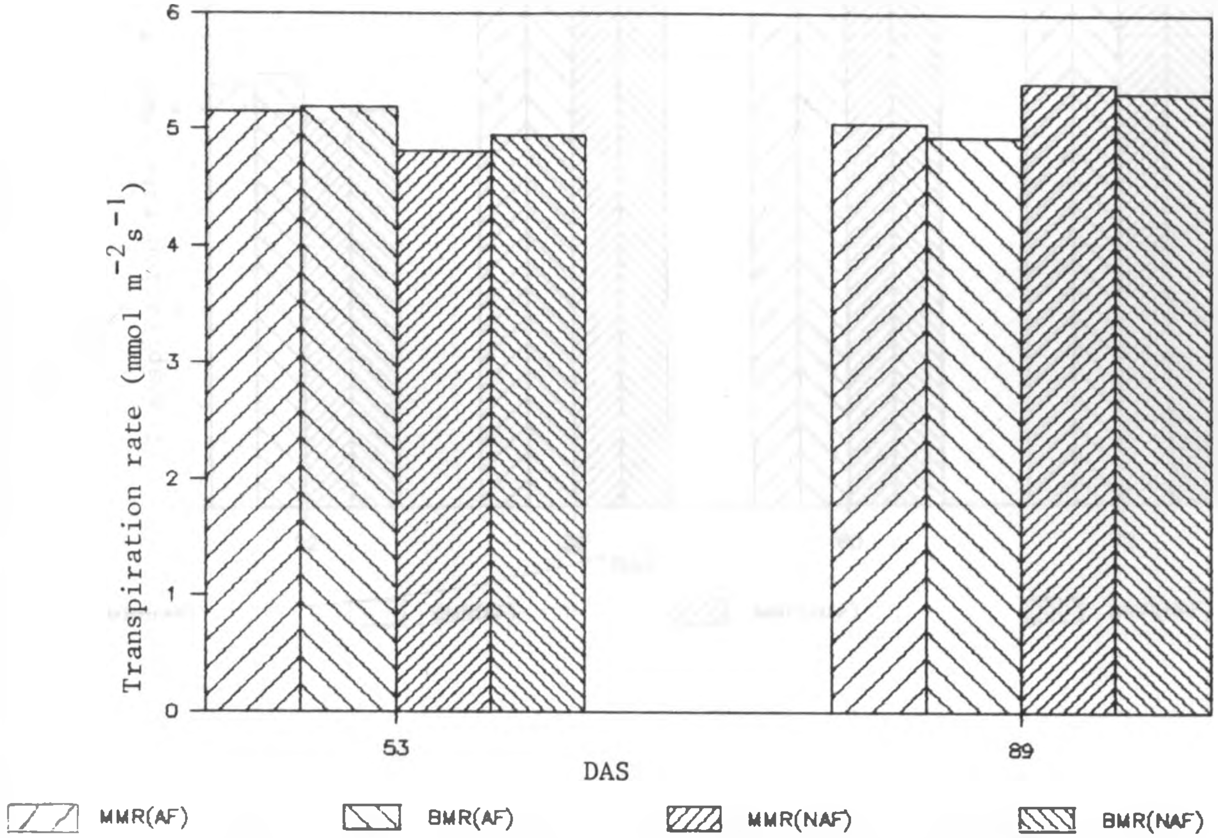


Fig. 3.8a. Variation in the mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 9.00 hours, for 53 and 89DAS during experiment 1.

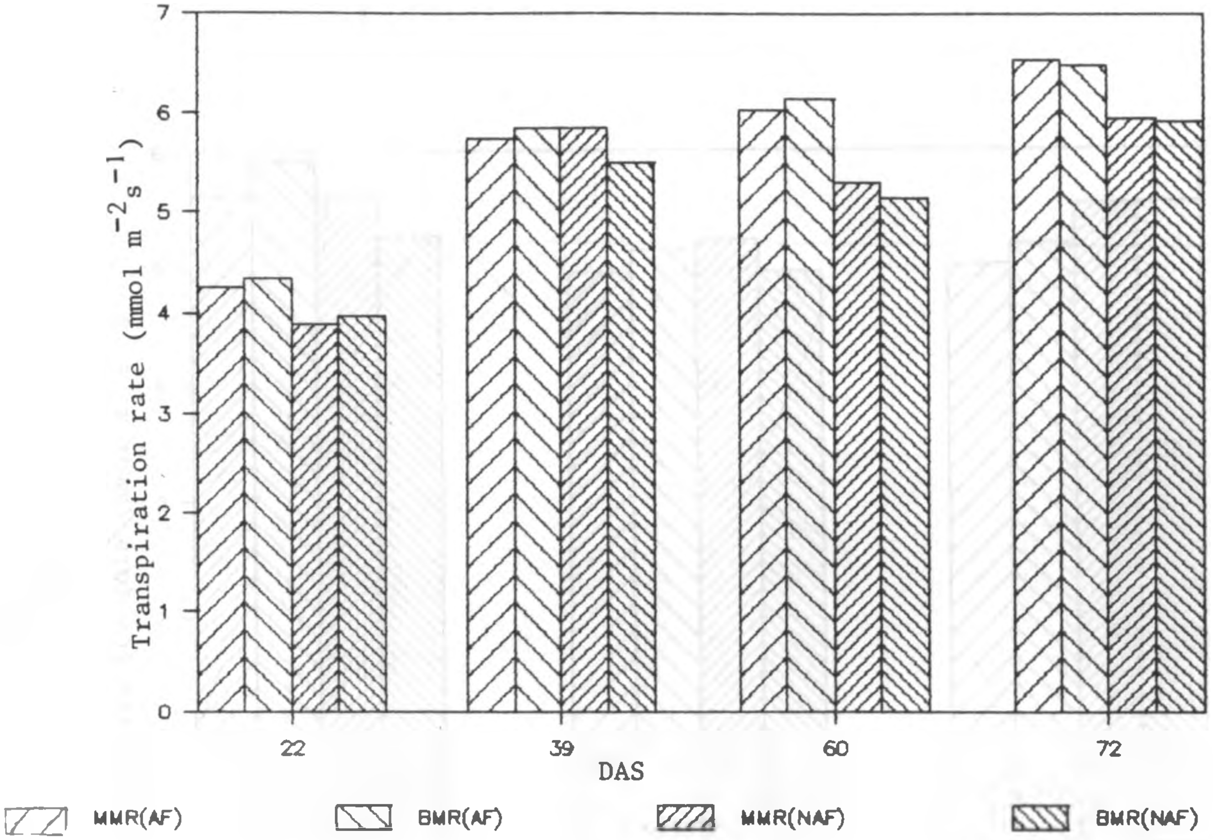


Fig. 3.8b. Variation in the mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 1

