The effects of contour hedgerows (alley cropping) on microclimate, soil and water conservation and competition on sloping lands for sustainable land use in Machakos district, Kenya.

By

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Declaration.

This is my original work and has not been presented for a degree in another University.

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Dedication.

This piece of work from my ideas, thoughts and endeavours is dedicated to my beloved parents: My father the late Mzee Kinama Mbui and my mother Mama Mbula Kinama whole played a vital role in educating, inspiring and encouraging me to aim high in widening my academic horizons.

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Abstract

The research was conducted in a semi-arid land of Kenya prone to land degradation when open for rainfed agriculture. Insufficient water and soil erosion limit plant growth and development. The area has erratic rainfall occurring in heavy high intensity storms which cause soil erosion. This study found such maximum high intensity storms occurring within the first less than 40 days of the respective season when, crop cover had not yet developed and partially replaced mulch cover in soil protection.

Shortage of more land in the high potential areas, has resulted in immigrants to the steeply sloping lands for farming and settlement purposes. The immigrants have brought with them inappropriate crop, animal and tillage technologies from the high potential areas to the ASAL with consequent land degradation.

Agricultural potential is marginal in the semi-arid Kenya. This potential needs to be exploited skilfully and in a well coordinated manner. The aim is to sustainably produce enough food and reduce dependence on famine reliefs for the new settlers, in ways which minimise environmental degradation. The purpose of the research was to contribute in the quantifying on-station potential of alley cropping in arid sloping lands. This was done through quantifying microclimatic management and manipulation using contour hedgerows with and without mulching and grass strips as well as mulch alone in soil and water conservation techniques. Also an on-farm

comparison was made between traditional soil and water conservation techniques and contour hedgerow intercropping technology and their effects on yields.

The on-station research was conducted at ICRAF Field Research Station, Machakos, for a period of six cropping seasons, alternating maize and cowpea. The on-farm survey was carried out for four seasons in Kakuyuni catchment.

To understand crop growth conditions, the on-station research entailed monitoring moisture in the soil profile using the Time Domain Reflectometry at the shallow 30 cm depth and a neutron probe metre for up to a depth of 120 cm (the soil depth exploited by both the crop and tree/grass roots). These measurements were used to determine (i) weekly soil moisture storage in the soil profile, (ii) seasonal water use and for some seasons water use efficiency in alley cropping vis-a-vis monocropping both with and without mulch but only without mulch for the grass strips, and (iii) losses through deep percolation in a soil water balance on sloping lands. Soil erosion and runoff losses in relation to on-station erosion control were also monitored through tipping buckets and collection tanks at the bottom of the steep slopes in the alley cropped, mulched, grassed and control plots, to understand their possible effects on yields and in the soil water balance. Soil evaporation losses were quantified by microlysimeters with a view to determine their relationship to the total rainfall and their role in the soil water balance and possibly in yield reductions.

Quantification of PAR % interception took place by using a ceptometer in alley and monocropping to understand its possible effects on the yields of associated crops and to determine for some seasons light use efficiency for the same. Crop and mulch cover were simply visually quantified to understand their effects on soil temperature, soil and water loss and possibly on growth conditions yields. Near surface soil temperatures (platinum resistance thermometers) as well as windspeed and direction (woelffle) anemographs) were also quantified in order to explain any effects they may have on yields. Quantification of yields was both on-station and on-farm for the various biological/organic and structural (inorganic) soil and water conservation structures.

From the results it can be deduced that:

(a) Combination of hedgerow and mulch was the most effective in the control of both soil erosion and runoff losses on our steep slopes in all seasons. Only this combination was promising enough for sustainable yields of sufficient level in the long run.

(b) Runoff losses(maximum in the order of 10% of rainfall) were low compared to the high soil evaporation losses (42 to 66 %) of rainfall) in the soil water balance, while percolation losses were extremely low and were only recorded in one season, that of (94/95) high rainfall.

(c) There was a general tendency to have grain and biomass yield increases in maize with increasing rainfall amounts, for the low rainfall (1993) to the rather average (1995), with the just below average rainfall (1994) in between. For cowpea, where the driest season was of average rainfall and the other two far above average, the yield pictures were much more complicated.

(d) Alley cropping resulted everywhere in reduced soil loss and runoff losses compared to the control plot but at the same time brought about yield depressions, both on-farm and on-station. This was notably through competition by the trees or grasses and the associated crops for water, light and nutrients. For maize highest yield depressions were in middle rows for hedges and adjacent rows for grass strips while for the cowpea they were always nearest to the hedges and grass.

(e) Use of mulch from existing hedgerows, without using external sources resulted in grain and biomass yield improvements in the hedge+mulch plot compared to hedge only with the exception of the driest maize year and for cowpea grain of driest and lest wet year despite the overall yield depressions. This mulch also resulted in reductions in soil evaporation in the mulched plots losses compared to the C plot.

(f) The barrier hedgerows resulted in more moisture being concentrated and conserved beneath the hedgerows than in the middle of alleys, as shown by the TDR and neutron probe results.

(g) Tree/crop interfaces resulted in increased PAR % interception but did not result in increased light use efficiency (LUE), that was highest in the sole maize crop. The hedge+mulch+ crop system had the highest LUE for maize. All values for cowpea systems fell in the range of 0.9± 0.2 g MJ^{-1} for the only year it was determined (94/95).

(h) Alley cropping resulted in less transpiration by maize system in 1994 but in more transpiration by maize system in 1995 than the controls but transpiration was highest in mulched controls. For cowpea crop systems alley cropping had throughout higher transpiration than in sole crops. As for water use efficiency it was always highest for un mulched control and hedge cum mulch systems for both cropping systems.

(i) To take advantage of weather advisories, grow maize in short rains and cowpea in long rains for the former are more reliable than the latter; water harvesting as well as drought tolerant crops to be practised/grown in below or low rainfall seasons for enhanced crop growth; keenly follow appropriate sowing dates and tillage as well as use water conservation structures including AF, that is H+M; compromise to use mulch in H+M and for other purposes; minimise soil evaporation without negatively affecting but preferably positively affecting yields (decomposing mulch); keep rainfall records and make use of them in strategic planning as food reserves.

(j) Soil erosion control and runoff by the traditional "fanya juu" terraces and to a somewhat lesser extent stone terraces (and occasionally trashline terraces) compared to the contour hedgerows and grass strips appear to be more effective for they don't result in yield depressions. The farmer must have realised the long term yield advantages of the "Fanya juu" terraces despite their initial construction costs and this may explain their wider use in this area.

CHAPTER ONE

1. INTRODUCTION.

1.1. General.

About 80% of Kenya's land mass of 583,000 Km^2 is Arid and Semi-Arid (ASAL). This area supports 20% of the estimated 25 million Kenyan population and half the total livestock population (Kinama, 1992). The rest of the land mass, categorized as high potential, supports the majority of Kenyan population and produces food for subsistence as well as for local and export markets. While most of the Kenyan population derives its livelihood from agriculture, there is very limited arable land remaining in the high potential areas for further agricultural expansion. The main attention for further increase in food production has been to open up more land for agriculture and settlement in the dry areas (Government of Kenya, 1983). The environments of these semi-arid areas, which include Machakos District, are however, fragile. They are characterized by erratic rainfall, which is most often insufficient in amount and poorly distributed over the crops' growing period. This results in moisture deficits during critical growth stages, such as the crucial tasselling and flowering stages, with consequent crop failures or very low harvestable grain yields. The rains occur in two distinct periods, namely the short rains from October to January and the long rains from March to June. The long term average for the former is 340 mm and for the latter is 288 mm, according to calculations made by Kinama (1990) for a period of 30 years for Katumani meteorological station. From the ICRAF research station at Machakos, the rainfall data from 1985-1995 for the short rains and the long rains are in the range of 310-370 mm and 300-410 mm respectively. These rains occur frequently during the earlier part of the seasons, when the ground is still bare and more subject to erosion (Moore, 1978). The potential or reference crop evapotranspiration is about 900 mm per season (Kibe et al. 1981). For the above mentioned periods, weather data from both Katumani and ICRAF research stations in Machakos District show that it is on average only in the months of November and April that total precipitation exceeds potential evapotranspiration. This shows that there is water deficit for crop and pasture production in the area. While the short rains are often reliable, the long rains have been described as very variable (Mutiso, 1991) and they occur in medium to high erosive intensities (Ahn, 1975). Braun (1977) has described rainfall in Machakos as bimodal with large variability in annual and seasonal rainfall and in rainfall reliability.

By and large, rain water in the semi-arid areas is subject to several losses and it is therefore important to quantify the effective rainfall which goes to production. These losses include soil evaporation, which has been described as high by Muchena (1986) in his work on the semi-arid soils of Kenya. Wallace (1991) estimated soil evaporation losses from millet in semi-arid West Africa as from 30-50% of the seasonal rainfall. In the temperate humid climates on loamy sand bare soils in spring in Denmark, Plauborg (1995) noted that soil evaporation was as high as 65% and 50% of accumulated potential evapotranspiration in a 13 and 23 day drying periods after wetting respectively. At Wagawaga, Australia, soil evaporation under a wheat canopy was estimated as 48% of the total rainfall (Leuning et al., 1994). Some of the rain is lost via runoff. This happens when soil can no longer accommodate more water by infiltration, and some water may find its way to the underground water sources through deep percolation. Some other losses occur when raindrops are intercepted by the plant canopy and cannot find their way to the soil, but lower evaporation from the leaves partly compensates this. A simple water balance equation for this study (see chapter 2) will consider the amount of precipitation received and its distribution via the above mentioned losses, in the experimental plot area, in order to determine the water available for crop production.

Studies at Katumani in Machakos, by Barber and Thomas (1979) using a rainfall simulator, on a gentle slope of about 5%, indicated that the infiltration rates of luvisols were as low as 7-20 mm h^{-1}. At the very high intensity of 50 mm h^{-1} rainfall, the percentage of rainfall lost as runoff in one storm amounted to 15% when the soil was still relatively dry and 67% when the soil was wet. These gave rise to soil losses of 173g m^{-2} and 852g m^{-2} respectively. This indicates that soil losses are high and soils will require proper water management techniques in order to minimise erosion and runoff losses, enhance effective rainfall and hence crop and pasture production.

The soils of the ASAL areas of Kenya have been described by the Kenya Soil Survey (Mbuvi and Van de Weg, 1975) as mostly Alfisols with a few pockets of vertisols according to the USDA Taxonomy classification system, or Haplic lixisols according to the FAO/UNESCO (1988) system. They have low organic matter content and are deficient in the plant nutrients Nitrogen and Phosphorus as well as in the trace elements Copper and Zinc (Ikombo, 1984). They are dark reddish brown, sandy clay loam, becoming sandy clay at the lower horizons (Mbuvi & Van de Weg, 1975; Barber et al., 1979; Kilewe and Ulsaker, 1984). They are shallow due to the presence of a pentroplinthite (Murram) horizon (Marimi, 1979). Due to low structural stability (Kiepe, 1995) the soils are highly erodible and prone to surface capping by intense rainfall.

The physical features of the ASAL areas range from low lying plains to moderately sloping and very steep slopes. Cultivation is also carried out on steep slopes exceeding the legal 35% slope limit permitted for cultivation (Gichuki, 1991). This is in conflict with the agricultural act which contains regulations governing land use (Government of Kenya, 1986a). According to the USDA (1951) land use capability classification system, the steeply sloping lands are categorized as non-arable and only suitable for forestry, grazing or conservation (see also Dent and Young, 1981). This classification is again in conflict with the act governing land use

(Government of Kenya, 1986a). Despite the legislation for protecting steep lands, arable farming has been going on and will continue on these sloping lands because to these farmers this is the only land they possess for farming purposes and they often are already immigrants, that have no other place to go.

Also from the socio-economic point of view, the majority of farmers in the ASAL areas are resource poor and they farm mainly for subsistence purposes, according to surveys conducted by Rukandema (1984). Because they lack resources, these farmers cannot get access to sufficiently cheap credit, due to lack of security for the same. This results in delays in or even absence of the procurement of farm inputs, the use of poor seeds for planting and the use of blunt tillage tools due to lack of funds to purchase new ones or repair these tools. This leads to delays in other farm operations and consequently low harvests. These surveys also indicate that there is a shortage of labour during the critical periods of weeding. In essence, most of the work on the farm is done by family members except on a few occasions where hired labour is engaged. Therefore, some yield losses from weed infestation and late harvesting occur.

On the other hand, the ASAL have experienced heavy immigration of people from the densely populated high potential areas in search of land for farming and settlement (Mbithi and Barnes, 1973; Mungai, 1991; Otengi, 1996). The settling populations have brought with them unadapted technologies such as high yielding hybrid maize seeds, beans, graded animals, ploughing implements *inter-alia*, but do not have experience in the best low input techniques of farming in the semi-arid areas. As a result, land degradation has occurred.

Due to extreme rainfall variability, these areas are prone to droughts and famines, which have forced the government to use its scarce resources for mounting famine reliefs. These areas occasionally import food from the neighbouring high potential areas to supplement their low food harvests. The small scale farmers in these areas therefore need land use technologies which will enable them to sustainably exploit the agricultural potential of the sloping areas to meet their food needs, while at the same time reducing the risks of land degradation.

Despite the above challenges facing the semi-arid areas, the government has made efforts to develop the agricultural potential in these areas in order to improve the food situation of small scale subsistence farmers. A closer look at the National Development plans for the periods 1978-1983, 1984-1988 and 1989-1993 (Central Bureau of Statistics) shows the government's commitment to developing these lands via increased funding to development projects in these areas. In 1989, the government created the Ministry of Reclamation and Development of Arid and Semi-arid areas and Wastelands and charged it with the development of environmentally sound policies to be followed in developing the drylands, in order to minimise environmental degradation. Moreover, the development plans 1989-1993 place more emphasis on strategies to do research into drought tolerant crops for the ASAL such as sorghums, millets, early maturing maize varieties, sweet potatoes, early maturing beans, pigeon peas, cowpeas, grams and oil seeds.

Also the government's research priorities focused on the need for increased food production while conserving soil moisture and soil fertility levels, in order to minimise reliance on expensive chemical fertilizers (Government of Kenya, 1981, 1986b and 1994). For these reasons, some of the research centres of the Kenya Agricultural Research Institute (KARI), such as the National Dryland Farming Research Centre (NDFRC), Katumani, have been set up with national mandates of developing crop technologies as well as soil and water resources management strategies which would make dryland farming sustainable.

Hitherto, however, development efforts in these dry areas have concentrated on agriculture and livestock enterprises and have neglected the role of agroforestry in the development of these areas (Hoekstra et al, 1984). Agriculture/livestock related developments had however experienced a shortage of firewood and fodder in the dry areas. A large need therefore exists to address the above mentioned needs of the small scale farmers in order to try to improve the food situation *inter alia* using agroforestry technologies.

Agroforestry refers to land use systems in which trees or shrubs are grown in association with agricultural crops, pasture or livestock and in which there are both ecological and economic interactions between the trees and other components (Young, 1989). Alley cropping is an agroforestry system in which crops are grown in the alleys formed by the tree/shrub hedgerows (e.g. Corlett et al. 1992).

An evaluation of the agroforestry potential that exists in Machakos district has been done by the International Centre for Research on Agroforestry (ICRAF) through the diagnosis and design methodology (D&D). Through the identification of farmers constraints and land use problems, this methodology aims at the design of appropriate agroforestry systems and at deriving research needs in order to address the critical needs of the farming community in the area. The D&D methodology carried out in Machakos district showed that the main problems facing the local community included: food insecurity, due to extremely variable weather, soil nutrient deficiencies, poor crop and animal husbandry practices, lack of animal fodder during the dry season and shortage of fuel wood.

In an effort to find solutions to such problems, KEFRI (Kenya Forestry Research Institute), in collaboration with KARI, with ICRAF as local consultants, started doing research in 1983. The Dryland Agroforestry Research Project (DARP), which is a project in

KEFRI, provides a link through which KEFRI, the TTMI (Traditional Techniques of Microclimate Improvement) Project at the University of Nairobi, the TTMI Project at Wageningen Agricultural University (Netherlands) and ICRAF collaborate in agroforestry research training. The TTMI project started in 1986 collaborative research with KEFRI through the IDRC (International Development Research Council) funded DARP at Machakos.

The TTMI - Project is providing research training and education at Ph.D. and the M.Sc. level that aims at contributing to solutions of urgent farming problems locally defined, with important agrometeorological components, and that starts with quantitative attention for traditional techniques and concepts. In the TTMI project an integrated quantitative approach of a maize/cassia alley cropping system was successfully applied within the DARP (Mungai et al, 1996a). The present study in the TTMI- project was carried out as well within this DARP context, where KEFRI was especially involved in the on-farm research components. The core of the on-station research work was carried out at ICRAF's research station in Machakos, where ICRAF provided both logistical and co-supervision support. The TTMI-Project provided most of the equipment (instrumentation) for field data collection. The study examined how alley cropping with on-surface mulching can help modify microclimate and provide soil and water conservation for sustainable crop yields of associated crops on sloping land. By such an approach, food security needs, soil fertility deficiencies, soil erosion problems and water runoff problems may be alleviated.

As small scale farmers on sloping lands have traditional soil and water conservation techniques, a comparison was made between the performance of the alley cropping technology, that is based on traditional concepts as using trees, and on-farm traditional techniques and between resulting crop yields. The main issue in this study was quantification of the hypothesis that alley cropping could be identified as one of the potential solutions to sustainable crop yields in the sloping dry areas of Machakos (Young, 1989).

Past experiments have, however, shown that there is competition for nutrients, water and light between the tree component and the crop component. For instance, using three tree species *Leucaena leucocephala*, *Gliricida sepium* and *Senna siamea* intercropped with maize and cowpeas, scientists at ICRAF's Research Station (Machakos) indicated that Leucaena was more competitive with adjacent crops than the other two species (Ong et al. 1992). This was clearly marked in a dry year (1987), where lower crop yields were recorded, possibly as a result of increased competition for moisture in *cassia*/maize alley cropping. Mungai (1991) reported a complete crop failure for the short rains of 1987 in his *cassia*/maize agroforestry treatment, due to severe competition for water, while some yields were obtained in the controls. Results of alley cropping in the semi-arid tropics of India have consistently shown a considerable reduction in crop yield, of 30 to 90%, when the alley width was less than 5 metres (Singh et al., 1989). They postulated that competition for moisture between the roots of trees and crops or shading by the trees was responsible for restricting crop growth in the alleys.

Other experiments have shown potential for erosion control. Soil loss at ICRAF Research Station with a 50 mm h^{-1} rainfall intensity produced 34 t ha^{-1} of soil loss at 14 % slope from control plots compared to soil erosion of 0.2 to 0.5 t ha^{-1} in a *mulched Senna*/maize alley system (Kiepe, 1995). Ong et al. (1992) observed the potential of agroforestry to control soil erosion on hill sides as evident in 2 to 3 years, when a sloping land was turned into a series of terraces. Raintree (1983) summarized the advantages of alley cropping in Embu district in Kenya as labour saved in natural build up of terraces by hedgerow bunds, soil erosion control, runoff reduction, increase in organic matter via mulching, nitrogen fixation, nutrient recycling and supplementary dry season fodder. Lal (1989) also stressed the importance of alley cropping for restoration of eroded lands, provision of fire wood and fodder as well as for covering against soil erosion in Rwanda. Furthermore, some relative yield benefits, not accounting for the area lost to the trees, have been reported in the semi-arid areas of Machakos by Nyamai (1987), Mwangi (1989) and Mungendi (1990), while maize yield benefits were also reported from sub-humid and humid Nigeria (Kang et al. 1981). Mungai et al. (1996b) got maize yield benefits in five cropping seasons which never compensated for the area lost to the alley trees under semi-arid conditions on flat soil in Machakos. The mean seasonal grain yield results on 14% slope from maize/senna alley cropping were 2.15 and 2.25 t ha^{-1} for hedge+mulch and sole hedge plots as compared to 2.1 and 2.5 t ha^{-1} in the control sole maize and sole mulch plots respectively, when no area was lost to the trees because maize was sown as addition to the alleys (Kiepe, 1995). The mean cowpea yields in alternating seasons in the same plots were 0.5 and 0.5 t ha^{-1} for the hedge + mulch and sole hedge as compared to 0.45 and 0.55 t ha^{-1} for the control sole maize and sole mulch plots respectively, when 10% of the area was lost to trees. These are high yields in the semi-arid areas of Machakos, but the differences between treatments are small, with the exception of maize in sole mulch plots. However, such yields should be followed over a longer period, to obtain information on long term sustainability.

The potential of alley cropping in semi-arid areas for sustainable sufficiently high crop yields on sloping lands needs to be confirmed by microclimate, soil and water conservation and tree/crop competition studies. In such previous studies, however, there has particularly been a lack of microclimatic data (Mungai, 1991) to help explain yield differences within alleys and from season to season, while most alley cropping yield data interpretation has been based on level to very gently sloping 3.5% land, with the work of Kiepe (1995) as a notable exception. At the same time, cheap and appropriate techniques of soil erosion control and water conservation have not been clearly identified. It is therefore a pertinent research issue to address these needs of farmers and to further interpret yields on sloping lands under conditions of absence of cover, cover by contour hedgerows, cover by mulch and in case of their combination.

1.2 Objectives of the study

The main objective of the research work was to study the level of yield sustainability of alley cropping (contour hedgerow intercropping) on the sloping semi-arid areas of Machakos, Kenya. This was mainly done by quantifying and understanding the effects of microclimate, soil and water conservation and competition between the trees and crops on crop yields. The hypothesis was that alley cropping with on surface mulching sufficiently conserved the soil, soil water and soil fertility to obtain yields that would not decline over time under equal soil water conditions. From this hypothesis, the specific objectives were to determine for the slopes and crops concerned:

(i) how mulch and crop cover influence soil water loss;

(ii) how runoff and soil erosion affect water balances and yields;

(iii) how soil moisture levels affect dry matter production, yields and water use efficiency;

(iv) how soil evaporation is affected by mulch, hedgerows and grass strips and how it affects water balances;

(v) how Photosynthetically Active Radiation (PAR) interception affects trees and crops dry matter production and light use efficiency;

(vi) how soil temperature is affected by mulch, hedgerows and grass strips and

(vii) whether windspeed and direction as affected by the slope have any major influence on crop yields;

In addition to the above other specific objectives were:

(viii) an inventory of traditional techniques of soil and water management applied on sloping lands in Machakos district/Eastern semi-arid Kenya and

(ix) to get a preliminary idea of how traditional methods compare with contour hedgerows in soil and water conservation and resulting crop yields.

CHAPTER 2.

2. LITERATURE REVIEW.

2.1 General: agroforestry and alley cropping

Agroforestry is an old traditional practice in which the natural resource base is shared by trees and crops, but what is new are the research approaches to sustainably improving it to meet the needs of man. These needs include food, fruits, fodder, fibre, firewood and timber, shade, and protection against strong winds. There are a number of such resource sharing agroforestry practices cited in the literature and a brief description of these will illustrate them as reviewed by Youny (1989):

(i) Rotational practices: (a) shifting cultivation is the earliest and most widespread practice of agroforestry, well known for its soil fertility restoration via fallows in the humid and sub-humid tropics; (b) improved tree fallow - rotation of crops with planted trees, better selected to obtain harvested products from the trees. The crops are grown for a few years followed by many years of tree growing; (c) Taungya - food crops are grown with commercial timber trees, interplanted during the first few years of tree establishment.

(ii) Spatial-mixed intercropping practices: (a) Trees on crop land - where many trees are grown on cropland for productive purposes, often with protective effects on the adjacent crop;

(b) multistorey tree gardens - these are highly sustainable productive intercropping systems which provide organic matter to

the soil as litter but also benefit from household wastes;
(c) plantation crop combinations - coffee and cacao with trees are classic examples.

(iii) Spatial-zoned intercropping practices: hedgerow intercropping (alley cropping and barrier hedges), where rows of trees or shrubs are intercropped with herbaceous crops in the alleys. When some or all of the hedgerow prunings are often used as livestock fodder, the term alley farming is used in preference to alley cropping.

(iv) Sylvopastoral practices: refers to trees on rangelands or pastures, where the trees and shrubs contribute to the system by direct provision of fodder and improvement of pastures (nutrients, shade, wind protection etc.) as well as nitrogen fixation.

(v) Practices with the tree component predominant:
(a) woodlots with multipurpose management - refers to planted forests which are managed with the intention of multiple production e.g. forest for fodder with some wood production; (b) reclamation forestry for multipurpose use such as wind breaks and restoration of degraded soils.

Strips of trees or shrubs are planted as windbreaks to protect crop fields, homes, livestock, canals or other areas from strong wind, blowing soil or sand. Traditionally scattered trees of sufficient density are used for the same (Stigter, 1985b). As strong winds are major causes of soil erosion and moisture loss from plants and soil in dry areas (Rocheleau et al., 1988), scattered trees, windbreaks as well as shelterbelts may reduce these losses.

The term alley cropping originated at the International Institute for Tropical Agriculture (IITA) in Nigeria where several prototype systems were proposed and tried (Wilson and Kang, 1980, Kang et al. 1981), initially for the maintenance of soil fertility as an alternative to shifting cultivation. Bohringer and Caldwell (1989) described alley cropping as having emerged as a potential cropping system suited to alleviate some of the constraints of the low input farmers in resource poor countries. In southern and central Nigeria, where conditions are humid and sub-humid, it is indeed seen as an alternative to shifting cultivation where it is no longer possible to leave land under fallow for 20 - 25 years for the soil to regain its fertility. With the increase in population, this fallow period has been reduced to 3 - 4 years.

Only more recently alley cropping has been taken to the semi-arid areas of the world, particularly for fodder production (Singh et al, 1989). However, Ong et al. (1992) note that evidence is accumulating in both India and Africa which shows that below 1000 mm rainfall, the advantages of alley cropping become marginal compared to cereal/legume rotations. Work in Machakos, Kenya, that confirms this for soil on flatland has already been mentioned in chapter 1. Alley cropping with *Leucaena* at the Kenyan Coast was noted to reverse the trend of declining maize crop yields compared to continuous cropping over 3 years(Bashir, 1988). This was attributed to improved weed control and improved fertility from

Leucaena loppings. The system involved the growing of maize (Coast composite var.) and green grams (*Phaseolus areus*) alternately in the long and short rains respectively in the alleys formed by the Leucaena hedgerows. Bashir et al. (1991) also noted that alley cropping maize with Leucaena resulted in an increase of maize yields per alley of 24-76 % compared to the sole maize treatment. Soil moisture conservation and nutrients conservation resulting from good weed control measures was felt responsible for the above maize yield increase in maize/leucaena alley cropping.

Rao and Coe (1991) pointed out that agroforestry systems differ from agricultural systems because of the presence of tree/crop interfaces and hence the need for large plots, large borders and long term monitoring. They noted that there is very little quantitative information available on statistical aspects for developing guidelines for measuring crop yields in agroforestry systems. Coe (1994) points out that it has been very difficult to get actual controls in alley cropping because of the expanding nature of tree roots from one experimental plot to the other which may complicate yield data interpretation. Nevertheless, alley cropping has been designed to permit continuous cropping while at the same time preserving the productive capacity of the soil. To achieve this, trees are pruned regularly to minimize resource competition and maximize nutrient availability to the crops (Nair, 1984).

Because of the recent origin of agroforestry as a research subject, alley cropping has attracted a lot of attention in agroforestry research today (Carter, 1995), despite lack of hard evidence for the benefits claimed from agroforestry such as erosion control, maintenance of organic matter, improvement of soil physical properties, augmenting nitrogen fixation and promotion of nutrient recycling (Young, 1991 and Ong, 1995). Mainly alley cropping works are reviewed in this chapter.

Many of the perceived benefits of trees in agroforestry systems in general are still hypothetical, with much of the evidence observational or extrapolated from natural, plantation or annual cropping systems. While much of the enthusiasm for agroforestry is for its value in marginal areas, the main documented work todate comes from areas of fertile, base rich soils, especially from two areas: (a) earlier mentioned experimental studies of hedgerow intercropping at IITA, Nigeria on entisols and alfisols, and (b) nutrient cycling work in cocoa and coffee plantations of Latin America on alfisols and andisols (Sanchez et al., 1985; Young, 1987). Sanchez et al. (1985), in their review, found very little scientifically sound evidence that agroforestry systems improve soil properties in the marginal areas and hence found it hard to adapt data from the above studies to acid base poor tropical Oxisols and Ultisols. In fact, Acheampong et al. (1992) note that ICRAF has little experience as compared to IITA and that the benefits of alley cropping, especially in the marginal areas, are less evident than earlier anticipated.

Some farmers believe that in alley cropping in semi-arid conditions trees strongly compete with their crops for nutrients, light and water. An agroforestry system with trees or shrubs which optimally share water, light and nutrients in time and space with the associated crops would be necessary to attract farmers. This includes more closed nutrient recycling, and therefore more efficient use of nutrients, using water from different horizons or differently in time and microclimate improvements. Some of the problems encountered are as a result of the fact that the majority of tropical tree root systems is entirely unknown (Jenik, 1978; Redhead, 1979). With more research being currently done on roots it will be possible to justify or dismiss some of the myths surrounding agroforestry. Ruhigwa et al. (1992) have pointed out that indeed the major constraint to alley cropping is competition of tree or shrub roots with those of companion food crops for available water and nutrients in the top soil. In their work in southern Nigeria they examined four tree species, *Acioa barteri, Alchornea cordifolia, Cassia siamea and Gmelina arborea,* for a depth of 120 cm and found that 73, 76 and 74% of the tree total roots were at the top layer of 20 cm. These roots were active fine roots, smaller than 2 mm diameter, and they concluded that competition was inevitable in the top 20 cm in such alley crop systems.

Carl (1985) has shown that a variety of nutrient conserving mechanisms reduce nutrient loss in tropical forests. He showed that (i) in wet lowland sites, there are greater quantities of calcium and potassium stored in the biomass than in the soil; (ii) in the drier sites some ecosystems have a larger proportion of below ground biomass than do the wet lowland sites; (iii) all natural forest ecosystems in the tropical and temperate regions have larger stocks of nitrogen in the soil than in the biomass.

There are also farmers that have the experience that some trees have their roots deeper than most crops and hence these trees are less likely to compete with crops. Deep roots have the capacity to intercept nutrients in the soil solution that would otherwise be lost by leaching and recycle them through litter to the soil surface roots (Ruhigwa, 1992). Associated with mycorrhiza systems these deep tree roots take nutrients more efficiently from the soil solution. Mycorrhizae associated with roots expand the plant root system and assist in extraction of nutrients from the soil, increasing uptake relative to leaching. They are particularly valuable in improving uptake of phosphorus (Julie, 1990).

Sanchez et al. (1985), in their review of soil dynamics under plantation crops, explained the magnitude of increase of exchangeable calcium and sometimes exchangeable magnesium recorded in top soil in the fallow enrichment stage at some sites, by establishment of a nutrient cycling mechanism capable of returning large quantities of bases to the soil, which are released from decomposing trunks, roots and stumps of cleared former forest. They also noted that nutrient levels do not appear to decrease under tree crops, implying prevention of leaching losses. There is evidence to suggest that when a tree canopy is established, cycling of the nutrients can begin. Russel (1983) measured negligible losses of phosphorus and measurable losses of potassium, calcium and magnesium under rain forest, *Gmelina arborea* and *Pinus caribea* plantation on sandy Ultisols at Jari, Brazil. He recorded lower leaching losses during mature growth stage at 1.5 years. In forest systems large amounts of nutrients are stored in the vegetation and the top soil, although the proportion of different nutrients stored in biomass and soil is known to vary.

Andriesse (1987) shows how bases are concentrated in the biomass compared to nitrogen and available phosphorus, which predominate in the soil. A similar distribution was recorded in Latin America (Sanchez, 1979). Some trees have shown some potential for selectively accumulating certain nutrients. For instance, Sanchez et al. (1985) report that litter and detritus from *Gmelina* contained twice as much calcium as that of virgin forest or mature pine plantation, while the magnesium content of litter was three times as much as in pinus litter. Work by Harcombe (1977) found slightly increased concentrations of at least calcium at depths of 90-100 cm. Results by Ball (1985) suggested that *Senna siamea* was superior to tree species like *Gliricidia sepium* and *Leucaena* *leucocephala* in terms of calcium recycling. Hence where calcium is deficient *Senna* trees are preferred for recycling this nutrient. However, it was also argued that the small amounts of roots in deeper soil layers may obtain nutrients but quantitatively this is likely to be small and their main function seems to be water uptake, especially in times of water stress (Nambiar, 1983). Toky and Bisht (1992) give an example that 62-80% of tree roots were less than 2 mm diameter and that this category decreased with increasing depth, while 78-84% of the root biomass was at the top 30 cm depth.

In an effort to explain the competition aspects in agroforestry in general and alley cropping in particular, Johnsson et al. (1988) examined the vertical distribution of roots of five tree species compared to the roots of maize at Morogoro in Tanzania. Their study showed that the roots of *Cassia siamea*, *Eucalyptus tereticornis*, *Eucalyptus camaldulensis*, *Leucaena leucocephala*, and *Prosopis chilensis* had similar rooting patterns to that of maize. These trees were likely to compete with maize for water and nutrients as their average root biomass was roughly twice that of maize. Their study further showed that *Cassia* and *leucaena* had significantly higher fine root mass than maize in the upper 60 cm of soil. Also the root distribution of many coniferous trees is in the top layers of soil, where most of the nutrients and water are taken up (Bowen, 1964).

Onyewotu et al. (1994) observed in semi-arid Nigeria that the yields of millet (*Pennisetum typhoides*) grown adjacent to a *Eucalyptus camaldulensis* shelter belt increased substantially by pruning the roots at a distance of 0.25 times the belt height (0.25H) from the trees. They also observed that roots of Eucalyptus penetrated into the cropped area, mainly at depths 0-70 cm, up to a distance of at least 1.5H. These roots were largely in diameter classes of 1-10 mm. They further noted that the highest depression of millet yield occurred between the hedge and 1.5H, suggesting that this was the zone of most active competition. Root pruning has been observed to have moisture conservation benefits useful to the intercrops. Otengi et al. (1994), in the cool semi-arid Laikipia in Kenya, observed that the intercrop growth benefitted more from water availed to them by root pruning *Grevilia robusta* than from soil moisture conserved by applying maize stalk mulches for runoff prevention. They further observed higher dry weight yields of cob and grain closer to the pruned than unpruned trees in 8 rows to 10.

Other root factors also affect water and nutrient uptake. For instance, Nye and Tinker (1977) showed that root length density, surface area or volume correlate more closely with nutrient and water uptake than root biomass. As Van Noordwijk et al. (1991) have shown, pruning may influence root distribution, since more and finer branched roots are formed when the trees are pruned at low level. In Machakos in Kenya, Umaya (1991) and Mungai et al. (1996b) reported that there was more overlap of maize and *Cassia* roots in the middle of the alley at their critical stages of growth, which was an indication of a likelihood of stronger competition under stress conditions, explaining part of observed maize yield differences. Through root trenching, they further found that the highest Cassia root density occurred at the 20-50 cm depth while in the middle of the alley Cassia/maize root associations were highest. On the whole, however, these authors found that more maize root length was in the upper 10 cm than below 20 cm depth. The maize/Cassia root associations at the upper depths were confirmation of active maize/Cassia competition for moisture and nutrients. Using supplementary irrigation at ICRAF field research station in Machakos, Howard et al.(1995), in an experiment involving Katumani composite and Leucaena, showed that competition for light alone between maize and Leucaena resulted in maize yield reduction by more than 30%. Shading in this experiment appeared to account for almost all the maize yield reduction in the system as was expected since competition for water was largely eliminated by applying irrigation, but nevertheless approximately 30% of maize yield reduction in the maize/Leucaena agroforestry system cannot be explained by the light response or shading alone..

2.2 Effects of slope steepness, length and shape as well as rainfall intensity on runoff and soil erosion.

Soil erosion involves detachment, transportation and deposition of soil particles. It will therefore depend on precipitation erosivity (capacity of the rainfall to cause erosion) and erodibility of the soil (vulnerability of the soil to erosion). Some soils' physical and chemical properties and the way they respond to rainfall determine the rate of erosion. When the silt (0.002-0.05 mm) or silt+fine sand (0.05-0.10 mm) fraction increases and clay decreases, erodibility increases (Wischmeier and Mannering, 1969). This is due to (i) the aggregation and bonding effect of clay, (ii) the detachability of sand and silt and (iii) the transportability of fine and nonaggregated particles (i.e silt) (Le Bissonais, 1995). The latter author noted further that soil texture, clay mineralogy, organic matter as well as cation iron and aluminium oxides and calcium carbonate affect aggregate stability and therefore its erodibility. On the effects of initial water content, Gollany et al. (1991) found that aggregate stability increases with clay content; and the effect was more pronounced at higher water content. Ekwue (1990) found a positive relation between organic matter and aggregate stability for soils with grass treatment and a negative relation for those with peat treatment. Splash detachment was reduced for both treatments: grass treatment reduced erosion by increasing aggregate stability, while peat acted as mulch.

Rainfall intensity will determine the kinetic energy of the rainfall and hence the ability of the rain drops to detach soil particles. Drop sizes are generally distributed from a fraction of a millimetre to an upper limit of about 6 mm in diameter and drops bigger than this break into smaller drops. Medium size drops have been shown to depend on rainfall intensity and their statistical median was shown to range from 1.4 to 2.7 mm for rainfall intensities of 2.5-51 mm h^{-1} (Rogers et al., cited by Bradford and Huang, 1995). These sizes increase with increasing rainfall intensity up to 100 mm h^{-1} and then decrease at higher intensities which occur at short periods of 5-10 minutes (Hudson, 1971) while the drop size distribution is normally constant at 100 mm h^{-1} (Bradford and Huang, 1995). Due to their physical properties these medium drops provide the impact for soil detachment.

In his review of field experience on soil erosion, Lal (1990) made the following key observations: (i) Soil losses from irregular slopes depend on the steepness of a short section immediately above the point of measurement; (ii) The effect of slope length on runoff and erosion is influenced by slope shape, which affects soil erosion by influencing the amount and velocity of overland flow; (iii) Convex slopes increase the velocity of overland flow, thereby increasing its detaching and transport capacity; (iv) Velocity is decreased on concave slopes, that cause deposition.

Lal (1976b), while working with straw mulches in West Africa, showed that there was an approximately exponential relationship between soil loss or runoff and slope steepness. This was calculated and expressed by $Y = as^b$ or ($\log Y = \log a + b \log s$), where s is the slope and Y is the runoff or related soil loss. Further, he calculated the relationship between runoff or soil loss and mulch rate from the equation $Y = a'm^{-c}$ or ($\log Y = \log a' - c \log m$), where m is the mulch rate. So runoff and related soil loss decreased exponentially with mulch rates. Mulch rates of 2 to 4 t ha^{-1} effectively controlled erosion. For the rain storms exceeding 25 mm h^{-1}, the most significant correlation for slope and soil loss was obtained from unmulched plots. Low mulch rates, of 2 t ha^{-1} effectively prevented soil loss even from steep slopes.

By simulating rainfall intensity on various slope steepness in U.S.A, already Duley and Haye found as early as 1932 that as the slope steepness was increased from 8% to 16%, erosion increased with increasing rainfall intensity and slope steepness. Kinama (1990) confirmed that steeper slopes had a higher potential of erosion hazard than lower ones in his studies on the Katumani/Kimutwa catchment. He did this by constructing erosion hazard maps which could be used as guidelines in land use planning to minimise environmental degradation on a catchment basis. Kilewe (1985) in comparing runoff plots and erosion traps in Kenya noted that there is a tendency for the Universal Soil Loss Equation (USLE) to overestimate the soil loss. In large basins there is a possibility of soil lost by erosion to get deposited within the basin, thus reducing the amount measured at the basin outlet.

As slope steepness increases, the number of drop impacts per unit surface area and the normal component of drop impact both decrease, thereby decreasing splash detachment; conversely, as slope steepness increases, the degree of surface sealing decreases and soil resistance or strength decreases, thereby increasing splash detachment (Poesen, cited by Bradford and Huangs, 1995). This author showed that, at 65 mm h^{-1} for 1 h, as slope steepness increased for 3 silt loams, overall splash detachment values for a 20% slope were about 1.3 times splash values for a 9% slope. For the clay loam and sandy clay soils, splash values at a 20% slope were less than at 9% slope. The sediment yield increased with increase in slope steepness from 9-20% It is worth noting that soil erosion by water occurs due to complex interactions of processes of detachment and transport of soil materials by rain drop impact and overland flow as well as temporary deposition (Thomas, 1991; Bradford and Huang, 1995; and Le Bissonnais, 1995).

2.2.1. Soil erosion and soil erosion rates

Soil erosion leads to loss of top soil and therefore loss of soil depth, and consequently to loss of organic matter, soil storage and water holding capacity, crusting and compaction as well as hardening of plinthite (iron-rich, humus-poor mixture of clay with quartz and other diluents or hardpan soil layer which is hard to plough). There is development of rills and gullies, which change microrelief, create larger soil variability and make tillage, mechanically or otherwise more difficult. When there is loss of soil nutrients through top soil erosion, this results in low cation exchange capacity (CEC), leading to chemical constraints and nutrient disorders. The latter include deficiency of major plant nutrients such as nitrogen, phosphorous and potassium (NPK) and of trace elements such as zinc and sulphur. Nutrient toxicity (Al, Mn) occurs as a result of having 60% Al saturation in the top 50 cm of soil of strong acidity and high toxicity (Lal, 1988, Stocking, 1984 and 1988 and Kilewe, 1989).

Many methods have been used to predict soil erosion rates such as the time series used by Dunne et al. (1978) and Kinama (1990); the Universal Soil Loss Equation (USLE) developed by Weishmeier and Smith (1978), now revised as RUSLE (FAO, 1993), the Soil Loss Estimator Model for Southern Africa (SLEMSA) developed by Elwell and Stocking (1982) and process based models such as in the Water Erosion Prediction Project (WEPP) by Foster and Lane (1987) and Laflen et al. (1991). The most widely used method, which has also been used in many local conditions, is the USLE. This equation is of the form: $A = R*K*L*S*C*P$ where, A = annual soil loss in t ha^{-1}, R = a rainfall erosion factor, to account for the erosive power of rain, related to the amount and intensity of rainfall over the year, K = a soil erodibility factor, L = length of the slope and S its steepness (Standard slope 9 % and length 22 m), C = a modifying factor to account for the effects of vegetation cover and management techniques, P = a physical protection factor to account for the effects of soil conservation measures (structures or vegetation barriers) spaced at intervals on a slope (as distinct from continuous mulches and improved cultural techniques which come under management techniques).

The soil erosion rate values derived for specific areas based on the above factors are used as guidelines in the design and planning of soil conservation projects in order to minimise soil erosion and enhance crop/livestock production. As we have seen, soil erosion in any given area is considered permissible in so long as the tolerable erosion rates are not exceeded. These T values depend on the soil depths of the areas of their application, in order to reflect real local soil situations. In the US, where the USLE was developed, for instance, the T values range from 5-11 t ha^{-1}. The values developed for Kenyan conditions range, based on the soil depths, from 3 t ha^{-1} for shallow soils of less than 25 cm to 27 t ha^{-1} for extremely deep soils (FAO, 1993). As specific T values for our area we found 5 t ha^{-1} (Kilewe, 1987) and 4.8 t ha^{-1} (FAO, 1993) for soil depths of up to 80 cm. Soil conservation efforts should be geared to keeping soil losses within these limits.

The soil formation rate, depending on the rate of weathering for the basement complex rocks, as found in the semi-arid areas of Kenya, is low: 0.01 mm yr^{-1} (Dunne et al, 1978). As most soil nutrients are concentrated in the top few decimetres of soil, the management of soil erosion in the semi-arid areas needs to be strengthened because the loss of these top soils through erosion can render them totally unproductive.

The use of fertilizers and manures normally compensates for the nutrient leaching and erosion losses which do not result in loss of soil depth, but what is difficult to replace is this shallow soils loss of soil depth. Eroded and deposited materials contain more nutrients than non-eroded materials (Gachene, 1989), which clearly points to the fact that erosion leads to loss of nutrients and hence to reduction in yields. Gachene (1995) observed further that decline in maize yields after severe soil erosion in Central province Kenya, was partly due to loss of plant nutrients. Lal (1981) has shown that soil loss from normal erosion was 16 times larger in natural plots than was applied desurfacing (uniform artificial removal of a layer of the soil) from the soil profile. For instance, in an alfisol in Nigeria, desurfacing and natural erosion affected maize yield differently. Maize grain yield fell 0.13 and 0.09 t ha^{-1} cm^{-1} of eroded soil for desurfacing to 10 and 20 cm depths respectively. On the same soil about 10 m away, however, the decline in grain yield caused by natural erosion was 2.6 t ha^{-1} mm^{-1} of eroded soil. This suggests that simulating soil erosion rates through desurfacing may underestimate real erosion rates in field conditions. Normally erosion under natural conditions is a selective process, which removes the fine soil particles containing plant nutrients, while desurfacing is not selective but removes all the fine and coarse particles fully.

Because the factors causing soil erosion interact, as shown in the USLE, proper management of any of the factors which will lead to lowered values in soil loss is crucial in the soil and water management strategies for improved crop/livestock production in the semi-arid areas of Kenya. Agroforestry plays a key role in manipulating the apparent slope length via establishment of contour barrier hedgerows, which through soil deposition finally develop naturally, with minimum costs, into level bench terraces. The contour hedgerow barriers cut down the volume and flow velocity of runoff water, reducing this way its erosive power and resulting in increased infiltration rates beneath the barrier (Kiepe, 1995). A further advantage of hedgerows is the provision of mulches, which give additional protective cover to the soil against the kinetic energy of rain drops before the crop establishes its own protective canopy cover. Mulches also line and occupy microdepressions but create them in flowing water, which increases hydraulic roughness and aid infiltration, reduce surface sealing and lower flow velocity and hence soil erosion. To some extent the presence of mulch may lead to increased microfauna which improve on soil macropores, improving soil structure and increasing the soil's resistance to erode (e.g. Mugendi et al., 1994)

2.3 Barrier effects of alley cropping (trees and crops).

Contour hedgerows as well as crop rows in alley cropping form barriers across the slope which are partly permeable. Nevertheless, on the slopes they are a physical flow obstacle and effectively cut down the length of the slope over which overland flow occurs. This forces runoff water to slow down, especially if the barriers are aligned along the contour, and infiltrate into the soil thereby reducing its erosive power. The rate of erosion is cited by Hudson (1971) as proportional to the square root of length of the slope: $E \alpha L^{0.5}$, where E is erosion rate and L is length of the slope.

Lal (1976a) indicated that soil erosion under 5, 10 and 15% slope was severe for alfisols and, if not controlled, will limit crop growth. Lal (1991) noted further that the establishment of contour hedgerows or strips of *Leucaena* on steep lands in the Philippines and Indonesia had led to the formation of natural terraces. The terrace formation was due to washed off soil accumulation in front of and immediately behind the hedges.