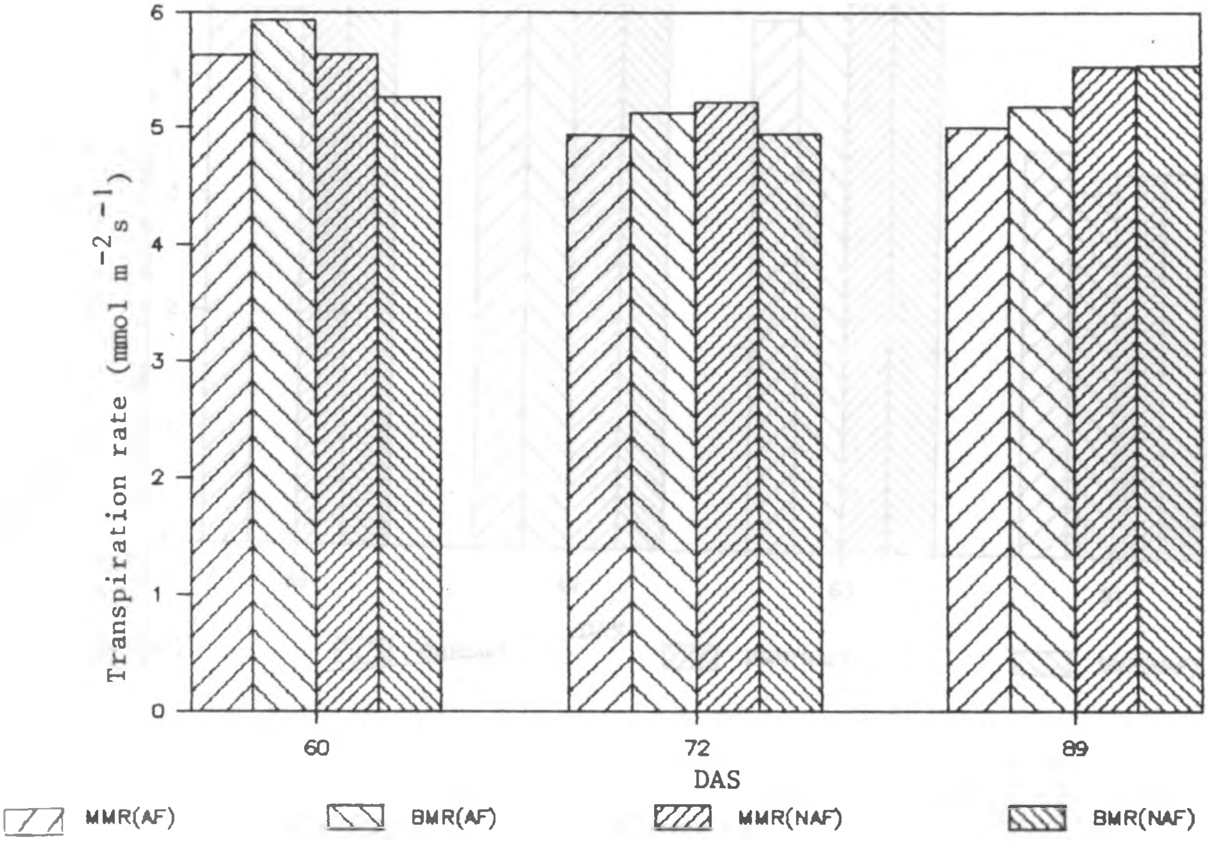


Fig. 3.8c. Variation in the mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 1.

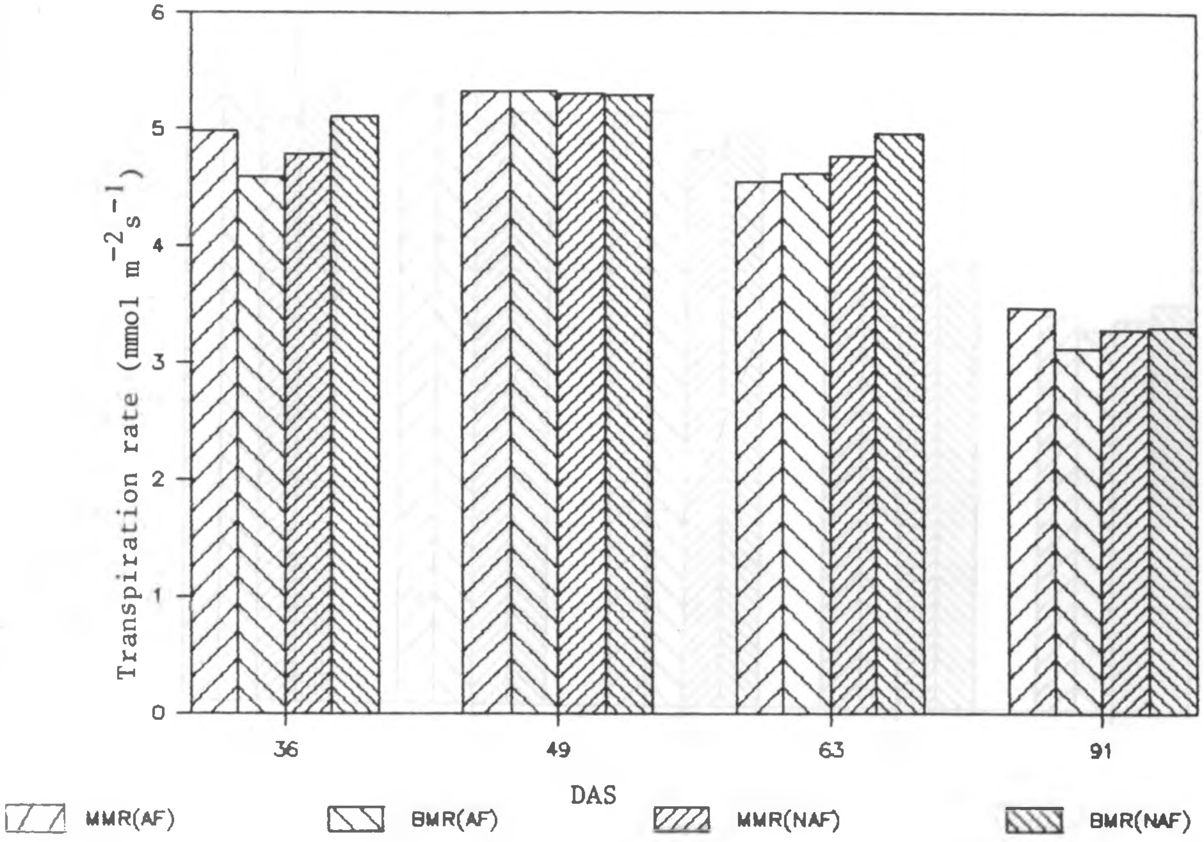


Fig. 3.8d. Variation in the mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 9.00 hours, for various DAS during experiment 2.

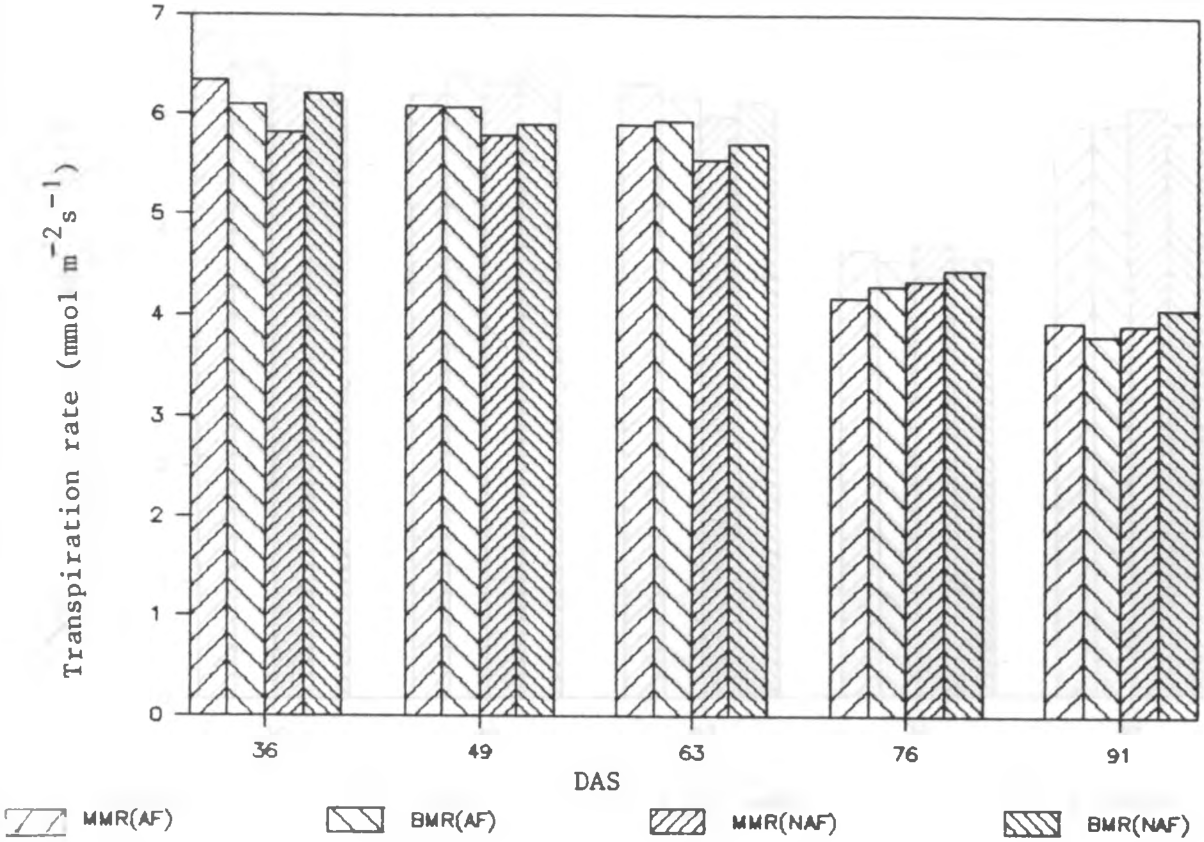


Fig. 3.8e. Variation in the mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 2.