Hedgerows have indeed been reported to reduce runoff (Young, 1989), but their effectiveness at different widths for storms of varying intensities have not been investigated. However, Young (1989) notes that despite the scanty experimental data there are strong indications that systems of barrier hedges and lined up crops or contour aligned hedgerow intercropping, can provide an acceptable means of controlling erosion on gentle to moderate slopes, up to 17% (30°). As indicated earlier, surveys conducted by Gichuki (1991) indicate that arable farming is being undertaken on slopes greater than the 35% legal limit for cultivation, and so the use of hedgerows in these areas may help reduce soil erosion problems as well. Pellek (1992) has also observed that it is on the marginal lands that the agroforestry technique of contour hedgerows can perhaps be of greatest benefit in the preservation of land quality.

Data on effectiveness of the barrier in controlling soil and water loss show that soil infiltration rates below the hedgerows are 3-8 times those in the alleys as a result of more macropores at the deposited top soil below the hedge than beneath the alley (Kiepe, 1995).

2.4. Effects of tree and crop cover in alley cropping.

Both, the canopy of the tree and of the crop component, protect the soil surface partially against raindrop impact. Already early experiments by Sreenivas et al. (1947) showed that there was more erosion occurring as a result of increasing canopy height. This is explained as follows. When rain drops are intercepted by plant canopies, the tendency is for them to coalesce, forming bigger drops, "gravity drops" of a size of 5 mm-6 mm diameter, which can erode on falling to the soil surface (drip erosion). Moss and Green (1987) showed that erosivity rose rapidly over the first 2 metres of free fall and that only drops released from less than 0.3 m above the soil surface had small to negligible erosivity. The erosive power of rainfall under shade trees in coffee plantations in Columbia has been reported to increase by as mulch as three times (Suarez cited in Wiersum, 1988)), but particularly at the edges. It is further noted there that only if woody perenials have a canopy close to the soil surface is the erosive power of throughfall drops less than that of incident rainfall. It can be deduced from these experiments that canopies of tall plants may cause more drip erosion than those of short plants. This casts doubt as to whether canopy is all that is needed for erosion control by raindrop impact. The canopy, when high, should be closed in such way that the force of dripping water is broken by lower layers of vegetation (Baldy and Stigter, 1997) in press. So leaf area distribution is an important factor in preventing drip erosion.

As further evidence, artificial removal of a canopy of an *Acacia auriculiformis* plantation in Java showed that the presence of canopy increased erosive power of rain water by 24% (Wiersum, 1985). In his review of agroforestry for soil conservation, Young (1989) observed that for various reasons there was no purpose in attempting to maximize canopy cover in agroforestry design. A better way of protecting soils against erosion would be via increased lower vegetative cover or soil organic matter content and mulch, including live mulch, on the soil surface. The hedgerows in alley cropping provide organic matter in the form of mulch which can be placed in the alleys as both manure and protective cover respectively, where mulch incorporated into the soil will contribute as soil organic matter to soil protection but mulch on the soil will be more protective, contributing to soil fertility on a different time scale. For soil protection, therefore, it is highly desirable to spread the prunings from the hedges evenly on the soil surface, instead of incorporating them into the soil.

There is a lot of evidence to indicate that ground surface cover protects the soil against erosion (see also next section). For instance, in Java the removal of the surface litter of an *Acacia mangium* plantation increased erosion by 20% (Wiersum, 1984). Young (1989) has also noted that an analysis of the causative factors of erosion indicate that the potential of the cover approach for reducing erosion is greater than that of the barrier approach. In terracing for example, the terrace embankment obstructs the runoff water but does not affect erosion by raindrop impact, which could be achieved by a cover crop or mulch placed on the terraces.

2.5 Effects of mulches.

2.5.1. Applications of mulches

Mulch is defined, in line with traditional concepts, as a shallow layer established naturally or artificially at the soil/air interface, with properties differing from the original unmodified soil surface (Stigter, 1985). Stigter (1984a, 1984b) reported that 45% of the useful information on mulch use supplied by participants to a newspaper questionnaire in Tanzania was exclusively on food crops while only 10% was on cash crops and in the remaining 45% of mulch information there were examples taken from both cash and food crops. In his review on mulches in Tanzania he noted their general use for reduction of water evaporation, improvement of soil temperatures, control of weeds, runoff water conservation, improvement of soil chemical properties after decomposition, improvement of soil microbial activities, and improvement of soil physical properties *inter-alia*. Reviews of early literature on many of these subjects may also be found in Davies (1975), but are now common knowledge. Below we have limited ourselves to the essentials needed for this study and mainly quoted more recent literature on these subjects.

2.5.2 Use of mulches in alley cropping

In review, mulches in alley cropping have been used for the provision of soil nutrients upon their release on decomposition (e.g Mugendi et al., 1994), for soil erosion control where the decomposition rate of the mulch is low, for moisture conservation upon retention of overland flow, reduction of soil evaporation as well as for the amelioration of soil temperature for enhanced crop production (Lal, 1989).

In his experiments at Katumani, Mugendi (1990) reported some cob yields per plant benefits (which is equivalent to expressing it as yield per row) between the alleys. This yield performance, however, seemed to depend on seasons and crop variety. Mwangi (1989) and Mugendi (1990) have observed that incorporation of mulch into the soil may result in additional nutritional value of the grains, as evident from higher concentration of the nutrients in maize grains of agroforestry compared to sole maize control. From experiments in two very contrasting seasons, the performance of maize in the mulched plots depended on season, mulch rate, and mulch type and was better in the wetter season (Mwangi, 1989). In his work at Machakos with the DARP, Nyamai (1987) found that *Leucaena* mulch when incorporated into the soil and used as manure increased the cob yields of maize and sorghum per row by 13% and 4% respectively when these crops were grown in the alley formed by the *Leucaena*.

Several seasons of data by Mungai (1991), also reported by Mungai et al. (1996b), revealed that the maize grain yield per row in the AF treatment with *Cassia* was higher than in the control above about 150 mm of total seasonal rainfall, although this increase was never sufficient to compensate for the cropping area "lost" to *Cassia* hedges. It was noted, however, that when the rainfall was below about 150 mm the opposite was true. In the worst case of the short rains of 1987, there was no crop yield from agroforestry plots even with the mulch while there was crop yield in the control plot. We also refer back to the work of Kiepe (1995) in Machakos discussed in section 1.1 where on average only the sole mulch plot gave appreciable yield improvements and only for maize. Mulch was limited there by the biomass growth of *Senna*.

2.5.3. Surface mulches as barrier

IITA established in Nigeria that the erosion control of a good mulching practice by pruning from hedges is likely to have a much greater benefit on crop yields than any other type of bund or terrace *per se* (Okigbo and Lal, 1978). Mannering and Meyer (1963) have reported that mulches reduce surface sealing, as indicated by increased infiltration rates, and also decreased rainfall and runoff energy for soil particle detachment and transportation. This was evident in the reduced soil content in runoff measurements. The mulches on the soil surface intercepted the falling raindrops and dissipated their kinetic energy, hence preventing detachment of soil particles. This consequently reduced sealing of the soil surface, enabling water to move into the soil profile instead of on the surface as runoff. Of importance in their study were the mulching rates. They noted that mulch rates of 1, 2 and 4 tons per acre provided sufficient protection from the rain drop impact energy to prevent the destruction of soil surface structure. At the same time, the effectiveness of the mulch in maintaining high infiltration was highly correlated with the percentage of surface cover. In Nanyuki, Kenya, 3 t ha^{-1} of maize stalks were found to be sufficient to increase soil moisture considerably on a 3% slope (Otengi, 1996).

In the East African highlands, Othieno (1975) and Othieno and LayCock (1977) showed that mulches were the most appropriate for controlling runoff and soil erosion as well as increasing yields in plantation crops. Khatibu et al. (1984) observed in Tanga and Zanzibar the effectiveness of mulches in the reduction of runoff and soil erosion. In the unmulched plots, 10% of the total rainfall was lost as runoff as compared to 0.01% from the mulched treatments, while the total soil loss from the mulched treatment was only less than 4% of that of the unmulched plots. In further work in Tanzania, on the evaluation of 6 t ha^{-1} of straw mulch compared to bare plots for the control of runoff and erosion, Ngatunga et al. (1984) showed that mulched plots were effective in the control of soil erosion, even on steep slopes of up to 22%. In Taiwan, Wang (1984) observed that soil erosion control from citrus orchards mulched with 10 t ha^{-1} of weeping love grass was as good as with level bench terraces. Greb et al. (1967), working with straw mulches, found that increasing quantities of straw mulch gave small but consistent increased storage of soil water, during the summer fallow years tested. Also early literature on this subject, like on all effects of mulches, may be found reviewed in Davies (1975).

The effects of different types of mulches on the soil have been investigated by several workers. We gave already a quantitative example from Lal (1976b) in section 2.2. Also earlier work, for instance Swanson et al. (1965), Adams (1966), Barnett et al. (1967) and Meyer et al. (1970) have shown that though mulching can prevent runoff and soil loss, its effectiveness depends on the quantity of crop residue as well as on slope gradient. Meyer et al. (1970) showed straw mulch rates of 0.56 and 1.12 t ha^{-1} to reduce soil losses to less than one third of those from unmulched areas during a series of intense simulated rainstorms. A 2.24 t ha^{-1} rate decreased soil loss to only 15% of that of no mulch, and the 4.48 and 8.96 t ha^{-1} rates reduced it to less than 5%. These results were obtained from a 15% slope and the reduced velocity due to mulching accounted for much of the resulting decrease in soil erosion. Stone mulches have as well been investigated by several workers. For example Chapman, Tsiang, Hide and Jung, cited by Lal (1976b), and

Meyer et al. (1972) reported that stone covers increase surface roughness and prevent surface sealing, thus decreasing runoff and soil loss. What seems to happen in stone mulches is that they help to absorb water, check erosion, reduce evaporation and narrow the temperature fluctuations between day and night. Nurzefa (1990) physically simulated stone covers in the Kenyan highlands at Kabete and showed that the percentage surface cover of the soil was exponentially related to the soil loss, with a correlation coefficient (r^2) of 98%. In Israel, stone covers of 25 and 50% levels on a loamy soil were shown to have significant effects on both the infiltration rates and soil erosion (Agassi and Levy, 1991). Laboratory studies also have shown that infiltration rates increased when rock fragments were on the soil surface, while infiltration decreased when they were embedded in the soil surface (Poessen et al., 1990). Lawes cited by Lal (1987) showed that mulching improved total porosity and that infiltration rates in mulched plots exceeded 12.5 cm per hour.

In an effort to explain the mechanisms of water losses from rainfall, a simple water balance equation as shown below indicates the various ways in which rain water loss occurs:

$P = ET + Rn + L$ where P is precipitation in mm, ET is actual evapotranspiration in mm (Esoil + Tplant + Eplant), where Esoil is evaporation from soil, Tplant is transpiration from plants and Eplant is evaporation of intercepted rainfall. Rn is runoff in mm and L are percolation losses in mm. It is Tplant, which goes to crop production, which water management technologies ought to improve on. Tplant can, from the agronomic point of view, be better expressed as water use efficiency (WUE), which refers to the water used to produce the yield per unit area. Gregory (1989) defines it as the shoot dry matter over the total rainfall less the ways in which water is lost for production, by evaporation, runoff and deep drainage. He makes the assumption that final grain yield is proportional to shoot dry matter. In the semi-arid areas, where the rainfall is erratic with high runoff and evaporation losses, Tplant may be low and consequently WUE will also be low. It should be noted here that the roots also form a fraction of the total plant biomass, but what is mostly considered is the above ground biomass. This root biomass has been estimated for cereals (e.g millet) in the semi-arid areas as 0.10-0.15, as a fraction of the total plant mass at maturity (Gregory and Squire, 1979). This fraction is frequently higher, in the order of 0.15-0.20, in legumes (Gregory, 1987). Because of the above, using grain yield or other total above ground biomass yield per unit of water transpired (or per total water received in rainfall and/or irrigation) is a better way of expressing WUE.

Experiences in FAO (1984) has shown that cultural practices such as tillage will accelerate evaporation from the plough layer, although self mulching may occur, while deep tillage may increase water losses when the land is fallow. At the same time, mulching with crop residues may be a disadvantage where soils are intermittently wetted because the absorbing organic matter remains wet much longer, thus increasing evaporation, and remains ineffective as an evaporation barrier.

2.5.4. Effects of mulches and additional shading on soil temperature.

Mulches act as cushions on the soil surface by intercepting solar radiation, hence reducing its direct effect to the soil. They can transmit, absorb or reflect incoming radiation and this depends on a number of factors. In shaping soil temperatures, the key factors are sky condition, soil moisture content, colour and porosity as well as, plant and/or other surface cover, including surface configuration (Stigter, 1985). Mulches absorb more radiation if their colour reflects little solar radiation. For instance Budelman (1989) while showing that mulching reduced soil temperatures at 5 cm depth, further noted that mulch from *Leucaena leucocephala* absorbed more radiation, resulting in increased soil temperature, due to its dark colour. At the same time, less radiation reaches the ground surface under mulches and where there is excessive canopy cover (in case of live mulch) shading the soil. In addition, mulches create an insulation layer in which air can be assumed to be stagnant or slowly moving by convection (Stigter, 1984b).

The use of mulches have been found not only to retain high moisture content but also to attenuate the increase of soil temperatures (Tian et al. 1993). In the rehabilitation of the Sahelian forest barren lands, Chase and Boudouresque (1987) found mulches to reduce the daily fluctuations of both surface and profile soil temperature. The decreased temperature fluctuations may have been due to the direct result of mulch shading and increases in soil moisture, which by increasing soil heat capacity stabilises soil temperature. Lal (1987) also showed that mulching, in this case with crop residues, regulates soil temperatures. Germination and seedling establishment of crops are adversely affected by high soil temperatures. For instance, when cleared and clean cultivated, soils with coarse textured sandy surface horizons have been shown to experience temperatures of 40-50^{0}C at depths of 1-5 cm for as long as 3-6 hours a day (e.g Lal, 1987). Seed germination requires optimal temperatures below or above which seed performance will be affected, leading to poor yields or even the death of seeds. Itabari et al. (1993) at the Machakos farmers training centre farm, showed that maximum bare soil temperatures at 2.5, 7.5 and 12.5 cm not only exceeded the optimal temperature for maize seeds, which is in the order of 34^{0}C above a basal temperature of 6^{0}C, but that mulching decreased soil temperatures during the first 8 days of planting by 6.2, 2.8 and 0.8^{0}C at these soil depths. The use of a crop residue mulch of 4-6 t ha^{-1} has been shown to regulate soil temperatures by decreasing the maximum near soil surface (5 cm depth) temperature by as much as 5-10^{0}C (Lal, 1987). Singh et al. (1989) observed that shading of crops close to the hedgerow modified the environment during the first 45 days of the cropping season. Shading of the crops at the edges of alleys increased from

30 to 85% of solar radiation in cowpea/*Leucaena* alley cropping. They noted that the yields of cowpea close to the hedge were in their case much lower than in the middle of the alley. This may, however, also have been fully or partly a competition effect for other inputs other than light. This shows the importance for studying shade, temperature, moisture and root effects simultaneously (Mungai, 1991). Mungai et al. (1996b) indicated that without surface mulch there were seasonal average soil temperature depressions of 2.5, 0.8 and 2.8^0 C at 7.5 cm depth in the eastern middle and western part of the alley below that of the control plot in a *Cassia*/maize agroforestry system. In this experiment at Machakos, it was concluded that soil temperatures in the N/S rows were good indicators of shading patterns. This observation shows that the effect of for example dry grass mulches on soil temperature is indeed consisting of an important shading component (at night reduction of long wave radiation escape) and an insulation component.

In mulched tea, both shading by the canopy and mulch as well as other mulch factors (architecture, moisture condition, wetness, degradation state) have been found to influence diurnal fluctuations in soil temperatures (Othieno and Ahn 1980; Othieno et al. 1985). Moreover, when the foliage cover is more than about 60%, such fluctuations in soil temperature (and their differences between mulches) become very small (Othieno, 1982). Otengi (1996), using Stigter's ratio as an indication of temperature dynamics in mulched and unmulched soils, showed that for a relatively light mulch of maize stalks (3 t ha^{-1}), there was a clear additional shade influence of Grevillea robusta trees on temperature dynamics in mulched soil and shading as a function of distance to the tree could be recognized. Othieno et al. (1985), using Stigter's ratio, were able to select mulches suitable for erosion control in tea but influencing temperatures least, in highland Kericho area in Kenya. Too low soil temperatures caused shallow root growth and subsequent dying at the first drought. Soil temperature dynamics also provide insight in mulch degradation rates. Additionally, Bussiere and Cellier (1994) in Guadeloupe measured and also used Stigter's ratio to estimate the thermal effects of mulch. The mulch which had been laid on the soil two months earlier induced lower daily temperature amplitudes and a decrease in average soil temperature of about 6K at 2 cm and 20 cm depth all through the period of 16 days.

2.6 Light interactions in alley cropping

The sum of reflected, transmitted and absorbed light by a crop equals the incident light on the plant canopy. Photosynthetically active radiation (PAR) or light which is absorbed by the foliage is a primary input for crop growth and yield formation, determining rates of photosynthesis. Its contribution to the other part of the energy balance is less than that of the non-PAR in solar radiation. Light is used for biomass production by chlorophyll and other leaf pigments. This is the part of the electromagnetic spectrum with wavelengths 400-700 nanometres (nm). The part of the PAR that is not absorbed by the crop is either reflected by the canopy or soil surface or absorbed by the latter. The measurement of PAR is essential in studies of light relations in tree and crop canopies. Knowledge of the spatial and temporal variation of the available PAR is useful in the design of overall systems and the optimisation of crop yields crop yields (Newman, 1989).

The interaction of PAR with the canopies of four crops was characterized by Wilson (1981) by calculating the percent reflectance (R) from the canopy, transmittance (T) through the canopy, and absorptance (A) by the canopy, as follows: Ri = 100 = R + T + A, with R = (Rr/Ri)x100, where Ri = incoming radiation measured above the canopy; Rr = Reflected radiation measured above the canopy; T = (Rt/Ri)x100, where Rt = Incoming Radiation measured below the canopy. So A = 100-T-R. This relationship for computing PAR absorption represents a PAR balance for PAR impinging on the canopy.

Wanjura and Hatfield (1986) showed that canopy reflectance is low in the PAR region. They further observed that reflectance increases rapidly beyond 700 nm near infrared (IR) region and is affected by internal leaf structure. As leaf area increased, there was a corresponding increase in near IR reflectance and PAR absorptance and a decrease in PAR reflectance and both PAR and near IR transmittance. Because this study was carried out using sole crops, there would be variations when alley cropping is considered, but the principles remain the same.

For instance, studies at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in India have shown that intercropping can produce more biomass than monocropping, due to increased PAR interception by the intercrop system (Marshall and Willey, 1983). Ong and Black (1992), in India, showed that intercropping pearl millet with groundnuts produced 15% more of PAR radiation interception compared to sole pigeon pea and twice that intercepted by the sole groundnut.

Monteith, cited in the Delta T Sunfleck Ceptometer user manual (1989), observed that dry matter production of a plant canopy is directly related to the amount of PAR intercepted by the canopy. Dry matter production can be modelled in three terms:
$P = efS$, where P = amount of dry matter produced (g m^{-2}), S = the flux density of PAR on the crop, f = the fraction of seasonal incident radiation absorbed by the crop (%), e = the conversion efficiency, where (e) and (f) are determined by crop physiology and management. For TTMI-Project results with this formula, see Muniafu (1991), who observed that the decreased yield of beans under water stress was due to a decreased assimilatory leaf area, which led to a decline in the amount of PAR absorbed (f) as well as a reduced photosynthetic rate caused by a drop in photosynthetic efficiency (e). When plant growth is not limited by either water or nutrients, the amount of biomass produced is limited by the amount

of radiant energy that a foliage can absorb after interception (Monteith et al., 1991). Many trials with arable crops and a few trials with trees have demonstrated that, biomass production per unit of intercepted radiation, or light use efficiency (LUE) or conversion efficiency (e) is a conservative quantity, provided stress is minimal. This (e) is usually between 1.0-1.5 g MJ^{-1} for C3 plant species in temperate climates and between 1.5-1.7 g MJ^{-1} for C4 plant species in a tropical climate (Monteith, et al., 1991). Coulson (1985) has estimated PAR interception as 63% of the total radiation and light use efficiency (e) for three bean cultivars, in his work at Kabete, Kenya as 1.6 g MJ^{-1}. Muniafu (1991) also calculated the PAR for the bean plant as 1.6 ± 0.1 and 1.3 ± 0.2 g MJ^{-1} for high and low water treatments respectively. This was in agreement with Russel et al. (1989) reporting of (e) for annual crops as ranging from 1.2-1.7 g MJ^{-1}. Hughes et al. (1981) have reported a value of 1.2 g MJ^{-1} in their work on dry crop pigeon pea (*Canjanus canjan*). But Linder cited in Russel et al. (1989), reported a value of (e) of 0.9 g MJ^{-1} (PAR) for *Eucalyptus globulus* in Australia over its first ten years and an average 1.7 g MJ^{-1} (PAR) for a number of evergreen stands, up to 55 years of age, including the conifers *Pinus radiata* in Australia, *Pinus sylvestris* in Sweden and England and *Pinus nigra* and *Picea sitchensis* in Scotland. The PAR is about 0.5 of the total radiation for solar elevations greater than 40^0 and this ratio is rather constant but somewhat varies with the sky condition, estimated as 0.51 ± 0.01 for cloudless days and 0.63 ± 0.02 for heavily overcast days

(Stigter and Musabilha, 1992). Taking PAR in days which don't have similar cloud cover will produce variation in the amount of PAR used for the calculation of (e).

Moss (1992) working with coconuts and using a mobile sampler for PAR measurement, found palms planted at higher densities to intercept more light than those of lower density and that using potassium as fertilizer increased light interception, hence demonstrating how energy use efficiency (LUE) is influenced by nutrient supply.

Alley cropping creates a general situation where in space and in time more radiation is absorbed by the resulting canopies of the two joint components, than by the sole crops. Monteith et al. (1991), at ICRISAT, noted that the purpose of growing pearl millet between the rows of *Leucaena* was to intercept more light throughout the year and therefore to produce more biomass. It should be noted, however, that alley cropping may result in competition for the available light and hence planting configurations limit the total dry matter jointly produced in the two components. When properly managed through pruning, hedgerows exert reduced shade and competition. Oduol (1994) notes that light interception in his work at Machakos and Maseno in Kenya with maize/*Sesbania* alley cropping was variable and was dependent on crown form. It has also been shown that accumulated dry matter in the trees was linearly related to accumulated intercepted radiation just as light interception depends on the leaf area index of the canopy structure of annual crops (Monteith, 1977; Cannel et al, 1987).

2.7 On-farm research.

With increasing pressure on the land, in Machakos district largely due to migration of people from the high and medium potential areas to the sloping semi-arid areas, it has become necessary to demarcate land into small portions. This has resulted in continuous cropping on the same pieces of land, with consequently declining crop yields as a result of land degradation. Farmers have used traditional techniques of soil and water conservation. An important example are "Fanya juu" terraces (earthen embankments of ridges of earth constructed on the contour across a slope with the soil dug from the trenches thrown upslope to control runoff and minimise soil erosion, by modifying slope length and degree). Other examples are cut-off drains, stone terrace structures, grass strips, wooden check dams, trash lines and mulching, all in efforts to minimise soil erosion and enhance *insitu* water conservation for enhanced crop yields. Some of the techniques of soil conservation, such as "Fanya juu" terracing, are put up with huge costs, as noted from the surveys conducted in Eastern Kenya (Kinama et al., 1995; Gichuki, 1991) and have to be repaired from time to time. Mortimore et al. (1994) note that there has been a greater increase in the use of terraces as soil and water conservation structures in most farms in Machakos district over the years, with the cropped land looking better conserved than the grazing lands.

After half a century of failed soil conservation projects in African developing countries, Critchely et al. (1994) observe that conservation experts and policy makers are changing their strategy for conservation by recognising the previously ignored traditional indigenous soil and water conservation practices by the land users themselves. A review of conservation practices by Wangia and Tory (1994) shows that a number of factors have affected the rate of adoption of soil conservation practices: (a) where land tenure is clearly defined, structural practices are the predominant soil conservation methods on individual and on communal lands; (b) labour and tools required to install structural practices are still major constraints; (c) adoption of agroforestry practices, use of fertilizers, manures, mulching etc is still quite low although there is good knowledge of these practices. Although economic benefits of soil conservation are not yet quantified in African countries, a few studies show that soil conservation is profitable, such as in the case of soil conservation in Kalia location, Kitui Kenya (Tjernstrom, 1989). This author also notes that the level of household income influences the level of soil conservation activities.

Farmers have also continued to use their traditional seed varieties, which they have managed to breed and select over many years of trial and error for their special qualities such as taste, large grain size, colour, disease and pest resistance as well as drought tolerance. Any new technology which would reduce the costs of soil conservation or minimise the risks of crop failure will be a great saving to the farmer. The scanty data available show that alley cropping has a great potential for protecting the sloping drylands (Young, 1989). In Embu, for instance, Raintree (1983) has mentioned the benefits of alley cropping as the build up of erosion control bunds with minimal costs, provision of mulch for fertility build up and erosion control, provision of supplementary feed, especially during the dry season, *inter-alia*.

In the research station, alley cropping techniques of protecting sloping lands can be compared with the use of grass strips. As the use of the grass strips is a traditional technique of soil erosion control, this provides a link between the on-farm and on-station research and it gives the farmer an opportunity to evaluate by demonstration the new technology of alley cropping along with the traditional grass strips he has been using. What seems to determine technology transfer and adoption is the perception of final benefits which the farmer will reap from the new technology. For instance, the fast rate of adoption and adaption of contour hedgerows in Philippines was directly attributed to both cash and erosion control benefits (Fujisaka, 1993). Other factors also determine the rate of technology transfer and adoption. In Kenya the national extension programme in the Ministry of Agriculture, Livestock and Marketing has for a long time been used for the transfer of research developed technologies to the farmers as it is more known to the farmers than the researchers. Onyango (1995) notes that there has been a rather weak research-extension liaison in Kenya and this may have affected transfer of developed technologies in research centres to the farmers. The same author further notes that "Fanya juu" terraces have been widely used despite the high construction costs, possibly because of the "myethya" groups, where groups of local farmers, unite to do group work on their private farms mainly in the construction of terraces. This group work via the" Myethya" groups has enabled low external input resource poor farmers to effect the construction of expensive "Fanya juu" terraces in this area.

Over the past, research on new technologies was done at the research stations and the validation of these technologies would later be done on selected farmers' fields where the farmer would normally provide labour and land. The farmers are then supplied with seed and fertilizer from the research station. The researcher would be coming to monitor the progress of the new technology from time to time. Because the technologies were developed at the research station and the researcher believed they would be superior to current farming practices of the farmer, it is likely that the farmer will take them with suspicion and as belonging to the researcher, as the farmer is only involved in the last stage of validation. As the farmer is reluctant to part with the farming practices he has used over many years (Oteng'i, 1996), the best way to convince a farmer of the benefits of a new technology is to involve him in all the stages of technology development, testing and actual adoption (Lal, 1991). As agroforestry research aims at developing appropriate agroforestry technologies and their transfer to the farmers for use (Nyamai, 1995), it is important that the developed technologies are transferred to the farmers using the best machinery and personnel for their effectiveness. Musyoka and Kaluli (1991) note that the Kenyan Ministry of Agriculture, Livestock and Marketing is better placed for the transfer of agricultural technologies, while the Ministry of Environment and Natural Resources is better placed for the transfer of agroforestry technologies, due to their specialised training in agriculture and forestry respectively. A careful coordination of these agents of technology transfer is crucial to avoid duplication and mix-up of efforts.

Participatory research represents one way to expand our agroforestry research capabilities in the complex conditions faced by the rural people (Rocheleau, 1991). Mule (1984) argues that improved technology does not exist until and unless farmers are aware of it, have adopted it and the technology results in higher incomes than would be received from the use of conventional practices. In essence, higher yields under experimental conditions are not sufficient evidence for consideration that research has improved decaying traditional practice. Experience with dryland farming in Machakos district indicates for example that recommended plant population for dryland composite Katumani maize had not been adopted by the farmers as expected. Rather, the farmers plant low plant populations as a safety against risks of losing yields or even getting a crop failure when the rains are below average, while higher yields are generally the researcher's criterion (Whiteman, 1981). The lesson to learn from such experience (e.g also Chambers, 1983 and Richards, 1985) is that of doing research both on-station and on-farm, with the farmer as a partner.

Carrying out on-farm research may also ensure that the most relevant aspects of the technology reach the farmer at costs they can afford. The involvement of the farmer in the problem identification, technology development and testing within the context of the farmers constraints will lead to easy adoption of the outcome of the technology as the farmer will be proud of his/her own efforts. For example in the Philippines, the adoption of hedgerows for erosion control and timber for cash was as result of involving the farmer in the on-farm research. The direct cash benefits for the farmer from the adopted technology (Fujisaka, 1993) convinced the farmer of the usefulness of the new technology. This farmer participation has also been brought up by Lal (1991), where he points out that it is the approach to research that is crucial and further stresses that the existing research networks, such as those organised by ICRAF and IITA, should address the issue of involving traditional cropping systems, native shrubs and the interests of the farming community. In fact, on-farm research in Nigeria indicates that the most appropriate outcome in the on-farm research is the farmers' interest (Summerg and Okal, 1988). Indeed, it is now being realised that small scale farmers will not adopt any technology which excludes the minor crops valued by the farmers along with the base crops such as maize and cassava in Nigeria complex crop mixture (Ikeorgu et al. 1989). This is a point worth considering while issuing recommendations to incorporate some of the minor crops grown by the farmers. Through close interactive monitoring of the on-farm research activities, farmers can identify specific technical problems and solutions that may be most appropriately addressed on the research station (Okali and Sumberg, 1986a). Sierra Leone farmers ability to experiment with new genetic materials and their ability to match rice varieties with particular niches (Richards, 1985) is a case in point to demonstrate the usefulness of taking advantage of indigenous technical research knowledge of the farmer, to advance on-farm research. In a case study at Kilimanjaro, Tanzania, agroforestry practices, developed out of a cultural awareness of ecological fragility and land pressures, seem to have helped to maintain a large and expanding population in an area prone to erosion and soil degradation (O'kting'ati and Mongi, 1986). In their case study, soil erosion inside the agroforestry farms appeared to be minimal compared with that on land not under agroforestry.

Moreover, labour constraints were mentioned earlier in chapter 1 as one of the problems facing farmers in the semi-arid areas of Kenya (Rukandema, 1984). As Allan (1988) puts it, the central role of labour time has been highlighted by many diagnostic on-farm research studies in southern Africa, which indicate that farmers often compromise on crop and livestock management, not because of lack of knowledge or lack of cash to purchase inputs or because inputs are not available, but because of time constraints. Appropriate production increasing innovations may therefore not be adopted because of their implications for labour time. For example the experiences of the Kenya Dryland Farming Research and Development project led to the conclusion that the rate of adoption of innovations was disappointingly poor (Tessema, 1983). The latter author observed that Kenyan farmers valued their leisure more than the gains they could get from clearing bush to encourage good forage growth. It seemed therefore that in terms of labour use, farmers choose the least burdensome way of doing a job, even if they were aware that an increased input will give a higher return.

One of the traditional techniques of soil and water management is early land preparation and early sowing in order to take advantage of soil moisture from the early rain showers. Early work on Taboran maize in Machakos by Dowker (1971), relating maize grain yield to the time of planting for three consecutive years 1959-1962, showed maize grain yield reductions to range from 4.7 to 6.3 % for every day's delay in planting. The best yield in this case was often obtained with seeding in a dry soil before the onset of rains. Late planting by the farmers is therefore likely to delay useful farm operations such as weeding and result in yield reductions in eastern semi-arid Kenya. Although many farmers appreciate the advantages of dryplanting and early planting, they argue that the causes of delayed farm operations during the dry season stem from the poor condition of draught animals which are normally weak due to lack of feeds, hard, dry and difficult to plough soils as well as use of blunt tillage tools.

In the Dryland Agroforestry Research Project (DARP), alley cropping was introduced to a group of farmers and schools, at Kakuyuni Catchment in 1985, in the form of on-farm trials, for it was believed that it is on the farm where situations are more realistic for testing an innovation than in the research station. This was done in order to monitor the performance of the alley cropping on the farmers' fields versus the on-station research which had been initiated by the DARP project at Katumani, Machakos. The yield results are not very clear as they are expressed in cobs per alley and are still in grey literature, but there is evidence that adoption of alley cropping by farmers has been poor as must be the also more general conclusion (Carter, 1995). This has been attributed above to such factors as labour requirements, competition of trees with crops resulting in lower yields than earlier thought, lack of sufficient inputs, lack of profitability, risks in general as well as food security, and the time factor before alley cropping benefits are realised by the farmer *inter alia*. Nevertheless, farmers have been found to be quite knowledgeable in tree husbandry in marginal areas. For instance, (Blomley, 1994) notes that *Melia volkensii* has been used by Kamba, Embu and Tharaka eastern Kenya farmers for their fuel and timber needs. Forest products like wood carvings have been one of the sources of income for the farmers in Machakos district (Mortimore et al. 1993). It may therefore be expected that more on-farm research carried out in Eastern semi-arid sloping Kenya under the farmer situation characterised by the above mentioned constraints will shed some more light as to what can be improved in traditional soil and water conservation techniques/alley cropping to boost the farmers' economic yields.

CHAPTER THREE.

3. MATERIALS AND METHODS.

3.1. Experimental site and field design.

3.1.1. Experimental site.

The on-station trials were conducted at ICRAF's Research Station at Machakos, which is about 70km South East of Nairobi and 7km from Machakos town. The station lies between latitudes 1^0 30' and 1^0 35' South and longitudes 37^0 and 37^0 15'East. It has an altitude of 1560 metres above sea level with slopes ranging from 0 to 22% while the experimental plots were established on sloping land of about 14%.

The site is semi-arid, receiving from between 310-370 mm for the short rains, which are from mid-October till January, and 300-410 mm for the long rains, which are from mid-March to July (see also the details in chapter 1). The soils are sandy clay loams over sandy clay developed in situ on rocks of the precambrian basement complex. The soils are about 150 cm deep and have been classified as chromic luvisols (Kibe et al., 1981). The same author revised the soils as Haplic Lixisols (FAO/UNESCO, 1988) or Kanhaplic Rhodustaff (Soil survey staff, 1990). They are dark reddish brown, sandy clay loam becoming sandy clay at the lower horizons (more details are already in chapter 1). Due to low structural stability, the soils are prone to slaking, highly erodible and prone to surface capping by intense rainfall. This risk is enhanced by low sub soil permeability (Kiepe, 1995).

3.1.2 Field design

The experimental plots were on land which had been under alley cropping, with hand hoe cultivation, and long term runoff/soil erosion monitoring since the establishment of the hedgerows in 1988. Grass strips (*Panicum maximum*) were established earlier, in 1984. The plant rows, the grass strips and the *Senna siamea* hedgerows were contour planted in about E/W directions. The experiments covered in this thesis were done over a period of six seasons. During the short rains cowpeas (*Vignia unguiculata, cv. K80 or SK-27*) were planted while maize (*Zea mays, cv. Katumani composite B*) was planted during the long rains. *Senna siamea,* a non-nodulating leguminous tree, was chosen because it was among the few multi-purpose trees/shrubs considered suitable for the area as contour hedgerows barriers. The tree species is drought tolerant and suited to the local semi-arid conditions as reported by Rao and Westley (1989). Its mulch is suitable for erosion control purposes because of the high amounts of tannin in the mulch (Kiepe, 1995).

Katumani composite B has been bred as a drought escaping crop for the semi-arid areas and has been widely adopted by the local farming community (Njoroge, 1984). The cowpeas have also been bred as a drought tolerant and high yielding variety and are popular with the farming community. Both the used varieties of cowpeas, K80 and SK-27, as well as the Katumani composite B were bred by KARI's National Dryland Farming Research Centre, Katumani, and the farmers use these maize and cowpea varieties along with their local varieties, because they mature earlier as compared to the local varieties, their taste is appealing and they are a source of income. Maize is the staple food while the cowpea is among the main grain legumes used as food in Eastern Kenya. After the short rains of 1992/93, the K80 was replaced with yet another high yielding and drought tolerant variety SK-27 from Katumani which was used for the rest of the research period. This was done because there was not enough K80 seed at the ICRAF field station for use in the experiments.

Senna siamea loppings obtained from the hedgerows were used as mulch. The hedgerows were cut to a height of 25 cm two weeks before the onset of the rains and spread uniformly on the soil surface. No external source of mulch was used except that from the hedgerows in the experimental plots.

The study consisted of five treatments with no replicates. The plots measured 10 m width x 40 m downslope and it was the sampling procedure which was replicated. This means that sampling points were replicated in each plot. The following treatments were used:

Treatment 1. Maize or cowpeas control (C)
Treatment 2. Maize or cowpeas + *Senna siamea* mulch (+ M)
Treatment 3. Maize or cowpeas + *Senna siamea* hedgerow + mulch (H+M)
Treatment 4. Maize or cowpeas + *Senna siamea* hedgerow with no

mulch (H-M).

Treatment 5. Maize or cowpeas + grass strip with no mulch (G-M)

There were four rows of maize in the alleys formed by the *Senna siamea* hedgerows. These hedgerows were 4 metres apart and within row plant distance was 25 cm. The closest maize row to these hedgerows was 50 cm. The spacing of the maize with on land area lost to the hedges was 100 cm by 27 cm, which gave a population of 37,037 plants/hectare. The G-M treatment had a population of 33,333 maize plants/hectare because the seven grass strips occupied an area of 70 m^2. The cowpeas between the hedgerows were planted at a spacing of 60 cm by 20 cm, with 10% of land lost to the hedges which gave a plant density of 75,000 plants per hectare in the H+M and H-M plots and a plant density of 83,333 plants ha^{-1} in the C and +M plots. The G-M plot had a plant population of 72,917 plants ha^{-1} as 70 m^2 was taken up by the grass strips. The distance from the hedgerow to the first row of cowpeas was 50 cm. There were six rows of cowpeas in the alleys of the agroforestry plots. The distances from the grass strip to the first row of maize and cowpea were 50 cm respectively.

No mulch was applied in the C plot. The second plot had its mulch obtained from the fourth, hedged, plot which had no mulch, while the third plot had mulch from its own hedgerows. The fifth plot had grass strips forming the alley and had no mulch. It had ten rows of cowpea and five rows of maize. The grass strips were cut two weeks before planting and at harvest. No fertilizer was used during the six seasons of measurement.

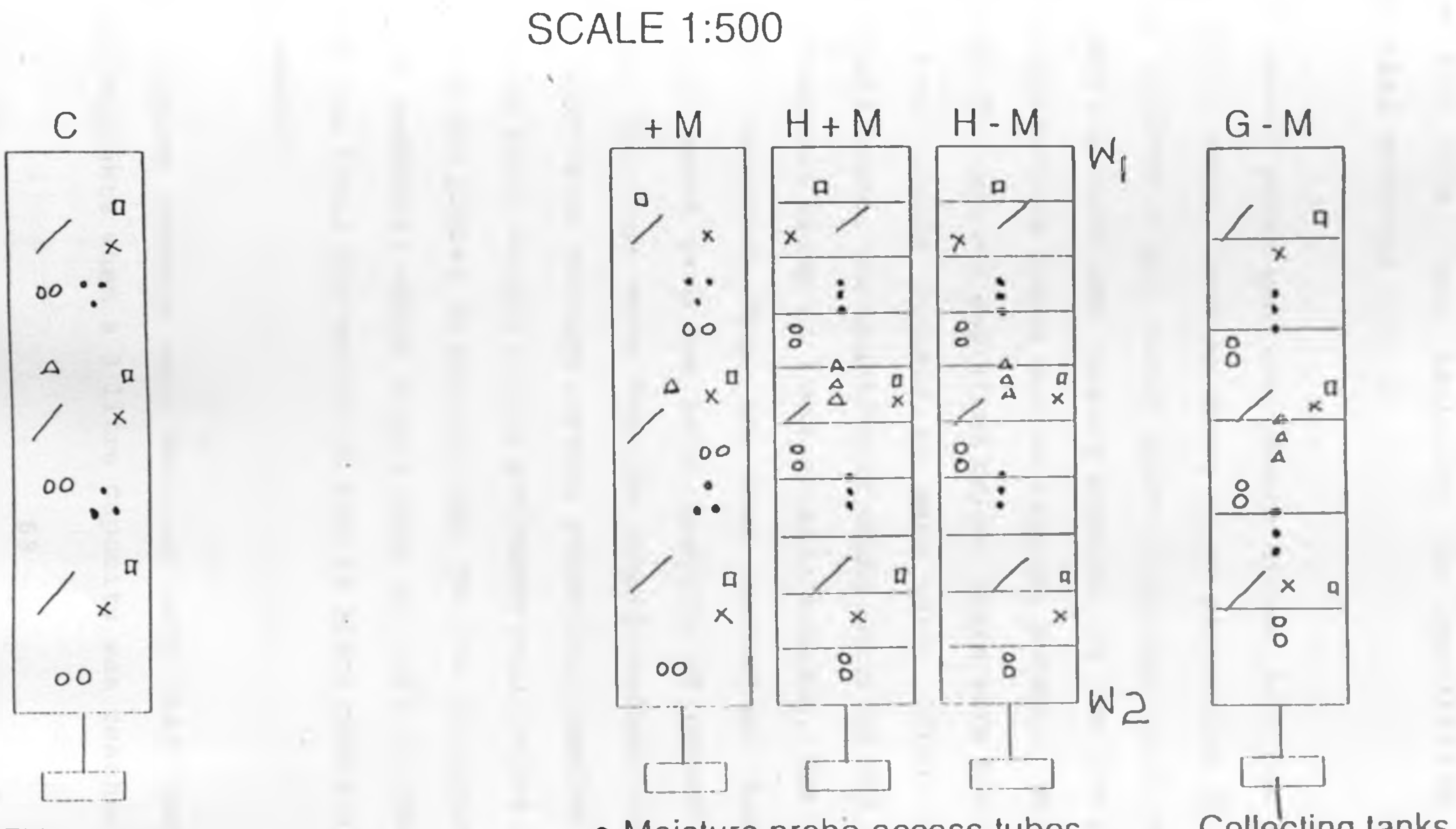
3.2. Rainfall and other routine parameters.

Apart from rainfall data, on both total amount and distribution, other meteorological parameters such as pan evaporation, air temperatures, relative humidity, wind speed, total radiation and sunshine hours are monitored in ICRAF's field weather station. The weather station was set up in the early 1980s in order to provide meteorological parameters for proper crop/agroforestry management practices in the semi-arid areas. The needed climatic data from this weather station were extracted and used for experimental data interpretation. The rainfall amounts were used in the water balance equation, the windspeed was used for comparison with the windspeeds measured near the plots, the air temperatures for comparison with the soil temperatures in the plots, total radiation for the computation of light use efficiency and pan evaporation for the comparison with soil evaporation in the experimental plots.

3.3. Set up of field quantifications.

3.3.1. Runoff and soil loss.

Runoff and soil loss were measured by collecting tanks measuring 1 m^3 and tipping buckets measuring 3 litres which were placed at the bottom of each runoff plot (fig. 3.1). The collecting tanks were connected to the runoff plots via PVC tubes which collected both



KEY

C	Control
+ M	Mulch
H+M	Hedge + Mulch
H-M	Hedge - Mulch
G-M	Grass - Mulch

● Moisture probe access tubes
○ Soil evaporation
× Mulch cover/crop cover
/ PAR measurement
☐ Grain yield and biomass yield
W Wind speed and direction
Δ Soil temperature

Fig. 3.1 Field layout Machakos ICRAF Research Station soil sediments and runoff water from the full 10 m x 40 m plots after every rainfall event. The collecting tanks were covered on the top side, thus excluding the possibility of any foreign material entering into it.

The runoff plots had iron sheets driven into the ground and fixed at their edges, leaving about 15 cm protruding in the air so that only sediments and runoff water from each plot entered into the collecting tanks and tipping buckets. In the G-M plot, there were four collecting tanks and no tipping buckets, while in the other plots, for reasons explained below, there were two collecting tanks and two tipping buckets in each plot. After the end of each rainfall event, the quantity of water entering the collecting tanks was measured using 20 litre plastic buckets. The summation of the runoff collected from the four collection tanks after every rainfall event gave the total quantity of runoff in the plot per season. The clear water from the plastic buckets was separated from the muddy water through careful decanting. Samples were then taken from the known weight of the wet muddy soil in the 20 litre plastic buckets and placed in erosion cups for the determination of the dry weight sediments after drying them at 105^{0}C in the laboratory and hence the total dry weight in the 20 litre containers for the plot per season.

The tipping buckets were designed such that they would tip off their contents when a 3 litre capacity was reached. One of the two tipping buckets was connected to a sampling pipe with seven pores. This tipping bucket had 1% of its content sampled by the seven pores on the sampling pipe as sediment, which was stored in a connected 10 litre plastic container. The other tipping bucket had nothing sampled from it but had its contents poured down at every tipping event. The sum of the quantity of water from the two tipping buckets, added to the water remains in the tipping buckets when they could not tip off because of insufficient collected water, and also added to the quantity of water from the two collecting tanks for all the rainfall events, gave the total quantity of runoff water in litres per season per plot.

As for the determination of the total soil sediments in the tipping buckets from C, +M, H+M and H plots, wet soil samples were taken from the wet soil sediments in the 10 litre containers and placed in erosion cups and taken to the laboratory for oven dry weight determination at 105^{0}C. Using these dry soil samples total dry weight in the 10 litre containers was calculated. The quantity of dry sediment obtained from the tipping buckets had to be multiplied by 200 since only 1% of the total sediment had been obtained from only one of the two tipping buckets. The sum of the total dry sediment weight from the tipping buckets and from the collecting tanks gave the total dry sediment weight in kilograms lost from the plot per season in the above plots.

A self recording rain gauge which was placed at the bottom of the plots was connected to a data logger (CR 21X, Campbell Scientific) for the purpose of recording rainfall data. The tipping bucket in the rain gauge would tip off when 0.2 mm had collected in the rain gauge. From these rainfall tips per second, rainfall intensity was obtained in mm per hour.

3.3.2 Soil moisture

3.3.2.(a). Neutron probe

3.3.2.a.(i) Introduction

The neutron probe meter measures the volumetric moisture content of the soil indirectly at various depths of the soil profile, averaged for the volume of the soil from which neutrons are scattered. This is a non-destructive method, as it measures soil moisture availability without taking samples although access tubes have to be installed. The meter is a probe with a fast neutrons emitter and slow neutrons detector that senses the moisture content of the adjacent medium in terms of the detector count rates. Our probe (Wallingford type I.H.III 1.85 GBq.AmBe, Abingdon, Oxford, England) was lowered inside an aluminium access tube of 4.15 cm internal diameter, 4.45 cm external diameter and 120 cm length, and the reading of the count rates is related to the required depth. Aluminium is preferred for use as access tubes because it is relatively transparent for neutrons (Raad, de, 1994). The fast neutrons will collide mostly with hydrogen nuclei present in the water molecules in the soil medium. After repeated collisions, the neutrons move at a lower speed and travel in a random direction.

This way a cloud of thermal neutrons will exist around the source. Some of the thermal neutrons will find their way back to the source. A detector which is situated above the source will detect the number of backscattered neutrons, which will be a measure of the hydrogen nuclei in the soil and hence a way of measuring volumetric moisture. The count rate readings should be related to the total hydrogen content or moisture of the soil (Ibrahim, 1992). Some soil elements have also an unusually high absorption capacity for slow neutrons, such as cadmium, boron and chlorine and hence complicate the interpretation of soil moisture content (Van Bavel et al., 1963). Care has also to be taken as some hydrogen in the soil is bound in clay particles or in soil organic matter (Rawlins, 1976).

Due to the heterogeneity of soils, it becomes very important for each soil type to have its own calibration curve (e.g Ibrahim, 1992; Oteng'i, 1996). Differences in slope of calibration lines for the same soil type may also be due to soil compaction and dry bulk density (e.g Greacen, 1981). Actually the emission of neutrons from a spherical volume around the source influences the detector count rates (e.g. Van Bavel et al. 1963; Ibrahim, 1992). This is the sphere of importance (or influence) and is taken as the source of 95 % of reflected thermal neutrons, which means that if all soil and water outside it is removed, it will yield 95 % of the expected neutron flux from an infinite similar medium. As follows from the above, hydrogen content of the soil is the determining factor for the sphere of importance. The water in the soil closer to the source/detector has greater influence in the count rates than that further away.

According to Visvalingam and Tandy (1972) and Kristensen (1973) $\theta_j = 100/(1.4+0.1*(\theta t))$ cm, where θ_j = is the radius of sphere of importance and θt is volumetric water content. Van Bavel et al. (1963) found from a comparable formula that data taken with a neutron probe at a depth of 20 cm and shallower were erroneous for all water contents below 35 %. The sphere of importance actually determines the depth at which measurements made could yield data with minimum error (Oteng'i, 1996). This sphere of importance is about 15 cm in wet soil and increases upto 50cm in dry soils (Gardner et al., 1991).

3.3.2. a. (ii) Calibration

Calibration is usually made by obtaining the readings of the instrument for a range of accurate independently determined values of soil moisture. A calibration equation is obtained from the relation between the readings of the instrument and calibration values. For our neutron probe it is of the form:

$\theta = a + bX$, where θ (cm^3 cm^{-3}) is the volumetric water content of free water (water released on drying at 105^0C for 12 hours).

X = calibration ratio of the count rates in the soil to the count rates in water, b is the calibration regression coefficient and a is an intercept.

The probe meter was calibrated in the field for all the required depths before it was used in the experimental plots. Four access tubes were installed near the experimental plots and left for about two weeks to allow the soil in contact with the access tubes to settle, during the dry season. The installation was done using an auger which extended up to 1.15 m depth, and a guide tube of the same external diameter as the access tubes, measuring 1 m long. The auger head fitted loosely inside the guide tube. The external end of the guide tube was fitted with a collar to receive blows from the rammer (fig. 3.2). It has also holes for a tommy bar used for turning and withdrawing the guide tube (fig. 3.3).

Disturbance to the ground surface was minimised by using a strong metal plate, 50 cm by 50 cm by 0.5 cm, with a 4.5 cm hole in the middle. The 1 m guide tube was used first and pushed into a 30 cm pre-augered hole. The auger was then used inside the guide tube to remove the soil to the required depth of 15 cm below the guide tube. The auger was also used to clear the soil cuttings, then the guide tube rammed further inside. This process was repeated until the desired depth of 120 cm was reached.

Soil samples (cores) were taken, four at each of the seven depths 0-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm, 90-105 cm and 105-120 cm using 4 soil rings of known volume (100 cm^3), from the soil pit which had been dug at about 10 cm from each access tube. The soil cores, of a length of 5 cm, were taken in the middle of each

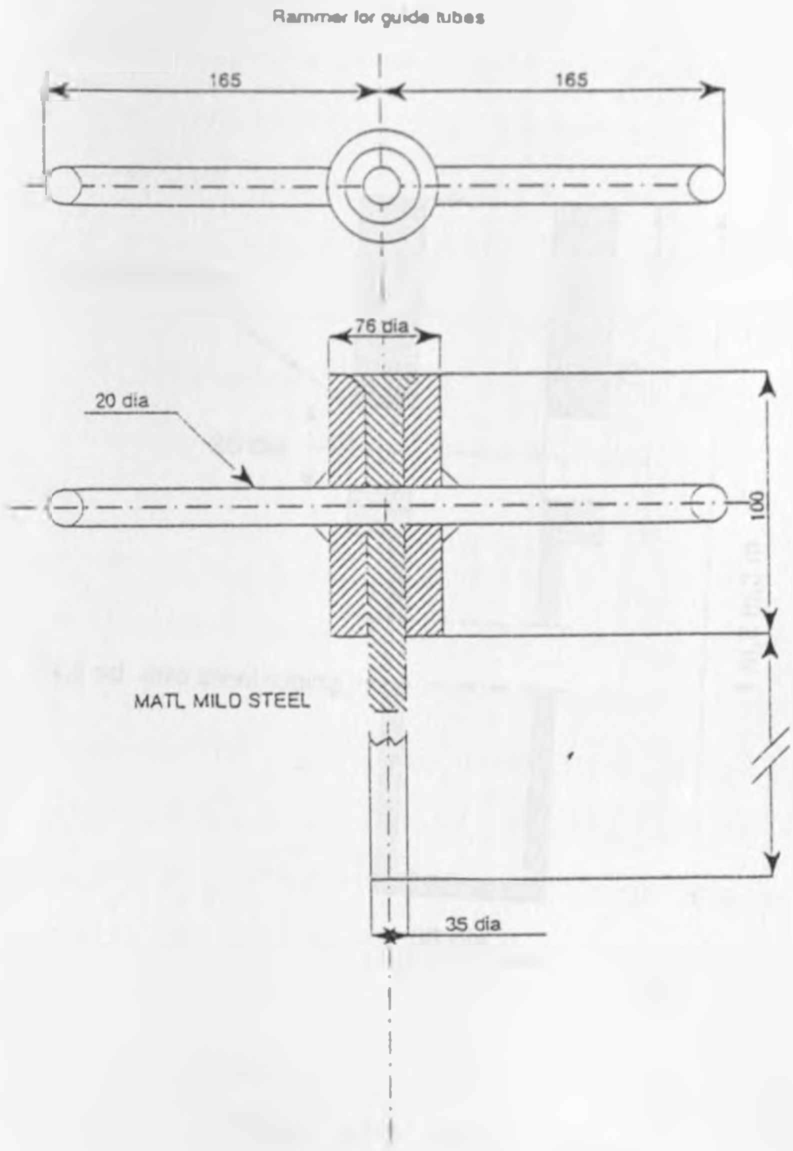


Fig. 3.2 Rammer for guide tubes.

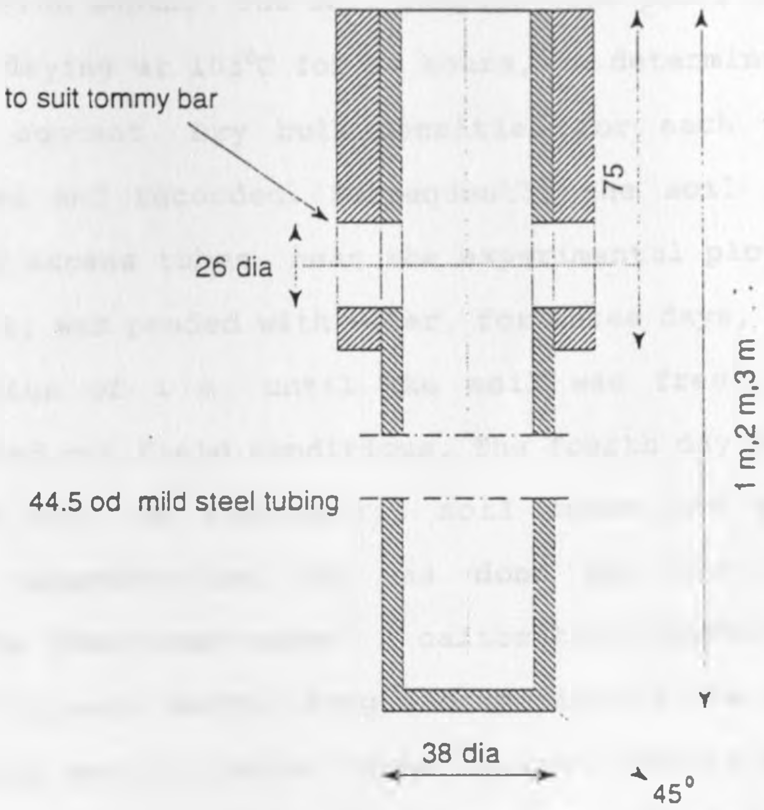


Fig. 3.3 Guide tube

soil depth to adequately represent each soil depth. Two neutron probe counts were taken from each of the seven depths together with four soil samples concurrently. The probe readings were taken half of each of the soil segments mentioned above. Using the next access tube (as a replicate) installed 10 m apart, the above procedure was done the same day for the seven depths so that eight soil cores and four probe counts were taken from the two similar access tube sites for the seven depths. The soil samples were taken to the laboratory for oven drying at 105^0C for 24 hours, to determine the volumetric moisture content. Dry bulk densities for each depth were also determined and recorded. Subsequently the soil around two more installed access tubes, near the experimental plots and placed at 10 m apart, was ponded with water, for three days, using drum rings at a radius of 1 m, until the soil was freely draining. This represented wet field conditions. The fourth day probe counts were taken as well as gravimetric soil cores for volumetric water content determination, as was done for the dry field soil conditions described above. A calibration equation was therefore derived for each depth using a composite of the volumetric water content and neutron probe counts for both the dry and wet soils for each depth. Since seven depths were used during the trial, each calibration equation for each of the above seven depths was used to convert the probe counts into volumetric water content, with an accuracy of 1.4 ± 0.5 percent volumetric water content.

3.3.2.a.(iii) Measurements

In each plot six aluminium access tubes were installed as described above at selected sampling points, using the special corers which ensured that there was minimum soil compaction and disturbance. In order to protect soil and water from entering the access tubes, rubber bungs were inserted into each of the probe tubes before, and immediately after taking measurements. In the C and +M plots, the first 3 access tubes were placed 10 m (downslope) from the top of the plots and about 4 m from the edge of the right side of the plots, two at 1 m apart within the plant rows and one tube between the rows downslope at 1 m from the first two access tubes. The second 3 access tubes were placed 25 m downslope from the top of the plot in a similar manner as the first ones, but this time two of the access tubes were placed within the rows at 1 m apart and the third was placed 1 m upslope between rows (fig. 3.1). These access tubes in the C and +M plots above were assumed to represent the sloping plot conditions. In the H+M and H-M plots, however, the access tubes were placed within the 4th and 7th hedgerows, 1 m from these hedgerows and 2 m from the same hedgerows respectively. These access tubes at 1 m and 2 m from the hedgerow were placed at the centre of the 1st and 2nd row of maize upslope and downslope in the 3rd and 7th alley respectively. For the cowpea, however, these last two pairs of access tubes were placed between the 1st and 2nd cowpea row at 10 cm downslope from the second row and between the 2nd and 3rd cowpea row at 20 cm downslope in the 3rd and 7th alleys respectively. These access tubes were assumed to represent the H+M and H-M conditions. In the G-M plot, the access tubes were placed in the 3rd and 5th grass strips, as well as 1 and 2 m from these grass strips respectively (fig. 3.1). The access tube positions with respect to both maize and cowpea plant rows were as described for the H+M and H-M plots above, but this was done in the second and fifth alley respectively (fig. 3.1).

In each plot the sampling points were in similar positions on the slope. The moisture content levels were taken at each of the seven depths (0-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm, 90-105 cm and 105-120 cm) at an interval of one week, from one week before planting throughout the growing period until harvest. To get total moisture in the soil profile, each depth's volumetric water content was multiplied by an appropriate length to get total soil moisture in mm. The sum of these seven depths was the total moisture in the soil profile upto 120 cm depth, in mm. The probe standard count rates were taken from water in a drum at a depth of 80 cm before taking probe counts in the experimental plots.

The neutron detector attached to the probe was lowered into the access tube (fig. 3.4). The count rates per depth in each plot were recorded for conversion into volumetric moisture contents, using the appropriate derived calibration equations, for analysis.

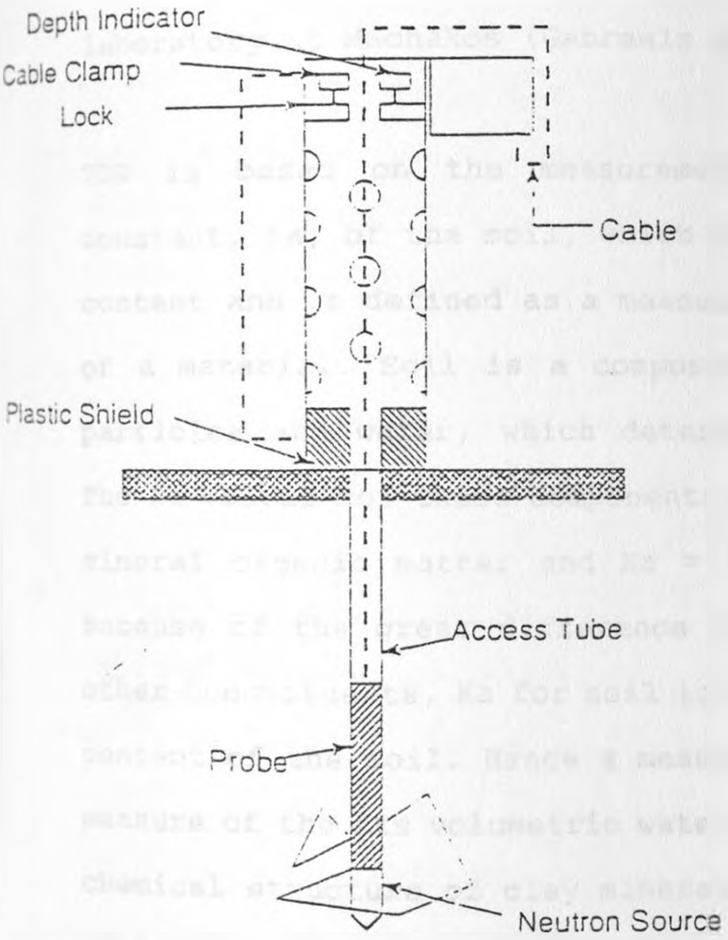


Fig. 3.4 Neutron probe detector.

3.3.2.b. Time Domain Reflectometry (TDR)

3.3.2.b. (i). Introduction.

TDR is also an indirect way of measuring the volumetric moisture content of the soil, particularly suited for the first top 30 cm where the neutron probe metre gives inaccurate moisture readings because of neutron escape into the air. The soil multimeter equipment (type FOM/Mts/92) of the Polish Easy Test TDR system had earlier been calibrated under the local field conditions and in the laboratory at Machakos (Gabreels and Vogtlander, 1993).

TDR is based on the measurement of the apparent dielectric constant, Ka, of the soil, which can be related to the soil water content and is defined as a measure of the degree of polarisation of a material. Soil is a composite of air, mineral and organic particles and water, which determine its electrical properties. The Ka values for these components are Ka = 1 for air, Ka = 2-7 for mineral organic matter and Ka = 80 for water (Raad, de, 1994). Because of the great difference in Ka for water compared to the other constituents, Ka for soil is highly dependent on the moisture content of the soil. Hence a measurement of Ka for soil is a good measure of the its volumetric water content. Because of the complex chemical structure of clay minerals, high clay content soils have high specific surface area. Since a few layers of water molecules around the soil particles are thought to have a restricted rotational freedom, the dielectric constant of these molecules are lower than that of bulk water. Organic matter in the soil has a further effect on the dielectric constant of the soil. This effect of organic matter content on the soil can be better understood by dividing the organic matter into dead and living portions. Young plant roots consist mainly of water. The TDR will interpret this fraction as soil moisture and hence overestimate soil moisture. The chemical nature of organic materials can lead to bonding of water on their surfaces which has the effect of lowering the dielectric constant and hence the moisture content of the soil.

Temperature has also an effect on the dielectric constant of the soil. Normally Ka of soil solids and air are assumed to be temperature independent, but the dielectric constant of water decreases between about 20^{0}C and 50^{0}C (Gabreels and Vogtlander, 1993). Consequently, the dielectric constant of the measured soil is changing with temperature, depending on its water content and this was accounted for in the TDR formula.

3.3.2.b.(ii) Field calibration.

Field calibration was carried out in a field irrigated twice every week. The TDR probe tubes were inserted at several depths and spots in the test plot. During each measurement the probe was inserted five times in a small circular area. Subsequently a core sample of 100 cm^3 was also taken at the same spot. The sampling volume of the core sample enclosed all these five measuring spots. This sample was dried at 105^{0}C in the laboratory and the volumetric water content compared with that from the five TDR readings of the five replicates. These measurements were taken in soils representing the general field conditions at Machakos field station. They were the soils also used for the laboratory TDR tests described below. The results showed that 95% of the TDR readings will have a deviation of less than 1.8% soil moisture from the general calibration line. They also showed that using the specific calibration formula for the Lixols, the above mentioned percentages reduced with 0.3% soil moisture.

3.3.2.b. (iii) Laboratory calibration.

The TDR was tested for six soil samples taken from different sites within the ICRAF field station. Two replicates were taken in each sample. The soils were all lixisols except one vertisol (black cotton soil). Since the TDR is equipped with several sensors, they were permanently installed in the samples. The measurements were started with wet saturated soils, which dried up in several weeks. Every other day the TDR readings were recorded and at the same time the samples were weighed. After these series of measurements the samples were dried in the oven at 105^{0}C and weighed again, so that the actual volumetric contents during the drying period could be determined gravimetrically. In this case the volumetric water content was obtained by taking the weight of soil samples of known volume before and after drying them in the oven at 105^{0}C for 24 hours. The difference in weight divided by the volume of the soil is the volumetric water content (Θ). The TDR volumetric values for these soil samples were compared with the determined gravimetric values of the soil samples. A regression equation was derived which showed the relationship between the TDR results and those obtained gravimetrically. What the calibration showed was that the results for the two methods were positively correlated $r^2 = 0.94$. So to use the TDR system a calibration is necessary for each specific soil and site (Gabreels and Vogtlander, 1993). The formula derived for use in the Machakos lixols was of the form: $\Theta_{grav} = 1.2* \Theta_{PET} - 3.4$ where Θ_{grav} = the gravimetric determined volumetric soil moisture content, Θ_{PET} = the Polish Easy Test TDR soil moisture content reading.

3.3.2.b. (iv) Measurement.

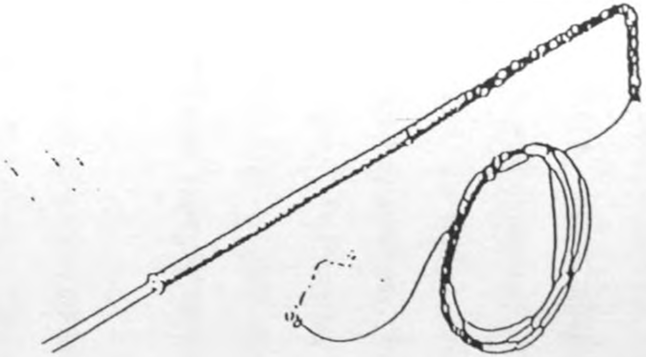
The TDR equipment measures the dielectric constant of the soil and relates this directly to the soil moisture content. It also measures soil salinity and temperature if needed. For sensor installation, a small hole, 2.5 cm diameter, was made in the soil at an angle of 45^0, taking care that the remainder of the soil remained undisturbed. This small hole was made using a thin iron bar, 2.5 cm diameter and length 1 m, which was driven about 37.5 cm at 45^0C into the soil using a wooden hammer supported by a wooden right angled block. It was in this soil hole that the two 10 cm long TDR probe needles, measuring 2 mm diameter and separated by a distance of 16 mm, were inserted in such a manner that they remained in contact with the soil at a depth of 30 cm perpendicular to the soil surface during measurement. The TDR probe needles are supported by a 2 cm outer diameter plastic PVC pipe. A cable of 5 m connects the sensors via the plastic pipe to the TDR meter (fig. 3.5). As the probe needles were placed in the pre-augered hole and made contact with the soil, the TDR screen displayed the volumetric moisture content, temperature and salinity at 30 cm depth respectively. Every sampling point had one hole made from where measurements could be taken. Five TDR readings were taken by having five insertions at every sampling point and their mean taken for use in the formula derived during the calibration.

The TDR readings were taken within 20 seconds when the TDR was set on mineral mode. It was through the use of this formula that correct volumetric moisture contents were obtained. In each plot three measuring points, were used which were replicated once. These were near the same positions where the access tubes had been installed.

3.3.3. Soil evaporation.

Soil evaporation was approximated by using a microlysimeter made of a PVC cylinder measuring 10.5 cm diameter by 15 cm depth. The PVC cylinders were locally constructed in Nairobi by an Engineering firm, with the assistance of ICRAF technicians. This cylinder held a soil core. The cylinder was encased by a PVC outer cylinder of slightly bigger diameter but of similar depth as the inner measuring cylinder.

In order to obtain a soil core, the inner cylinder was driven into



The Sensorstick.

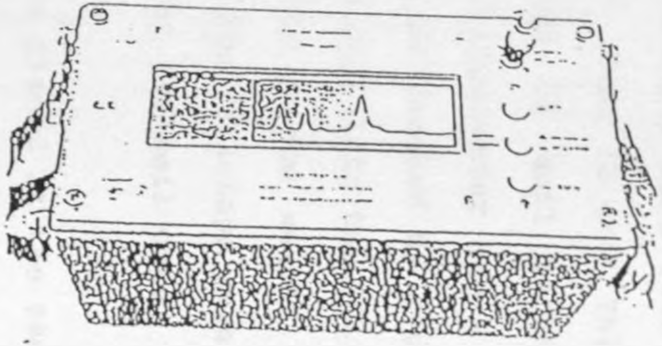


Fig. 3.5 The TDR metre box and the sensor stick

the soil using a wooden hammer. This was done causing minimum soil disturbance so that the soil core obtained remained in the same condition as the surrounding soil. The soil core was then carefully removed using a panga and trimmed at the bottom with a sharp knife. The soil core was tightly closed at the bottom end by a cylindrical glassy encasing material of slightly smaller diameter than that of the inner cylinder, reinforced with plastic cellotape. The soil core (microlysimeter) was placed back into the soil with the external cylindrical encasing such that the microlysimeter was slightly above the soil level (2 cm). This was to ensure that no runoff and splash water or soil particles entered into the microlysimeter. The microlysimeter had a wire holding it by the sides so that it could be weighed by a portable balance and the microlysimeter replaced back into the soil (fig. 3.6). The weight of the internal cylinder + the weight of the glassy encasing material + the wire and the cellotape were determined and recorded before the preparation of the soil core.

Six microlysimeters were placed at the sampling points in each of the five treatment plots (fig. 3.1). In the C and +M plots, two microlysimeters were installed at 10 m downslope from the top of the plots, 25 m downslope and 35 m downslope respectively, with those in the +M plot having mulches placed on them. At these positions, the two microlysimeters were placed 1 m apart parallel to the crop rows, across the slope and halfway between these plant rows. In the H+M, H-M and G-M plots, the microlysimeters were

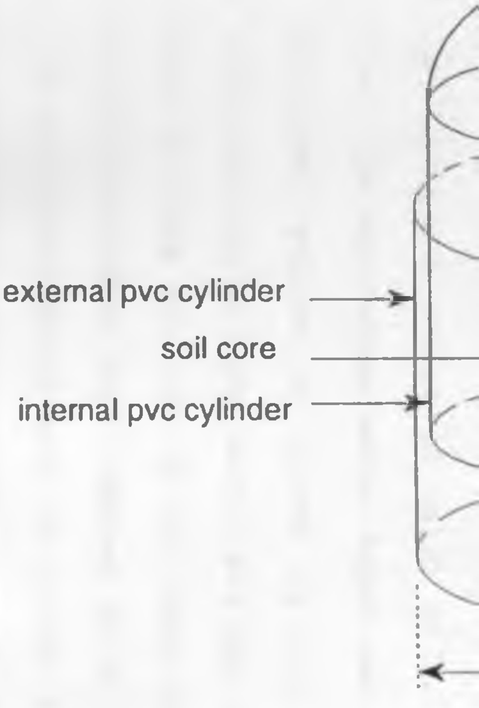
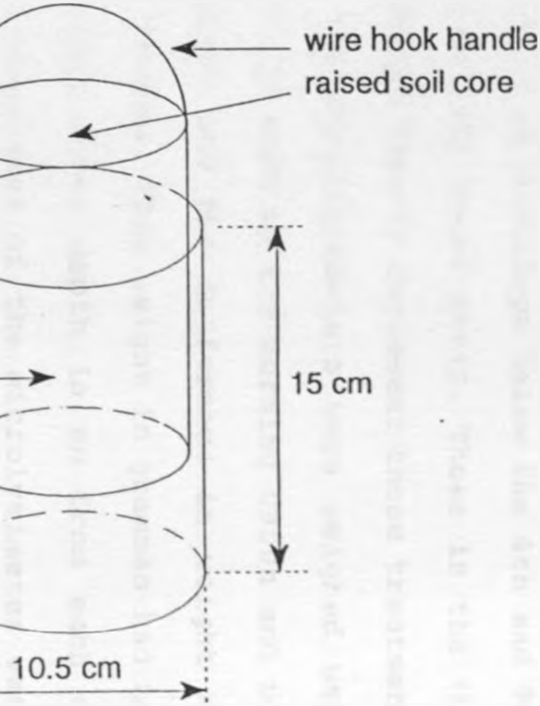


Fig. 3.6



Microlysimeter

installed at 1 m and 2 m below the 4th, above the 7th and below the 9th hedgerow and below the 3rd, above the 5th and below the 6th grass strip respectively. This way they were replicated three times. In these positions, they were placed midway between the 1st and 2nd row and between the 2nd and 3rd row of maize. For the cowpea, they were placed between the 1st and 2nd cowpea row 10 cm upslope and 3rd and 4th row 30 cm upslope from the 7th and the 5th grass strip, and between the 1st and 2nd row 10 cm downslope and 3rd and 4th row 30 cm downslope below the 4th and 9th hedgerow and below the 3rd and 6th grass strip. Those in the +M and H+M plots had mulch placed on them to represent those treatments. To get soil evaporation, the microlysimeters were weighed using a portable balance (± 0.1 g) both in the morning 0900h and in the afternoon 1600h local time, and the difference in weight represented the water loss in grammes. This weight in grammes had to be multiplied by the equivalent water depth in mm from each microlysimeter. Because the surface area of the microlysimeter was calculated as 82.658cm^{-2}, and the equivalent volume of water of 0.1 g weight was calculated as 100cm^3, the equivalent water depth was obtained from dividing the equivalent volume of 100cm^3 by the area of the microlysimeter. This equivalent depth was 0.012 mm. Such data were obtained about four to five or even up to seven days following every rainfall event in rainfree days (Daamen et al, 1993). After these five days the microlysimeters were no longer representative of the surrounding soil conditions except when the microlysimeter was more than 100 cm deep. In our case the microlysimeter depth was greater than 100 mm. The results during rainy days have been found unreliable (Allen, 1990; Daamen et al, 1993), so the soil cores were also replaced after every consecutive rainfall event or when it rained within the measuring time interval. The total evaporation loss per season was obtained by taking the sum of all the measuring time intervals water losses for each treatment, the estimates of soil evaporation during rainy days as well as those when there were no rains after the measuring intervals. Several microlysimeter measurements were carried out during rainy days with some clear portions of the wet days allowing for measurements. This was done to form a basis for assumptions for the soil evaporastion estimates during wet days. On the average the evaporation losses during such wet days was about 4 mm per day. The microlysimeter values were normally below pan evaporation values. The microlysimeters were necessary as they provided values on soil evaporation which are useful in partitioning the various water losses in the water balance equation.

3.3.4. Photosynthetically active radiation (PAR).

3.3.4 (a).Introduction

A ceptometer (Model SF-80, Decagon Devices, Pullman) was used to measure PAR once every week. The ceptometer consists of a 80 cm probe tube with 80 light sensors placed at an interval of 1 cm. It has a microprocessor which scans the 80 light sensors every one minute and takes the mean of these every 30 minutes. It then keeps this in its memory and displays it on the screen. The data are in μmol m^{-2} s^{-1} and are manually recorded for analysis. The ceptometer is fitted with a bubble level to guarantee horizontality during measurements. The ceptometer also has a function through which other useful parameters, such as the sun fleck fraction (canopy gap fraction), are monitored simultaneously if wanted.

3.3.4.(b) calibration

In the ceptometer only one sensor has an absolute calibration. The other sensors are calibrated against this one sensor and the calibrations stored in the memory. This calibration remains for as long as the batteries are not changed. So a change of batteries leads to loss of calibration information and must be followed by a new calibration before any new measurements are made, to avoid making errors in taking measurements (Ceptometer User manual, 1988). A calibration was done in bright sunlight on a cloudless day. This was done by shifting to function 7 and holding down buttons A and B and pressing the function key. The letters "PLL" appeared on the left hand side of the ceptometer display screen, an indication that the ceptometer had been calibrated and was ready for use. The calibration standard was the maximum PAR at solar noon and was supposed to be the same as above the crop during measurements. An already calibrated ceptometer was used as a check to compare the PAR of the newly calibrated values after calibration.

3.3.4 (c) Measurement

Initially the PAR was measured by taking three subsequent PAR readings across the row directions at each of two marked sampling points, i.e. points at which measurements were made in the five plots to represent sole crop conditions in the C and +M plots and in the same alleys in the H+M, H-M and G-M plots, to represent tree/grass and crop conditions in these plots. These three measurements were taken at an angle of 60^0 (across the crop rows) at each of the two sampling points in each of the five plots during the first cowpea 92/93 season. With the probe having a length of 80 cm, from the middle of the place of measurement it measures 35 cm outwards. At this angle it was expected that more leaf area would be exposed to the light sensors. The sampling points were then increased to three to increase precision in the same positions across the rows for the other five seasons. The PAR intercepted by the crop canopy was measured by placing the instrument above the canopy and then below the canopy at about 5 cm from the soil surface, around midday when the sky was clear. Further measurements were made in the open as a control just before the real measurements were made at the measuring points. When measurements were made on cloudy days then it was indicated so. The difference between above and below crop canopy measurements multiplied by 100 gave the PAR intercepted in percentage. In the C and +M plots, the measurements were taken at 5 m, 20 m and 32 m downslope from the top of the plots to represent slope and crop conditions in these fields (fig.3.1). These were done over and across a maize row and over and across two cowpea rows in these sampling points, about the same positions on the slope where measurements were done in other plots for comparison purposes (fig. 3.1). As for the H+M and H-M plots, the PAR measurements were made in and above the 2nd (+ downslope of the, 5th (+ upslope of the) and 8th (+ upslope of the hedgerow, and 1 m from these hedgerows as well as 2 m from these hedgerows respectively (fig. 3.1). This was assumed to represent hedgerow trees and crops in the alleys and the slope plot conditions. The PAR measurements in the G-M plot were made in and above the 2nd (+ upslope of the), the 4th (+ upslope of the) and the 6th (+ upslope of the) grass strips, 1 m from these grass strips as well as 2 m from these grass strips respectively. This is assumed represent the grass strips/crop and crops in immediate rows in the alley. The PAR measurements were started when the maize crop was about 20 cm high (this was 10 cm high for the cowpea) and continued until the crop was harvested. Because it was necessary to better partition the PAR % interception by the crops respectively the hedgerows and grass strips, more PAR measurements were made for the 94/95 cowpea crop season. These measurements were done above the tree canopy, below the tree canopy, above the cowpea crop canopy and also below the crop canopy of the cowpea crop row next to the hedgerow. These measurements were taken at exactly the same measuring points as before except that an extra measurement was taken at the tree/crop interface at 70 cm from the hedgrow/grass strip, 20 cm downslope of the cowpea row next to the hedge/grass strip,in order to separate the PAR denied to the crop by the tree/grass shade. This way it was possible to know the proportion of shade from the tree affecting yields at the crop/tree interface. The PAR % intercepted by the canopy in the sampling points in each treatment was compared with the amount of above ground biomass produced and was then used for the determination of light use efficiencies.

3.3.5. Mulch and crop cover.

Mulch and crop cover were determined by a quadrat sighting frame measuring 1.3 m by 1.3 m. This frame was divided into smaller squares of 10 cm by 10 cm. This equipment was placed on top of the soil and approximately parallel to it, just after the mulch of lopped hedge prunings had been evenly spread on the sloping mulched plots. The sighting frame was kept parallel to the crop rows. Using the small squares in the quadrat frame, one looks through them from above and records what full squares are covered by mulch and those covered fully by bare soil. Those portions in the sighting frame which were partially covered by either the mulch or soil would be added together to approximately full squares. Those squares occupied by the mulch were expressed in percentage out of the whole quadrat area.

After the crop had germinated and was tall enough, i.e. 10 cm and 20 cm height for cowpeas and maize respectively, the same sighting frame used for mulch determination was also used for crop cover at the same measuring points. For the three components of bare soil, mulch cover and crop cover to be determined the sighting frame was placed above the point of measurement and supported by four hooked iron rods approximately parallel to the ground. From this raised position, one looks through the frame and counts the full squares occupied by the bare soil, the mulch and the crop canopy and records the appropriate percentages of the quadrat taken by each measured component. This measurement was done at three positions in each plot and measurements were taken at these points throughout the life cycle of the crop. When the crop was quite tall as in the case of maize, the sighting frame was held parallel to the ground by adjusting the height of the supporting iron rods. A stool was then used in order to take cover measurements frame above the sighting frame. At the same time, canopy cover by the hedgerows and grass strips were also monitored by the sighting frame at the time of taking mulch cover at three measuring points in the agroforestry and grass strip plots respectively.

In the C and +M plots, the measurements were taken at 5 m, 20 m and 35 m downpslope from the top of the plots representing prevailing plot cover and slope conditions (fig.3.1). In the H+M, H-M plots, % cover by the crop and mulch were measured in the 2nd, 5th and 9th alley and in the G-M plots in the 2nd, 3rd and 5th alley respectively. The % cover by the hedgerows and grass strips were measured in the 2nd, 5th and 9th hedgerows and in the 2nd, 3rd and 5th grass strips respectively (fig. 3.1). The figures showed that three measurements were giving a sufficiently accurate average. The ten day mean mulch and crop canopy cover as well as the hedgerow cover were recorded for the entire season.

3.3.6. Soil temperature, with platinum resistance thermometers.

3.3.6.(a). Calibration.

The instruments used for the monitoring of the hourly soil temperatures at a depth of 7.5 cm were platinum resistance thermometers obtained from the Netherlands. They are temperature sensors that generally have a wire wound element whose resistance changes with temperature in a known and highly repeatable manner. They were taken to the National Department of Meteorology at Dagorreti (Nairobi) for calibration before being used at the experimental site. This was done because the original calibration papers got lost after the platinum resistance thermometers were brought. The thermometers were tied together and placed in a FRIOLABO calibration chamber where temperature can be carefully controlled and varied. The sensors were connected to the data logger, where the temperatures were monitored and displayed while the chamber temperature was indicated by the calibration thermometer of the chamber. The chamber temperature was set at 0^0C and allowed to stabilise before taking the indicated chamber temperature. The chamber temperature was then increased, with an interval of 1^0C, until 45^0C, covering the range of temperatures expected in the field. These temperatures were carefully noted and then cooling was started at an interval of 1^0C, until reaching the initial zero temperatures. From the sensor readings from all the eleven sensors and the indicated chamber readings, a regression equation was derived.

3.3.6.(b). Measurements

The thermometers were inserted into the ground to a depth near 7.5 cm. A screw driver was used to make a small hole at an angle of about 60^0 to the ground surface, where the temperature sensor was inserted. As during calibration, thermometers were connected via wire cables to a data logger (CR 21 X, Campbell Scientific), installed at the side of the experimental plots. The temperature sensors were monitored (sampled) every 4 minutes and the mean for every hour calculated, which was stored by the data logger. After every week the data stored in the data logger were retrieved into the lap top computer for analysis. From the hourly temperature for each day, a daily mean temperature was obtained. These daily mean temperatures were used to calculate a weekly mean temperature for each thermometer sensor in each plot.

In the C and +M plots, there was only one soil thermometer, placed between the crop rows (in the middle between maize and cowpea rows) at 15 m from the top of the plot. There were three soil thermometers in the H+M, H-M and G-M plots. The latter were placed inside the 5th hedgerow (H1+M; H1-M), and in the alley 1 m (H2+M; H2-M) and 2 m (H3+M; H3-M) below it. For the G-M plot, the thermometers were placed inside the 4th grass strip (G1-M), and 1 m (G2-M) and 2 m (G3-M) below it (fig. 3.1). For the H+M, H-M and G-M plots, the temperature sensors were therefore situated midway between the 1st and 2nd, and the 2nd and 3rd maize row while they were situated between the 1st and 2nd cowpea row 10 cm upslope and between 3rd and 4th cowpea row 30 cm upslope. The sampling points were assumed to represent the tree/crop or grass/crop situations in these plots. The temperatures sensors in the +M and H+M were below soil covered with mulch.

3.3.7. Windspeed and direction.

Two Woelfle anemographs (Lambrecht manufacturing instruments-Germany) were used to measure the hourly mean windspeed and direction, in metres per second and degrees respectively, on a twenty four hour basis every day. These anemographs were placed between the H-M and G-M plots, one up slope and one down slope, near the plot edges at a distance of about 40 m apart (fig. 3.1). The equipment consisted of an iron mast, 2 m high, four adjustable rigs with adjusters and wooden pegs, which kept the mast vertical and firmly held to the ground. A wind vane is mounted at the upper end of the mast, indicating the direction from which the wind is coming. There are three anemometer cups fixed on arms, used to rotate by the wind speed and measuring wind run. They move due to differences in wind pressure. Below the wind vane a mechanical clock work is mounted, with a graph paper chart, where windspeed and direction are plotted. The mechanical clock was wound up monthly by hand. The calibration "ladder rule" provided by the rers was used to determine average hourly windspeeds. The direction during the month was estimated from the traces on ne graph paper chart made by the wind direction recording rollers. The recording paper chart was designed to last for a month, after which it was replaced with a new role of paper chart.

At the end of every month, the recorded data on the chart were removed for interpretation. The data were worked out by taking the mean windspeed and direction of every hour for the two wind sensors for thirty days (see chapter 4). The windspeed and direction from the anemographs were compared with the same data from the ICRAF field weather station, for the periods of the short rains 1992/93, the long rains 1993 and the short rains 1993/94.

3.3.8. Grain and biomass yields.

Except for the 92/93 rainy season, when harvesting was done from the whole alleys and expressed on per hactare basis, since no adquate preparations had been made to harvest on a per row basis, grain and total biomass yields per row were determined at harvest time for every season in every experimental plot. This involved taking four 10 m long rows of maize and six 10 m long rows of cowpea plants respectively from 4 m * 10 m areas at three sampling points in the C, +M, H+M and H-M plots. All the five maize and ten cowpea 10 m long rows respectively at the sampling points in the G-M plot were harvested (fig. 3.1). For the C and +M plots, the samples were taken from positions 5 m, 20 m and 30 m from the top of the plots downwards respectively (fig. 3.1). This was done to avoid bias in picking the best of the plants as well as to avoid picking plants affected by the border effects. In the H+M and H-M plots, the sampling was done in the 1st, 5th and 8th alley respectively. For the G-M plot, sampling was done by harvesting in the 1st, 3rd and 5th alley respectively.

The samples were weighed for determination of the total above ground biomass (grains + stovers + empty cobs). Then the shelled grains were separated from the rest of this above ground biomass (stovers + empty cobs) for determination of the harvest index. The above remaining ground biomass and grain yields were placed in paper bags for the determination of dry weight, in grammes, in the ovens in the laboratory, at 80^0 Celsius for 48 hours. The sample weights were taken using portable balances before taking them to the laboratory for dry weight determination. Using these sample weights, yields on a per row basis, per plot basis and per hectare basis were determined. In the C and +M plots, the mean weight from the four maize and six cowpea 10 m rows of plants from 4 m * 10 m area was used to determine total yield per hectare. This yield per hectare was checked by harvesting the whole C and +M plots. Because in the H+M, H-M and G plots 10 m of every plant row in the sampled three alleys were harvested, from the alley mean yields the total yield per plot was determined. At the same time, also the yield per row was determined in relation to the position of the row in the alley and its location on the slope.

The total dry weights of regrowth of the *Senna* biomass and of regrowth of the grass biomass, from the hedgerows and grass strips respectively, were also determined. Representative fresh 1 kg biomass samples were taken from the harvested 10 m long hedgerow in the 1st, 5th and 9th hedgerow in the H+M and H-M plots as well as from the harvested 10 m long grass strips from the 1st, 3rd and 5th grass strip 10 m rows at crop harvest time respectively. This was necessary for the determination of the light and water use efficiencies in the five treatments (see chapter 4).

3.3.9. On-farm research

3.3.9.(a) Experimental site

The experimental area for the on-farm research was Kakuyuni catchment, 180km East of Nairobi, situated on the semi-arid, gently sloping Yatta plateau. This plateau is about 1200m above sea level. It lies at a latitude of 1^0 24'South and a longitude 37^0 41'East.

The soils are well drained, shallow to deep, dark red friable clays. In many places the soils are rocky (nito-rhodic ferrasols and nitochromic cambisols). In some depressions a poorly drained, very dark greyish brown to black, very firm to slightly calcareous clay can be found. The topography ranges from level, via gently sloping to moderately sloping, with a few steep slopes of >35%.

The catchment receives about between 250-300 mm of rainfall per season, which is insufficient in amount and usually poorly distributed over the growing periods. The rainfall from our research period was recorded using one simple rain gauge located at the Kakuyuni KEFRI tree nursery site, manned by KEFRI field staff. The long rains season of 1994 resulted in a complete crop failure and no rainfall data were recorded at Kakuyuni for this season.

This catchment was chosen because it is rather similar in its topography, soils and climate to that at the on-station experimental site. Of importance was the fact that alley cropping (hedgerow intercropping) had been introduced in the catchment area before to a few farmers chosen by the DARP project in collaboration with ICRAF and KARI. This was in the form of multi-purpose trees or shrubs such as *Leucaena leucocephala*, *Senna siamea* and *Gliricidia sepium*, adapted to the semi-arid conditions.

3.3.9.(b). Research approach

The objective of the on-farm research was to carry out a diagnostic farm survey of existing traditional soil and water management techniques as well as of general farming activities in the semi-arid areas of eastern Kenya. The yield performance trends of the crops on the research station under alley cropping were to be compared with the yield performance trends of the crops under alley cropping and under the traditional techniques of soil and water management on-farm.

The research method used was interviewing farmers, via a designed questionnaire (Appendix 3.1 - 3.5), about their traditional techniques of soil and water management and conservation as well as on the general farming systems of the farming community in the area. The questionnaire was designed with the assistance of the local administration, agricultural extension officers, KEFRI extension staff, women group leaders, church leaders and local schools. Participation of this local leadership was crucial, for it was the machinery used to inform most farmers on the objective of the survey. This was necessary to secure cooperation and attention, while carrying out the survey at later stages, for the farmers now knew already the aims of the survey.

The other method used was making observations on the agricultural activities while in the extensive tours of the catchment as well as visiting markets. Experienced, knowledgeable, aged persons were often taken round the catchment on guided tours so that they could be asked questions, on what they thought were the best methods for water and soil conservation, such as stone terraces, grass strips and mulches, on sources of income, on the onset of the rains, on values of trees and on other problems in the community and how they had tackled them over the years.

Finally, quantification was done by conventional means. In this method, plant density per hectare was obtained by counting plants from pegged sampling areas of 10 m^2, and plant spacing was obtained, using a tape measure, from pegged and sampled areas. We also quantified slope steepness in degrees, from various areas, using a clinometer. The percent slope was determined by taking the vertical heights with a theodolite and the upslope distance between them in metres. Using the upslope distance and the two vertical heights at the two points, the % slope was calculated by the difference in vertical height divided by the horizontal distance and multiplied by 100. Crop grain yields and biomass yields were obtained by harvesting from sampled areas of 10 m^2 placing the yields in paper bags, taking them to the laboratory for drying and weighing, using portable balances, in the same way as on-station. The yields per hectare were obtained using the yields obtained from the sampled 10 m^2 areas. These measurements were obtained in alley cropped farms, farms with traditional techniques of soil and water conservation and on farms with no conservation structures. The last mentioned areas under crop, with no trees or conservation structures, in the above sampled farms were used as control plots.

3.3.10 Data analysis.

Data analysis was carried out using Mstat. C soft ware from Michigan State University (1990), for analysis of variance determination (ANOVA). Duncan's Multiple Range Test (DMRT), was used to separate the treatment means and make comparisons between them when the differences between treatments were statistically significant at $P = 0.05$. The method as explained in Gomez and Gomez (1984), ranks all the means in a descending order, computes the standard error, computes the total number of treatment values of the shortest significant ranges and finally identifies and groups together all treatment means that do not differ significantly from each other. These are then ranked alphabetically in a descending order. Linear regression analysis using Lotus 123 programs was used to determine correlations and their coefficients.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS.

4.1 Evaluation of field design and set up of experiments.

The following observations apply:

(a) The field plots were big enough to fairly represent general field conditions but inevitably plot variations were induced by some soil heterogeneity, for example due to the presence of some isolated iron concretions (murram) in the hedged plot (H-M) which may have enhanced runoff. There were also variations in slope steepness within plots, as the plots were quite long.

(b) The field plots were part of a long term experiment where *Senna* trees had earlier been established. Because the plots were quite large, each plot average was assumed to be representative for the whole unless specified differently, meaning that replicates were considered represented by measurements within the same plot.