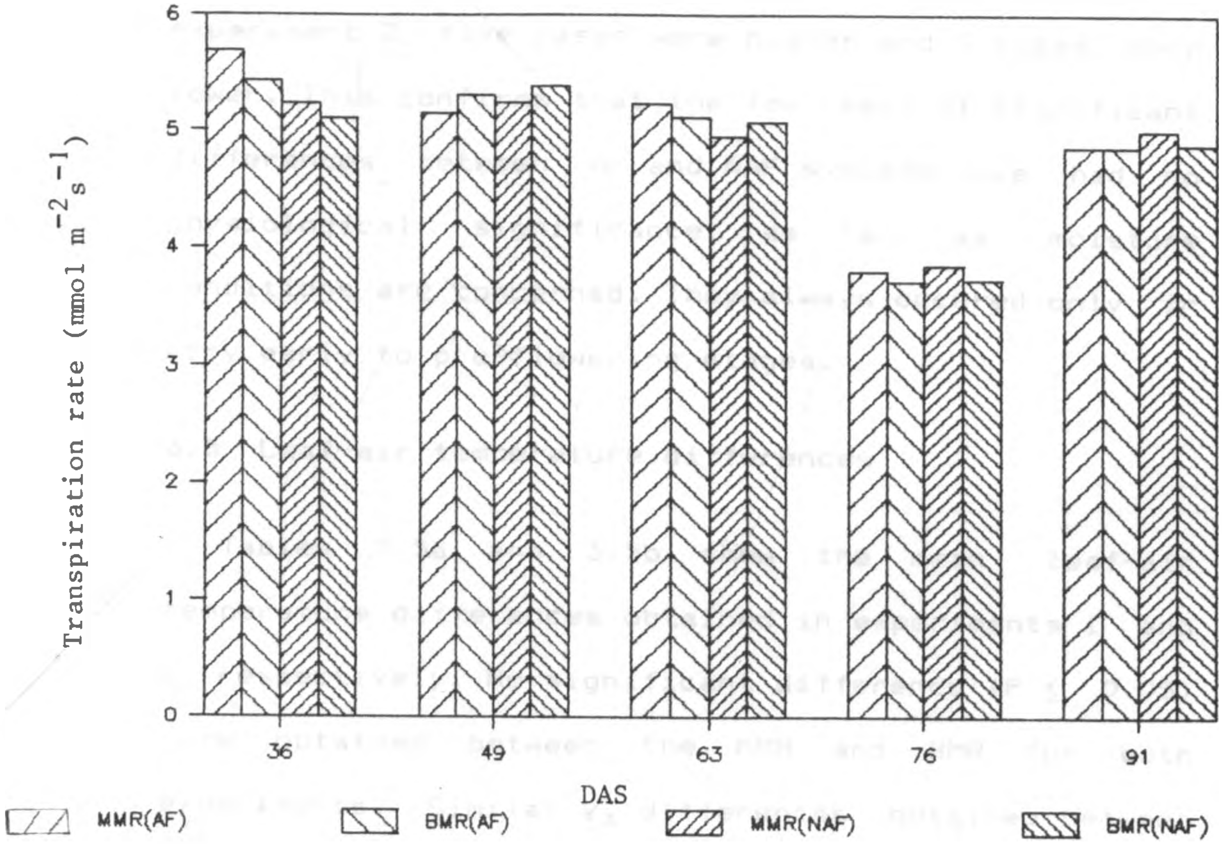


Fig. 3.8f. Variation in the Mean transpiration rates of maize leaves in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 2.

rates of both MMR and BMR of the AF system were higher than both MMR and BMR of the NAF system in three cases but lower in two cases in experiment 1. In experiment 2, five cases were higher and 3 cases were lower. This confirms that the few cases of significant differences between AF and NAF systems have had no physiological significance as far as moisture conditions are concerned. They always occured only in very early to pre-flowering stages.

3.5 Leaf-air temperature differences

Tables 3.5a and 3.5b show the mean leaf-air temperature differences obtained in experiments 1 and 2 respectively. No significant difference ($P \leq 0.05$) were obtained between the MMR and BMR for both experiments. Similarly, differences obtained between the AF system and the NAF system were not statistically significant ($P \leq 0.05$). The mean values obtained were all negative since the air temperatures were always higher than the leaf temperatures.

Figures 3.9a, 3.9b and 3.9c show the mean leaf-air temperature differences in the AF system and in the NAF system for Experiment 1. Figures 3.9d, 3.9e, 3.9f show the mean leaf-air temperature differences for experiment 2. Generally, no clear differences can be observed between the MMR and the BMR in the AF system

DAS	Row/system	Time of measurement		
		9.00hrs	12.00hrs	15.00hrs
47	MMR(AF)	-0.67	-0.51	-0.73
	BMR(AF)	-0.65	-0.48	-0.51
	MMR(NAF)	-0.48	-0.41	-0.59
	BMR(NAF)	-0.52	-0.37	-0.61
	F-ratio	2.9 ns	2.0ns	1.9 ns
53	MMR(AF)		-0.67	
	BMR(AF)		-0.57	
	MMR(NAF)		-0.56	
	BMR(NAF)		-0.53	
	F-ratio		1.6 ns	
60	MMR(AF)		-0.69	
	BMR(AF)		-0.67	
	MMR(NAF)		-0.65	
	BMR(NAF)		-0.59	
	F-ratio		1.5 ns	
75	MMR(AF)		-0.49	
	BMR(AF)		-0.46	
	MMR(NAF)		-0.35	
	BMR(NAF)		-0.38	
	F-ratio		2.9 ns	
81	MMR(AF)			-0.63
	BMR(AF)			-0.73
	MMR(NAF)			-0.60
	BMR(NAF)			-0.59
	F-ratio			2.8 ns
89	MMR(AF)	-0.49	-0.61	-0.67
	BMR(AF)	-0.47	-0.54	-0.73
	MMR(NAF)	-0.43	-0.49	-0.77
	BMR(NAF)	-0.37	-0.51	-0.79
	F-ratio	2.5 ns		1.2 ns

Table 3.5a. Mean leaf-air temperature (°C) for various DAS and times of measurement during experiment 1.

DAS	Row/system	Time of measurement		
		9.00hrs	12.00hrs	15.00hrs
	MMR(AF)	-0.53	-0.81	-0.65
	BMR(AF)	-0.57	-0.69	-0.63
	MMR(NAF)	-0.55	-0.83	-0.55
45	BMR(NAF)	-0.59	-0.69	-0.55
	F-ratio	0.4 ns	2.3 ns	1.6 ns
	MMR(AF)	-0.53	-0.66	
	BMR(AF)	-0.52	-0.67	
	MMR(NAF)	-0.45	-0.58	
57	BMR(NAF)	-0.41	-0.59	
	F-ratio	1.6 ns	2.2 ns	
	MMR(AF)	-0.45	-0.93	
	BMR(AF)	-0.43	-0.87	
	MMR(NAF)	-0.39	-0.85	
64	BMR(NAR)	-0.41	-0.90	
	F-ratio	1.1 ns	0.2 ns	
	MMR(AF)		-0.87	-0.63
	BMR(AF)		-0.85	-0.57
	MMR(NAF)		-0.80	-0.59
71	BMR(NAF)		-0.73	-0.59
	F-ratio		1.2 ns	0.6 ns
	MMR(AF)		-1.26	-0.74
	BMR(AF)		-1.09	-0.77
	MMR(NAF)		-1.22	-0.69
77	BMR(NAF)		-1.21	-0.72
	F-ratio		0.9 ns	0.1 ns
	MMR(AF)		-0.35	-0.74
	BMR(AF)		-0.33	-0.76
	MMR(NAF)		-0.44	-0.63
92	BMR(NAF)		-0.40	-0.76
	F-ratio		2.5 ns	0.5 ns

Table 3.5b. Mean leaf-air temperature (°C) for various DAS and times of measurement during experiment 2.