(c) Experimental set up:

(i) PAR - It was assumed that to obtain information on agronomically significant effects there was a fair replication of the measuring points in all the plots via the use of many measuring points (see chapter 3) to increase accuracy. Great care was taken to take PAR readings when the ceptometer was level to minimise errors of PAR % interception. At the same time, PAR measurements were only taken when the sky was clear or about clear around midday, to minimise variations in light composition. Care was further taken to recalibrate the ceptometer every time the batteries went down and were changed, since the calibration information gets then lost.

(ii) Neutron probe and the TDR - These were also assumed to be fairly replicated to detect agronomically significant effects in the plots, as a large number of access tubes had been placed across the alley, situated right from the hedgerows and grass strips towards the centre of the alley, measuring over the depth of the senna/maize or grass/maize rooting zone, as earlier described in Kiepe (1995). The combination of the two kinds of equipment ensured that soil moisture levels were represented till close to the surface.

(iii) Quadrat sighting frame - This represented a measure of crop/mulch/hedgerow cover over a large area and errors from manual counting of the small squares were kept to a minimum through experience of the use of the sighting frame. There were problems of counting the squares when maize plants were tall as one had to stand on a ladder/or stool while counting the grid squares.

(iv) Tipping buckets and runoff/soil collection tanks - This equipment determined the washed off soil (or soil loss) and runoff water in the plots with errors of upto 5% incurred as a result of differences in sampling by different persons. This was kept to a minimum through use of experienced personnel. One weakness with the set up of the runoff collection tanks and tipping buckets was that during very heavy storms not all runoff water was collected, as the collection tanks would overflow, notably in the control plot.

(v) Microlysimeters - Special efforts were made to keep errors during measurements to a minimum. It was not possible to estimate the losses which occurred during rainy days, because the protocol adopted (Daamen et al. 1993) left this out. It should be argued that for days with much rainfall the evaporation would be below average, while on days with one or a few occasional showers the evaporation would be above average. Taking evaporation on such days the same as in the first dry day following a day with rainfall, will on the average keep the errors low. Daamen et al.(1993) estimate the accuracy of the protocol to be ±0.1mm.

(vi) Platinum resistance thermometers - Although there were not enough thermometers for replication, the representative measurements were as accurate as indicated by the calibration regression equations derived for the platinum thermometers, but the major error was due to depth variations. The needed accuracy due to representativeness was not high, as soil temperature was not a very determining factor for most of the time. For the larger differences due to mulching this accuracy was sufficiently high and may be estimated as between ±0.5 and ±1.0^{0}C.

(vii) Anemographs - These represented measurements depending on the slope but were discontinued with the breakage of one of the anemographs. The collected data gave sufficient information on variations.

(viii) Yield measurements - It was known from experience that there were enough sampling points in each plot to accurately represent plot crop yields.

4.2. Rainfall and other routine weather parameters.

The rainfall/pan evaporation distribution results for the six rainy seasons as extracted from the stations meteorological data are presented in figures (4.1-4.6). Figure (4.1) shows that the short rains of 92/93 were exceptionally wet, with 662 mm of well distributed rainfall. This season was also characterized by having high rainstorms, e.g. 80 mm in a day in December, resulting in runoff overflow in the collection tanks.

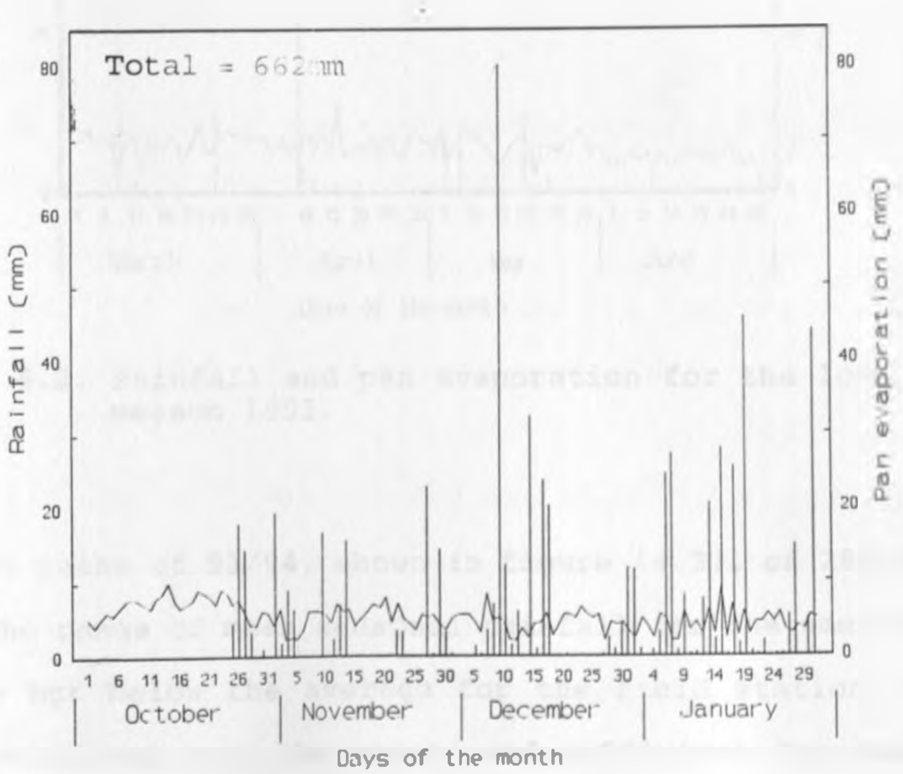


Figure 4.1. Rainfall and pan evaporation for the short rainy season 92/93.

The 1993 long rains, shown in figure (4.2), were exceptionally poor, with 108.5 mm of rainfall poorly distributed over the season, with consequent moisture deficits at the critical tasselling stages leading to very low yields.

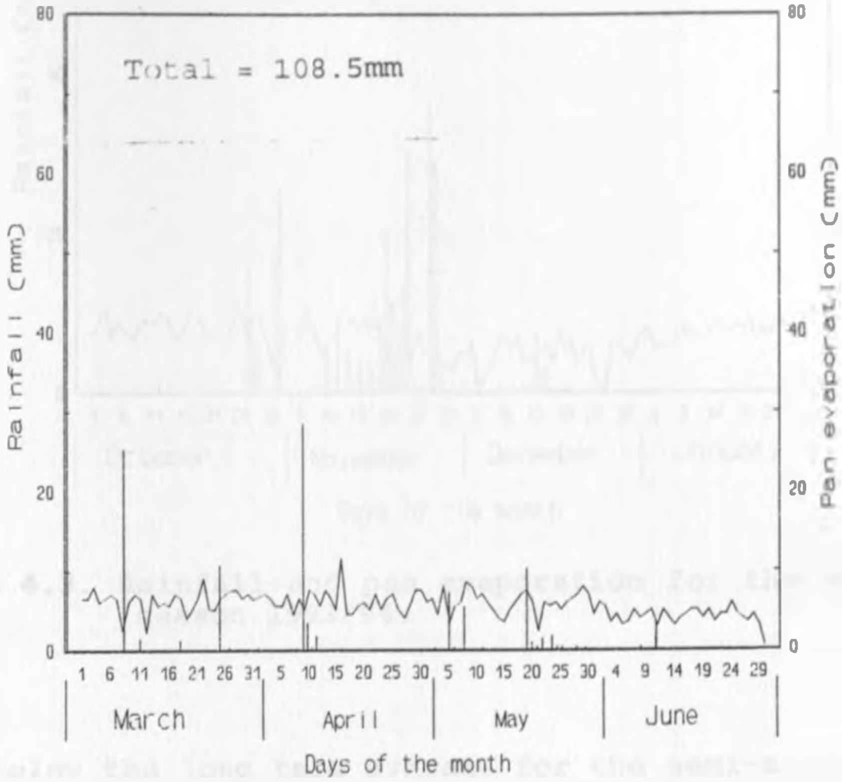


Figure 4.2. Rainfall and pan evaporation for the long rainy season 1993.

The short rains of 93/94, shown in figure (4.3), of 288.5 mm, were within the range of mean seasonal rainfall for the semi-arid areas of Kenya but below the average for the field station. They were well distributed over the season and sufficient for cowpea water requirements.

The long rains of 1994, of 242.4 mm, shown in figure (4.4),

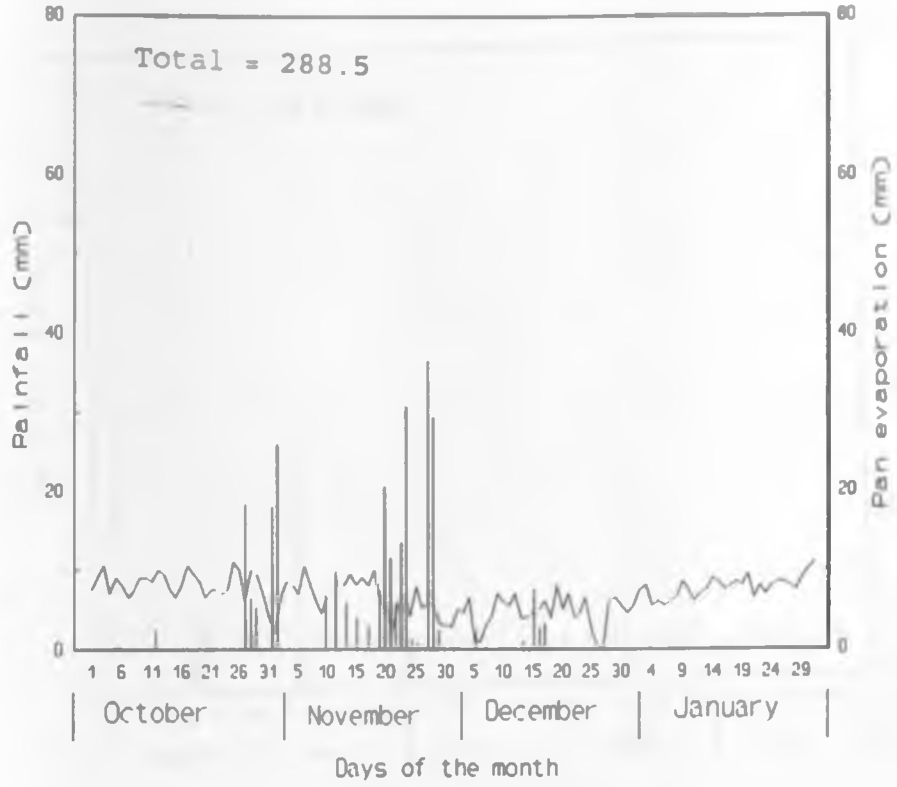


Figure 4.3. Rainfall and pan evaporation for the short rainy season 1993/94.

though below the long term average for the semi-arid areas of Kenya were well distributed over the season.

The short rains of 94/95, of 549 mm, shown in figure (4.5), were well above average and well distributed over the season.

The long rains of 1995, with 285 mm, shown in figure (4.6), were just within the average range for the semi-arid areas of Kenya and well distributed over the period from crop development stages to harvesting.

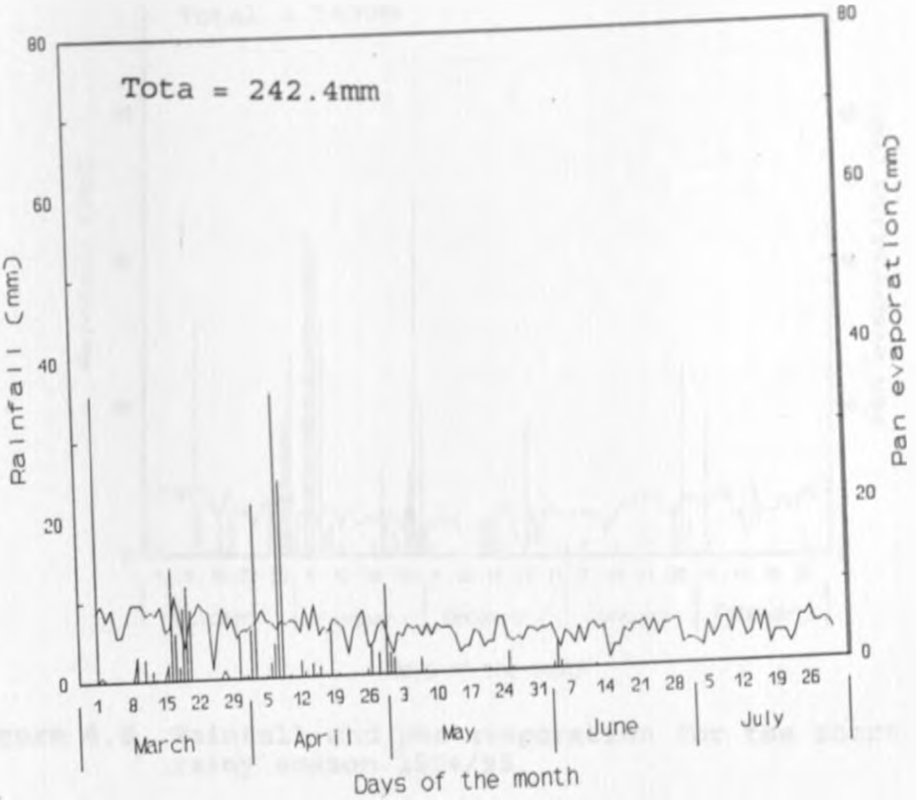


Figure 4.4. Rainfall and pan evaporation for the long rainy season 1994.

The seasonal rainfall data have been summarised in Tables 1a, 1b, 1c and 1d. It was noted that there were variations in rainfall totals within the station's rain gauges in various field plots. Although reasons may be several, the rainfall data from these experimental plots were used to determine rainfall intensities (Tables 1a, 1b, 1c and 1d).

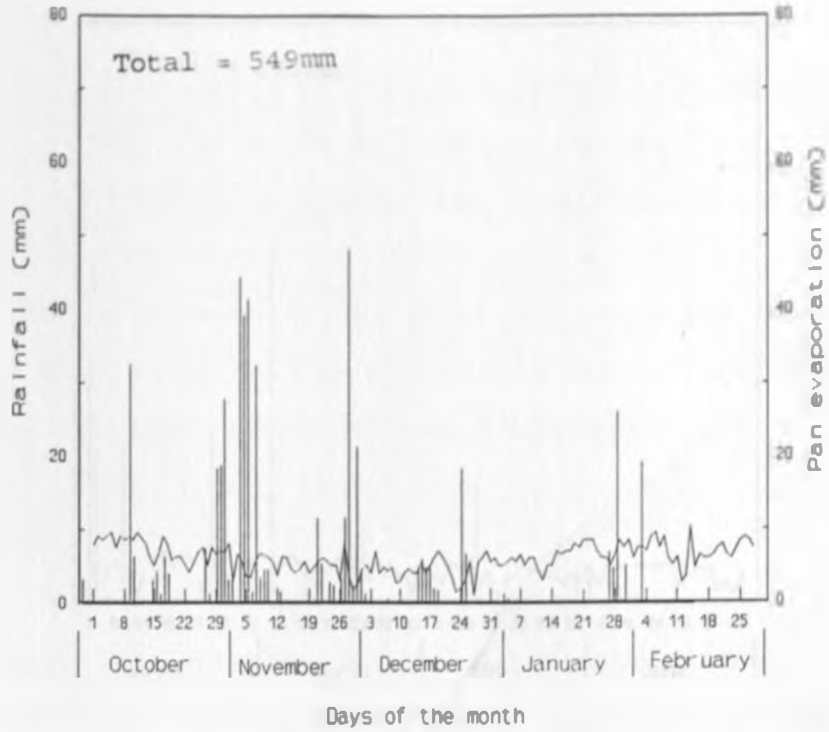


Figure 4.5. Rainfall and pan evaporation for the short rainy season 1994/95.

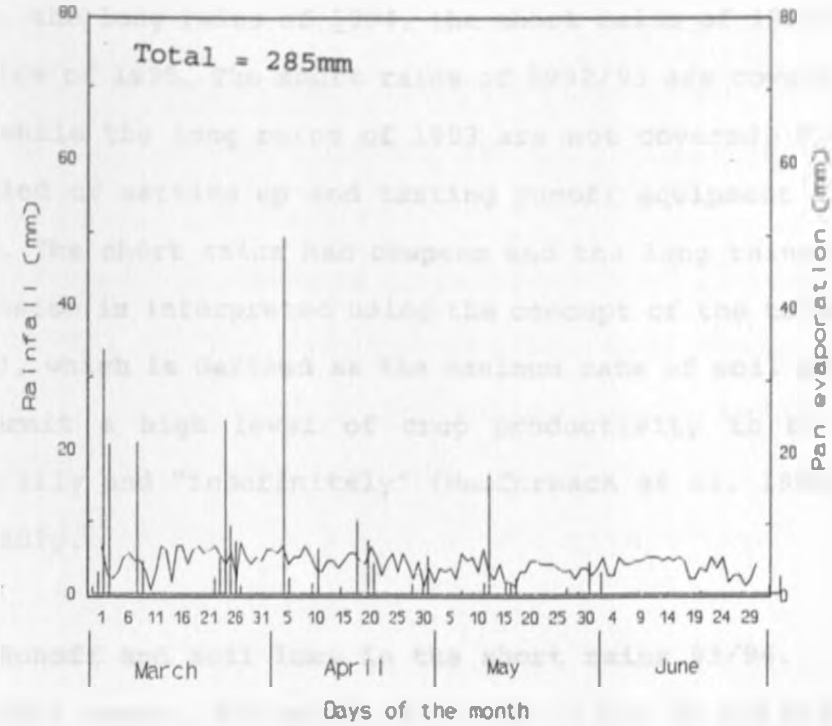


Figure 4.6. Rainfall and pan evaporation for the long rainy season 1995.

4.3 Runoff and soil loss.

The results presented and discussed cover the short rains of 1993/94, the long rains of 1994, the short rains of 1994/95 and the long rains of 1995. The short rains of 1992/93 are covered in Kiepe (1995) while the long rains of 1993 are not covered, for this was the period of setting up and testing runoff equipment and tipping buckets. The short rains had cowpeas and the long rains had maize. Soil erosion is interpreted using the concept of the tolerable soil loss (T), which is defined as the maximum rate of soil erosion that will permit a high level of crop productivity to be obtained, economically and "indefinitely" (MacCormack et al, 1982), that is *sustainably*.

4.3.1 Runoff and soil loss in the short rains 93/94.

During this season, the mulch rate used in the +M and H+M plots was 2.4 t ha^{-1}. The soil loss results in figure (4.7) show that except for the C plot, which had lost 2.55 t ha^{-1} with no soil erosion control structure, the mulch in the +M plot, mulch and contour hedgerow barrier in the H+M plot, hedgerow barrier in the H-M plot and the grass strip barrier in the G-M plot reduced soil erosion to less than 1 t ha^{-1} per season. Although all the plots had erosion rates below the T = 5 t ha^{-1} for the region (Kilewe, 1987), the grass strip was the most effective control structure in the season (with a loss of 0.15 t ha^{-1}) followed by mulch in the +M plot (0.45) t ha^{-1}) which was followed by H+M and H-M with (0.5 and 0.7 t ha^{-1}) respectively. Figures in the text have been rounded off to the nearest 0.05 t ha^{-1}.

In terms of runoff control, the H+M was the most effective (0.5 mm) while C had lost 10 mm, 20 times the runoff water collected at H+M. The +M (1 mm) had lost about 10 times less runoff than the C plot, while the H-M plot (4.5 mm) had lost about 2 times less and G-M (2 mm) had lost 5 times less compared to this same C plot respectively. Figures were rounded off to the nearest 0.5 mm.

At maximum rate, the percentage of rainfall lost as runoff was only a bit more than 3 %. The rainfall for the season was light, with only few high intensity rainstorms causing runoff and erosion (fig. 4.3). The rainfall intensities as calculated from the tipping buckets data ranged from 10 to 60 mm h^{-1}, with highest intensities occurring in high rain storms.

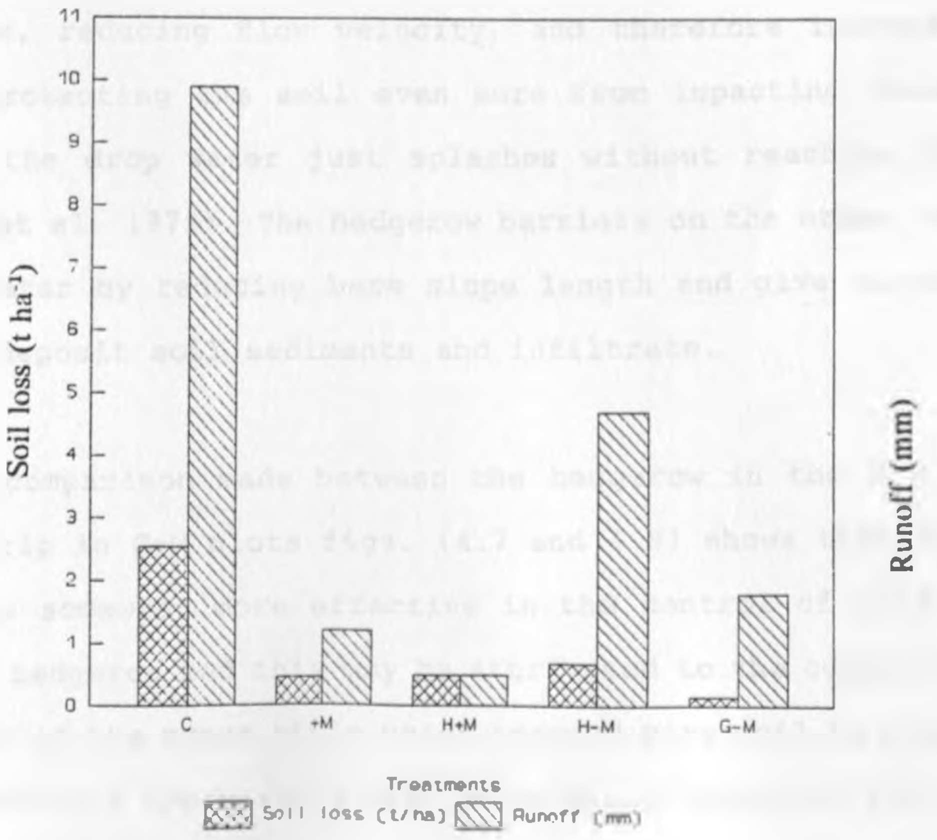


Figure 4.7. Seasonal soil loss and runoff for the short rainy season 1993/94.

4.3.2 Runoff and soil loss in the long rains 1994.

During this period mulch rates of 1.9 t ha^{-1} were used in the +M and H+M plots. The results in fig. (4.8) show that the mulch in +M, the mulch and hedgerow barrier in the H+M, the hedgerow barrier in the H-M and the grass strip barrier in the G-M plots were very effective in the control of soil erosion this season in comparison to the C plot (9.7 t ha^{-1}). The combination of the hedgerow barrier and the mulch was the most effective in the control of soil erosion (0.05 t ha^{-1}). This order of plots in erosion control effectiveness was confirmed by G-M > +M > H-M, with 0.2 t ha^{-1}, 0.8 t ha^{-1} and 1.5 t ha^{-1} respectively fig. (4.8). An explanation for the effects is that mulch lines and occupies microdepressions on the tilled soil surface but creates them in flowing water. It increases hydraulic roughness, reducing flow velocity, and therefore increases flow depth, protecting the soil even more from impacting rain drops, because the drop water just splashes without reaching the soil (Foster et al. 1979). The hedgerow barriers on the other hand trap runoff water by reducing bare slope length and give runoff water time to deposit soil sediments and infiltrate.

A first comparison made between the hedgerow in the H-M and the grass strip in G-M plots figs. (4.7 and 4.8) shows that the grass strip was somewhat more effective in the control of soil erosion than the hedgerow and this may be attributed to the compactness and thickness of the grass strip which trapped more soil as compared to the thinner and appreciably less dense senna hedgerow. Soil loss in the C plot (9.7 t ha^{-1}) exceeded T = 5 t ha^{-1}, which further points to the need for soil erosion control structures in this area.

As for the runoff control, the mulch and hedgerow in the H+M had 4.5 times less runoff compared to the control, (1.8 mm against 8.4 mm) fig.(4. 8). The grass strip barrier in the G-M plot had only 2 times less runoff. The mulch in the +M and hedgerow in the H-M plots followed with about 1.5 times less runoff than the C plot respectively. The order of effectiveness in runoff control after H+M plot was therefore G-M > +M > H-M (or 4.8 mm, 5.6 mm and in 5.8 mm respectively). On the whole, however, the maximum percentage of rain lost as runoff was only 3.5% of the total rainfall in the season.

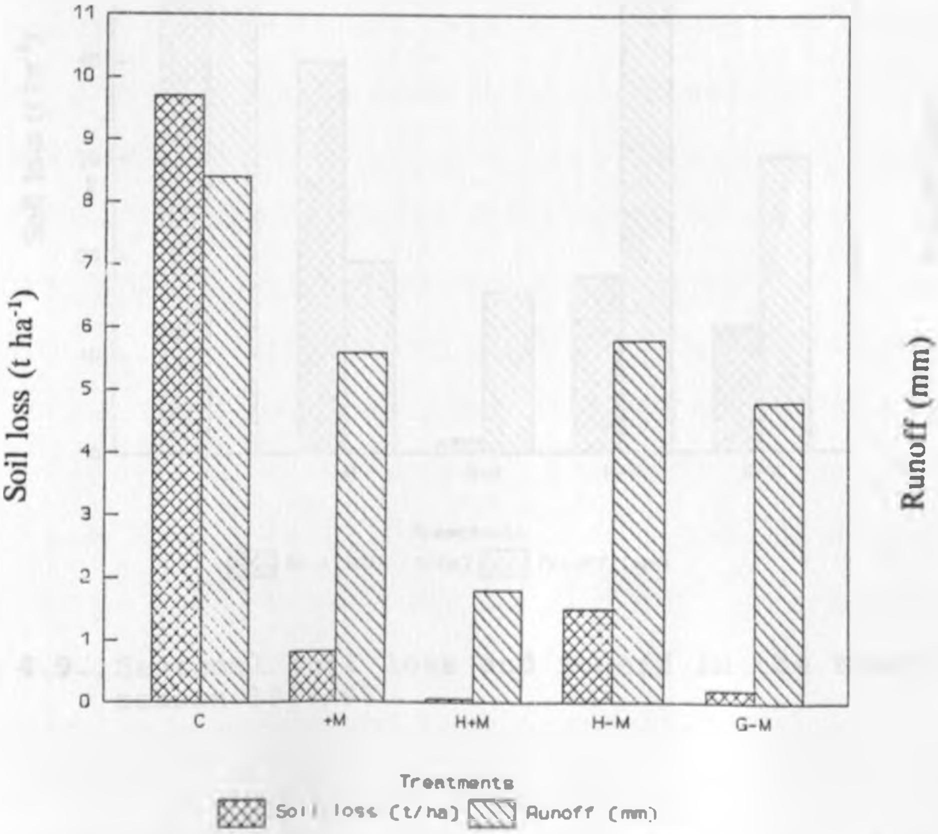


Figure 4.8. Seasonal soil loss and runoff for the long rainy season 1994.

4.3.3 Runoff and soil loss in the short rains 94/95.

During this season, mulch rates of 1.3 t ha^{-1} were applied on the +M and H+M plots before planting. The results in fig. (4.9) show that the H+M with more than 40 times less soil loss (1.4 t ha^{-1}) was most effective in the control of soil erosion compared to the C plot (60.7 t ha^{-1}).

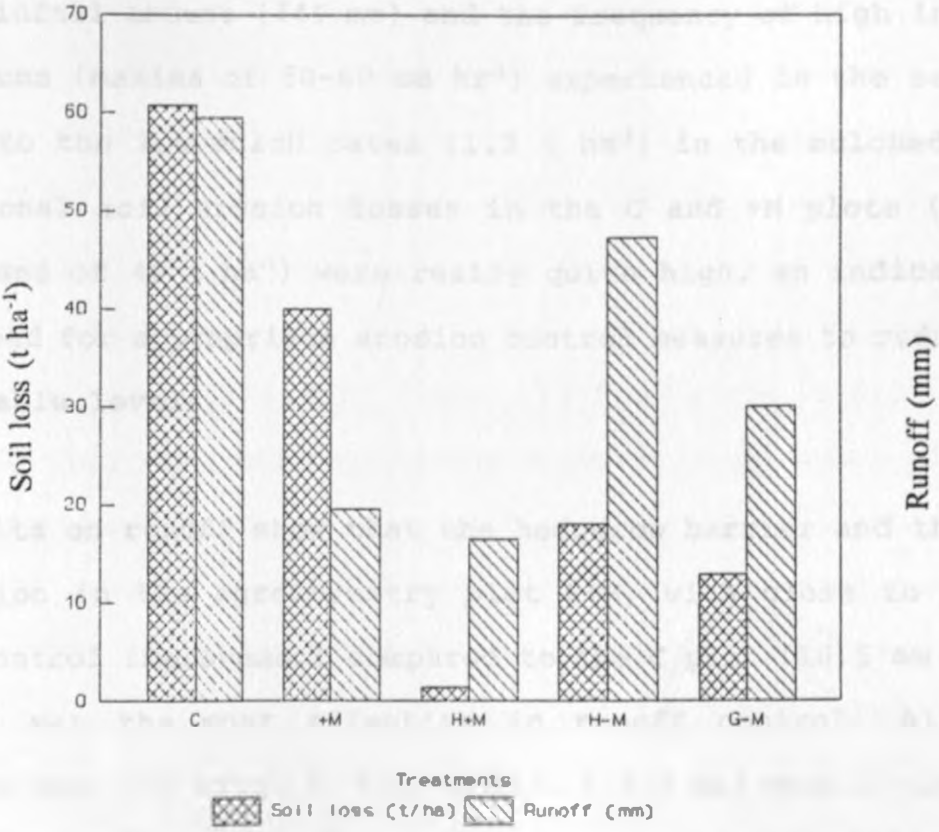


Figure 4.9. Seasonal soil loss and runoff in the short rainy season 1994/95.

The grass barrier in the G-M plot had a bit less than 5 times, the barrier in the H-M plot had abit less than 3.5 times and the mulch in the +M plot had 1.5 times less soil loss (respectively 12.9 t ha

^{1}, 18 t ha^{-1} and 40 t ha^{-1}) compared to the C plot. respectively. It is evident that the grass strip in G-M was superior to the mulch in the +M plot and slightly superior to the hedgerow in the H-M plot in the control of soil erosion. On the whole, however, it was only the mulch and hedgerow barrier in the H+M plot which reduced soil erosion to below the T value of 5 t ha^{-1}, while the other control structures, including mulch, grass strip and hedgerow had values above this T value and hence were not sufficiently effective in the control of runoff during this season. This was due to the high total rainfall amount (549 mm) and the frequency of high intensity rain storms (maxima of 50-60 mm hr^{-1}) experienced in the season as well as to the low mulch rates (1.3 t ha^{-1}) in the mulched plots. The seasonal soil erosion losses in the C and +M plots (of more than 60 and of 40 t ha^{-1}) were really quite high, an indication as to the need for appropriate erosion control measures to reduce them to tolerable levels.

The results on runoff show that the hedgerow barrier and the mulch combination in the agroforestry plot H+M, with close to 4 times runoff control improvement compared to the C plot (16.5 mm against 59.5 mm) was the most effective in runoff control. Also more effective were the mulch in the +M plot (19.5 mm) with 3 times, the grass strip in the G-M plot (30 mm) with 2 times and lastly the hedgerow barrier in H-M plot (47.3 mm) with only slight runoff improvement compared to the C plot respectively. These effects are small for G-M and lower values but in line with grass strips of 1.5m width having been found relatively effective in soil erosion and runoff control (Fissiha, 1983).

At the same time, the results show that a rather large 11% and 9% of the high total rainfall in the season were lost as runoff in the C and H-M plots respectively. The mulch rate of 1.3 t ha^{-1} as quite low, because of the low rainfall in the previous 1994 long rainy season. This may explain the ineffectiveness of the mulches in the control of erosion during this short rainy season. During the season there were several rain storms with high rainfall intensities (48-60 mm h^{-1}) and these must be particularly responsible for the high rates of runoff and soil erosion in this season, as rainfall amount and intensity are correlated with rainfall erosivity (Elwell and Stocking, 1982). The low intensity rainfall storms, of the order of 10 mm h^{-1}, rarely caused soil erosion. This is in agreement with what has been experienced earlier in East Africa, that although tropical rain is more erosive in general than temperate rain, little or no erosion occurs with rainfall of low intensity (Ahn, 1975). Kiepe (1995) further confirmed that soil erosion in the tropics is by a few heavy rain storms. It should further be noted here that the soil erosion rates and runoff amounts in this season are also rather high because the cowpea plant was infected with a disease at some stages in its development, which reduced the canopy available for raindrop impact interception.

4.3.4 Runoff and soil loss long rains 1995.

For this season, mulch rates of 2 t ha^{-1} were applied to the +M and H+M plots two weeks before planting. The results in fig. (4.10) show that the mulch and hedgerow barrier in the H+M plot, with more than 300 times less soil loss (0.1 t ha^{-1}) compared to the C plot (32.9 t ha^{-1}) was the most effective in the control of soil erosion.

The grass strip barrier in the G-M plot and the mulch in the +M plot (2 t ha^{-1}) improved soil loss control both by more than 15 times, and the hedgerow in the H-M plot (13.3 t ha^{-1}) by 2.5 times compared to the control respectively. The mulch in the +M and the grass strip barrier in the G-M plot appear to tie in their effectiveness for erosion control. The hedgerow was rather weak as a barrier for erosion control. This could be attributed to the observed absence of compactness in the hedgerow barrier compared to the grass strip. Indeed, the hedgerow barrier had soil erosion in excess of the T value for the region.

As for the runoff control, the H+M (1.3 mm) was more than 15 times better compared to the C plot (20.5 mm) and as before acted as the most effective water loss control structure. The grass strip in the G-M plot (9.3 mm) and the mulch in the +M plot (9.6 mm) showed more than 2 times improvement in runoff control compared to the C plot. The H-M plot (18.2 mm) lost almost twice the runoff lost in the G-M plot and was therefore close to the C plot. The plots which were more effective in the control of runoff were indeed equally more effective in the control of soil erosion, as earlier found in the 1994 season. The highest percentages of rainfall lost as runoff were 7% and 6% in the C and H-M plots respectively, and this was relatively high as the season was just about average. Several storms had high intensity rainfall, ranging from 30-60 mm h^{-1}, which accounted for most of the soil loss and runoff in the treatments in this season. In particular, 90% of the soil sediments were lost in a single storm of almost 57 mm, which occurred on the 35th day after the onset of the rainy season, which appears to be in a risky period for all seasons, (Table 1).

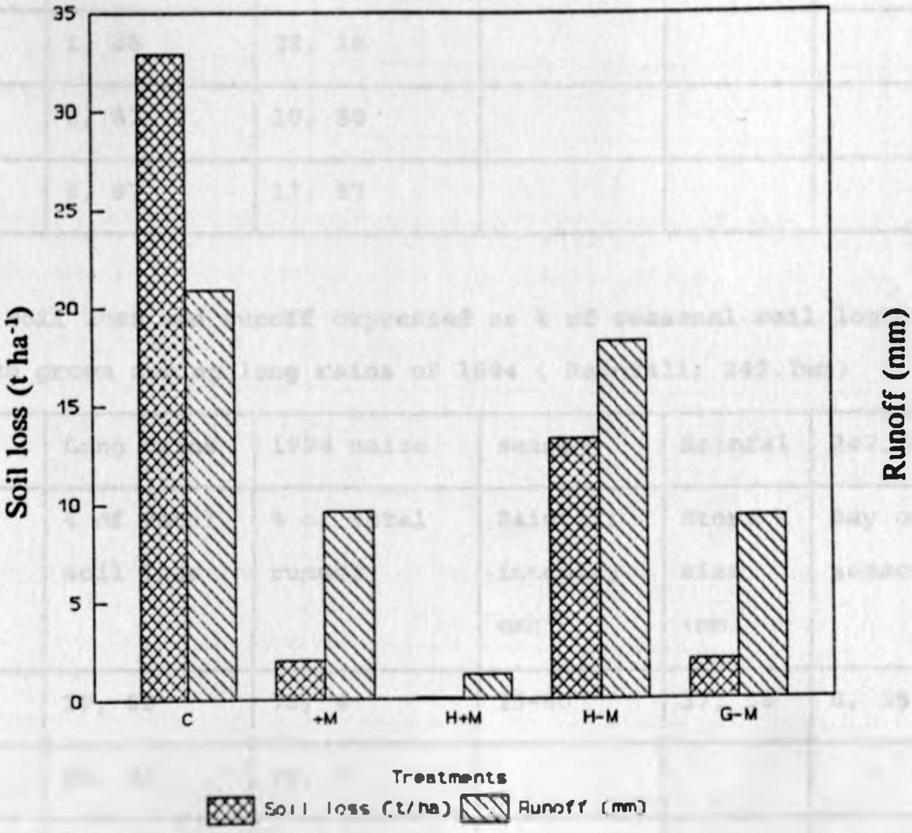


Figure 4.10. Seasonal soil loss and runoff in the long rainy season 1995.

Table 1a. % Soil loss and runoff expressed as % of seasonal soil loss and runoff. Cowpea grown during the short rains of 93/94. (Rainfall:288)

Treatment	% of total soil loss	% of total runoff	Rainfall intesity mmh^{-1}	Storm size (mm)	Day of season
C	31, 31	44, 34	24-48	48, 23	35, 36
+M	49, 33	22, 51			
H+M	1, 88	22, 18			
H-M	3, 87	10, 80			
G-M	8, 87	17, 57			

Table 1b. % Soil loss and runoff expressed as % of seasonal soil loss and runoff. Maize grown during long rains of 1994 (Rainfall: 242.2mm)

Table 1b	Long rains	1994 maize	season	Rainfal	242.2mm
Treatment	% of total soil loss	% of total runoff	Rainfall intesity mmh^{-1}	Storm size (mm)	Day of season
C	29, 68	78, 4	25-60	37, 56	6, 35
+M	45, 31	79, 3			
H+M	1, 46	66, 14			
H-M	1, > 90	23, 31			
G-M	39, 20	33, 17			

Table 1c. % Soil loss and runoff expressed as % of seasonal soil loss and runoff. Cowpea grown during the short rains of 94/95 (Rainfall: 549mm)

Treatment	% of total soil loss	% of total runoff	Rainfall intesity mmh^{-1}	Storm size (mm)	Day of season
C	31, 49	31, 32	50-60	77, 61	30&35
+M	28, 60	30, 44			
H+M	13, 75	19, 72			
H-M	42, 36	30, 33			
G-M	18, 66	32, 28			

Table 1d. % Soil loss and runoff expressed as % of seasonal soil loss and runoff. Maize long rains of 1995 (Rainfall: 285mm)

	1995 long	rains maize	season	Rainfall	285mm
Treatment	% of total soil loss	% of total runoff	Rainfall intesity mmh^{-1}	Storm size (mm)	Day of season
C	90	69	60	57	35
+M	93	87			
H+M	87	80			
H-M	90	75			
G-M	96	86			

In tables 1a, 1b, 1c and 1d, columns two and three show the proportion of soil and runoff losses expressed as a percentage of the total soil and runoff for the season. The fourth column in these tables shows the range of rainfall intensity which produced the runoff and soil loss portions as a percentage of the total runoff and soil loss in columns two and three. Column six shows the day of the season when the rainstorm occurred. The size of the rain storms in column five emphasise the usefulness of only a few storms in the seasons responsible for high proportions of soil loss and runoff respectively.

4.4. Mulch and crop cover.

The results for the seasons short rains 92/93, long rains 1993, short rains 93/94, long rains 1994, short rains 1994/95 and long rains 1995 on percent crop/mulch and hedgerow cover are presented and discussed. The mulch rates used in the +M and H+M plots for the six seasons were 1.90 and 1.89, 1.80 and 1.65, 2.4 and 2.35, 1.9 and 1.93, 1.2 and 1.3 and 2.01 and 1.96 t ha^{-1} respectively. The differences in the same were due to variations in the previous seasons' rainfall as well as powdery mildew effects on the Senna leaves which to a certain extent also affected the mulch output.

4.4.1. Mulch and crop cover for 92/93 short rains cowpea season.

Fig. (4.11) shows both the percent crop/mulch cover for the season in the C, +M, H+M, and H-M plots as from 12 to 65 DAS. At 12 DAS, the mulch cover in the +M and H+M plots of about 35 and 36 %, combined with the 15 and 9 % crop cover respectively, provided a combined cover of 50% and 45 % respectively, which may be supposed to be sufficient soil cover (Stocking,1988) against erosion by both rain drop impact interception and runoff water impedance fig.(4.11.). This was not the case for the H-M plot, where the initial poor crop cover was poorly intercepting rain drop impacts and runoff impedance was only provided by the hedgerow barrier. The

C plot was the only plot where the form of protection against rain drop impact was only by the poorly developed crop cover, but with no other protection against runoff erosion.

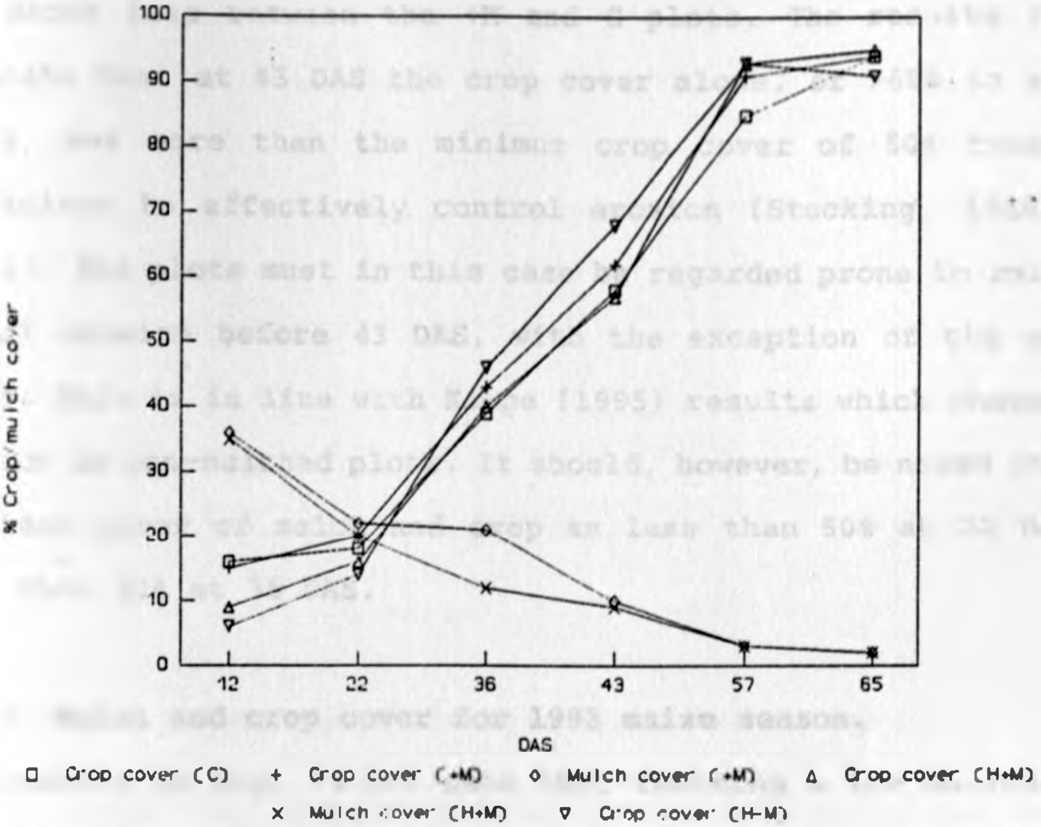


Figure 4.11. Crop/mulch cover (%) for cowpea, short rains 1992/93.

As most data in figs. (4.1-6) and tables 1 and 2 in this study confirm, many of the erosive rain storms occur during the first five to six weeks of the rainy season (Moore, 1978), when soil is bare or vegetation cover is low, stressing the importance of providing means to reduce the risk of soil erosion.

The results also show that at 36 DAS the crop had established only around 40% cover and had not attained the 50% cover that has been considered sufficient to protect the soil against rain drop impact (Stocking, 1988). The mulch cover was decomposing with time and although it was just below the optimal 2-4 t ha^{-1} (Lal, 1976b), it particularly accounts for the differences obtained in soil erosion and water loss between the +M and C plots. The results further indicate that at 43 DAS the crop cover alone, of >60% in all the plots, was more than the minimum crop cover of 50% considered sufficient to effectively control erosion (Stocking, 1988) fig. (4.11). The plots must in this case be regarded prone to rain drop impact erosion before 43 DAS, with the exception of the mulched plots. This is in line with Kiepe (1995) results which showed high erosion in non-mulched plots. It should, however, be noted that the combined cover of mulch and crop as less than 50% at 22 DAS but more than 50% at 36 DAS.

4.4.2. Mulch and crop cover for 1993 maize season.

The results in fig. (4.12) show that reaching a low maximum crop cover development in C and +M took some time because of lack of moisture for most of the season. This resulted in very poor crop cover in all the plots. Such poor crop cover is insufficient to intercept rain drop impact and reduce risk to soil erosion early in the season, when other ground cover is very poor.

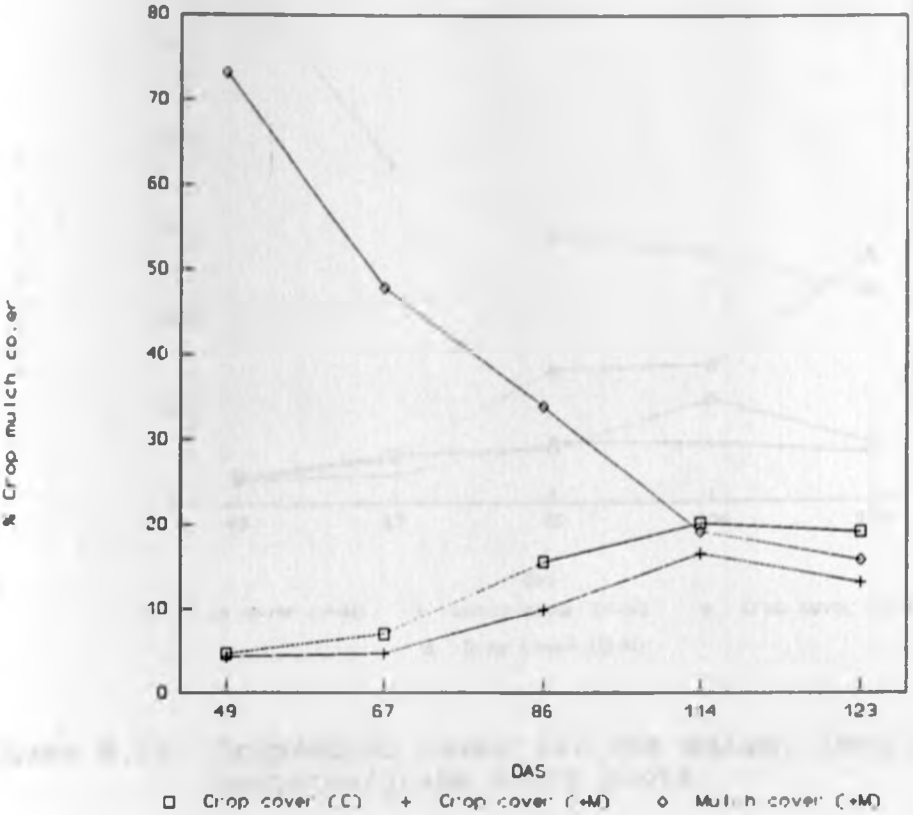


Figure 4.12. Crop/mulch cover (%) for maize, long rains, C and +M plots.