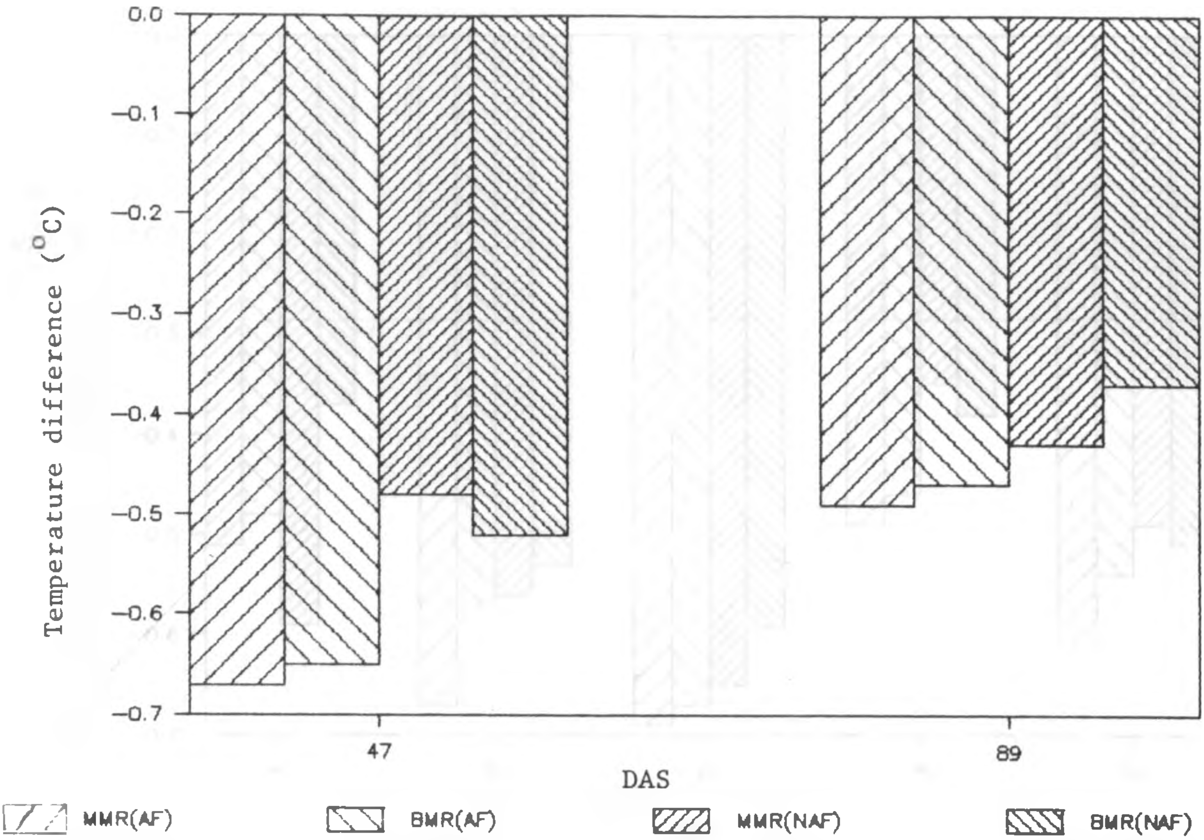


Fig. 3.9a. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 9.00 hours, for 47 and 89DAS during experiment 1.

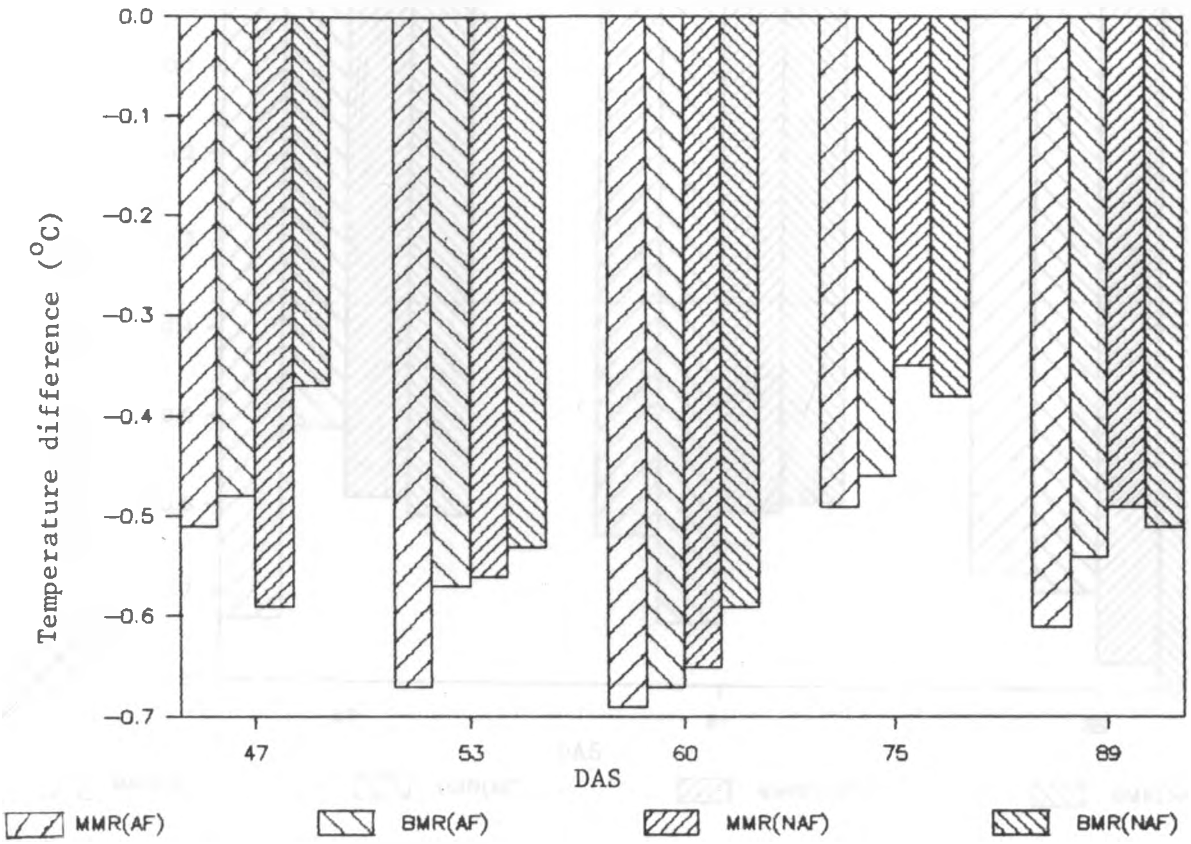


Fig. 3.9b. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 1.

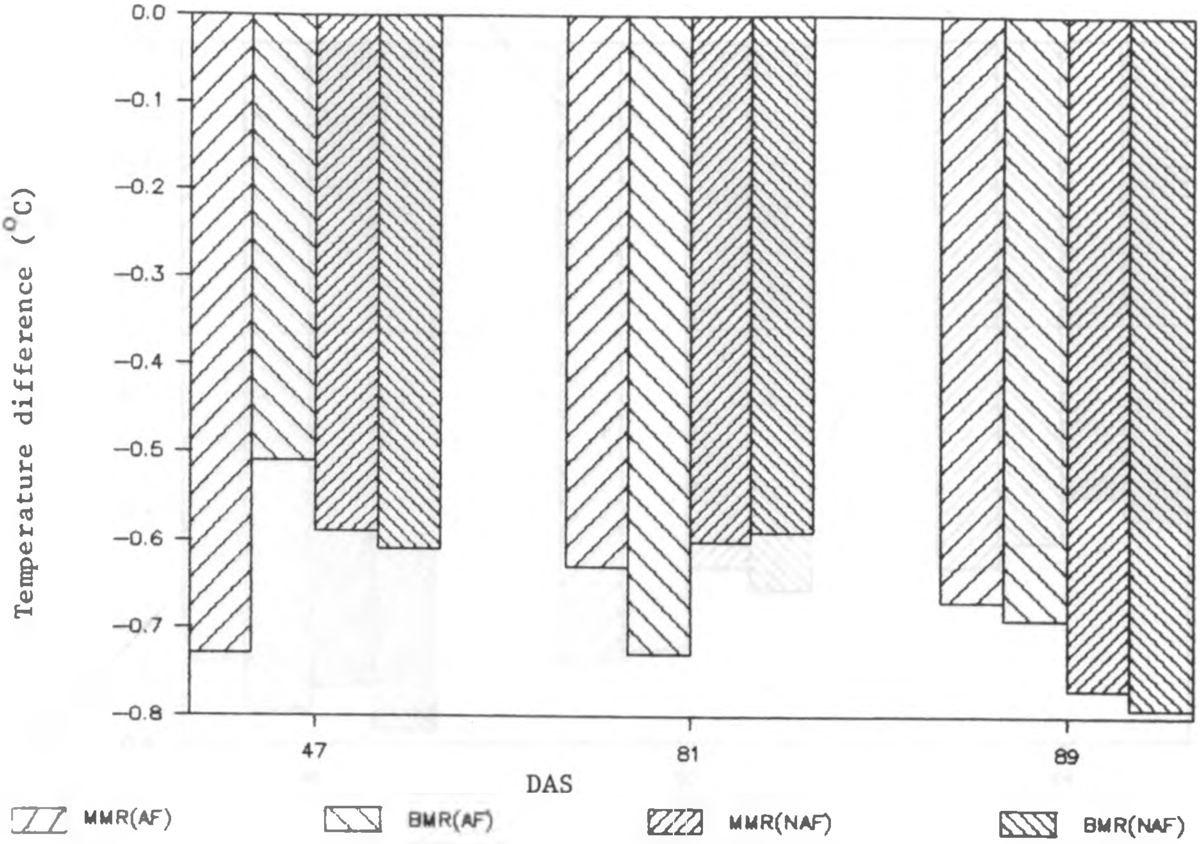


Fig. 3.9c. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 1.

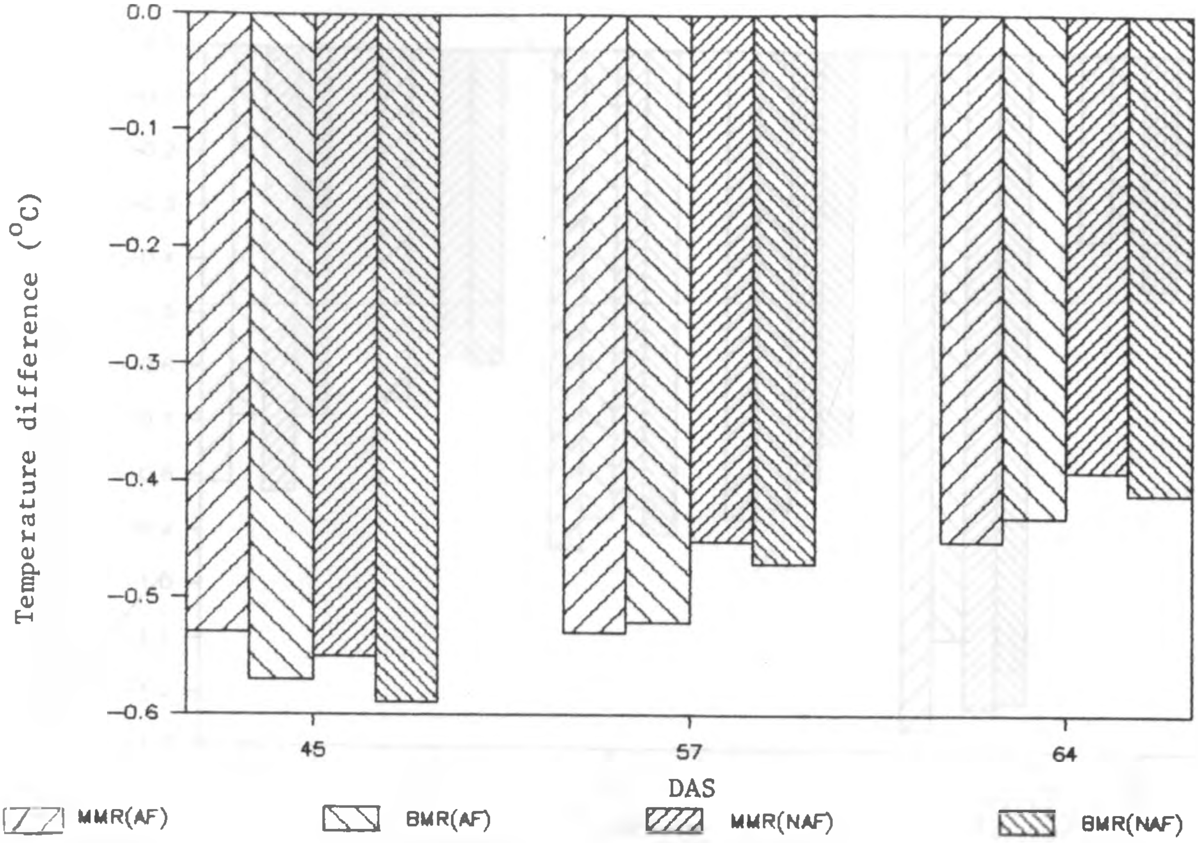


Fig. 3.9d. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 9.00 hours, for various DAS during experiment 2.

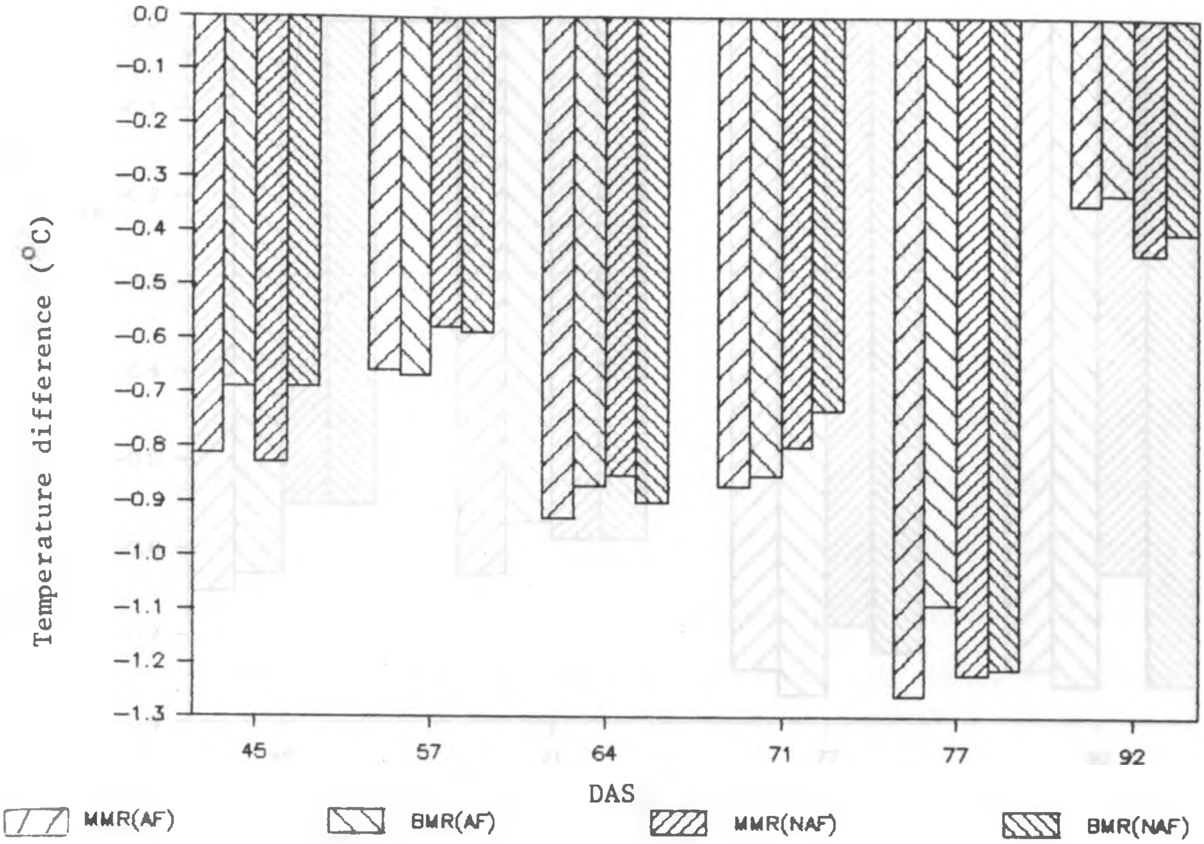


Fig. 3.9e. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 12.00 hours, for various DAS during experiment 2.