There were relatively low rates of mulch (1.8 and 1.65 t ha^{-1}) in H+M and +M already at the beginning of the season figs. (4.12 and 4.13). Most of it remained undecomposed at the end of the season, due to lack of sufficient moisture to activate decomposition, and decreasing cover was due to termite activity and wind blow. Even the best crop cover (not including the grass strip cover) in the G-M plot fig. (4.13) remained below 30% at their peak, because of drought. There were no runoff/soil loss data for this season.

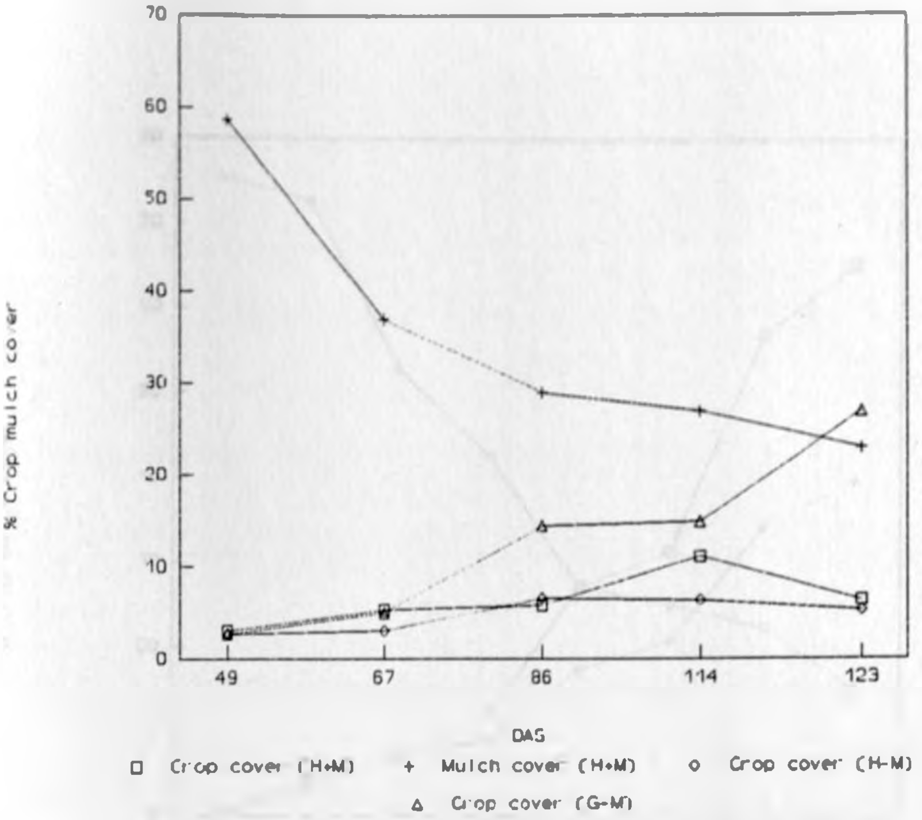


Figure 4.13. Crop/mulch cover (%) for maize, long rains 1993, hedgerow/grass strip plots.

4.4.3. Mulch, crop and hedgerow cover for 93/94 short rains cowpea season.

From this season up to the long rains of 1995, % cover by the hedgerows and grass strips with respect to the areas they occupied on the plots were also monitored.

The results in figs. (4.14 and 4.15) show that there was sufficient % mulch cover in the +M and H+M plots (> 50%) at planting to protect the soil against appreciable soil particle removal by rain drop impact and transportation by runoff, thus reducing soil erosion.

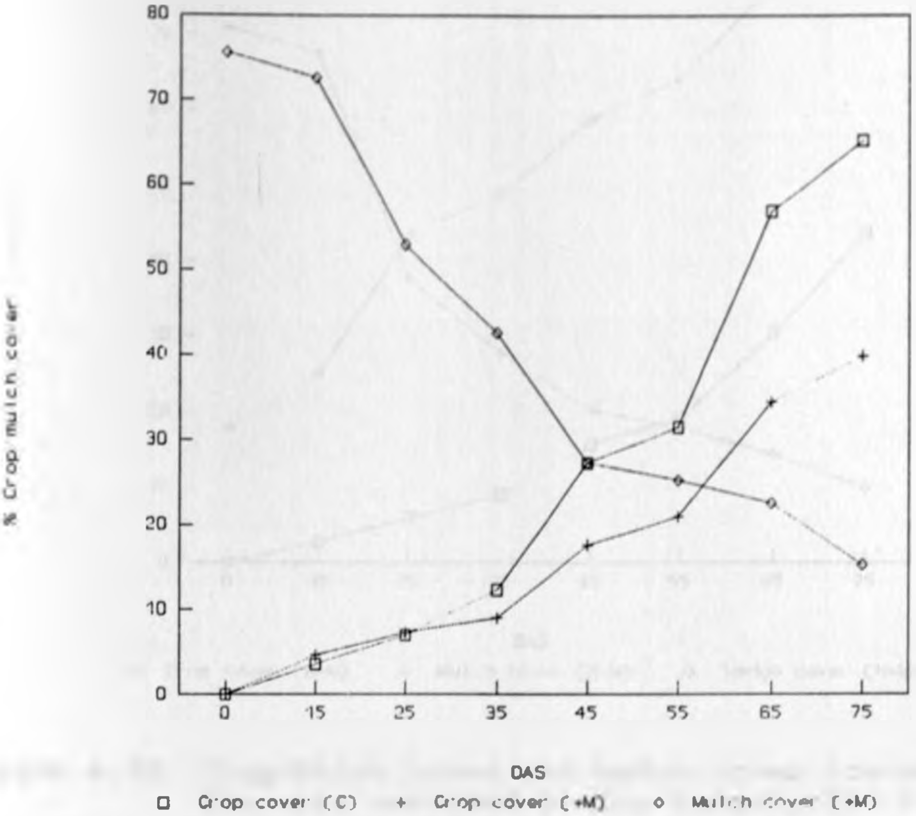


Figure 4.14. Crop/mulch cover (%) for cowpea, short rains 1993/94, control and +M plots.

The results also show that one month after emergence (about 35 DAS), the crop had only reached just over 10% cover at maximum while mulch cover had gone down to 40% through decomposition and termite activity. This shows that crop cover alone was insufficient for erosion control and hence the need for mulch cover to supplement this insufficiency, particularly at the earlier part of the season.

Because of the absence of mulch, the C, H-M and G-M plots figs.

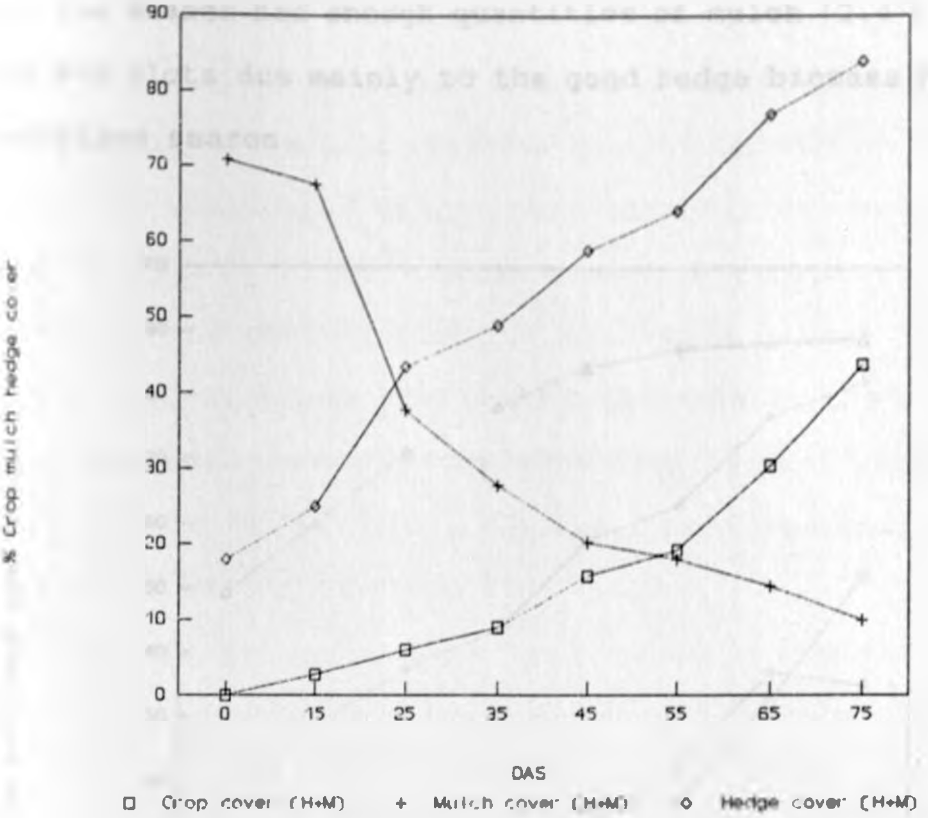


Figure 4.15. Crop/mulch cover and hedge cover (relative to the area occupied by the hedge), in (%) for short rains 1993/94, for H+M, for cowpeas.

(4.14 and 4.16) were particularly prone to erosion. This is also shown in table 2. The crop cover in the season for +M, H+M, H-M and G-M plots remained low, apart from the control, and was even still <40% at two weeks before harvest figs. (4.14, 4.15 and 4.16). The crop cover at the control had actually reached about 60% two weeks before harvesting fig. (4.14). The cover provided by the hedgerows and grass strips with respect to the area they occupy in the plots is still small and most of the cover was from the crop in the H-M and G-M plots respectively. Hence raindrop impact interception was mostly by the crop cover. It was the hedgerow barrier and grass strip barrier effect that controlled erosion by runoff in the H-M and G-M plots, but there was little erosion control via their cover. The season had enough quantities of mulch (2.4 t ha^{-1}) in the +M and H+M plots due mainly to the good hedge biomass harvest from the previous season.

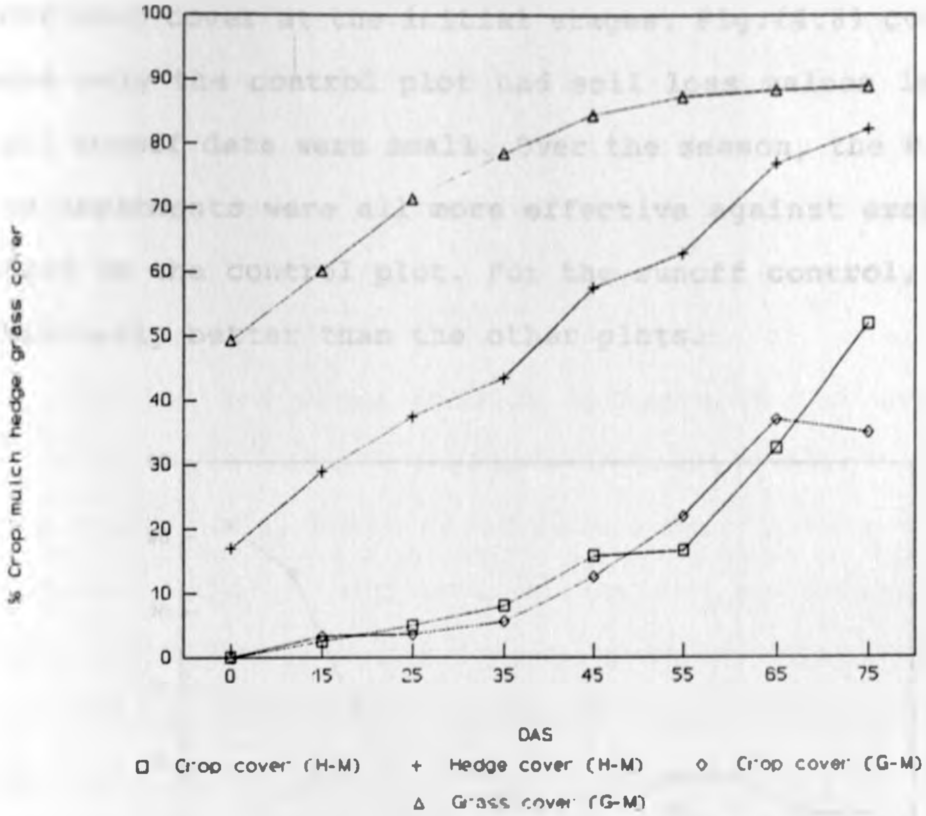


Figure 4.16. Crop cover, hedge cover (relative to the area occupied by the hedges) in the H-M plot and grass cover relative to the area occupied by the grass strip), in % in the G-M plot. Short rains 1993/94, cowpeas.

4.4.4. Mulch, crop and hedgerow cover for long rains 1994 maize season.

Figs. (4.17 and 4.18) show that the mulch covers at planting in the +M and H+M plots were just over 80% and 70% respectively, and could therefore be considered effective in the control of erosion even without crop cover at the initial stages. Fig.(4.8) confirms this, because only the control plot had soil loss values larger than T and all runoff data were small. Over the season, the H+M, H-M, G-M and +M treatments were all more effective against erosion control compared to the control plot. For the runoff control, the H+M was substantially better than the other plots.

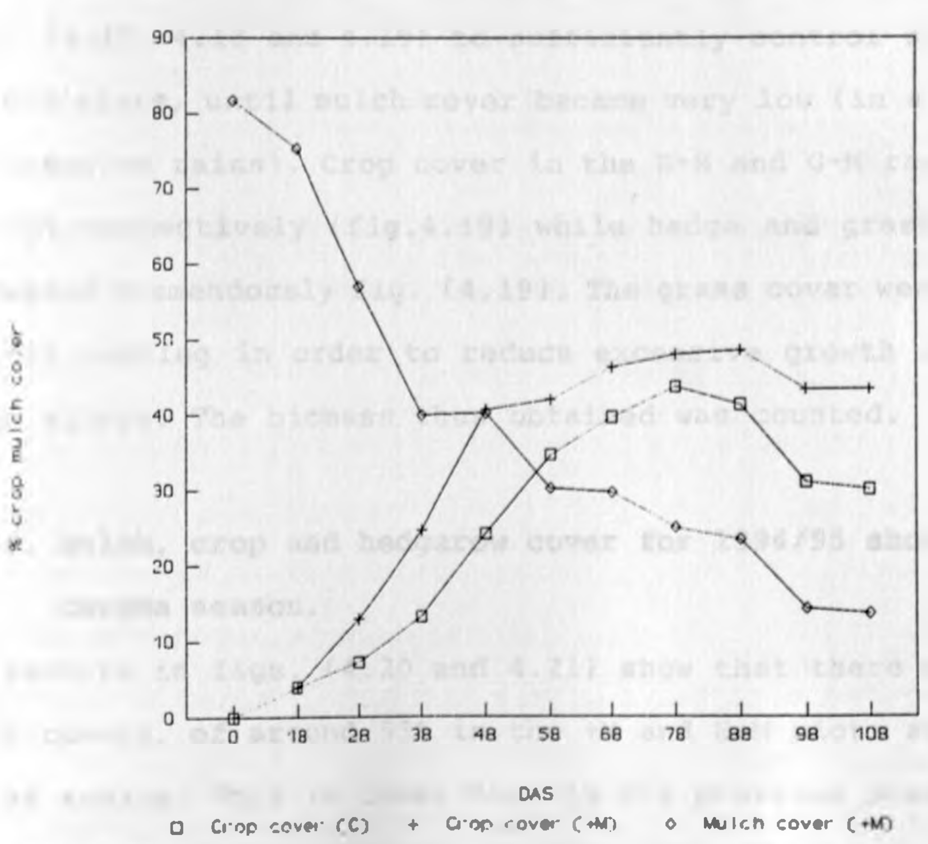


Figure 4.17. Crop/mulch cover (%) for maize, long rains 1994, for C and +M plots.

By 28 DAS fig. (4.17) shows that crop cover development had only reached 13% in the +M plot. This crop cover in +M had reached 40%, which is below the 50% cover considered about adequate for effective erosion control, by 48 DAS, as compared to 16-26% in other plots figs. (4.17-4.19). At this time also mulch cover in the +M and H+M had gone as low as 40% and 26% respectively figs. (4.17 and 4.18). There was additional cover provided by the hedge in the H+M plot, which was also the case for H-M and G-M plots figs. (4.18 and 4.19) respectively throughout the crop growth period, but of course only near the hedgerows. Although crop cover development was quite variable in all the plots, there was, of course except for the C, H-M and G-M plots, enough joined cover of crop and mulch figs. (4.17, 4.18 and 4.19) to sufficiently control erosion in +M and H+M plots, until mulch cover became very low (in a period with no intensive rains). Crop cover in the H-M and G-M remained at 25 and 30% respectively (fig.4.19) while hedge and grass covers had increased tremendously fig. (4.19). The grass cover went down at 48 DAS via cutting in order to reduce excessive growth in the grass strip alleys. The biomass thus obtained was counted.

4.4.5. Mulch, crop and hedgerow cover for 1994/95 short rains cowpea season.

The results in figs. (4.20 and 4.21) show that there were low mulch covers, of around 55% in the +M and H+M plots at the start of the season. This is lower than in the previous season because the rain was below average in the long rains of 1994, which affected the Senna hedgerows where the mulch loppings were obtained. These figures and fig. 4.22 show also that the crop cover had a maximum near 35% (H+M; C) but was also as low as near 10% (H-

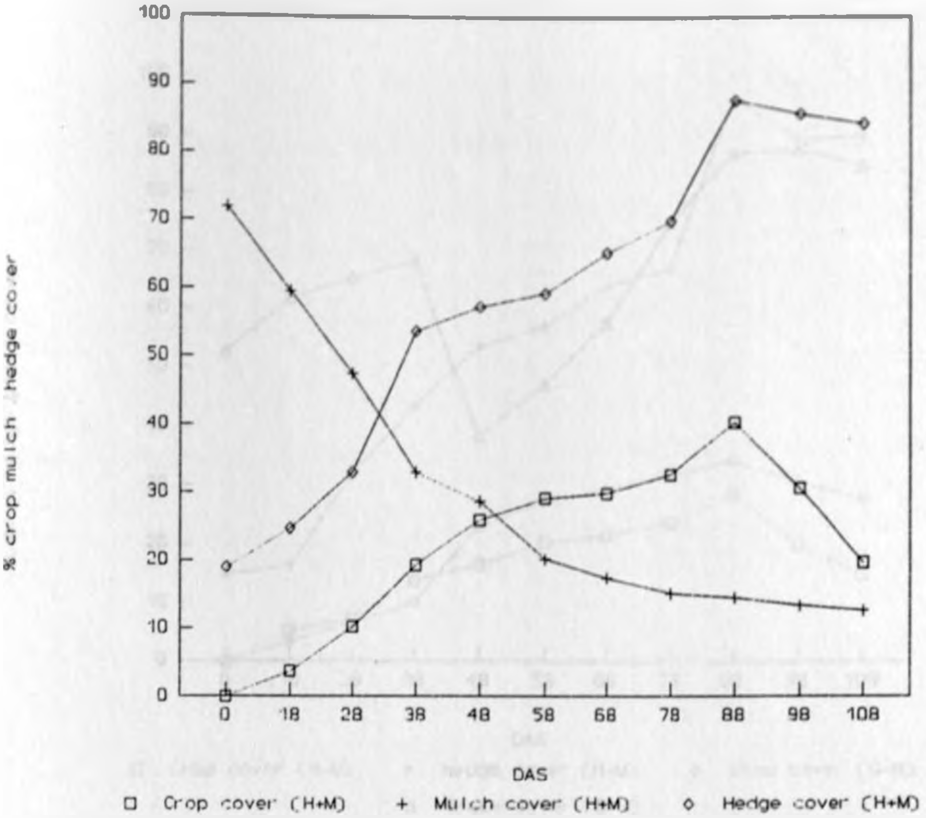


Figure 4.18. Crop/mulch and hedge cover (relative to the area occupied by the hedge), in (%), for maize long rains 1994, for H+M plot.

M; by 36 DAS and mulch cover had gone as low as about 30 and 25% in the +M and H+M plots respectively. This was an indication that crop cover alone was at this stage not sufficient for effective erosion control, but together with the mulch it was. This is also shown and confirmed in table 2. The cover by the hedge in H+M as well as H-M and by the grass in G-M, relative to the hedge and the grass area, had however reached 50, 43 and 87 respectively at 36 DAS. By 56 DAS, for C and +M as well as, by 66 DAS for H+M, crop cover alone had adequately developed to provide sufficient cover for erosion control, but the H-M cover only reached about 40% while the G-M plot remained below 40% cover (fig. 4.22) due to stunted crop

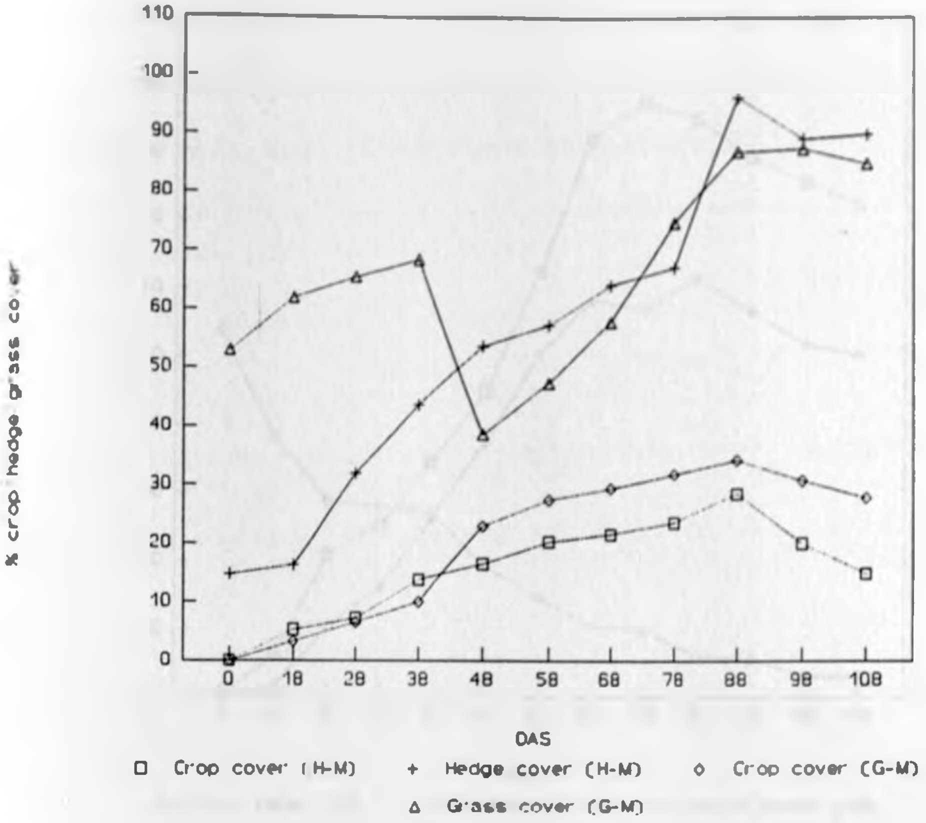


Figure 4.19. Crop cover, hedge cover (relative to the area occupied by the hedge, in the H-M plot and grass cover (relative to the area occupied by the grass strip) in the G-M plot, in (%), long rains 1994, maize.

growth. The mulch cover was quite low at this stage of crop development, mainly due to decomposition and termite activity. The crop cover in the sampled areas was not representative of the diseased parts of the plot and so runoff and soil loss may have been larger than would be expected based on the crop cover figures alone. The hedgerows and grass strip barriers were however fully established figs. (4.21 and 4.22) for the control of runoff.

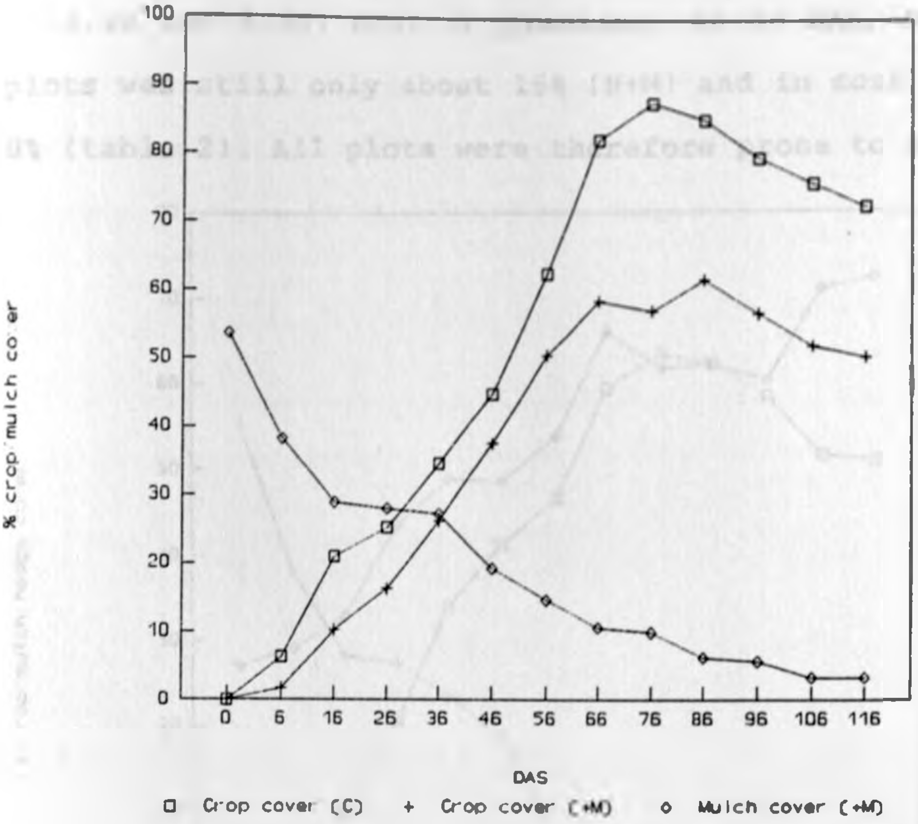


Figure 4.20. Crop/mulch cover (%) for cowpea, short rains 1994/95, control and +M plots.

4.4.6. Mulch, crop and hedgerow cover for 1995 long rains maize season.

Figs. (4.23 and 4.24) show that initial mulch cover in the H+M and +M plots were near 80 and over 90 % respectively, which was sufficient to protect the soil against rain drop impact when crop cover was nil at planting. There was some additional cover (relative to the area occupied by the hedges) by the hedges in the H+M and H-M plots, while there was even more cover (relative to the area occupied by the grass strip) by the grass in the G-M plot figs. (4.24 and 4.25) also at planting. At 58 DAS, crop cover in all plots was still only about 15% (H+M) and in most cases closer to 10% (table 2). All plots were therefore prone to soil erosion risk, except +M and H+M plots, where there was additional mulch cover, together always more than 50%. This proves again the need for the mulch provided by the agroforestry plots for erosion control. Figures 4.23, 4.24 and 4.25) show that although initially there remained still variations in crop cover development and crop cover was rather low, the situation had improved at 78-88 DAS, when crop cover in all plots was over 50% (for H+M and H-M) and 60% for the others respectively, crop cover alone now being effective in

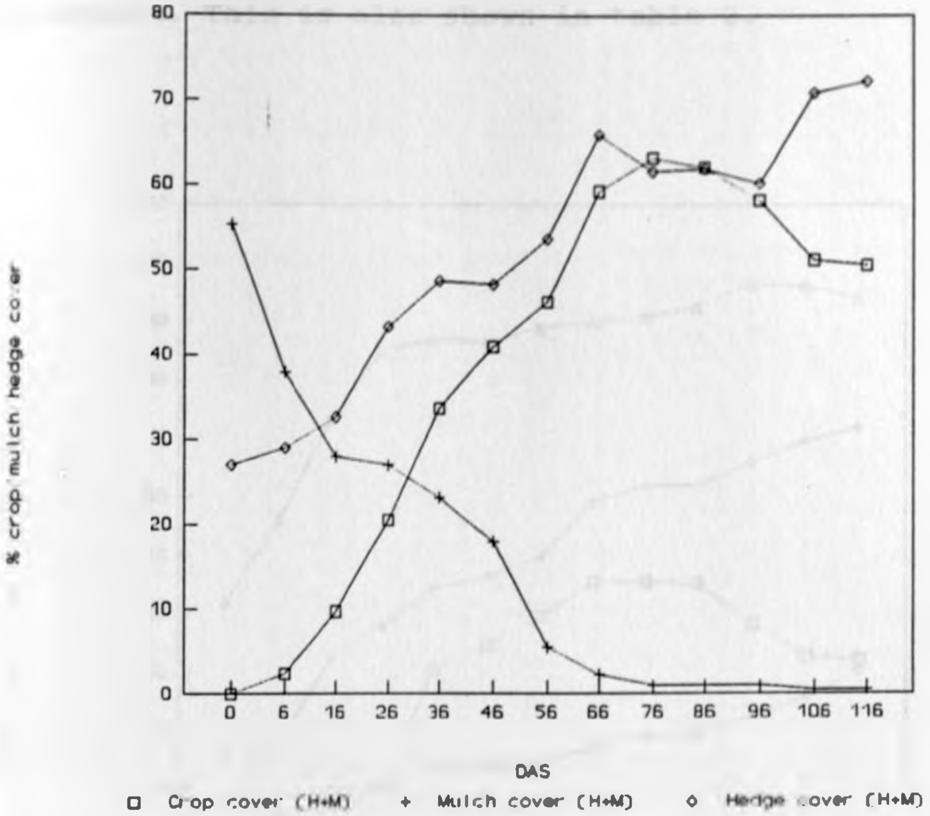


Figure 4.21. Crop/mulch cover and hedge cover (relative to the area occupied by the hedge), in % for cowpea, short rains 1994/95, for H+M plot.

erosion control. Because of the slow cover development in the maize crop, it is likely that in the non-mulched plots the risk of erosion was initially high, and especially during the rain storms of the first four to five weeks (Table 1), during crop establishment. This is also shown in table 2.

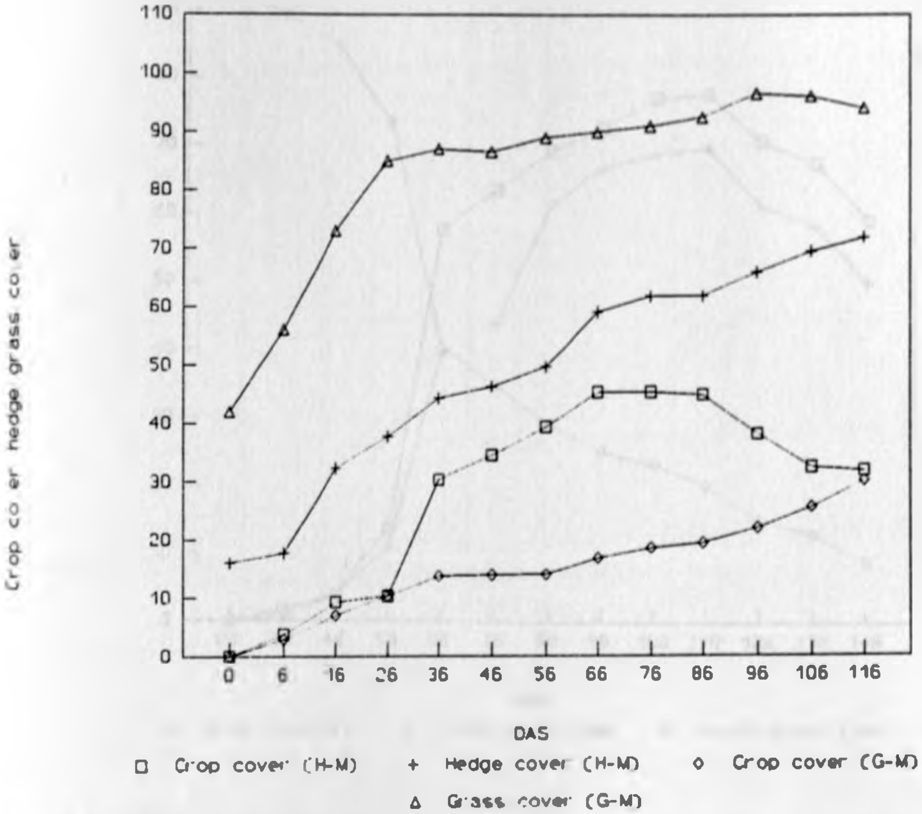


Figure 4.22. Crop cover, hedge cover (relative to the area occupied by the hedge) in the H-M plot and grass cover (relative to the area occupied by the grass strip) in the G-M plot, in % for cowpea, short rains 1994/95.

On the whole, however, the mulch cover in the six seasons, though most often below the optimal 2-4 t ha^{-1}, did help in the interception of rain drop impact, impedance of runoff and hence reduction of erosion. The mulched plots for the short rains 1994/95 (fig. 4.9) are an exception to this rule, which may be due to the cowpea disease that may not have been representatively measured in the crop cover of fig (4.20). See also section (4.10.5).

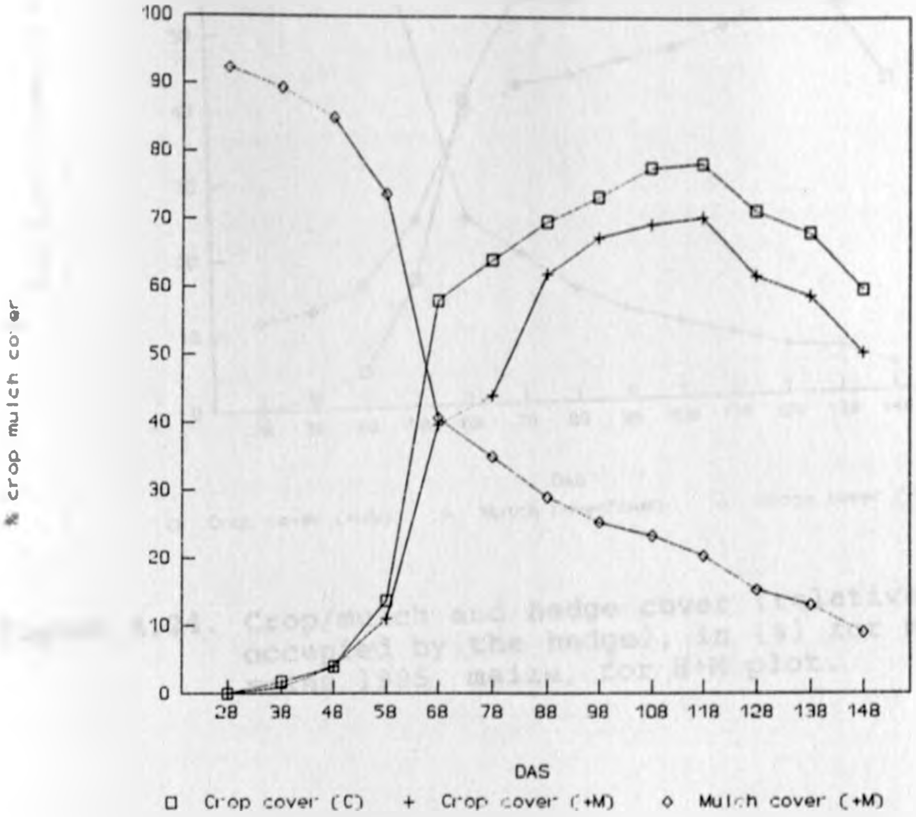


Figure 4.23. Crop/mulch cover (%) for maize, long rains 1995.

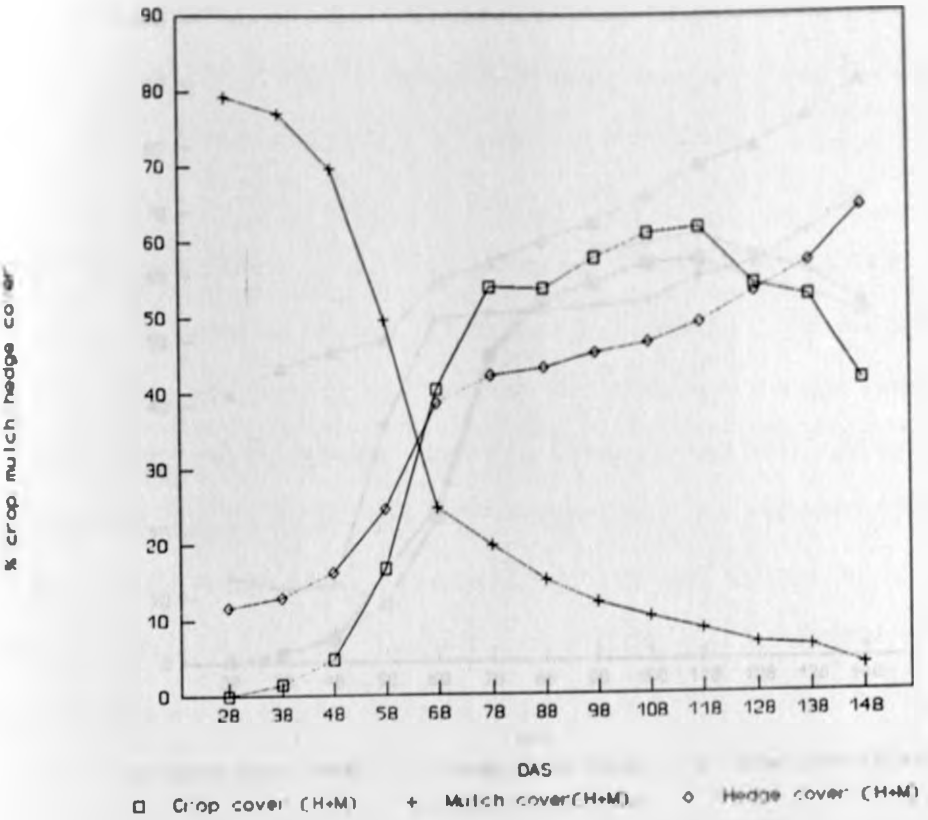


Figure 4.24. Crop/mulch and hedge cover (relative to the area occupied by the hedge), in (%) for maize. long rains 1995, maize, for H+M plot.

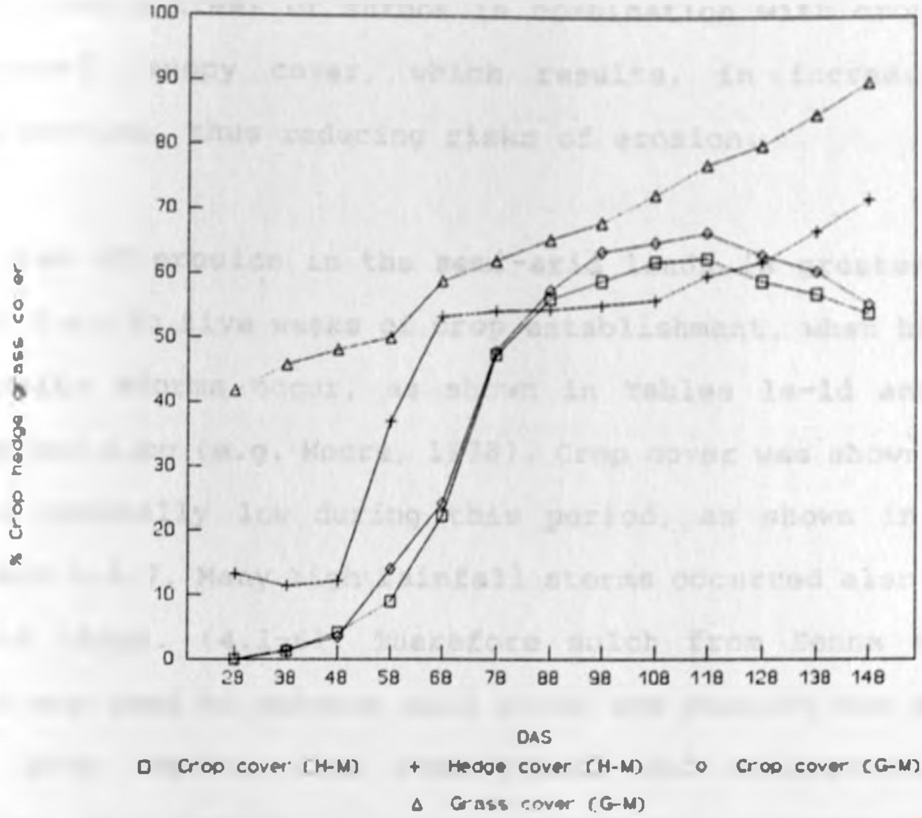


Figure 4.25. Crop, hedge (relative to the area occupied by the hedge) in H-M plot and grass cover (relative to the area occupied by the grass strip) in the G-M plot, in %. Long rains 1995, maize.

4.4.7. Additional summarising discussion.

The role of vegetation cover in the interception of rainfall kinetic energies for erosion control has been stressed by many researchers (e.g Elwell and Stocking, 1976). The basis for erosion control through vegetation cover is based on the fact that there is a curvilinear relationship between soil loss and percentage vegetation cover and that erosion is little different whether cover is 100% or 60% (Elwell, 1980; Elwell and Stocking (1974). This relationship is also true for cover and runoff (Elwell and Stocking 1976, Lang, 1979). As mentioned in section 2.4, in agroforestry trees or shrubs in combination with crops result in increased canopy cover, which results, in increased raindrop interception, thus reducing risks of erosion.

The risk of erosion in the semi-arid lands is greater during the first four to five weeks of crop establishment, when high rainfall intensity storms occur, as shown in Tables 1a-1d and 2 in this study see also (e.g. Moore, 1978). Crop cover was shown in our case to be generally low during this period, as shown in Table 2 in section 4.4.7. Many high rainfall storms occurred also during this period (figs. (4.1-6). Therefore mulch from Senna agroforestry plots was used to enhance soil cover and cushion the soil against rain drop impact, slow down runoff and consequently minimise erosion. This provided the protection before the crop reached about 50% cover necessary for effective erosion control "on its own" and is an indicator as to how important agroforestry is in soil erosion control. The level of % cover effective for erosion control is important in soil conservation research and planning and in reaching realistic cover management objectives in the semi-arid areas of Kenya. The use of manure and fertilizers for instance enhances a crop's ability to grow fast and reach early the required crop cover for effective erosion control. In their absence, additional protective cover, which can be obtained from mulch from agroforestry tree species, is then the more necessary in low external input agriculture if soil erosion is to be minimised to tolerable levels. Although the main aim of the hedgerows and grass strip barriers was erosion control by runoff control, there were some additional % canopy cover benefits derived from the hedgerows and grass strips respectively.

The crop cover of 50% advocated in Stocking (1988) has been obtained from well managed crops, on experimental plots in research stations, on soils that are uneroded and with optimum plant density. The results in Table 2 from this study show a situation where no fertilizer was used and where competition for water and nutrients as well as diseases (in cowpea) constrain crop cover development. This author further argues that there is a problem of erosion control using vegetation cover, for it requires continuous sensitive and knowledgeable management of both the soil and the crop to be fully effective. In fact, whenever vegetation cover is maintained at the level of 50-60% but varying according to type of cover and soil, the interactive processes between the soil and the plant are sufficient to cope with erosive forces. However, most crop cover barely reached 30% in the first month of crop development (Table 2), when rainfall intensity was high (Tables 1a, 1b, 1c and 1d), demanding the use of mulches (Table 2) obtained from the hedgerows to cushion the soil against raindrop impact and reduce flow speeds. The low crop cover over the seasons occurred at optimal plant populations and it is therefore unlikely that this situation will be any better outside the research station. Maize and cowpea are row crops and they take time to show increased cover and therefore better erosion control has to be achieved by other means. To do this through the use of mulches combined with hedgerows was successful in most cases but depended on mulch availability from the growth of a previous year.

When the rainfall amount and intensity, mulch cover percent and mulching rate and crop cover development are integrated, it may be possible to explain the relative erosion rates in different seasons. In the 93/94 season, for instance, the erosion rate was low because of within average mulch rate (2.4 t ha^{-1}), average initial mulch cover of >70% in figs. (4.14 & 4.15), when crop cover was low, average rainfall (288 mm) of medium maximum intensities (10-50 mm h^{-1}) within the first month, reaching maximum intensity in the second month of rainfall of 50 mm h^{-1}, when cover had established. This produced only 2.6 t ha^{-1} per season and only 10 mm of runoff fig. (4.7). In this season, the two characteristic high storm (Table 1a, 48 and 23 mm), and high intensity rainfalls produced over 60% of the total soil loss in all the plots in the season as well as over 70% of the total seasonal runoff in the C, +M, H-M and G-M plots (see Table 1a). Crop cover though still low was higher at 55 DAS than in the first month of the rains (Table 2).

Table 2. Comparisons of three different dates of crop cover and mulch cover (in %) for four seasons. Cowpea and maize were grown in the short and long rains respectively.

year	DAS	C	+M	H+M	H-M	G-M
93/94						
	35	12	9(42)	9(27)	8	6
	55	32	21(25)	19(18)	17	22
	75	65	40(15)	44(10)	52	35
1994						
	38	13	25(40)	19(33)	14	10
	58	35	42(30)	29(20)	20	28
	78	44	48(25)	33(15)	24	32
1994/95						
	36	35	26(27)	33(23)	30	14
	56	63	50(15)	46(6)	39	14
	76	88	57(10)	63(1)	45	18
1995						
	38	2	1(90)	2(77)	1	2
	58	14	11(73)	16(49)	9	14
	78	64	44(35)	54(20)	48	48

() = mulch cover.

When this is compared to 1994/95 cowpea season, there was only 55()32% mulch cover on average at planting, with 1.3 t ha^{-1} mulch rate, and crop cover development was low in the first month of the rains (figs. 4.20-4.22). Rainfall was well above average (549 mm) and with high storms (fig.4.5) with high intensities, of 50-60 mm h^{-1} (Table 1). This situation produced 61 t ha^{-1} of soil loss and 60 mm of runoff in the C plot (Fig.4.9) because the soil was poorly protected against raindrop impact and runoff water. Table 1c shows that there were two main rainstorms, of 50-60 mm hr^{-1} intensity which produced over 78% of the total soil loss and over 60% of the total runoff in all the plots in the season. These two storms occurred when crop cover was still low, at the end of the first (during the first) month of the rains, and the risk of soil erosion by rain drop impact high (Table 2). This clearly shows that it is only a few high intensity rainstorms that are responsible for soil erosion in the semi-arid areas of Eastern Kenya.