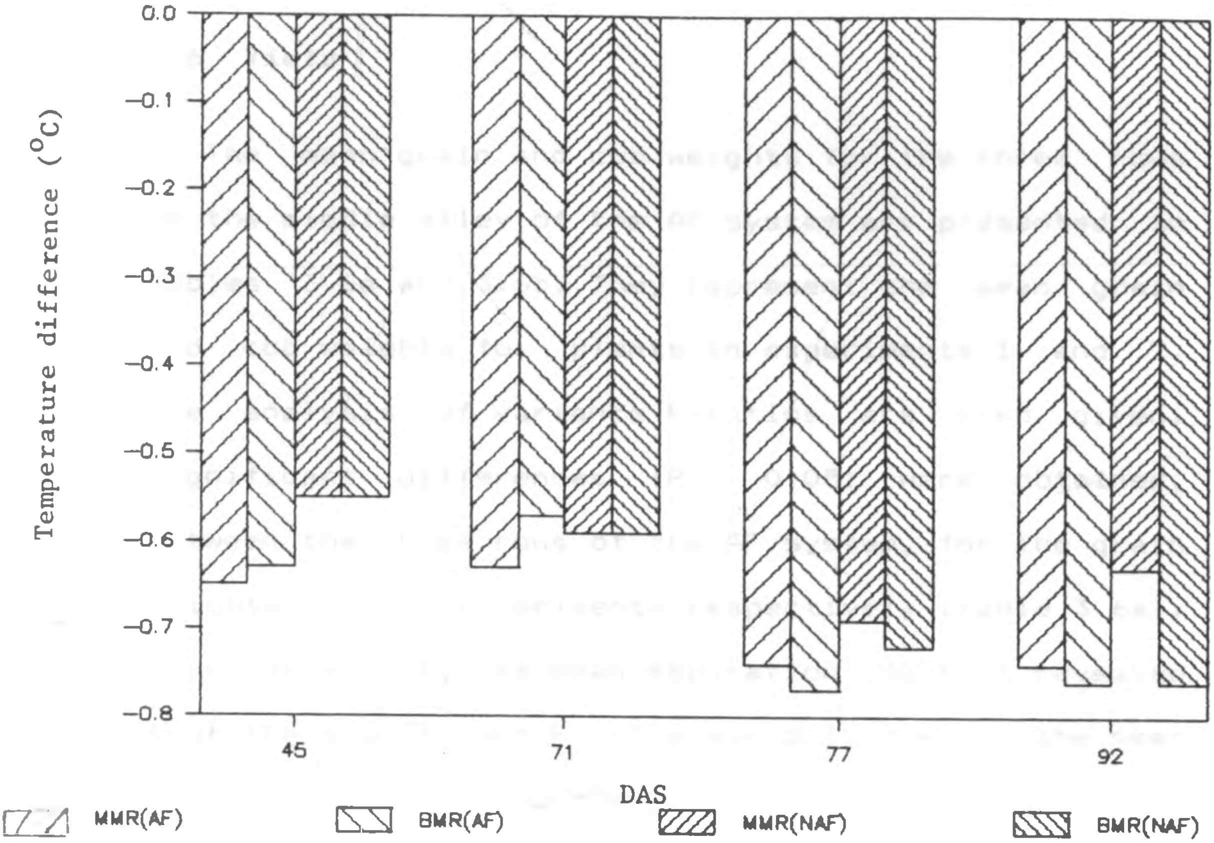


Fig. 3.9f. Variation in the mean leaf-air temperature differences in the MMR and BMR of AF and NAF systems, at 15.00 hours, for various DAS during experiment 2.

for both experiments. However, the differences in the AF system appeared generally to be somewhat lower (Figs. 3.9a-3.9c for experiment 1, Figs. 3.9d-3.9f for experiment 2).

3.6 Yield

The mean grain and cob weights for the three rows in the middle alley of the AF system are presented in tables 3.6a and 3.6b. They represent the mean grain and cob weights for plants in experiments 1 and 2. The analysis of variance F-ratios are also given. Significant differences ($P \leq 0.05$) were obtained, between the three rows of the AF system, for the grain weights in both experiments respectively (table 3.6a). In experiment 1, the mean separation LSD test revealed that the significant F-value was only due to the mean of the border maize row on the eastern side (BMRE) (Fig. 2.1) being significantly higher than the MMR (Fig. 2.1). The BMRE and the border maize row on the western side (BMRW) (Fig. 2.1) were not significantly different ($P \leq 0.05$). The ranking of the means showed that the BMRE produced the highest mean grain weight per plant followed by the BMRW. The MMR produced the least grain weight per plant. In experiment 2, the LSD test showed that the BMRE produced significantly higher grain weight per plant than the BMRW. The mean grain weight per plant of the MMR was not

	EXPERIMENT 1			EXPERIMENT 2		
Row	Mean	S.E	Rank	Mean	S.E	Rank
BMRE	94.4	4.7	1	85.0	4.2	1
	(67.8)+	(3.2)	(1)	(55.5)	(4.1)	(2)
MMR	79.8	3.4	3	73.5	5.1	2
	(60.8)	(3.5)	(3)	(52.6)	(3.2)	(3)
BMRW	86.3	3.9	2	67.8	4.2	3
	(66.8)	(4.2)	(2)	(58.6)	(3.9)	(1)
F-ratio	3.19 *			3.78 *		
	(0.11 ns)			(0.64 ns)		
LSD, 0.05						
BMRE-MMR	= 11.35 *			12.65 ns		
BMRE-BMRW	= 11.19 ns			12.45 *		
MMR -BMRW	= 11.26 ns			12.60 ns		

Table 3.6a Mean grain weight per plant (g) in the middle alley of the AF system and in the NAF system.

\+ Values in brackets represent mean grain weight per plant, their S.E., ranks and F-ratios in the NAF system.

	EXPERIMENT 1			EXPERIMENT 2		
Row	Mean	S.E	Rank	Mean	S.E	Rank
BMRE	107.6	5.5	1	92.5	4.8	1
	(80.9)+	(3.9)	(1)	(63.3)	(4.7)	(2)
MMR	91.5	4.2	3	89.0	5.9	2
	(74.2)	(4.1)	(2)	(59.9)	(3.7)	(3)
BMRW	104.0	4.7	2	78.5	4.8	3
	(77.6)	(5.1)	(3)	(67.9)	(4.5)	(1)
F-ratio	3.08 *			1.96 ns		
	(0.60 ns)			(0.93 ns)		
LSD, 0.05						
BMRE-MMR	= 13.38 *					
BMRE-BMRW	= 13.26 ns					
MMR -BMRW	= 13.30 ns					

Table 3.6b. Mean cob weights per plant (g) in the middle alley of the AF system and in the NAF system.

\+ Values in brackets represent mean cob weights per plant, their S.E., ranks and F-ratios in the NAF system.

significantly different ($P \leq 0.05$) from the BMRE. The BMRE had the highest mean grain weight per plant followed by the MMR and the BMRW was ranked number three. Averaging the two experiments, the middle row yielded lowest. Averaging all BMR's, they yielded 9% more in average than the MMR's.

The results of the mean cob weights per plant for each row of the middle alley of the AF system are presented in table 3.6b, for experiments 1 and 2. There was a significant difference ($P \leq 0.05$) between the mean cob weights per plant in the three rows of the AF system in experiment 1. The LSD test showed that the BMRE differed significantly ($P \leq 0.05$) from the MMR. The BMRE and BMRW were not significantly different ($P \leq 0.05$). The MMR was not significantly different ($P \leq 0.05$) from the BMRW. These results reflected those of the mean grain weights. The ranking was as in the grain weight, with BMRE producing the highest mean cob weight and the MMR producing the least. In experiment 2, the mean cob weights produced per plant were not significantly different ($P \leq 0.05$) between the three rows. However, the ranking of the means was as in the the grain weights. The BMRE was ranked first followed by the MMR and last was BMRW. The same is true for the ranking of all averages, with BMR's outyielding MMR's by 6% in cob weights.

The comparisons between the mean grain and cob weights per plant in the AF and NAF systems are presented in tables 3.6c and 3.6d for experiments 1 and 2 respectively. The maize grain yield per plant was significantly different ($P \leq 0.01$) between the AF and the NAF systems for both experiment 1 and 2. In both experiments, the mean grain yield per plant was higher in the AF system.

The mean cob weight per plant data for both experiment 1 and 2 are shown in table 3.6d. It is evident from the F-values that during both experiments the mean cob weights per plant were statistically significantly different ($P \leq 0.01$), due to the low mean cob weights in the NAF system.

The yield results closely followed those of the other parameters whereby the soil moistures was in some cases significantly higher in the AF system than in the NAF system (Table 3.2a, 3.2b). The stomatal resistances of the AF system maize plants were in some cases lower (Fig. 3.7a-3.7e) while transpiration rates were sometimes higher (Fig. 3.8a-3.8f). The NAF system plants may, therefore, have suffered from water stress for most of the growth period.

System	Mean grain weight per plant (g/plant)			
	Experiment 1		Experiment 2	
	Mean	S.E.	Mean	S.E.
AF	86.9	2.4	75.4	2.7
NAF	65.3	2.1	55.7	2.2
F-ratio	45.33 **		32.53 **	

Table 3.6c. Comparison of maize grain weights per plant between the AF and NAF systems.

System	Mean cob weight per plant (g/plant)			
	Experiment 1		Experiment 2	
	Mean	S.E.	Mean	S.E.
AF	101.1	2.8	86.7	3.0
NAF	77.5	2.5	63.6	2.5
F-ratio	38.9 **		34.1 **	

Table 3.6d. Comparison of maize cob weights per plant between the AF and NAF systems.

CHAPTER 4

DISCUSSION AND CONCLUSION

4.1 Competition for soil moisture and possibilities of water stress in alley cropping AF system

Horizontal soil moisture gradients were previously found with different trees as hedgerows (Prajapati *et al.*, 1971; Huxley *et al.*, 1989; Singh *et al.*, 1989). In all these examples, the soil moisture increased away from the hedgerows, indicating that tree roots were more actively taking up soil moisture than the annual crops. However, the present study (Fig. 3.1a, 3.2a, 3.3a, 3.4a, 3.5a, 3.6a) showed that soil moisture within the alleys of the AF system was almost uniformly distributed throughout the important stages of plant growth; vegetative, flowering and grain filling. The gradients observed were virtually not statistically significant. This suggests that the below ground interaction between the *Cassia* and maize roots did not result into severe competition for soil moisture. If any, this would be at the furthest distance from the hedgerow (Umaya, 1991). Root studies carried out on the same plot (Umaya, 1991) showed that in the early stages, maize roots were separated in space from the *Cassia* roots, with maize roots mostly occupying the top 10cm depth while *Cassia* mostly occupying 20-50cm depths. However in the later stages of growth, especially from flowering, maize roots grew deeper, causing more overlapping with *Cassia* roots. These findings indicate that the roots of the two plants were for a large part but not completely separated in space. Competition for water was not severe, because large soil moisture gradients were not observed within the AF alleys. Umaya (1991) suggests that observed yield differences between rows may have been due to competition for nutrients due to more overlapping roots at further distances from the hedge. The amount of rainfall received and its distribution was more than the average per season (Table 3.1a and Appendix 1) and more than the minimum of 200mm required per season for Katumani maize variety (Mwenda, 1983). Rainfall for the two experimental seasons was therefore adequate for normal growth of the maize and *Cassia* without severe competition for other resources than nutrients taking place. The improved water retention capacity of the soil by adding the organic matter from *Cassia* mulch, as shown by the high moisture content in the AF plots (Table 3.2a, 3.2b), may also have contributed to eliminate the possibility of severe competition for soil moisture.

Plant leaf measurements of stomatal resistance, transpiration rates and leaf-air temperature differences, being known plant water stress indicators, were used as above ground indicators of competition for soil moisture between *Cassia* and maize both in the MMR and in the BMR. A significant difference in the response of these parameters between MMR and BMR, if observed, could have occured in cases of water stress, suggesting the existence of competition between the plants in the AF plots. However, these three plant physiological measurements were insensitive to measurement position. The rate of water absorption by the maize roots was therefore apparently not affected by the presence of *Cassia* roots and the plants in one row did not show any significant difference with respect to their stomatal resistance.

Plant growth conditions influence stomatal response to water stress (Hsiao, 1973). Under field conditions, the threshold of leaf water content below which the stomata begin to close is lower than under controlled environmental conditions (Hsiao, 1973; Schulze, 1986). It is likely that in the present study the threshold level was not attained, although lower soil moisture conditions may have been experienced by the maize plants away from the hedge. Maize has also been demonstrated to undergo osmotic adjustment as an adaptation characteristic which allows the stomata to remain open even under very low water potentials (Michelena and Boyer, 1982; Sobrado, 1986; Macharia, 1988). The maize variety used in the present study was recently demonstrated to have these characteristics since its photosynthesis was observed to be less sensitive to severe drought as compared to other high altitude varieties (Macharia, 1988). This adaptation characteristic would easily conceal mild drought stress effects on the plants from being detected.

The response of stomata as indicated by stomatal resistance and transpiration rates revealed that during some times of measurement, the maize plants in the NAF systems were experiencing mild water deficits. Under these conditions the stomata tended to become abit more closed and therefore somewhat higher stomatal resistances and lower transpiration rates were obtained of which the difference proved to be statistically significant (Table 3.3a, 3.3b, 3.4a, 3.4b). These results were in agreement with the soil moisture data which showed that the AF system had significantly more moisture than the NAF system in some cases.

4.2 The influence of alley cropping AF practices on soil moisture content

Alley cropping has been demonstrated to have microclimate improvement effects under semi-arid conditions (Singh *et al.*, 1989). These may include: shading, windbreak effects, soil and air temperature improvements and concentration of water run-off by hedgerows. Direct radiation from the sun is reduced by the tree/shrub foliage and this lowers the evaporation rates from the plants and the soil. The reduction in wind speed by the hedgerows helps to lower the desiccation effects of the wind. The presence of foliage also helps in the redistribution of rain water from the surrounding areas. This positive change in microclimate especially help to improve the moisture content of the soil. The present study showed that the soil in the AF system had in some cases significantly (in the statistics sense) more moisture than the NAF system and this might have been partially due to the improvement of the microclimate.

The application of mulch improves the soil physical properties and this includes the water retention capacity of the soil (Yamoah *et al.*, 1986b; Lal, 1989b). The better soil moisture retention capacity is attributable to the favourable soil organic matter content and improved soil structure (Lal, 1989b). Previous research on *Cassia* and other perennial shrubs showed that *Cassia* produce abundant and persistent prunings, hence soils mulched with it may get higher moisture holding characteristics (Yamoah *et al.*, 1986b). The high moisture content in the AF system found in this study may, therefore, have resulted from the presence of mulch which may have contributed to high organic matter content in the soil.

During the last DAS measurement (Table 3.2a), the soil moisture of the NAF system was higher than in the AF system. This was probably because there was a higher root density of both *Cassia* and maize as well as a higher degree of overlapping (Umaya, 1991) which caused greater water uptake. Such effects have also been found at windbreaks (Rosenberg, 1967). Additionally, the presence of the regrown *Cassia* may have contributed greatly to the water loss through transpiration. Windbreaks have been demonstrated to have similar effects (Rosenberg, 1974). Precipitation at this time was also quite low (Table 3.1a). This was not, however, repeated during experiment 2, probably due to much higher rainfall and lower evaporation rates (Table 3.1a).

In general, it may be concluded that a higher sampling rate of soil moisture would have given more significance to smaller differences, but this would in the present interpretations not have added much to the conclusions. This applies to all other parameters used for stress indications as well.

4.3 Effects of hedgerows on crop yield

Crop yield observations consisted of grain and cob weights. The average yield profile within the alleys of the AF system generally showed that the BMR performed better than the MMR. The maize row on the eastern side also performed better than the MMR and the maize row on the western side (Table 3.6a, 3.6b). The yield data of this study are in line with those of Mungai (in prep.) but are at variance with what was expected from *Cassia* competition and what has been obtained elsewhere by other researchers. Alley crop yields have been found to increase away from the hedgerows (Yamoah *et al.*, 1986a; Huxley *et al.*, 1989; Singh *et al.*, 1989). These findings have always been associated with competition for soil moisture and nutrients between the crop close to the hedgerow and the perennial shrub. Competition for soil moisture causes water stress to the crop, thus affecting major physiological functions (subsection 1.2.4). The yield results obtained in this study may have been influenced by microclimate improvements. The soil moisture content was in some cases slightly higher near the hedgerows. Soil temperature modifications may have taken place within the entire period of experimentation. It has been previously found (Mungai, in prep.) that the soil temperature in the alleys is lowest on the eastern side followed by the western side and highest at the centre. It is likely that the soil temperatures were influenced by hedgerows, and this might have affected the maize growth, especially as the growing point of maize remains close to the soil for a long time. However, these explanations are not conclusive. More likely is an influence of overlapping roots, which was shown to be higher at distances further from the hedge, which may have influenced nutrient uptake (Umaya, 1991). Mwangi (1990) showed fertility to be a limiting factor also for AF system under all conditions.