For the 1994 long rains season compared to the 1995 long rains season, they had slightly below and about average rainfall of 242.2 and 285 mmm respectively, with initially high mulch covers of >70-80% and 80->90%, respectively for mulch rates of about 2 t ha^{-1}, while both seasons had low crop covers (figs. 4.17 - 4.19 and 4.23 - 4.25). The rainfall characteristics for the two seasons were, however, different.

In 1994, two main rain storms of 37 mm and 56 mm of 25-40 and 50-60 mm h^{-1} rain intensities respectively. They were both occurring within the first five weeks of the rainy season (Table 1b) and accounted for more than 59% of the total soil loss in the season, for all the treatments except for the H+M plot where soil loss was less than 50% (Table 1b). These two rain storms also produced over 50% of the total runoff for the season in all the plots with plot C experiencing an overflow (Table 1b). The crop covers in both the 1st and 2nd months were less or only slightly more than 40%, with the mulch covers in the +M and H+M plots being less than or equal 40% (Table 2). In 1995 there was only one high rain storm, of 60 mm h^{-1} intensity, compared to the two rain storms of (25-60)mm h^{-1} rain intensity) in 1994 figs. (4. 4 and 4. 6). This difference in rainfall intensity (Tables 1b and 1d) accompanied by low vegetation cover (Table 2) was responsible for the higher erosion rate in C as well as the other plots in 1995 than in 1994. In both cases the addition of mulch reduced erosion rates, 10 and more than 15 times respectively (Figs.4.8 and 4.10). Adding hedgerow barrier reduced erosion to negligible amounts (Figs.4.8 and 4.10). For the 1995 rainy season, Table 2 shows that although the +M and H+M plots had mulch cover, the crop cover in all the plots was quite low in the second month of rainfall. At five weeks after the onset of rains, a single high intensity (60 mm h^{-1}) of 57 mm rain storm produced over 87% of the total soil loss and over 69% of the total runoff for the season, in all the plots, as shown in table 1d.

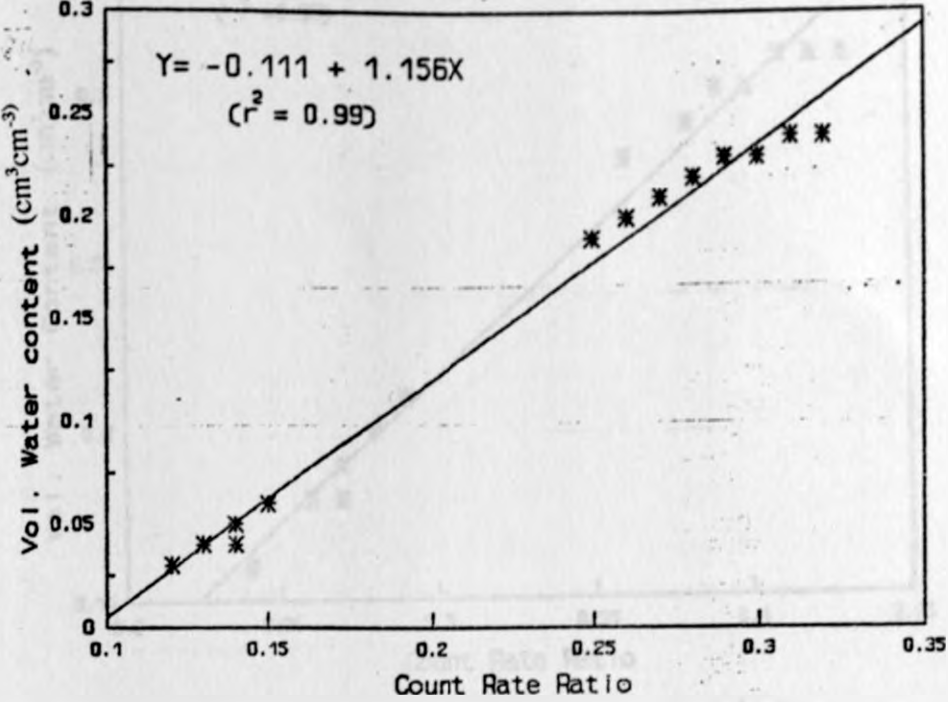
4.5. Soil moisture.

4.5.1 Neutron probe calibration.

The results for a composite calibration for both dry and wet field conditions for each of the seven soil depths are shown in figs. (4.26-4.29). The calibration equations derived for the seven depths as shown in the above figures also show that there was a fairly high correlation between the volumetric water content measured in $cm^3\ cm^{-3}$ and the count rate ratios. The bulk densities were in addition determined in $g\ cm^{-3}$ for the seven depths. These were 1.36, 1.44, 1.50, 1.50, 1.53, 1.62 and 1.65 gcm^{-3} for 0-30, 30-45, 45-60, 60-75, 75-90, 90-105 and 105-120 cm depths respectively. The mean bulk density for the seven depths was $1.51 \pm 0.1\ cm^3\ cm^{-3}$. The dry bulk densities showed a trend to increase with increasing depth, as expected because of the increasing clay content with increasing depth. When the moisture contents in the seven depths were merged and correlated with the count rate ratios in the same depths, the square of the coefficient of correlation (r^2) value obtained was 0.78 ($r = 0.88$) which was much lower than the r^2 values for individual depths. The regression equations for these individual depths were therefore preferred for use instead of a single equation for all the depths.

Neutron Probe Calibration

(a) 0-30cm depth



(b) 30-45cm depth

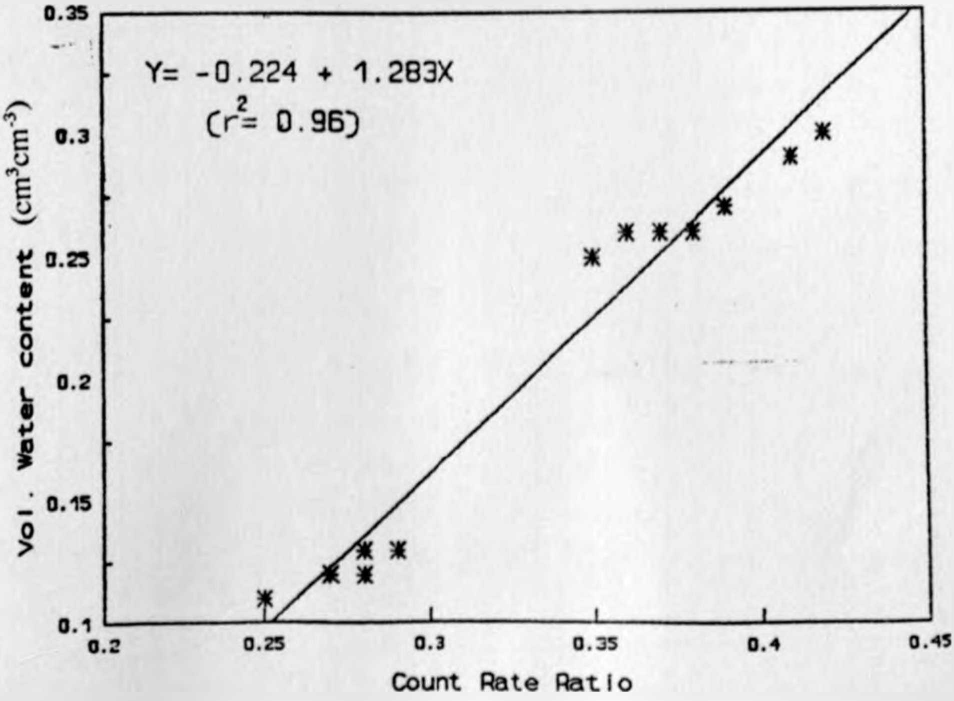


Figure 4.26. Field neutron probe calibration for (a) 0-30 cm depth and (b) 30-45 cm depth.

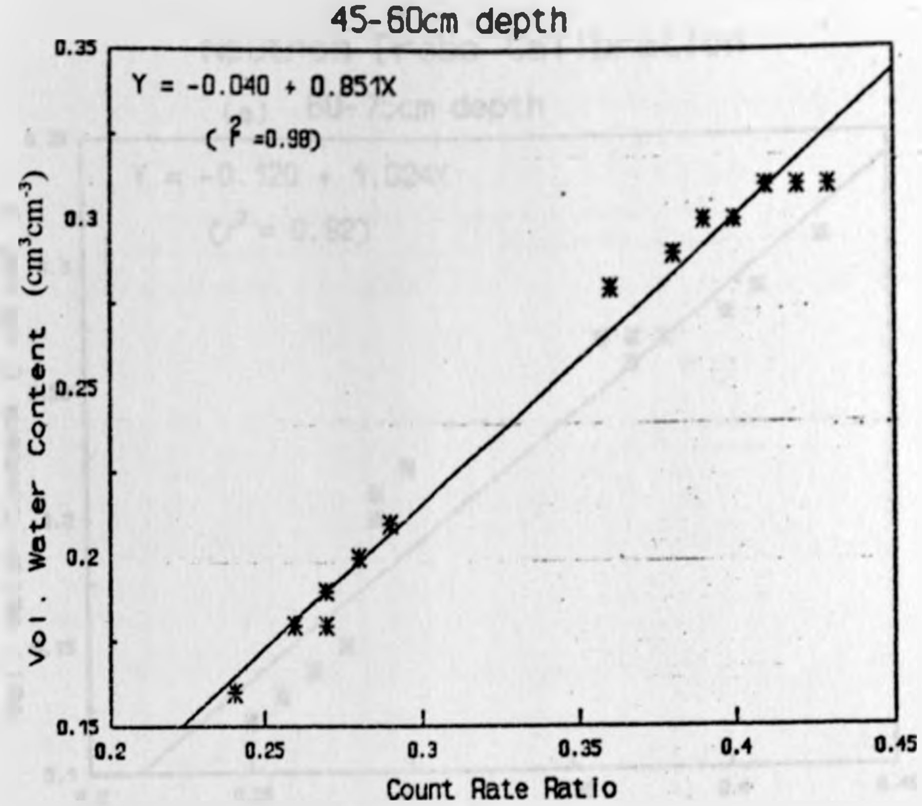
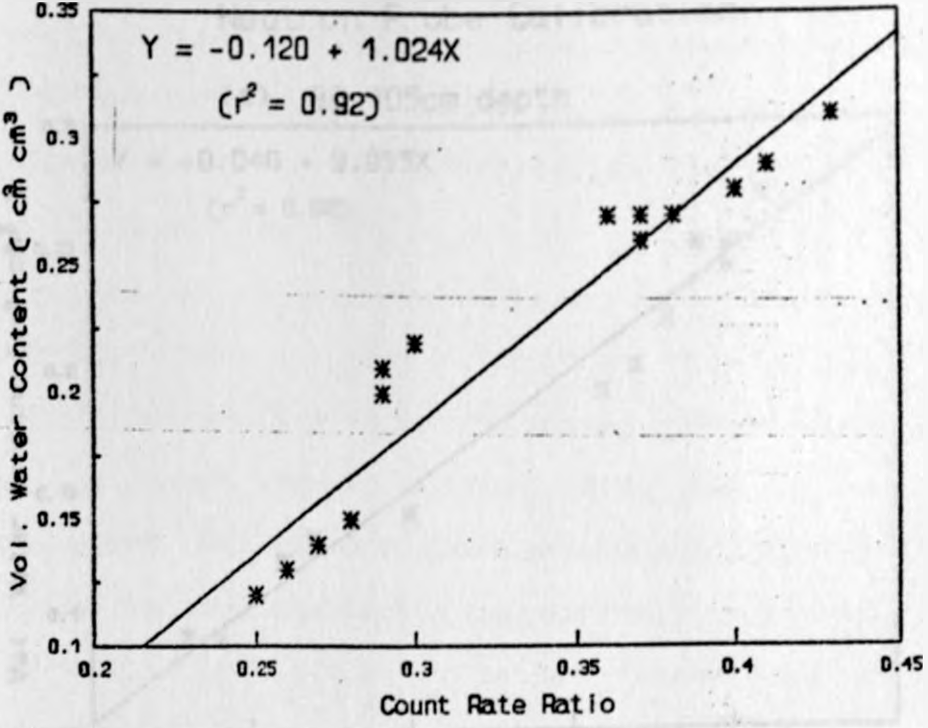


Figure 4.27. Field neutron probe calibration for 45-60 cm depth.

Neutron Probe Calibration

(a) 60-75cm depth



(b) 75-90cm depth

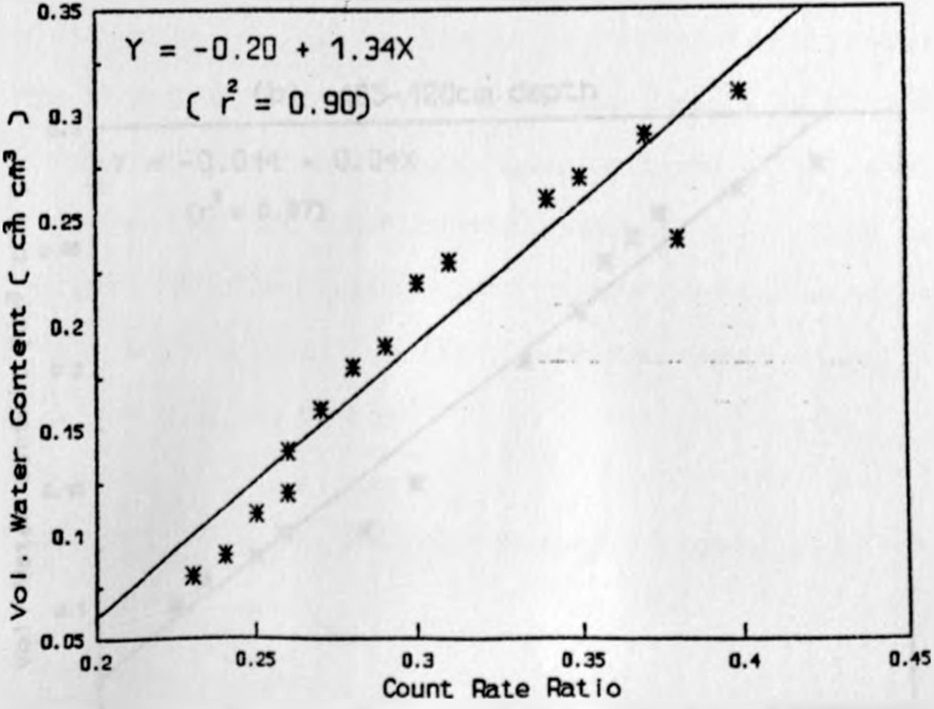
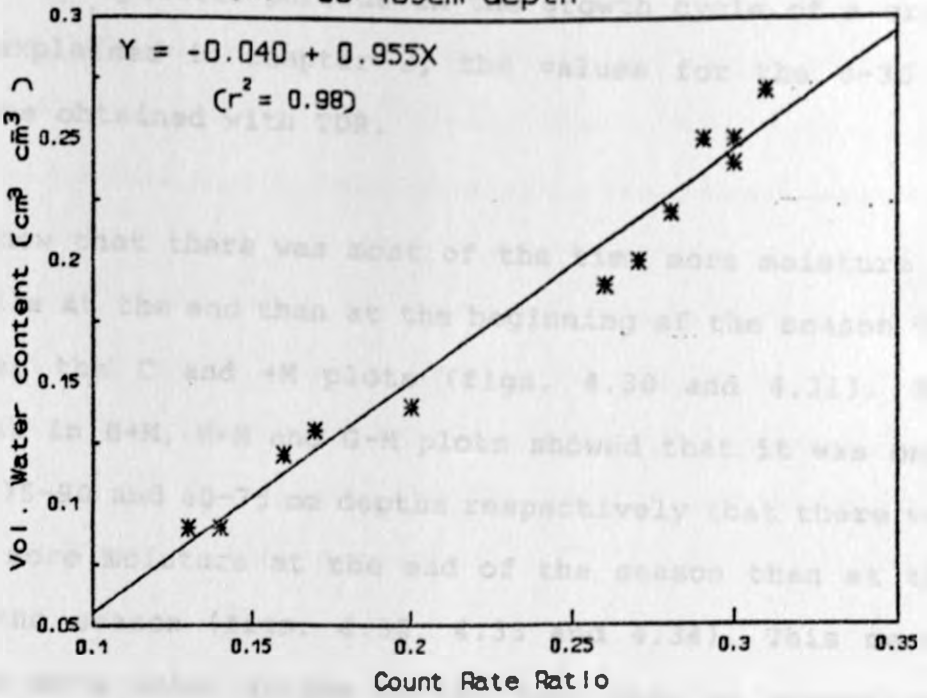


Figure 4.28. Field neutron probe calibration for (a) 60–75 cm depth and (b) 75–90 cm depth.

Neutron Probe Calibration

(a) 90-105cm depth



(b) 105-120cm depth

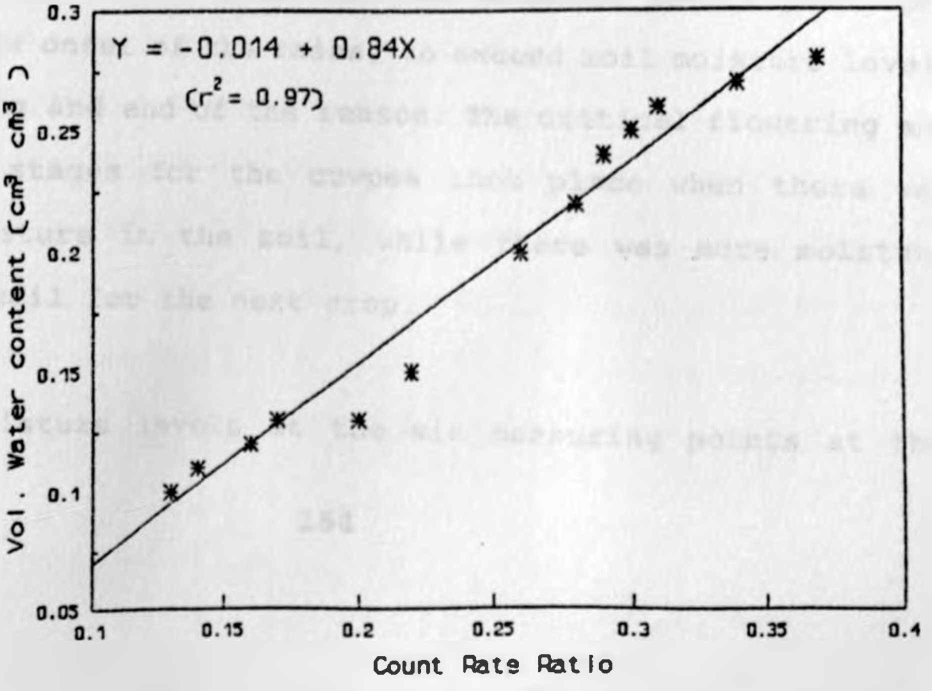


Figure 4.29. Field neutron probe calibration for (a) 90–105 cm depth and (b) 105–120 cm depth.

4.5.2 Soil moisture for the short rains of 92/93.

Figures (4.30-4.34) show the moisture levels, averaged over the plots, as at planting, flowering and at harvest for the season. These moisture levels were extracted from the entire season's moisture data analysis to illustrate what was happening to the soil moisture at these specific periods in the growth cycle of a crop. For reasons explained in chapter 3, the values for the 0-30 cm layer are those obtained with TDR.

The results show that there was most of the time more moisture in the soil profile at the end than at the beginning of the season for all depths for the C and +M plots (figs. 4.30 and 4.31). The moisture levels in H+M, H-M and G-M plots showed that it was only beyond 60-75, 75-90 and 60-75 cm depths respectively that there was substantially more moisture at the end of the season than at the beginning of the season (figs. 4.32, 4.33 and 4.34). This meant that there was more water uptake by the tree/crop or grass/crop roots components at the upper soil depths in the agroforestry/grass plots than in the C and +M plots. The moisture levels per depth went up with the onset of the rains, to exceed soil moisture levels at the beginning and end of the season. The critical flowering and grain filling stages for the cowpea took place when there was sufficient moisture in the soil, while there was more moisture stored in the soil for the next crop.

The average moisture levels at the six measuring points at the seven depths for the five treatments, as taken as the average over the entire season's data analysis, are shown in figures (4.35-4.39). The purpose of these additional figures is to show, as far as possible, an overall picture of the distribution of total moisture at these measuring points, especially with respect to the distances from the hedgerows or grass strips, in an effort to explain this way per row yield differences in the Senna and grass alleys of this study. Points 1 and 2 were measuring points within plant rows while point 3 was between plant rows in all seasons. These average moisture levels at each of the measuring points in C and +M plots (figs. 4.35 and 4.36) show that there were moisture variations among the depths which tend to be particularly large near the surface and at larger depths. They appear to increase with increasing depths at or beyond 75-90 cm, possibly due to differences in increasing clay content.

The moisture trend in the H+M plot varied with depth (fig. 4.37). The H3-M position showed lowest average moisture at a depth of 60-75 cm and beyond. The picture for averaged moisture at the H1+M and H2+M was not clear cut, but the differences were overall small (fig 4.37). The H3-M (fig.4.38) position had lowest moisture at 0-30, 75-90, 90-105 and 105-120 cm, while the H2-M position had highest moisture content at 0-30, 30-45, 45-60 and at 105-120 cm depths. Apart from the H1-M position being clearly lowest from 30-75 cm depth and highest at 75-105 cm depth, the picture on moisture pattern to the centre of the alley from the hedgerow was not clear (fig. 4.38). There were also variations in moisture with increasing depth for the G1-M, G2-M and G3-M (fig. 4.39). Except for the 0-30 cm depth, the G1-M position had the highest moisture. The G2-M position had lowest moisture at 30-45, 45-60 and 60-75 cm depth. The G3-M position had lowest moisture at 60-75, 75-90, 90-105 and 105-120 cm depths. This showed again only a clear moisture increasing trend of G1-M> G2-M > G3-M at 60-75 cm depth and beyond.

The entire season's data at the six measuring points (i.e at two sampling places with three points of measurement for each place numbered like in the figs. 4.35-4.4.39) were subjected to an ANOVA, assuming a complete randomised block design, in order to check whether there were differences at the points of measurement as well as for different depths and treatments. The moisture differences at the measuring points taken individually over the plots showed that there were statistically significant differences among points of measurements, depths and between treatments at $P \leq 0.05$, and CV = 39.05%. The seasonal average moisture levels over the five plots at the points of measurement (L.S.D = 0.011, S.E = 0.004) had the average first measuring points 1st and the two averages of the second two points of measurement 2nd. These two levels were statistically significantly different.

Separation of the within treatment average seasonal moisture means by Duncan's multiple range test (DMRT), as described in Chapter 3, ranked the moisture contents at the three points of measurement in the C, +M, H+M, H-M and G-M plots as shown in Table (i) in Appendix 4.1. In this Table, the second two points of measurement in the C and +M plot were ranked together, while the first measuring points were ranked separately. This meant that the moisture content at the first measuring points (between plant rows) and at the second two measuring points (within plant rows) were statistically significantly different at LSD = 0.025 and SE = 0.09. However, the points 1 were higher in the C plot but lower in the +M plot. The case for the H+M plot showed that the measuring point in the hedge had moisture which was statistically significantly higher from moisture at 1 and 2 m positions from the hedge. In the H-M plot, the three measuring points were not statistically significant because they were ranked together. The G-M plot moisture data showed that the position in the grass strip was ranked 1st and those at 1 and 2 m from grass strip jointly 2nd, as the 1st position had moisture which was statistically significantly higher than other positions.

The results also showed that the seasonal average moisture contents at the seven depths of measurement taken individually over the plots were also significantly different among treatments. Separating and ranking these depths' means over the plots (that is points of measurement) by DMRT at LSD = 0.012, SE = 0.006 and $P \leq 0.05$ showed that 90-105 cm depth (ranked 1st) had highest mean moisture content everywhere, although not statistically significantly different with all other depths in the +M plot and the H-M plot. These rankings of the moisture levels for the five treatments are shown in Table (ii) in appendix 4.1. It is indicated there were further statistically significant differences among depths within treatments (LSD = 0.04; SE = 0.014). It should be realised that LSD values should also be feasible from the point of view of the measurement averages treatment, as obtained with the equipment used. It is assumed that our measurements fulfil this condition. One important feature appears in this table. The moisture levels at all depths in the five plots were generally high as the season had above average rainfall in the season.

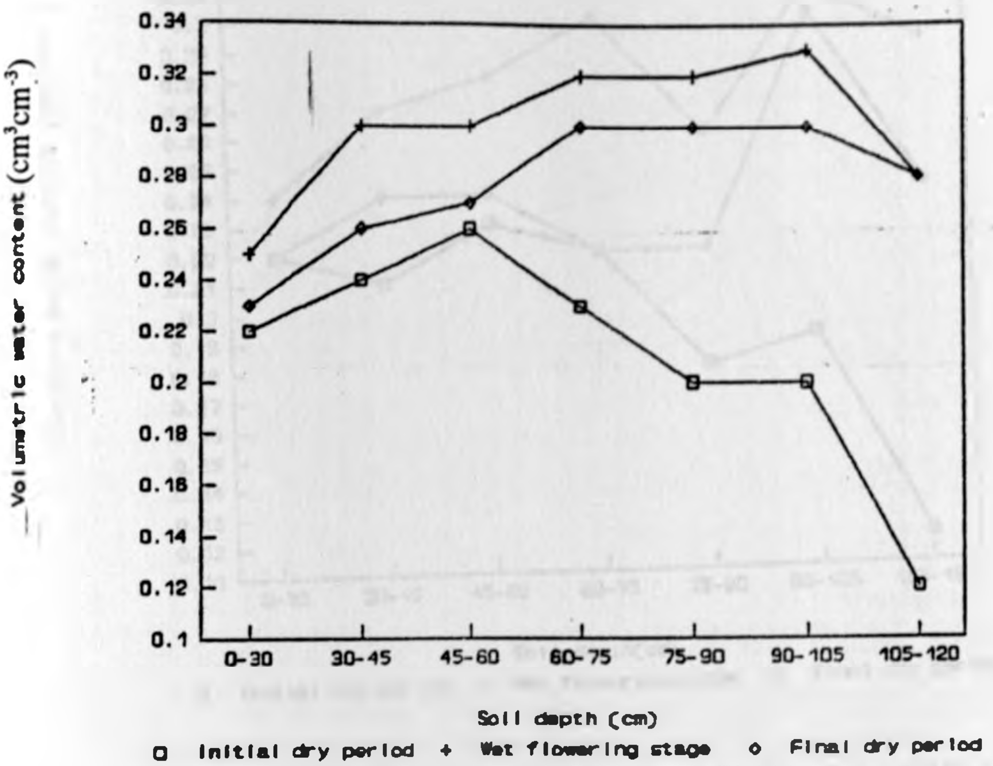


Figure 4.30. Average soil moisture levels per depth at planting, flowering and harvesting stages. C plot short rains of 92/93.

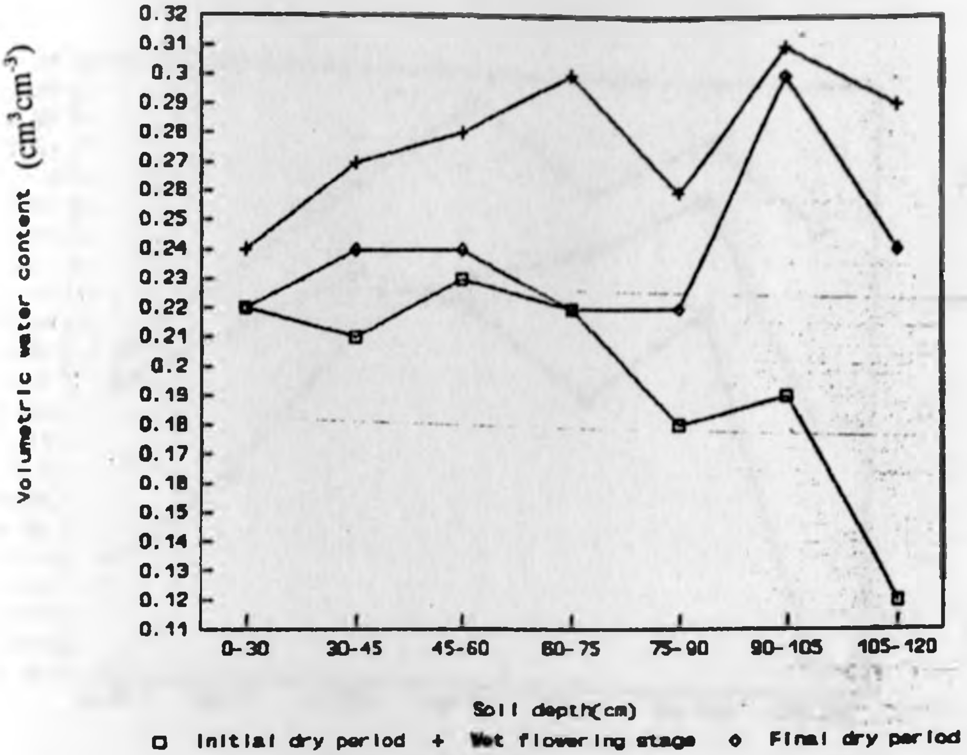


Figure 4.31. Average soil moisture levels per depth at planting, flowering and harvesting stages. +M plot, short rains for 92/93.

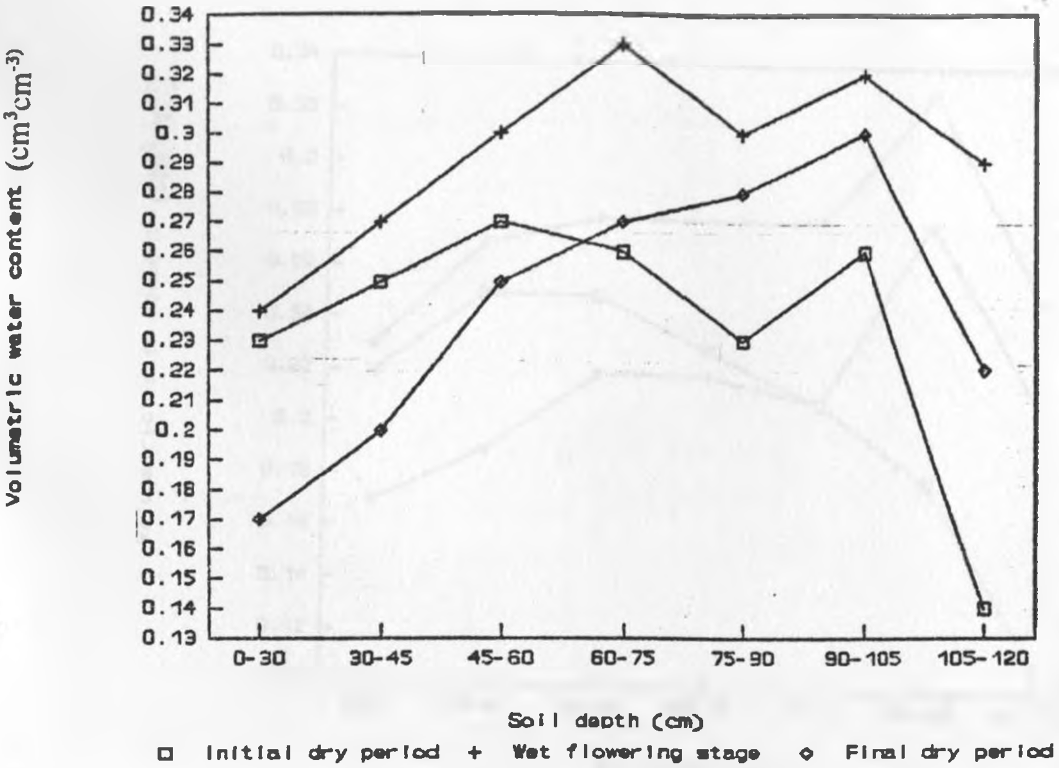


Figure 4.32. Average soil moisture levels per depth at planting, flowering and harvesting stages. H+M plot, short rains of 92/93.

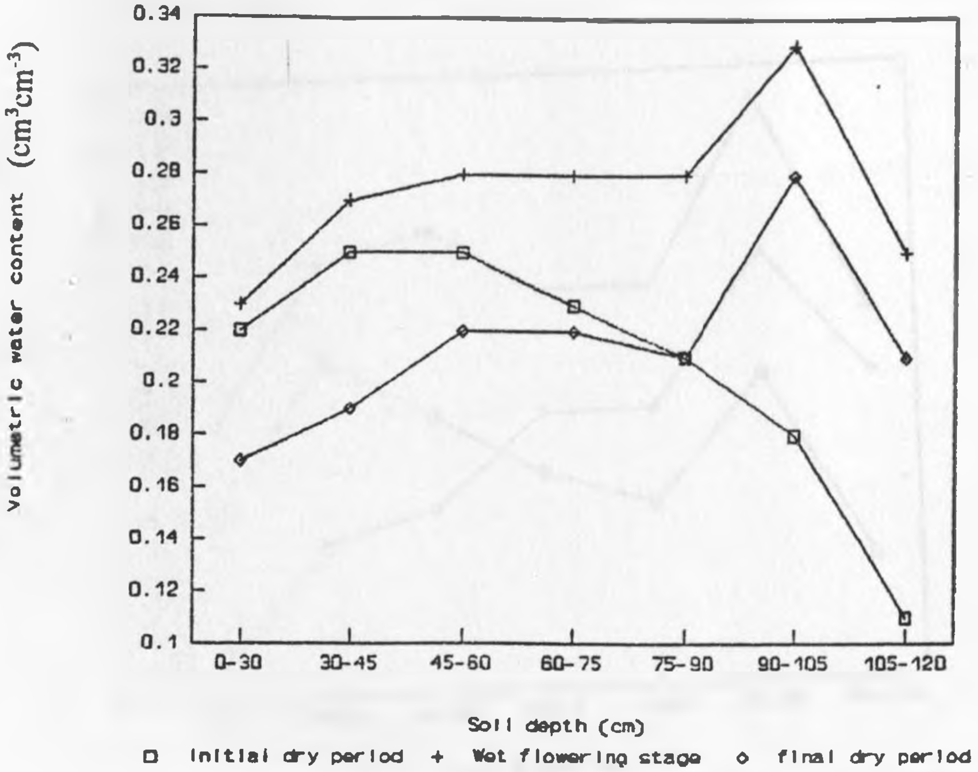


Figure 4.33. Average soil moisture levels at planting, flowering and harvesting stages. H-M plot, short rains of 92/93.

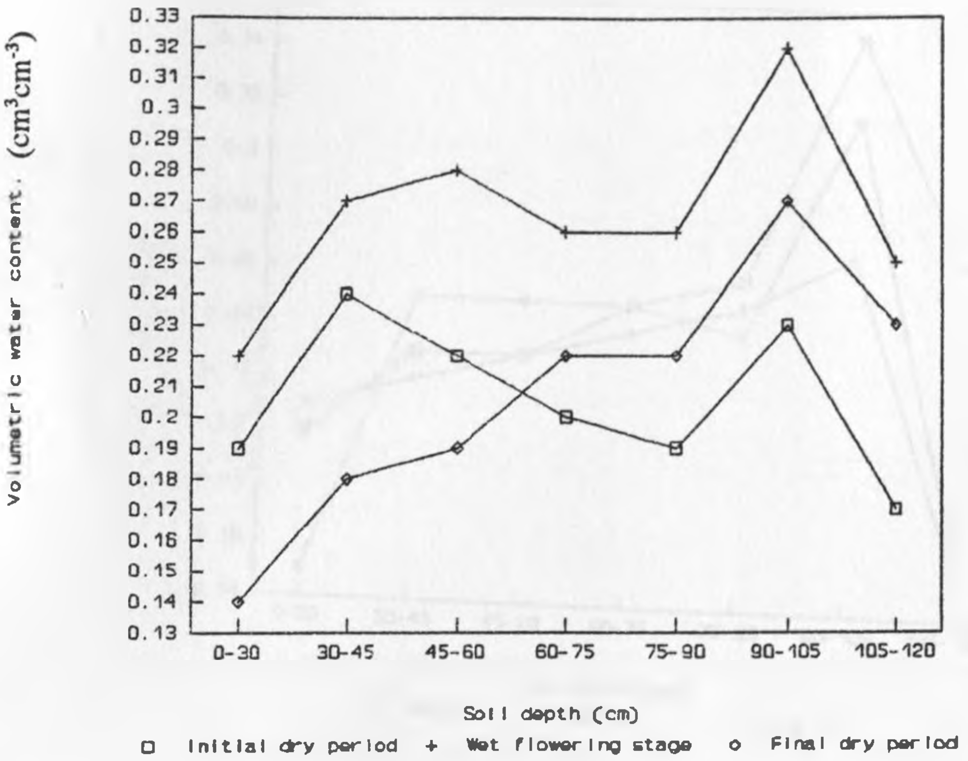


Figure 4.34. Average soil moisture levels per depth at planting, flowering and harvesting stages. G-M plot, short rains of 92/93.

N.B The pick moisture levels in depths 90-105 cm are possibly because of increase in clay content with increasing depth. This is characteristic of this depth in many other seasons shown in this chapter.

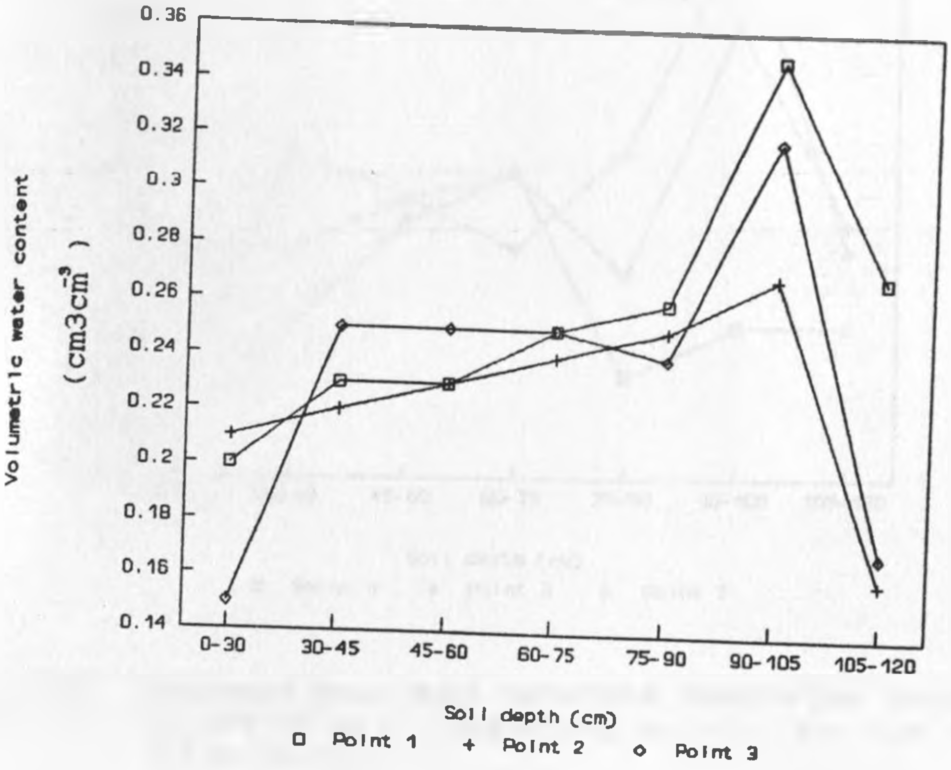


Figure 4.35. Seasonal mean soil moisture levels per depth at the measuring points placed at 1 m apart in the C plot. Short rains for 92/93.

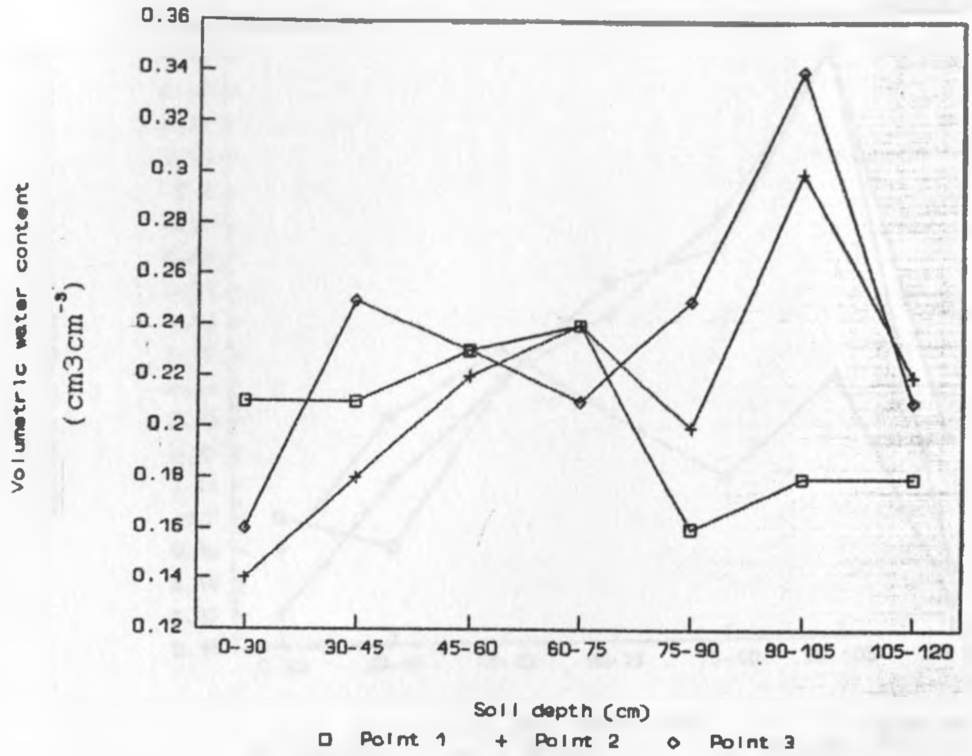


Figure 4.36. Seasonal mean soil moisture levels per depth in the +M plot (measuring points) for the short rains 92/93.

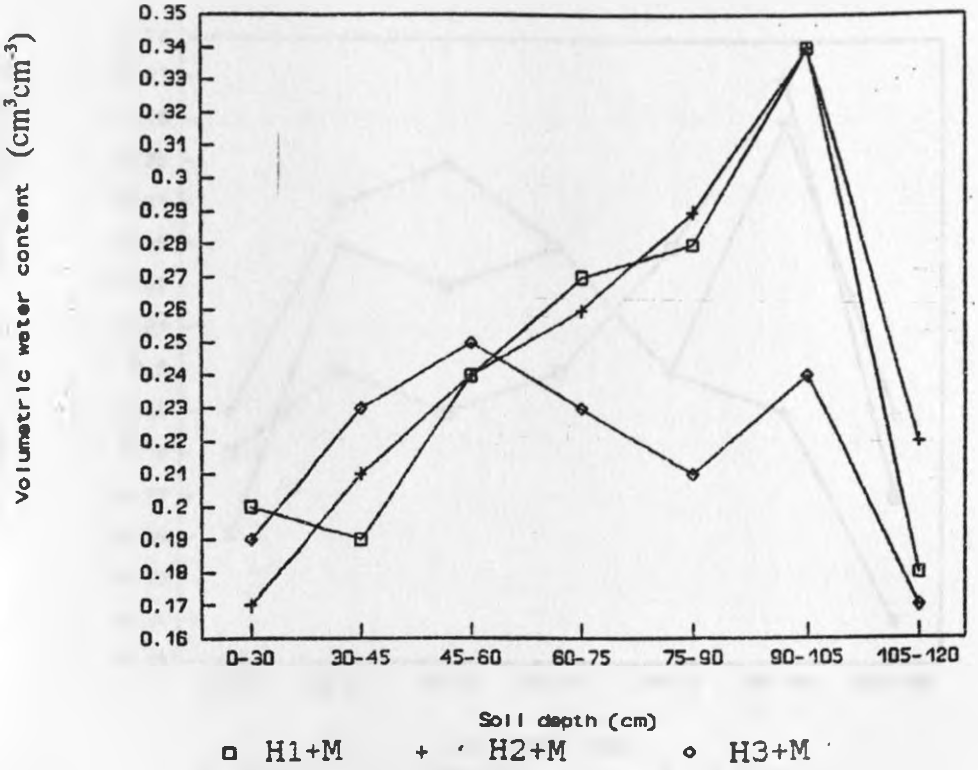


Figure 4.37. Seasonal mean soil moisture levels per depth in the hedge, 1 m from the hedge and 2 m from the hedge. Short rains of 92/93.

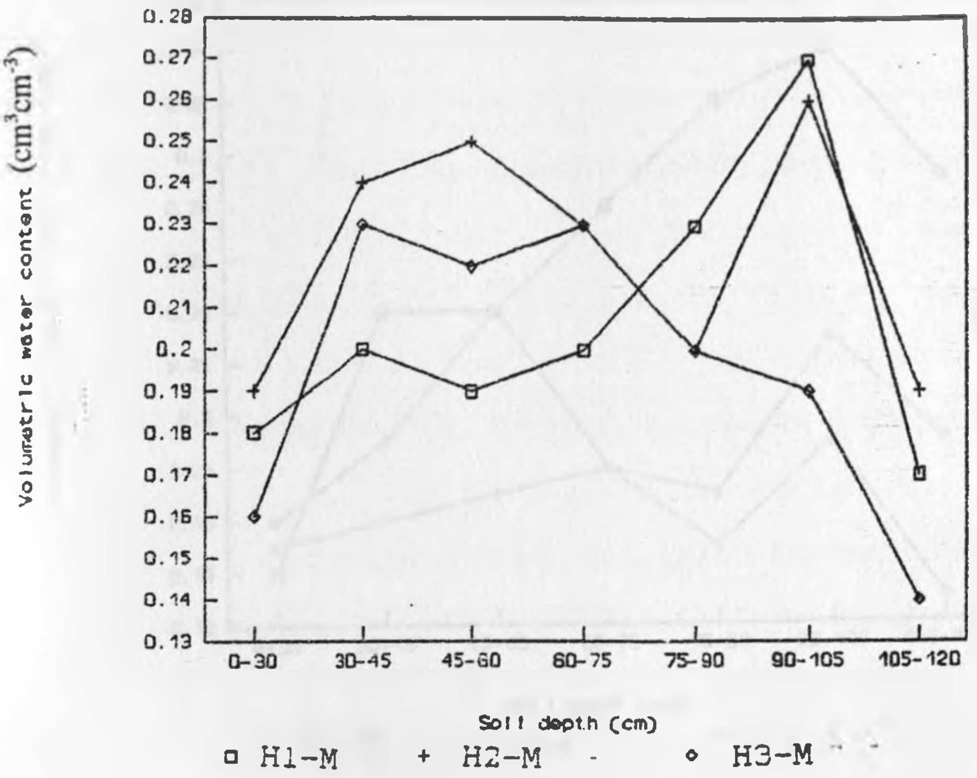


Figure 4.38. Seasonal mean moisture levels per depth in the hedge, 1 m from the hedge and 2 m from the hedge. H-M plot, short rains for 92/93.