The overall performance of maize in the alley cropped plots (AF system), irrespective of their position in the alleys, was better than in the NAF system (Table 3.6c and 3.6d). This improved performance is attributed to the addition of mulch, which improved the soil nutrient and soil moisture status (Yamoah *et al.,* 1986a; Mwangi, 1990). In addition, the soil temperatures were moderated, while indeed the soil water holding capacity improved through increased soil organic matter content. These factors combined to enable the maize plants in the AF system to perform better under the limiting nutrient conditions during most times of the growing season.

Grain yields under the sole crop of maize were also elsewhere found to be lower than in the alley cropping system involving *Cassia* (Yamoah *et al.*, 1986a) and this was attributed in part to poorer soil physical properties and nutrients especially nitrates. Root growth in the sole crop of maize was also found to be restricted, affecting the uptake of major nutrients. Straw mulch on the surface was found to encourage greater lateral root spreading by reducing soil temperature and improving soil moisture content, and this led to better maize plant growth (Chaudhary and Prihar, 1974). A similar effect is expected in the mulched plots under alley cropping agroforestry system.

4.4 Conclusions

Based on the data presented, on the study at Machakos, it was found that soil moisture distribution in the alleys of the AF system was rather uniform, showing that competition was apparently minimum or absent for all depths involved in the study. This was enhanced by the above average rainfall received during the two cropping seasons. The root distribution studies (Umaya, 1991) partially concurred with these findings. The presence of the *Cassia* hedgerows and its prunings also contributed to the high soil moisture content in the AF system.

There was statistically significantly higher soil moisture content in some cases of the AF system, especially during drier periods of the cropping season. This occurred for most parts of the growing period and was probably due to a combination of microclimate improvement arising from shading effects, windbreak effects and water collection by the foliage and improved water retention capacity of the soil, whose organic matter content may have been increased by the presence of mulch.

The stomatal resistance, transpiration rates, and leaf/air temperature differential measurements made on the maize plants showed that competition for soil moisture between the *Cassia* and maize was minimum and that there was no water stress to override other factors to cause severe physiological malfunctions. Maize plants in the NAF system were more likely to suffer from water stress than the AF system maize plants, due to the lower water holding capacity of the soil.

Maize yields were positively affected by proximity to the *Cassia* hedgerows. The maize in the middle rows performed poorly relative to the BMR, probably due to higher effects of competition with overlapping roots of *Cassia* (Umaya, 1991) and other maize rows for nutrients. Soil temperature effects of the hedgerows may also have contributed to this effect. Maize in the AF system performed better than in the NAF system, most likely due the improved water holding capacity of the soil because of the incorporation of mulch.

4.5 Recommendations

4.5.1 Potential of *Cassia*/maize alley cropping system under semi-arid conditions

This study has shown that under the high rainfall conditions, competition for water between *Cassia* and maize was, if present, at a minimum level. Mungai (in prep.) showed that under drier conditions, the alley cropping system perfomed poorly. Therefore, under limiting water conditions typical of semi-arid zones *Cassia siamea* Lam. is not a suitable alley tree/shrub to be intercropped with maize where competition for soil moisture and nutrients have been demonstrated to exist (Mungai, in prep.).

Despite the mulching treatment, it has been shown that the nutrients are still a limiting factor (Mwangi, 1990). This may therefore necessitate addition of mulch from outside sources. Also, nitrogen fixing *Cassia* varieties should be tried out to further improve the soil nutrient status, since nitrogen is one of the major limiting nutrients under semi-arid conditions. The tree preferred for the system should be sufficiently deep rooting so that there is no competition for nutrients (always) and no competition for water under conditions of drier years. A suitable system, in addition, is where the maize yield should be able to compensate for the area covered by the hedgerow. This was however, not fulfilled in the *Cassia*/maize alley cropping system of the present study.

A suitable multipurpose tree/shrub chosen for the alley cropping system provide various uses. Trees planted along the contours help in controlling soil erosion caused by wind or water. At the same time the trees provide fuelwood for the rural population when they are lopped. Due to the limiting costs of mineral and organic fertilizers the agroferestry trees/shrubs provide mulch to sustain the fertility of the soil in the semi-arid areas. Such plants should be fast growing and the leaves easily decompose to release nutrients. A deep rooting tree/shrub is also useful in recovering nutrients that leach beyond the root zone of the crop plant. These nutrients are absorbed and recycled through litter fall. The organic matter content increase due to mulching and the soil structure is also improved. These effects contribute to the water retention capacity of the soil. The accompanying crop therefore, benefits from the stored water for its growth.

4.5.2 Future research strategies

Further research in this area of agroforestry is encouraged since previous results have demonstrated that competition for water and nutrients between maize and *Cassia* is very likely. Therefore, future research should be:

1: with *Cassia* species that fix nitrogen;

2: with trees that have less overlapping root zones;

3: with trees that produce more mulch yield or additional mulch from other plots;

4: systems that are less risky to try out in on-farm trials.

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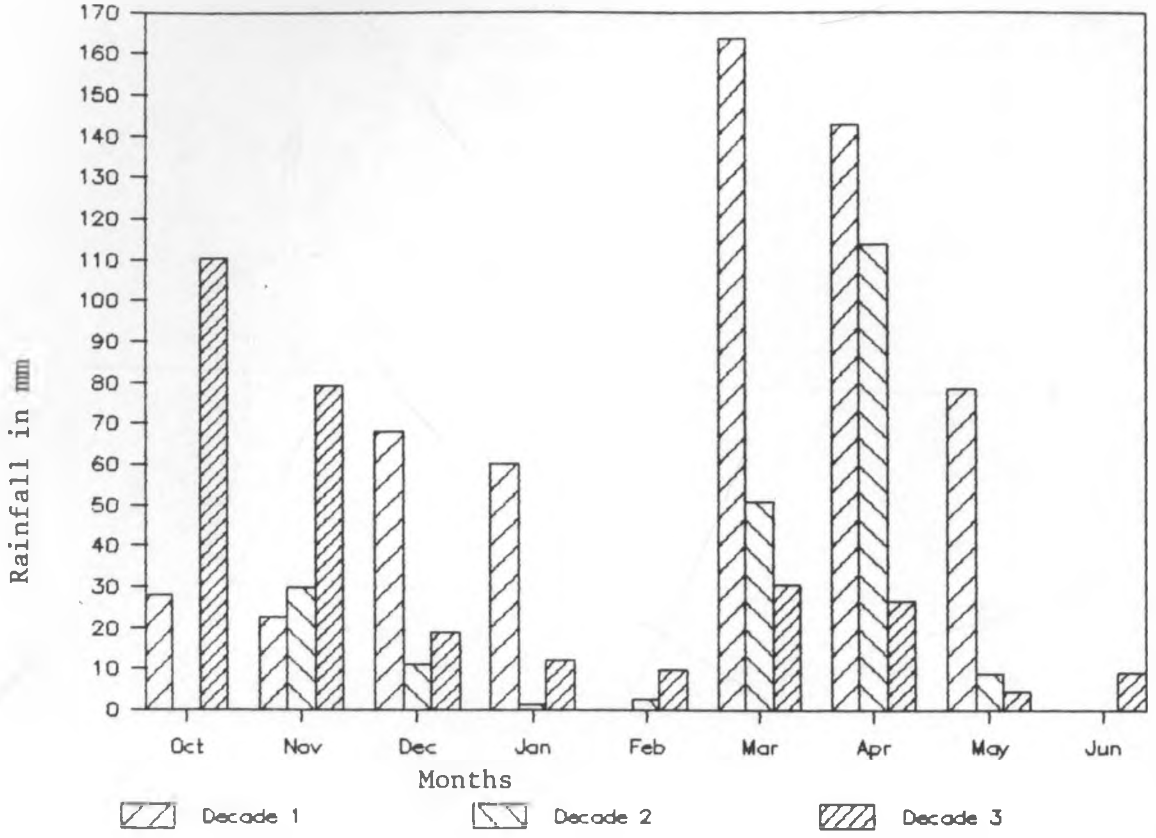

Appendix 1. 10 day rainfall distribution at the ICRAF field station, Machakos, from October 1989 to June 1990.