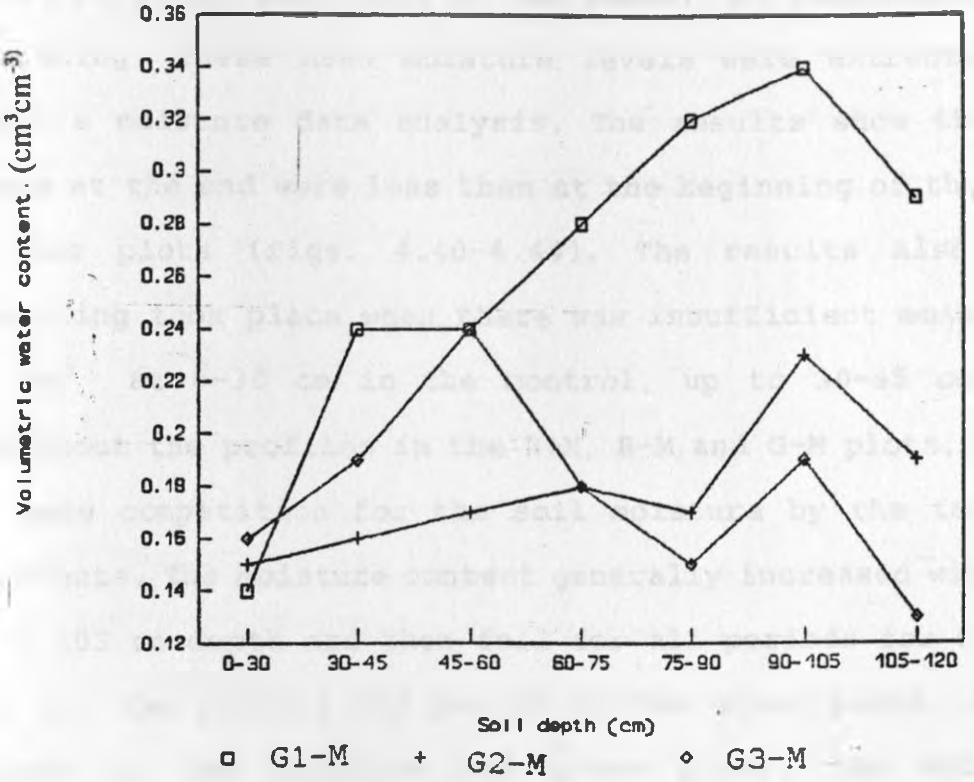


Figure 4.39. Seasonal mean soil moisture levels per depth in the grass, 1 m from the grass and 2 m from grass. G-M plot, short rains of 92/93.

4.5.3 Soil moisture for the long rains of 1993.

Figures (4.40-4.44) show the moisture levels, averaged over the plots, as at the beginning of the season, at tasselling and at dry harvesting. These mean moisture levels were extracted from the season's moisture data analysis. The results show that moisture levels at the end were less than at the beginning of the season for all the plots (figs. 4.40-4.44). The results also show that tasselling took place when there was insufficient moisture: <0.10 cm^3 cm^{-3} at 0-30 cm in the control, up to 30-45 cm in +M and throughout the profiles in the H+M, H-M and G-M plots, where there was more competition for the soil moisture by the tree or grass components. The moisture content generally increased with depth for up to 105 cm depth and then fell for all periods for C and +M and only for the initial dry period in the other plots. For the dry periods in the hedgerow and grass plots, the soil moisture increased with increasing depth for up to 60 cm depth (figs. 4.42, 4.43 and 4.44) and then followed a mildly declining trend for up to 120 cm depth (for G-M till 105 cm).

From the seasonal mean moisture analysis, the three averages of the three pairs of points of measurements in figs. (4.45-4.49) show that the G3-M had more moisture than the G2-M and G1-M for 30-45 cm and higher (fig. 4.49), as there was apparently less competition for moisture between grass and crops further in the alley than nearer the grass strip. There were moisture level variations at the measuring points in the C plot and particularly in the +M plot (figs. 4.45 and 4.46) as earlier explained. The moisture trends showed that there were strong fluctuations, at a low moisture level, in the H1+M (least) and H1-M; H2+M, H2-M (least); and in H3+M, H3-M (least) points of measurement (figs. 4.47-4.48). Only in H+M (from 60-75 cm onwards) and H-M (from 45-75 cm) was some concentration of runoff water at the hedgerow barriers noticeable. For the G-M plot, there was a clear increase in moisture content at 30-45 cm depth and beyond in G3-M. The moisture contents at G1-M and G2-M were much lower and their mutual relation rather unclear (fig. 4.49).

An ANOVA was carried out for the overall average moisture levels for the season at the points of measurement, as was done in 4.5.2, in order to show a picture at the hedgerows/grass strip, 1 and 2 m from these barriers, which will help in explaining per row yield differences in the alleys. The overall results of the ANOVA showed that there were statistically significant differences in moisture levels between treatments, among the points of measurements and among depths $P = \leq 0.05$ and CV = 46.3%. The results showed that overall average seasonal moisture differences also averaged over the depths at the points of measurement, were statistically significant at L.S.D = 0.004, S.E = 0.002. A separation of the means and their ranking, using DMRT for the points of measurement, ranked the overall moisture contents at the 1st and 2nd measuring points together and the 3rd one separately. When each plot was examined separately, there were also moisture differences within plots (LSD = 0.009; SE = 0.003). In the C and +M plots, the 1st point of measurement was (between plant rows) ranked separately from the other two (within plant rows) which were ranked together (Table (iii) in appendix 4.2). The H+M had the moisture levels with in the hedge, and at 1 and 2 m from the hedge ranked together, as the differences between these were not statistically significant. For the H-M plot, the within hedge position was ranked separately from the positions 1 and 2 m from the hedge with the latter positions having statistically more significantly more moisture than the former although all values were very low. The again low G-M plot values showed that the position 2 m away from the grass strip was ranked separately, with a higher value, from the values obtained within the grass strip and 1 m from grass strip which were ranked together. The differences between the 3rd position with higher moisture and 1st and 2nd positions with lower moisture were statistically significant (Table (iii) in appendix 4.2).

As the moisture means among depths (taken individually at the measuring points) were statistically significantly different at LSD = 0.007, SE = 0.002 at $P \leq 0.05$, DMRT was used to separate and rank moisture means at the seven depths. Near surface layers are everywhere ranked lowest, the highest ranking occurs within 60-75 cm downwards, and in deeper layers in the C and +M plots, compared to the other plots. All these moisture level differences within each plot (LSD = 0.05; SE = 0.005) are shown in Table (iv) in appendix 4.2. The depths shown to be ranked together are not statistically significantly different while those in different ranks are. This table shows of course again that there were generally higher moisture levels in the C and +M plots than the generally quite low moisture levels in the AF and G-M plots where competition for moisture from crop/grass or crop/tree was high in a very dry 1993 long rainy season.

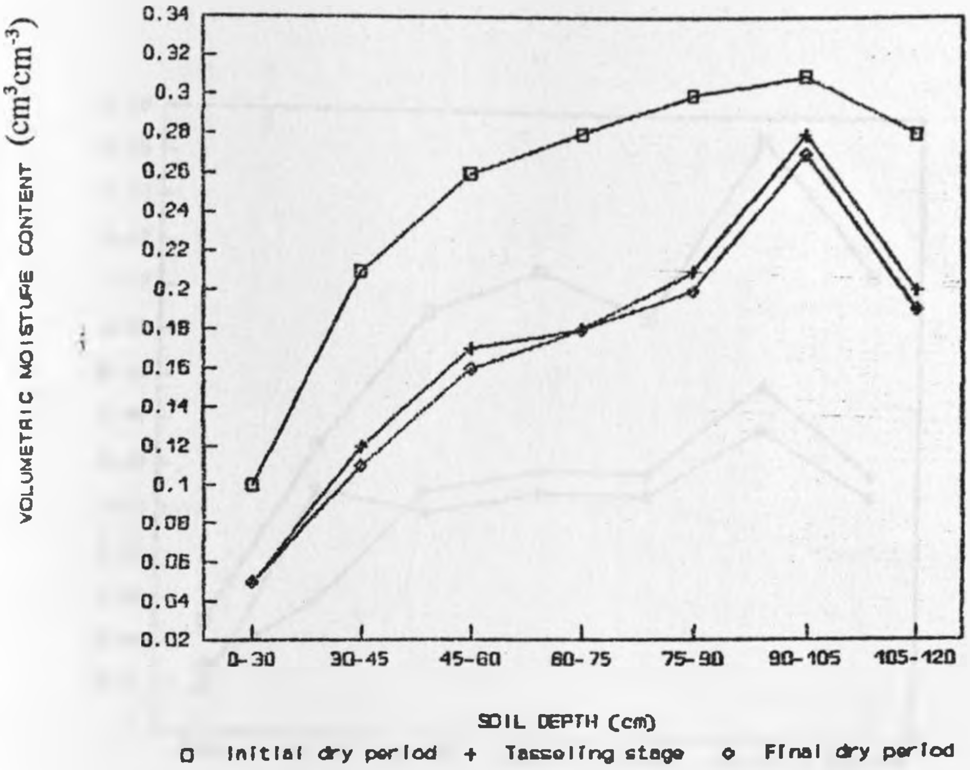


Figure 4.40. Mean soil moisture levels per depth at planting, tasselling and harvesting stages, C plot, Maize, long rains of 1993.

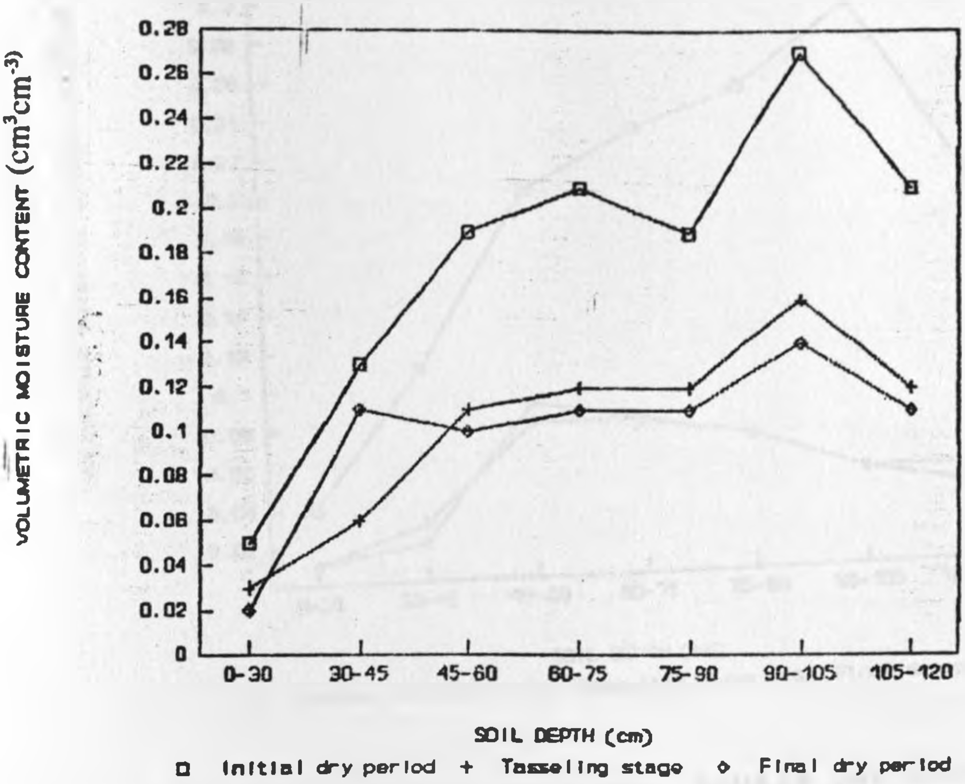


Figure 4.41. Mean soil moisture levels per depth at planting, tasselling and harvesting stages, +M plot. Maize, long rains of 1993.

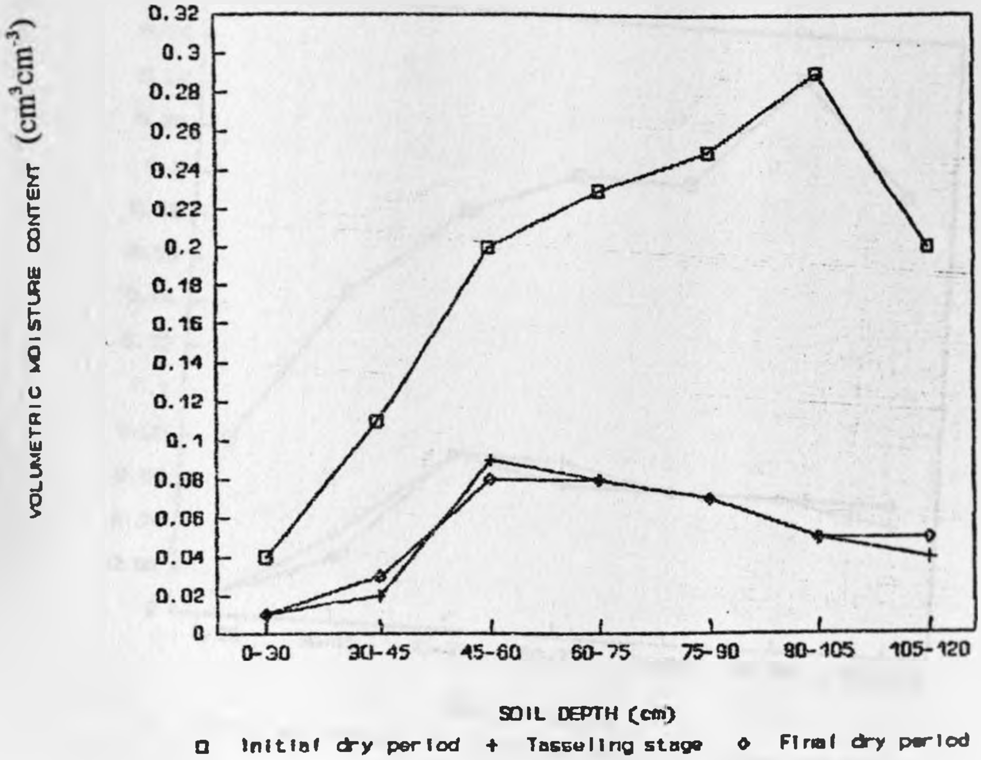


Figure 4.42. Mean soil moisture levels per depth at planting, tasselling and harvesting stages H+M plot. Maize, long rains of 1993.

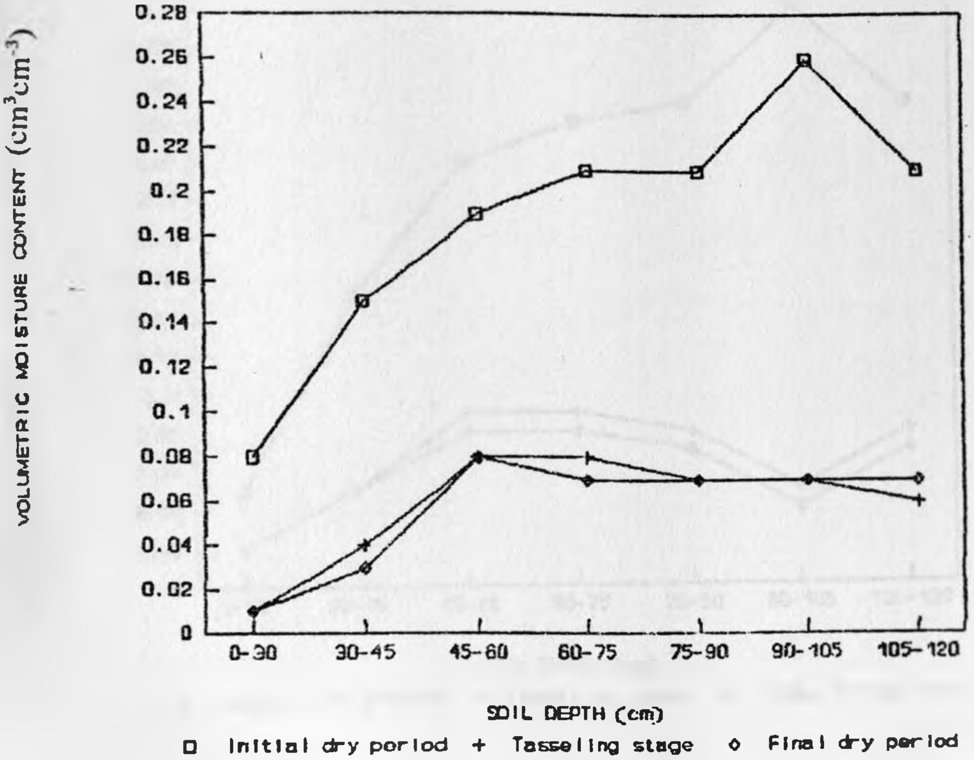


Figure 4.43. Mean soil moisture levels per depth at planting, tasselling and harvesting stages, H plot. Maize. long rains of 1993.

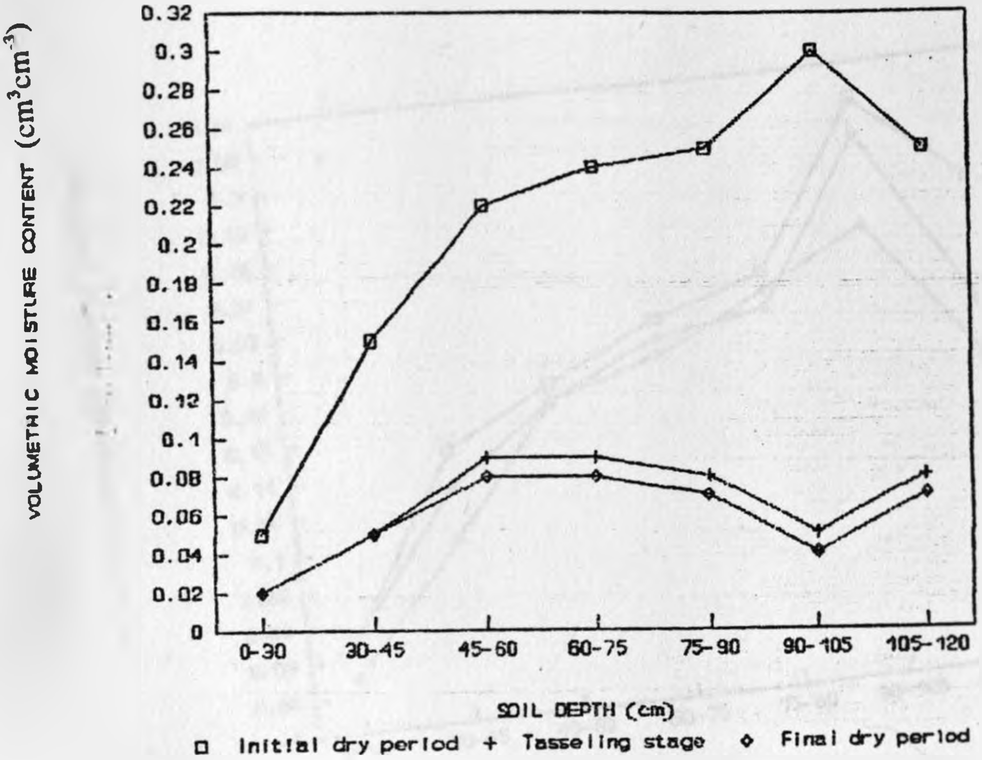


Figure 4.44. Mean soil moisture levels per depth at planting, tasselling and harvesting, G-M plot. Maize, long rains of 1993.

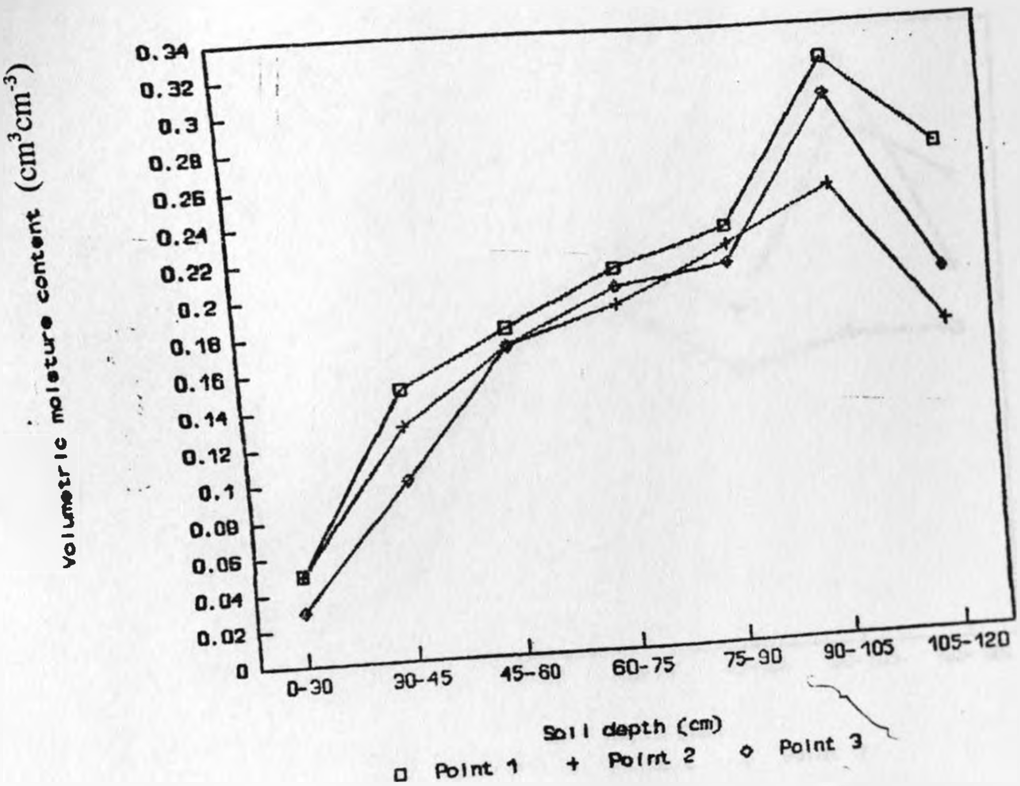


Figure 4.45. Seasonal soil moisture levels per depth (at measuring points) in C plot. Maize, long rains of 1993.

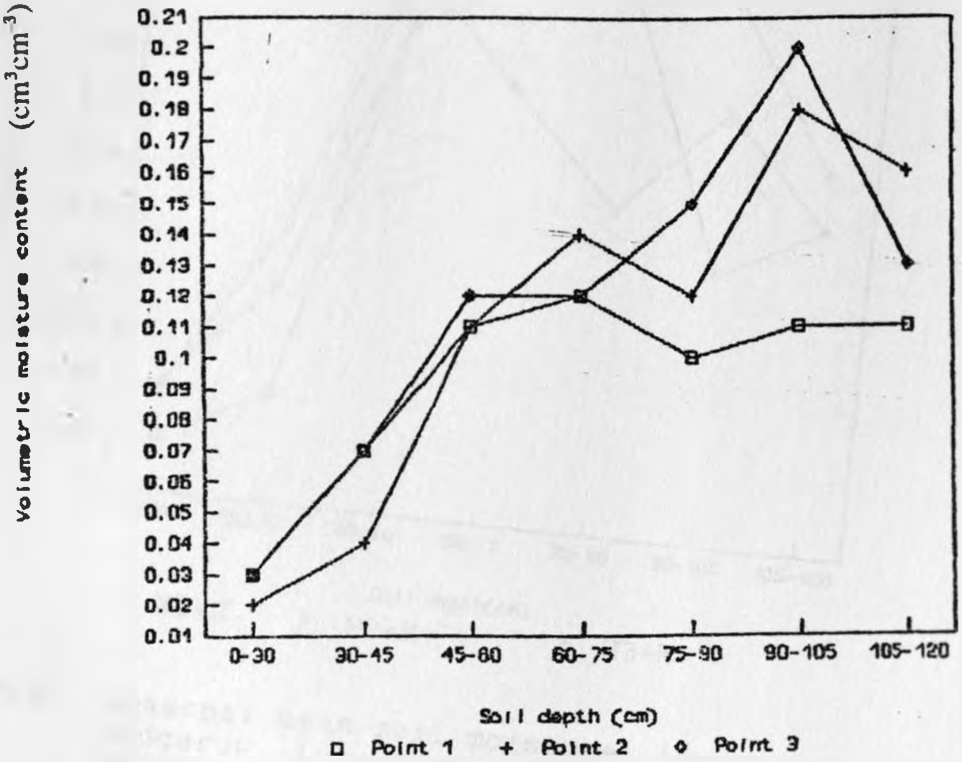


Figure 4.46. Seasonal mean soil moisture levels (at measurir points) +M plot. Maize, long rains of 1993.

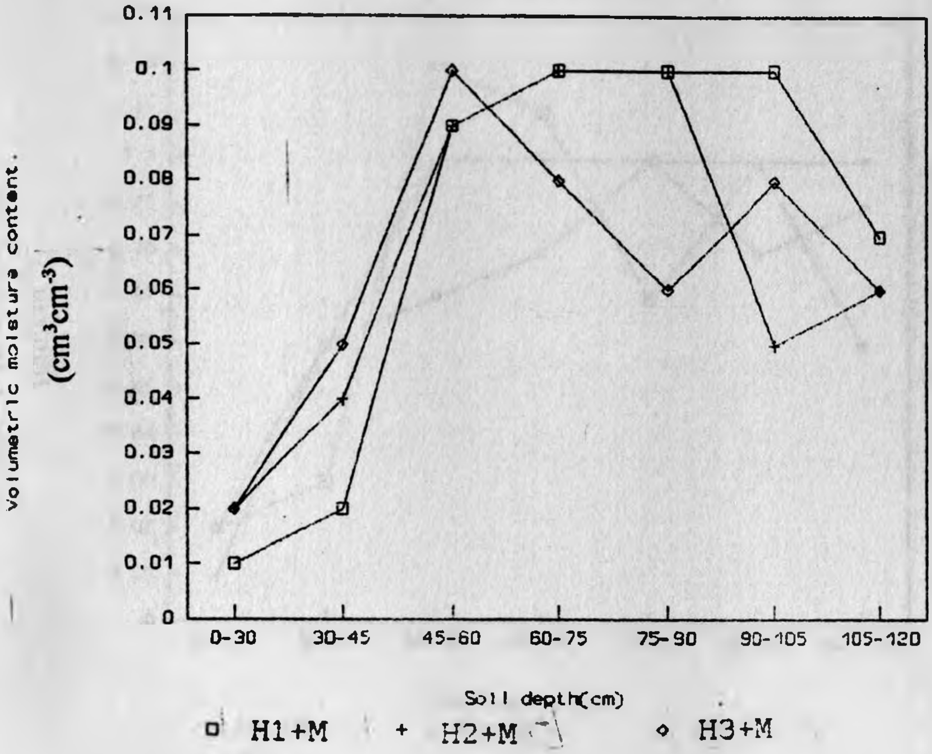


Figure 4.47. Seasonal mean soil moisture levels in the hedgerow, 1 m from the hedgerow and 2 m from the hedgerow. H+M plot. Maize. long rains of 1993.

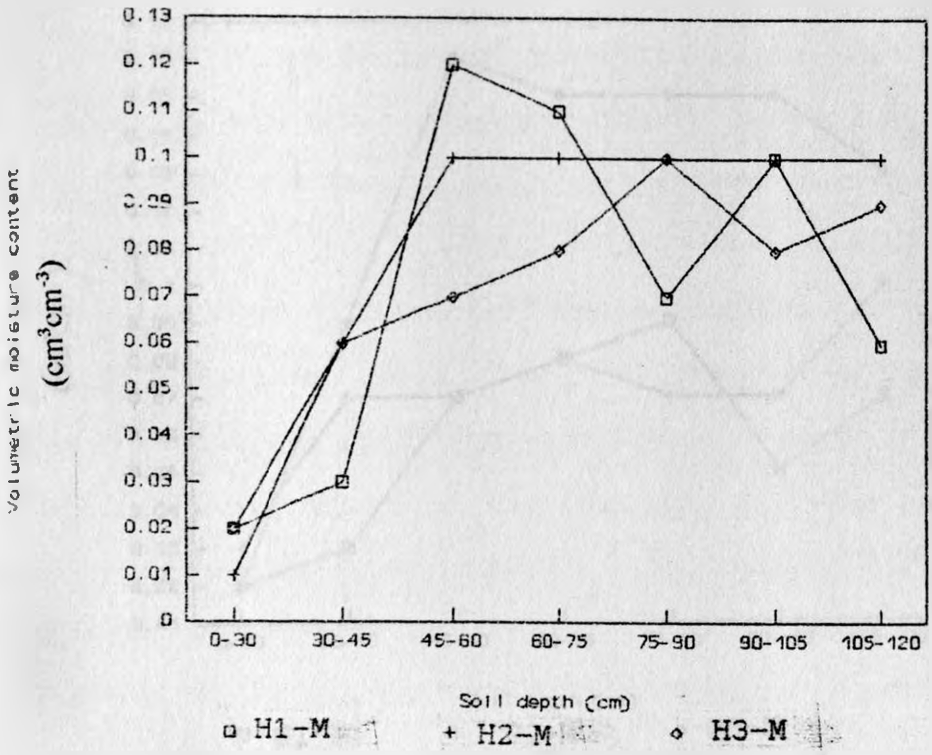


Figure 4.48. Seasonal Soil moisture levels in the hedgerow, 1 m from the hedgerow and 2 m from the hedgerow, H-M plot. Maize, long rains of 1993.

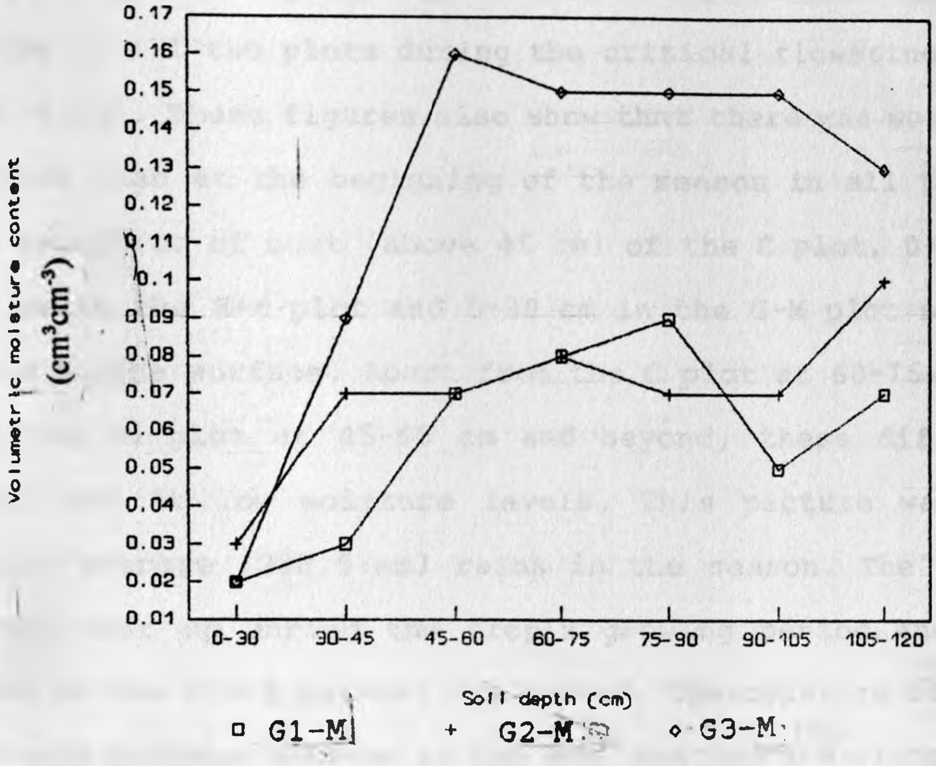


Figure 4.49. Seasonal mean soil moisture levels in grass, 1 m from grass and 2 m from grass, G-M plot. Maize, long rains of 1993.

4.5.4 Soil moisture for the short rains 93/94.

Figures 4.50-4.54 show the mean moisture levels at planting, flowering and harvesting as extracted from the season's moisture data analysis. They show that there was sufficient moisture at all depths in all the plots during the critical flowering stage (figs. 4.50-4.54). These figures also show that there was more moisture at harvest than at the beginning of the season in all the plots with the exception of most (above 45 cm) of the C plot, 0-30 cm and 90-105 cm in the H+M plot and 0-30 cm in the G-M plot so differences close to the surface. Apart from the C plot at 60-75 cm and beyond and the +M plot at 45-60 cm and beyond, these differences were small and at low moisture levels. This picture was due to the within average (288.5 mm) rains in the season. The soil moisture levels went up during the crop's growing period and declined as shown at the final harvest dry period. The moisture reserves at the end were however smaller in the H+M, H-M and G-M plots (figs. 4.52-4.54.) as compared to the C and +M plots (figs. 4.50 and 4.51), because the agroforestry/crop components jointly extracted more moisture than the sole crops in C and +M plots. The results also show that the moisture content generally, but not exclusively, increased with increasing depth up to 105 cm before declining particularly when the soil was wet (figs. 4.50-4.54). When the soils were relatively dry, at planting and at harvest, only in the C and +M plots the soil moisture increased with depth for up to 105 cm before declining but it increased with depth for up to 60 cm before more or less levelling in the H+M, H-M and G-M plots.

The seasonal mean moisture distributions among the six points of measurement showed that there was a tendency of having somewhat more moisture at the hedgerow barrier (so at H1+M and H1-M) than at 1 and 2 m from the barrier at higher depths (that is from 60 cm respectively from 75 cm onwards), while this picture was not clear cut at the shallow depths in these plots (figs. 4.57-4.58). In the G-M plot, however, the points at 2 m (in most cases) and 1 m overall away from the grass strip barrier had more moisture than the point in the barrier itself (fig. 4.59). This was possibly due to the aggressiveness of the grass and the competition between the grass and the crop rows nearest the grass strip for this season of average rainfall (288.5 mm). For the C and +M plots in (figs. 4.55 and 4.56), the moisture levels had some variations. They generally increased with depth as already explained, as opposed to the trends in plots with agroforestry components. This difference could be due to tree roots extracting water at higher depths compared to the crops.

A similar analysis as carried out for the earlier two seasons was done for this season. This showed generally that the seasonal soil moisture differences (taken individually over depths in all plots) at the points of measurement, among treatments and depths were statistically significantly different at $P = \leq 0.05$; Cv = 45%. Separating and ranking these seasonal means, averaged over depth at the points of measurement at all the plots (LSD = 0.004; SE = 0.002), ranked points 1 and 2 together and point 3 separately, with point three having more moisture than points 1 and 2. The within treatment differences in moisture levels (LSD = 0.009; SE = 0.004) are shown in Table (v) in appendix 4.2. The Table shows that the C plot had statistically significant differences among the three points of measurement with point 1 (1st rank, for between plant rows) having higher moisture levels than points 2 and 3 (2nd rank, for within plant rows). The +M plot had points 1 and 2 ranked together and point 3 ranked separately as it had significantly less moisture than the first two points. Such results point at too low a measuring point density. The H+M plot results showed that the three points of measurement (in the hedge, 1 and 2 m from hedge) were in one rank with no moisture differences. The case for the H-M plot was that the wetter positions in the hedge and 1 m from the hedge were ranked together, with the drier position 2 m from the hedge being ranked second. The G-M plot had the 1 and 2 m positions from the grass strip wetter and ranked together with the drier position in the grass strip being ranked separately.

As the analysis showed that there were statistically significant differences among depths, DMRT was again used to separate and rank the moisture means for the five plots at these depths at LSD = 0.007; SE = 0.002. With C abit of an exception all two surface layers as well as the deepest layers had lowest moisture everywhere. Highest moisture was between those layers (30-105 cm) with indeed large differences between maxima and minima. These differences within treatments (LSD = 0.0150; SE = 0.0054) are shown in Table (vi) in appendix 4.3. The depths shown to be ranked together are again not statistically significantly different while those in different ranks are. The table also shows that there were generally higher moisture levels in the middle layers of the G-M plot followed by those of the the C plot while those layers in the the +M and AF plots had rather similar medium level moisture contents.

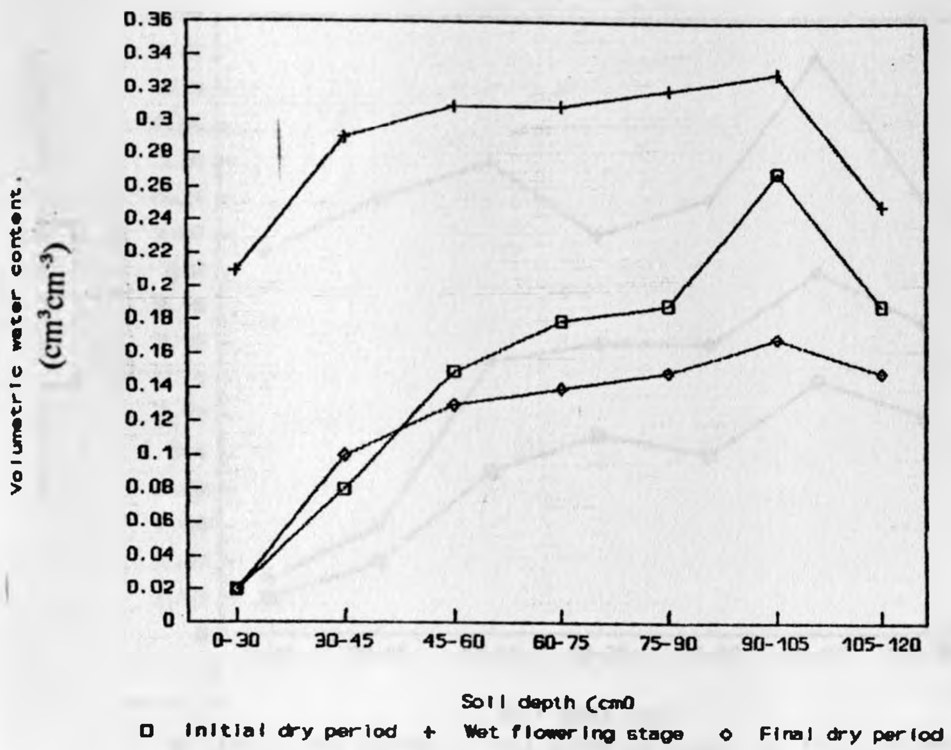


Figure 4.50. Mean soil moisture levels at planting, flowering and harvesting stages. C plot. Cowpea, short rains of 93/94.

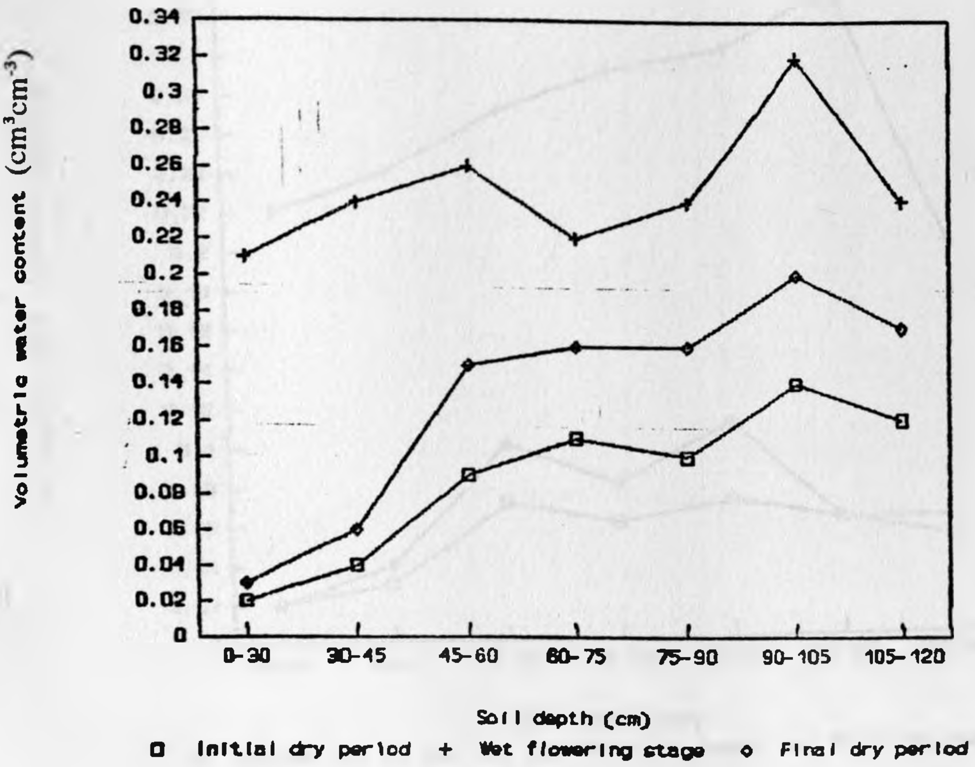


Figure 4.51. Mean soil moisture levels at planting, flowering and harvesting stages, +M plot. Cowpea, short rains of 93/94.

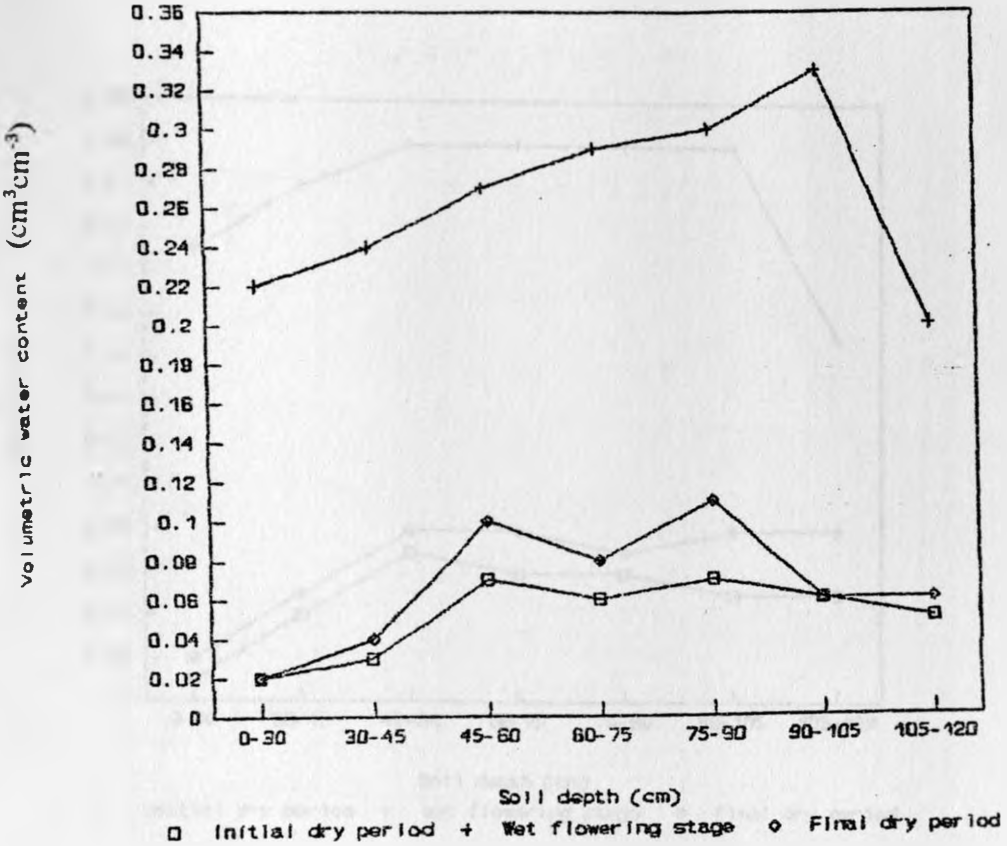


Figure 4.52. Mean soil moisture levels at planting, flowering and harvesting stages. H+M plot, for the short rains 1993/94.

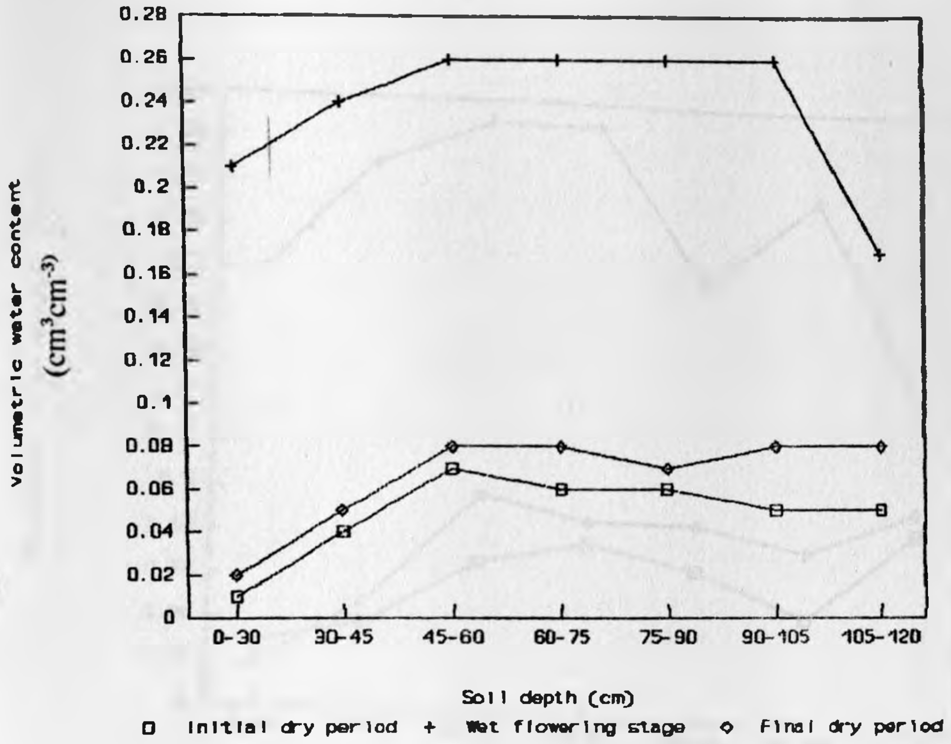


Figure 4.53. Mean soil moisture levels at planting, flowering and harvesting stages. H-M plot, short rains of 1993/94

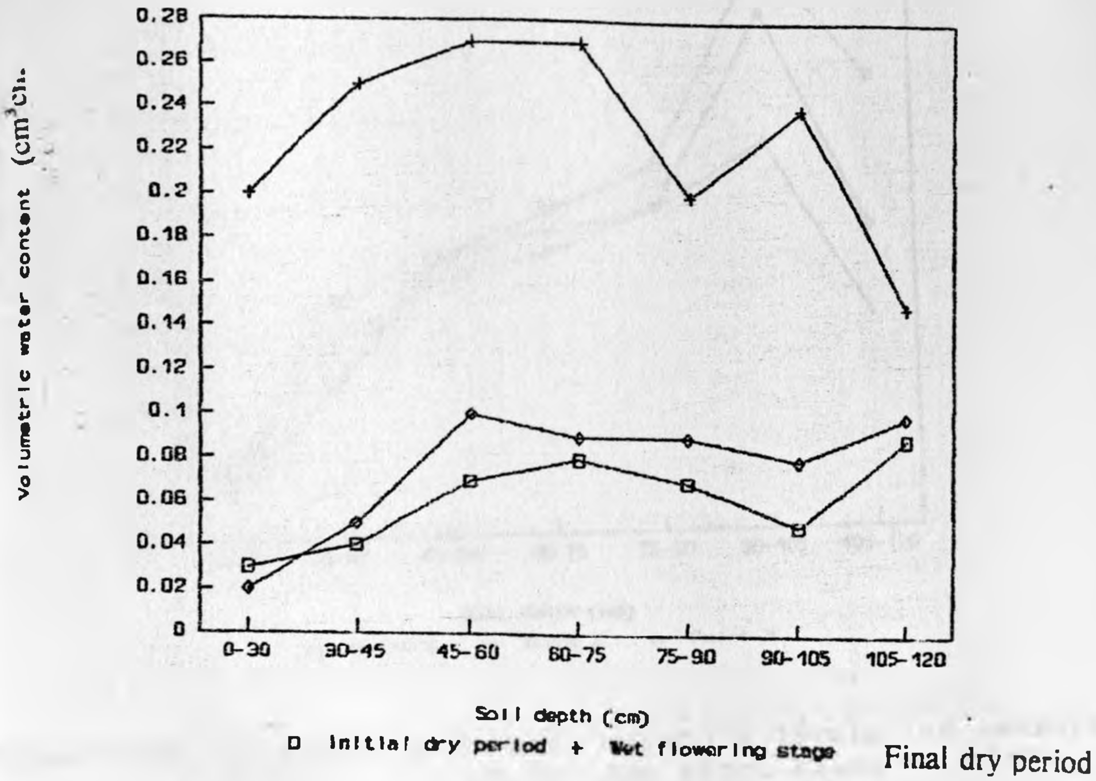


Figure 4.54. Mean soil moisture levels at planting, flowering and harvesting stages. G-M plot, short rains of 93/94.

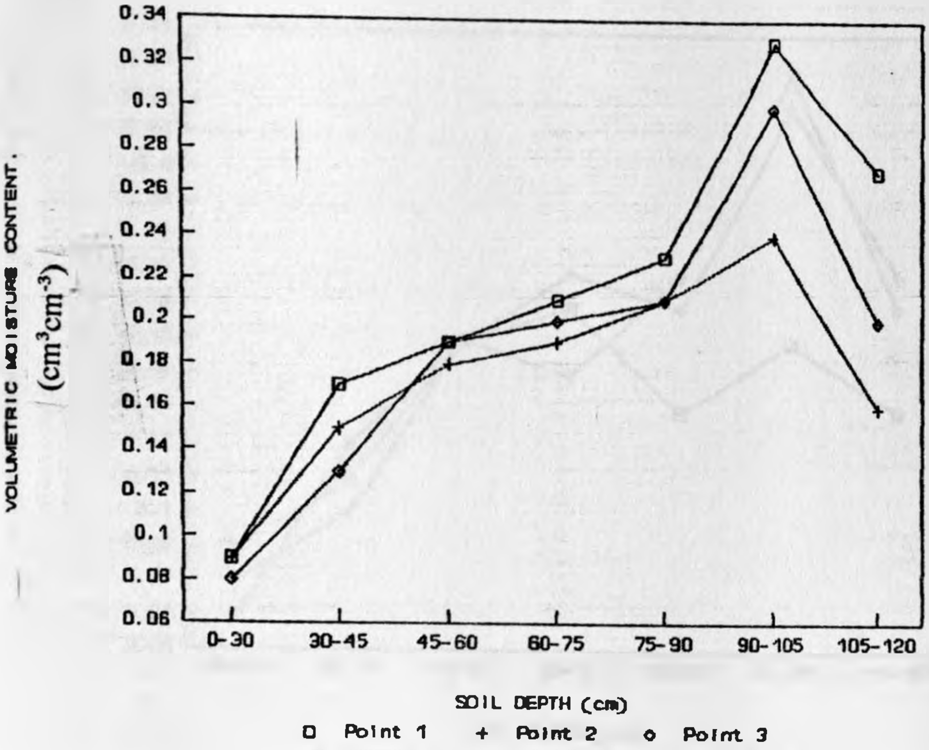


Figure 4.55. Seasonal mean soil moisture levels (at measuring points), C plot for the short rains of 93/94.

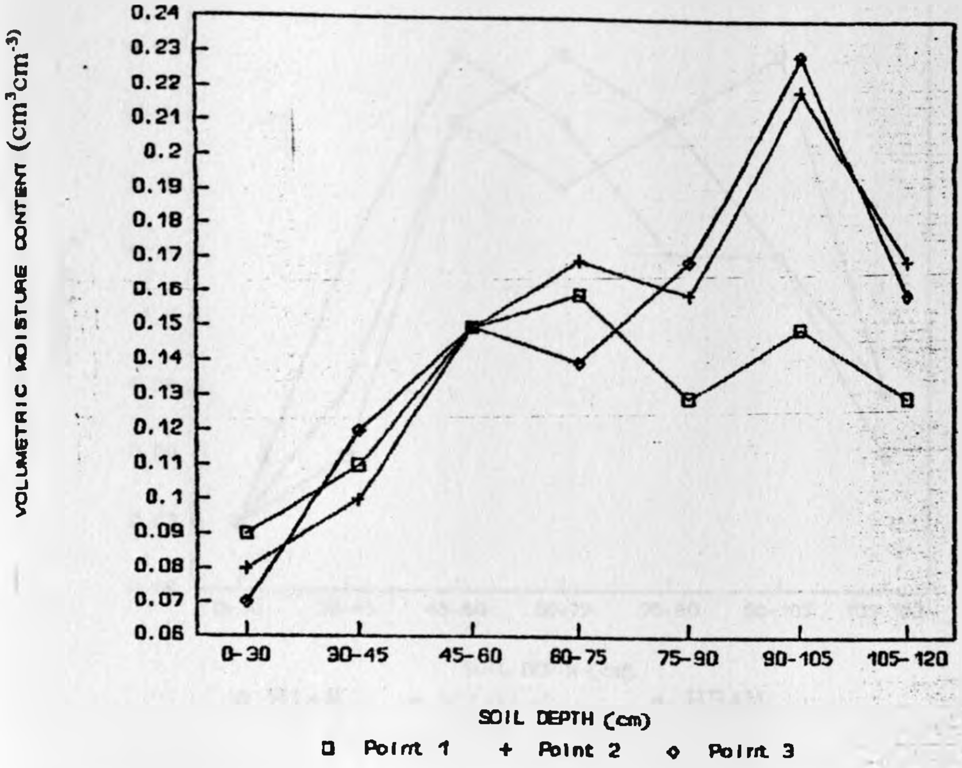


Figure 4.56. Seasonal mean soil moisture levels (at measuring points) +M plot, for the short rains of 93/94.

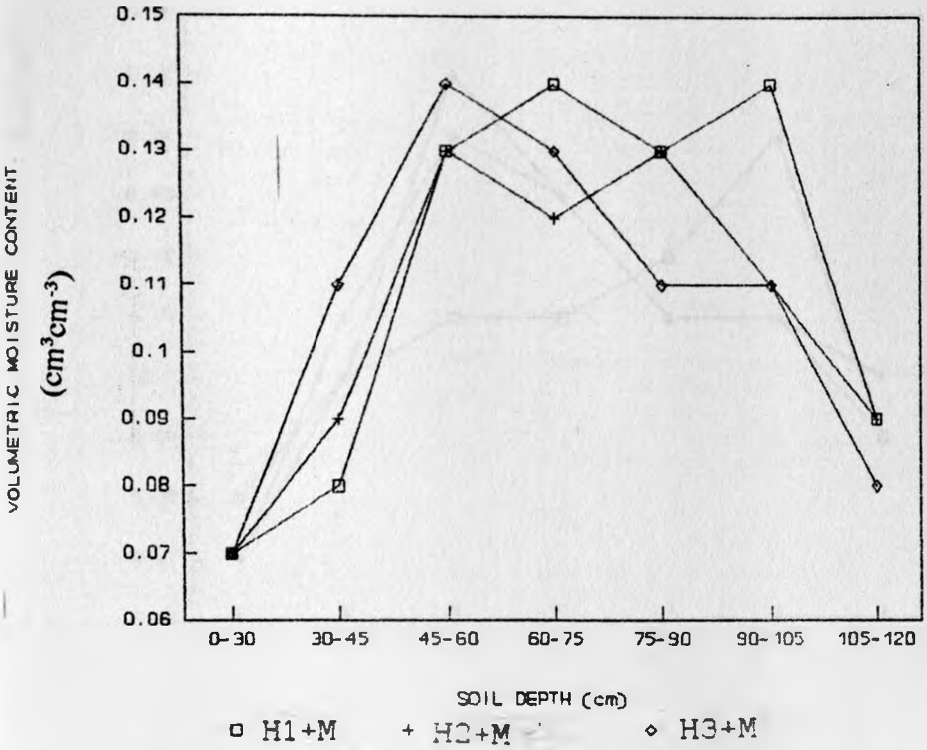


Figure 4.57. Seasonal mean soil moisture levels in the hedge, 1 m from the hedge and 2 m from the hedge. H+M plot for the short rains of 93/94.

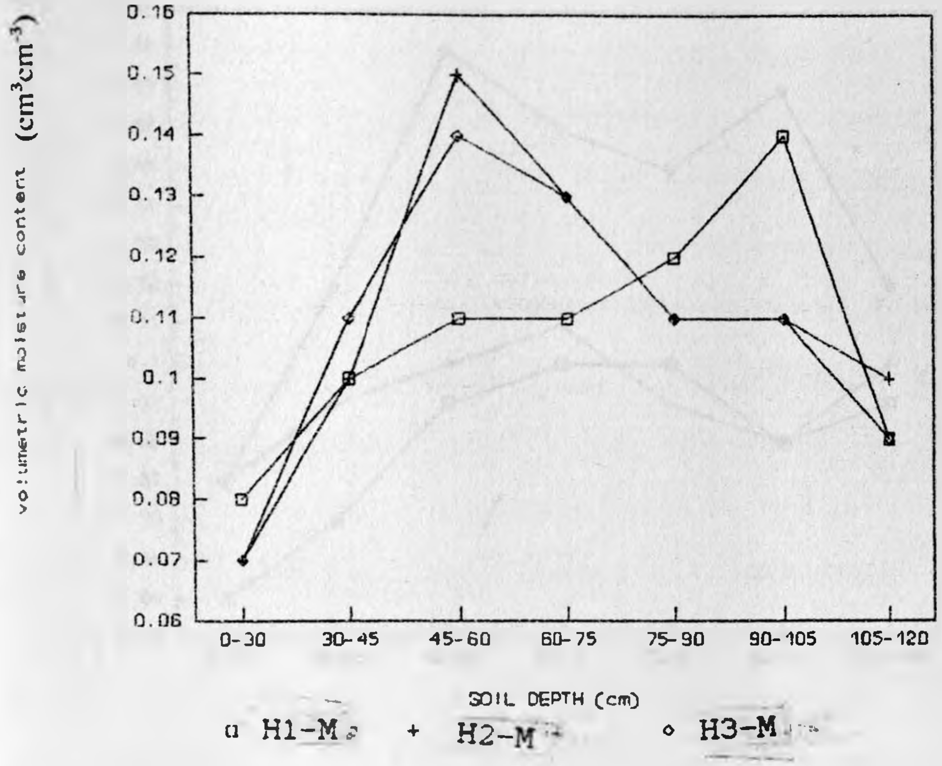


Figure 4.58. Seasonal mean soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H-M plot for the short rains of 93/94.

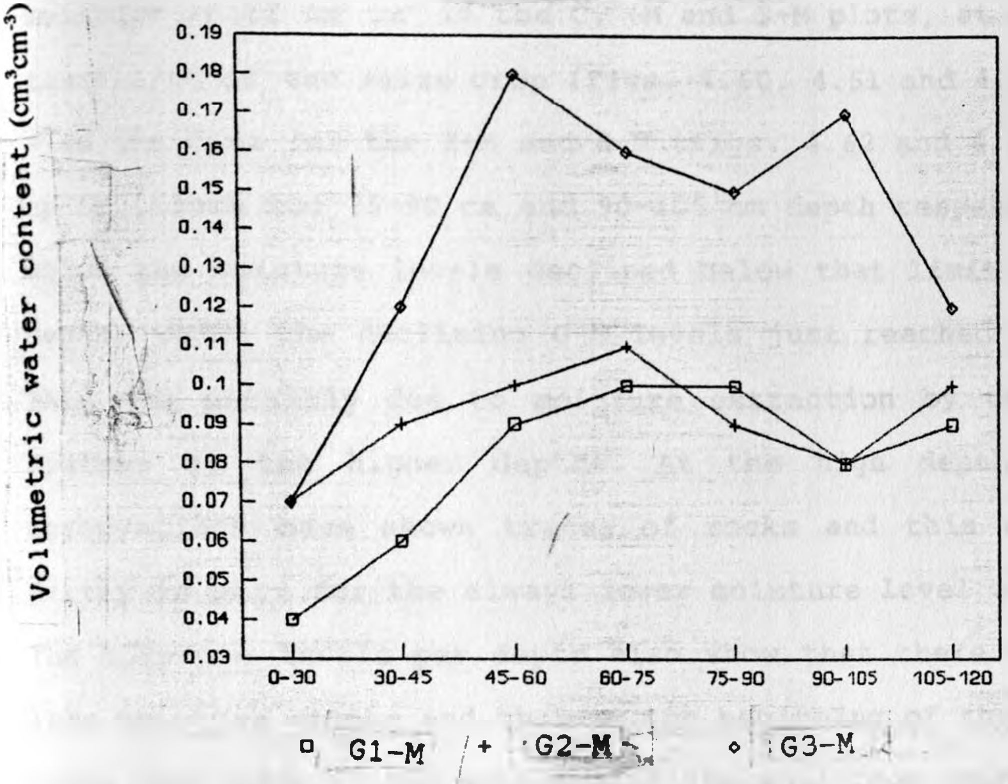


Figure 4.59. Seasonal mean soil moisture levels in grass, 1 m from grass and 2 m from grass. G-M plot for the short rains of 93/94.

4.5.5 Soil moisture for the long rains of 1994.

Figures (4.60-4.64) depict the mean moisture levels as extracted from the season's moisture data analysis. They show that there was moisture >0.12 $cm^3\ cm^{-3}$ in the C, +M and G-M plots, at all depths at tasselling of the maize crop (figs. 4.60, 4.61 and 4.64). This was also the case for the H+M and H-M (figs. 4.62 and 4.63) plots for up to (close to) 75-90 cm and 90-105 cm depth respectively, after which the moisture levels declined below that limit up to 120 cm depth, while the declining G-M levels just reached 0.12 $cm^3\ cm^{-3}$. This was possibly due to moisture extraction by the tree/grass systems at the higher depths. At the high depth of 120 cm, observations have shown traces of rocks and this could account partly in part for the always lower moisture level at this depth. The moisture levels per depth also show that there was generally less moisture at the end than at the beginning of the season. This shows that most of the moisture in the soil from rainfall and part of pre-seasonal storage was in this season taken up by the crop or crop/tree or /grass combination for their growth needs, leaving no more or little soil moisture for storage for the next crop's use. This was due to the seasonal rainfall (242.4 mm) being below average for this area and its distribution over the season.

A soil water balance equation (sections 2.5.3 and 4.5.11) was used during this season to calculate the transpiration (Tr) (see calculation example in section 4.5.11 for Tr) and hence water use efficiency (WUE), in tables (14-16) in section 4.7.7, since soil evaporation (since 1994) and runoff losses had both been measured during this season. Total soil water in the soil profile has been calculated in Table 3, taking into account any anticipated seepage losses (see section 4.5.11 for a calculation example on percolation). In table (vii) in appendix 4.4, it is shown that from weekly measurements volumetric water content in each layer (at the left side of Table (vii) was multiplied by the appropriate depth of that layer (at the right side of Table (vii)) to get mm of soil water storage per layer for that depth interval. For instance, a measurement of 15 mm of water storage in the 4th row and the 9th column of Table (vii) was obtained by multiplying the 1st soil layer of 300 mm by the volumetric water content of $0.05 cm^3 cm^{-3}$ (column 2) for that depth. The sum of the water storages in mm in each of the seven layers gave the total water storage in the soil profile of 120 cm as shown in the last column of Table (vii). This is because the seven depths comprised the average 1.2 m rooting depth at the experimental site.

From table (vii) in appendix 4.4, also showing the volumetric water content at each depth (at the left side of the Table (vii), it is checked by inspection of the volumetric water results whether the volumetric water content exceeds the FC for each soil depth. If the soil moisture content in any of the depths exceeds the field capacity for that depth, then the surplus or excess soil moisture after subtracting FC is recorded as water loss through percolation. For instance, there was no percolation at 0-30cm since no volumetric water content exceeded the calculated FC of 0.26cm^{3}cm^{-3} for that depth in column 2. In columns 3 to 7 representing the 30-105 cm depth, in table (vii) also, no volumetric water content in those columns exceeded the calculated FC of 0.34 cm^{3}cm^{-3}. In column 8 the volumetric water content throughout the season did not exceed the calculated FC of 0.32cm^{3}cm^{-3} for the depth 105-120 cm depth. This means that no water loss was recorded, using only probe measurements taken once a week. We do not know whether any percolation of water occurred during periods without measurements. We can only therefore assume from the measurements that no losses occurred. The sum of all the percolation losses from each depth were added together for each plot for the whole season, to get seasonal percolation losses for these plots in mm of soil water. As there were no percolation in 1994 long rainy season, see calculation example for percolation in section 4.5.11 for 94/95 rainy season. The seasonal percolation losses were then subtracted from the value of ET sections 5.3 and 4 and 4.5.11 (see water balance equation also in section 4.5.11). The value of ET was obtained from seasonal probe readings from the calculations of soil water storage obtained by making adjustments for the rainfall received into the soil during the crop's growth period, as shown in table (viii) in appendix 4.3 for the calculation example. For instance, to get ET from Table (viii) in appendix 4.3, rain water of 35.8 mm is added to the soil water of 163.5 mm and then the following week's soil water of 172.5 mm is subtracted to give 26.8 mm as shown in the last column of Table (viii) in appendix 4.3.

Since seasonal runoff (Rn) for each treatment was recorded in section 4.3, this figure was also subtracted from (P to get) the value of ET above. Still there is the value of seasonal water loss via soil evaporation (Es) in (section 4.6 a for calculation example) which, when subtracted from the ET will now give the transpiration (Tr) which is used in crop production and calculation of water use efficiency, as earlier mentioned. The negative values in Table (viii) at the end of the season are expected as the soil was getting drier at harvest. Other low values especially in week 8 which was wet may have been due to suspected percolation as rains occurred earlier in week 8 before neutron probe measurements were taken and this error will also affect the Tr value later on.

Table 3. Weekly moisture storage (mm) long rains, 1994.

WEEK	C	+ M	H+M	H-M	G-M
1	171.0	163.5	66.0	87.0	87.0
2	192.0	172.5	99.0	124.5	133.5
3	172.5	166.5	67.5	79.5	106.5
4	169.5	151.5	64.5	76.5	82.5
5	168.0	177.0	91.5	103.5	99.0
6	180.0	159.0	69.0	97.5	88.5
7	171.0	163.5	64.5	84.0	82.5
8	171.0	163.5	79.5	78.0	85.5
9	255.0	237.0	177.0	190.5	193.5
10	225.0	207.0	138.0	141.0	150.0
11	196.5	186.0	102.0	109.5	121.5
12	183.0	165.0	85.5	97.5	114.0
13	180.0	153.0	88.5	93.0	106.5
14	165.0	138.0	73.5	76.5	109.5
15	145.5	115.5	55.5	61.5	90.0
16	132.0	105.0	55.5	57.0	90.0
17	124.0	99.0	48.0	58.5	82.5
18	120.0	88.5	48.0	46.5	78.0
19	115.5	79.5	46.5	40.5	61.5
20	105.0	70.5	45.0	39.0	69.0
21	115.5	76.5	45.0	40.5	67.5
22	105.0	67.5	45.0	39.0	55.5

Using the analysed data for the season, the moisture levels at each depth in each plot were extracted. The seasonally averaged moisture levels per depth at the six (three pairs) of measuring points showed that there were higher moisture values beneath the hedgerows H+M; H-M compared to 1 and 2 m away from the hedgerows respectively (figs. 4.67 and 4.68). In the G-M plot, however, there was more moisture at G3-M than at G1-M and G2-M respectively (Fig. 4.69), for this somewhat below average (242.4 mm) season, as found in the previous season for an average rainy season. In C and +M plots, however, there were variations as earlier observed at the measuring points (figs. 4.65 and 4.66), with increasing differences with depth (after initially closer increasing moisture levels with depth). These average seasonal moisture differences (taken individually over depth in all plots) at the points of measurement, among treatments and depths for the five plots, were statistically significantly different at $P = \leq 0.05$. CV = 52%.

The DMRT used to separate and rank moisture means, averaged over depths for each depth, over the plots (SE = 0.001, LSD 0.004) showed that points 1 and 3 were ranked together while point two was ranked separately. There were statistically significant differences in moisture levels within treatments (LSD = 0.0086; SE = 0.0031) as shown in Table (ix) in appendix 4.5. This table shows that there were statistically significant differences at the points of measurement in the C plot and so the three moisture levels were placed in different ranks, with moisture between plant rows larger than within plant rows. For the +M plot the moisture levels at the three points now with moisture of measurement were also placed in three different rankings, but with the points 2 and 3, very close. Rounding off is sufficient in this last case to provide statistically significantly different values. The H+M plot values showed that the positions 1 and 2 m from the hedge had somewhat less moisture than the also low value in the hedge position, sufficiently so to be placed at different ranks, since the moisture differences were statistically significant. The H-M plot also showed that the position in the hedge had slightly more moisture than the 1 and 2 m from hedge positions, again for low values overall. In summary, there was more moisture in the hedgerows than at 1 and 2 m from the hedgerows in H+M and H-M plots respectively. The case for the G-M was that the position at 2 m from the grass strip (1st rank) had considerably more moisture than the position in the grass strip (2nd rank) and the one 1 m from grass strip (3rd rank), which themselves differed less. Separation and ranking of the individual seven depths for all the five plots gave statistically significant differences among them at LSD = 0.006 SE = 0.002. With the exception of H-M, for the 30-45 cm layer, all two top surface layers and the lowest layer had again lowest moisture values. With some permutations, the other layers had higher moisture values with highest differences among them running from 0.03-0.04 $cm^3\ cm^{-3}$). These differences within plots (LSD = 0.013; SE = 0.005) are shown in Table (x) in appendix 4.5. From this table also those moisture means which were ranked together had no statistically significant differences but there were statistically significant differences between different ranks. The picture confirmed from this table is that the C and +M plots had generally higher moisture levels than the AF and G-M plots. This must have been due to the presence of crop/tree or crop/grass combinations which compete for water among other growth resources.

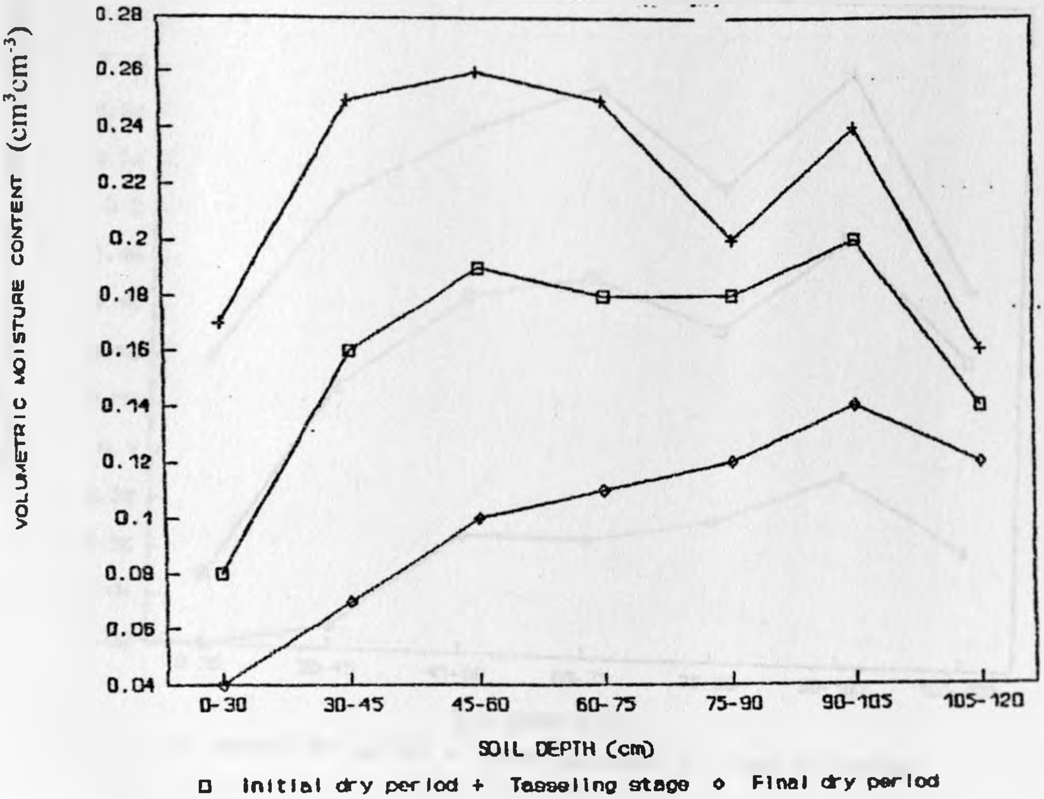


Figure 4.60. Soil mean moisture levels at planting, tasselling and harvesting stages. C plot. long rains of 1994.

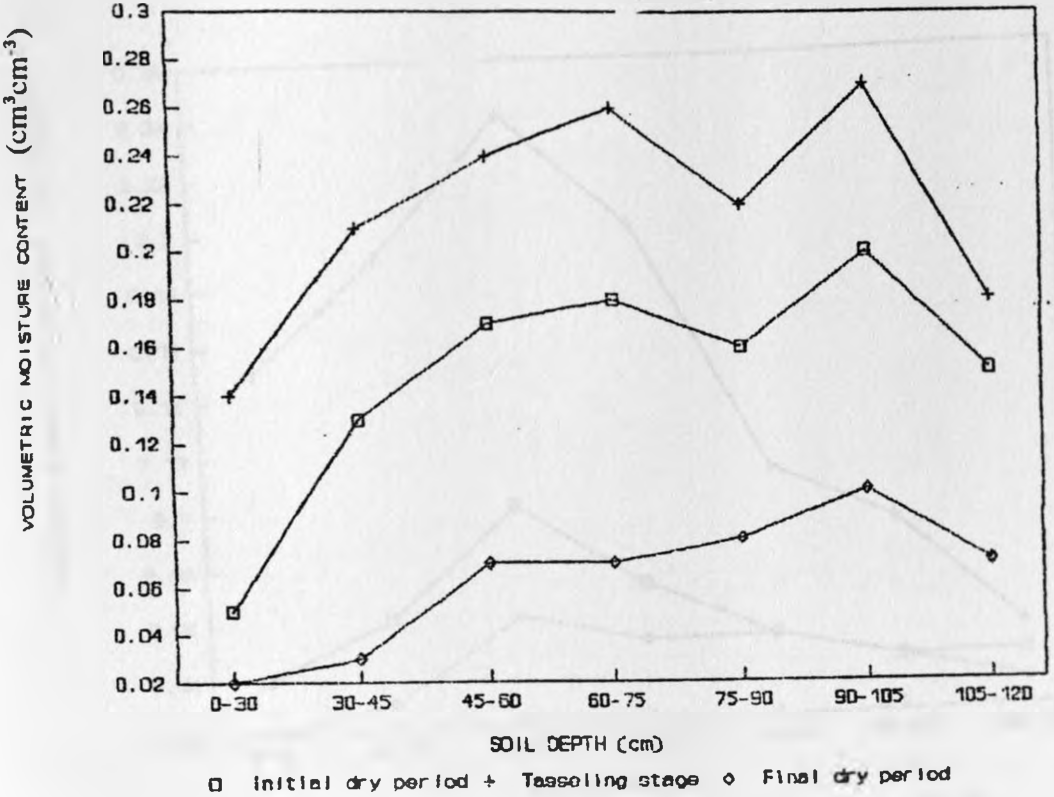


Figure 4.61. Soil mean moisture levels at planting, tasselling and harvesting. +M plot, long rains of 1994.

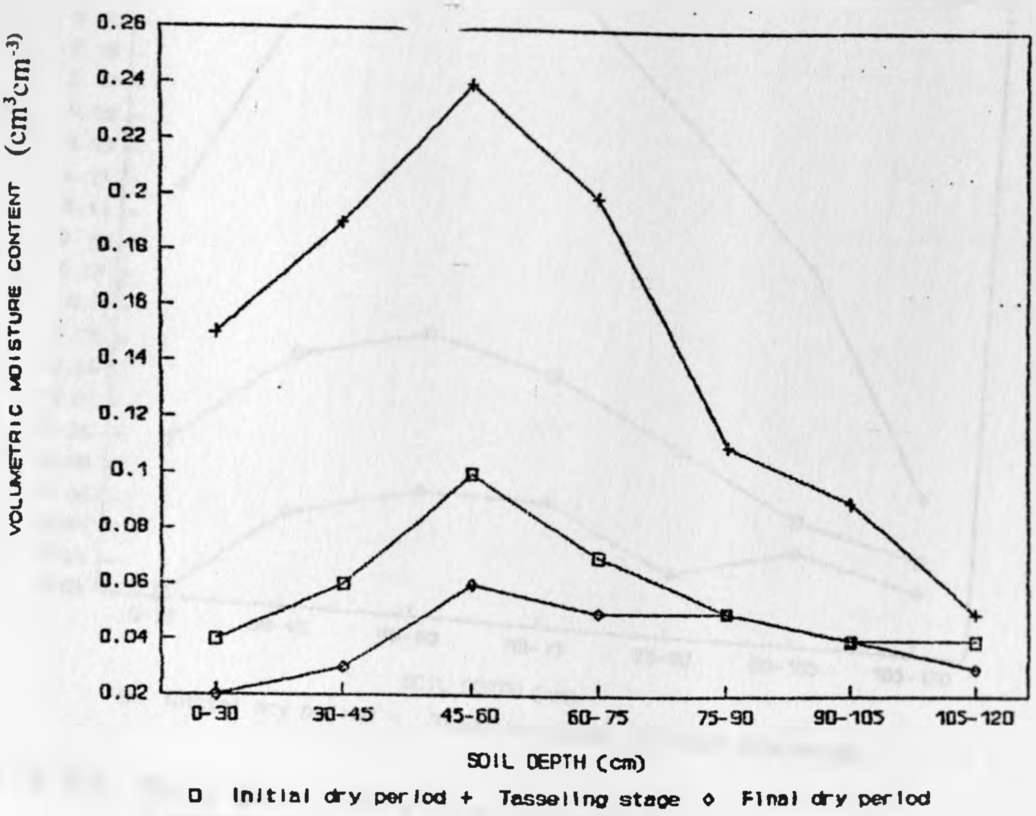


Figure 4.62. Soil mean moisture levels at planting, tasselling and harvesting. H+M plot, long rains of 1994.

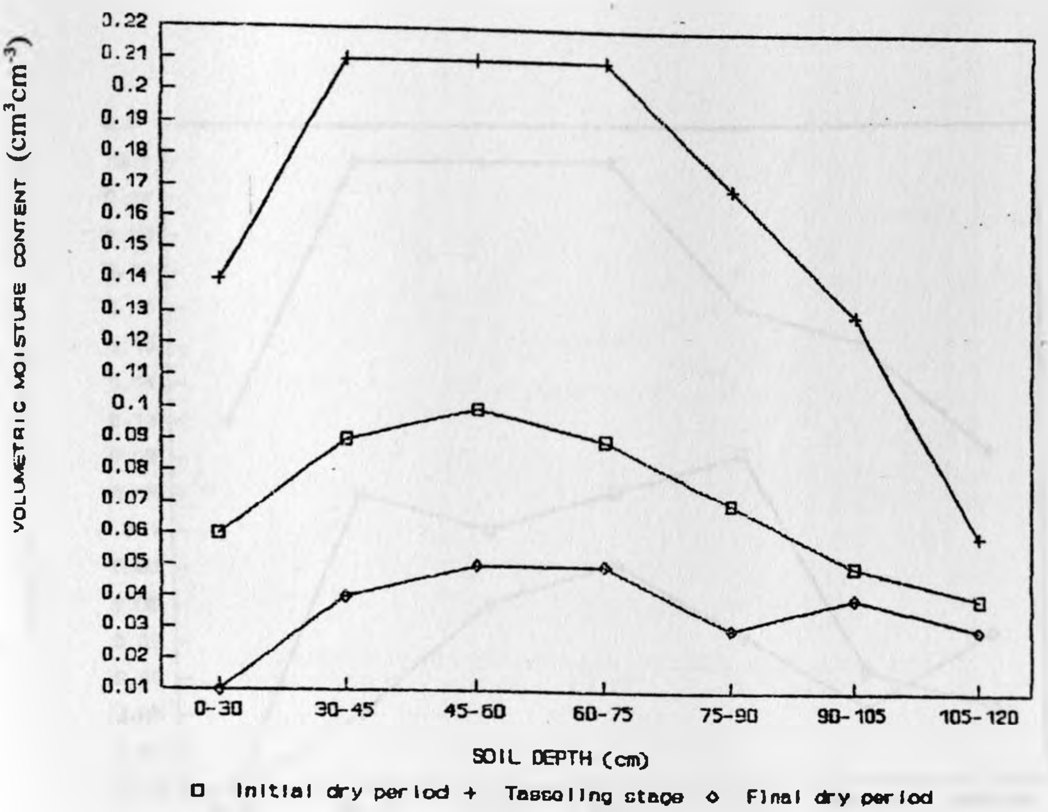


Figure 4.63. Soil mean moisture levels at planting, tasselling and harvesting stages. H-M plot, long rains of 1994.

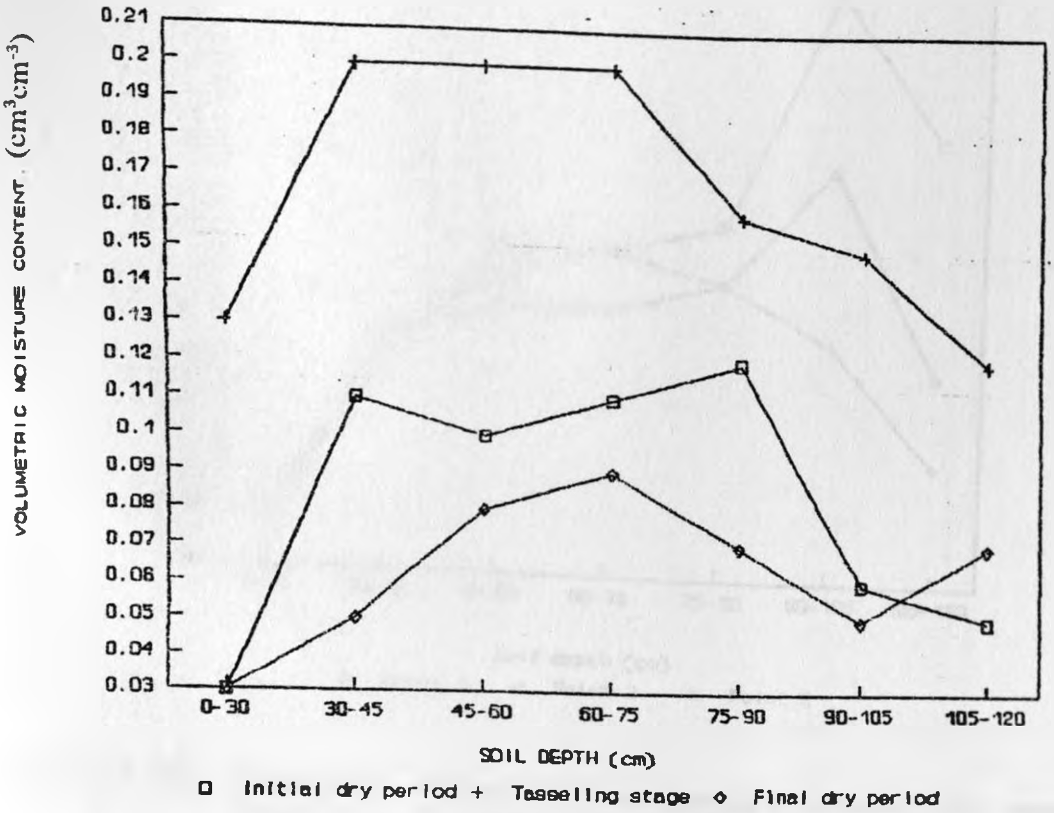


Figure 4.64. Soil mean moisture levels at planting, tasselling and harvesting. G-M plot, long rains of 1994.

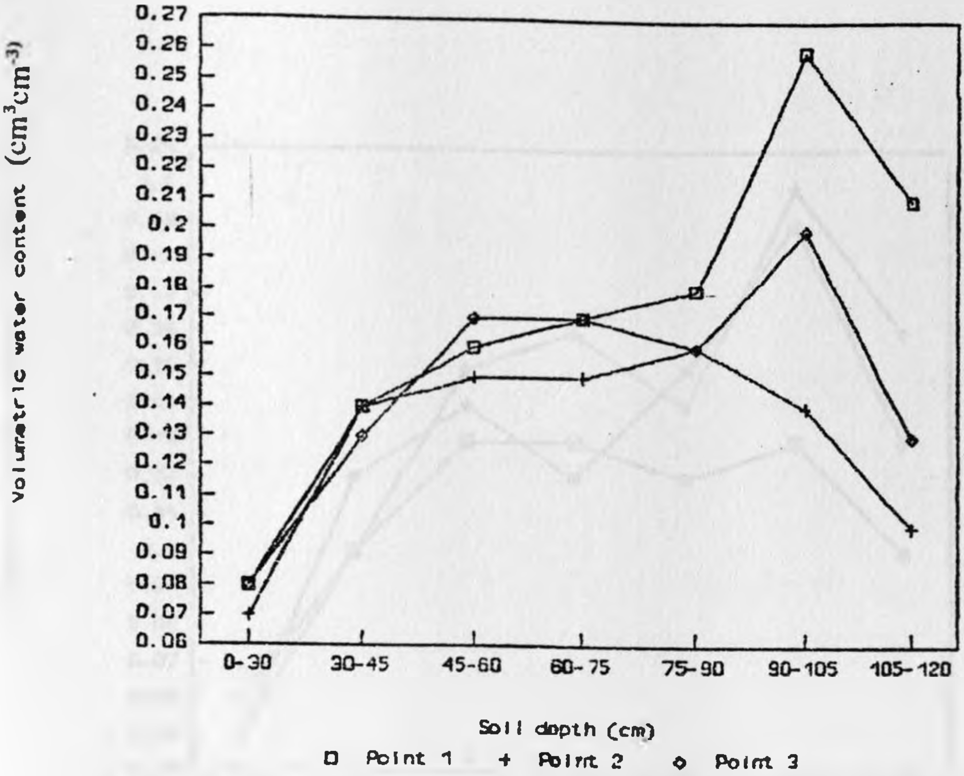


Figure 4.65. Seasonal mean soil moisture levels (at measuring points). C plot, long rains of 1994.

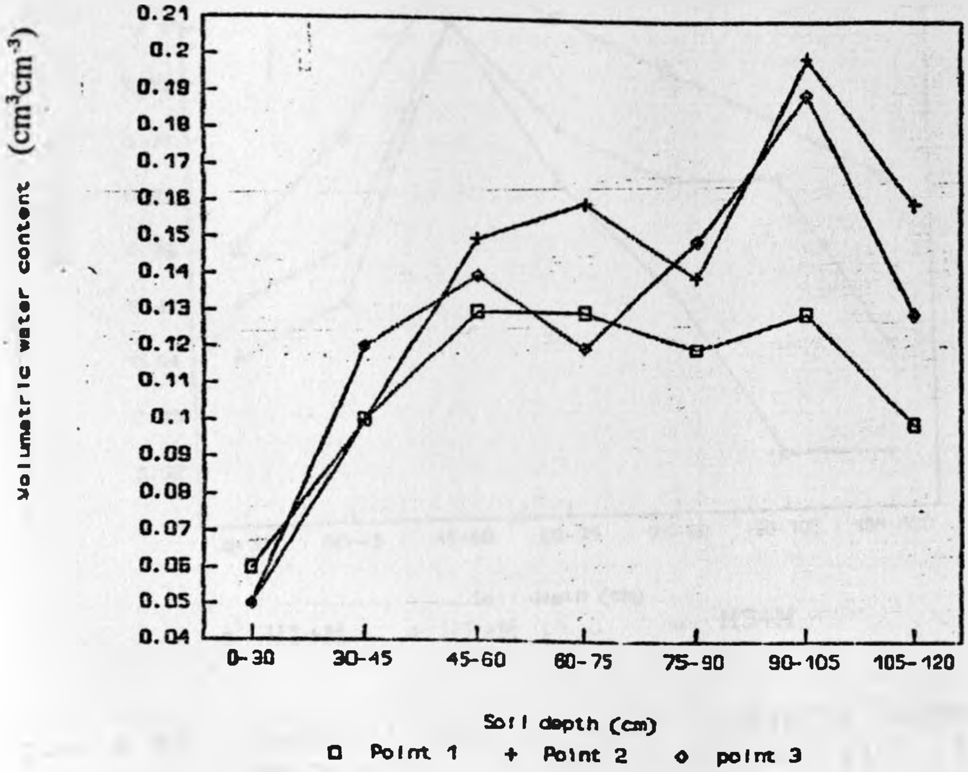


Figure 4.66. Seasonal mean soil moisture levels (at measuring points). +M plot, long rains of 1994.

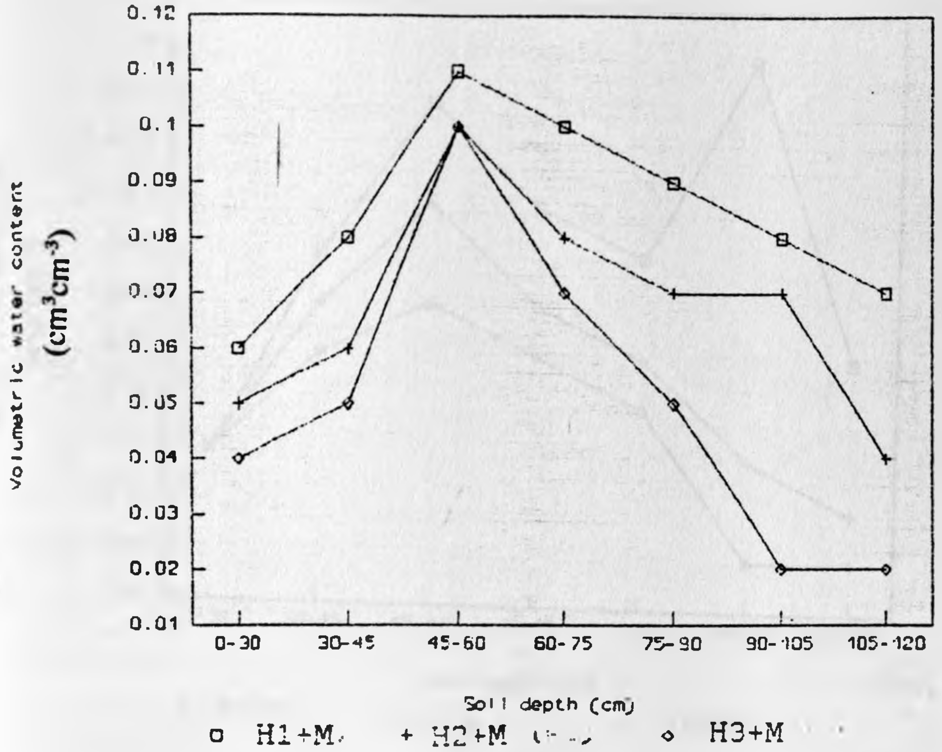


Figure 4.67. Seasonal soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H+M plot, long rains of 1994.

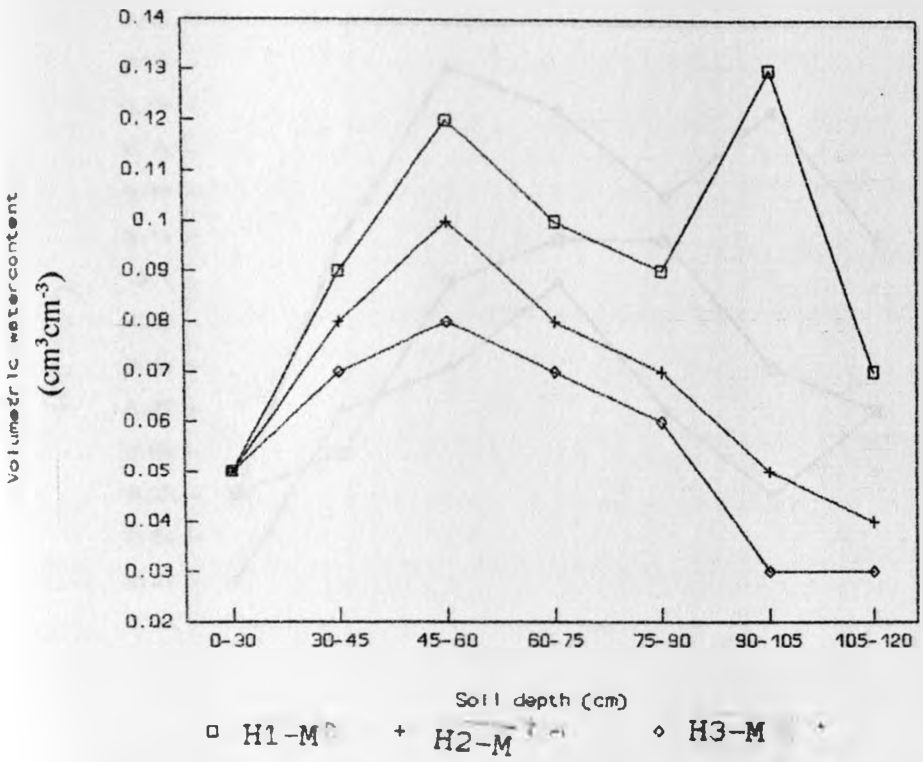


Figure 4.68. Seasonal mean soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H-M plot, long rains of 1994.

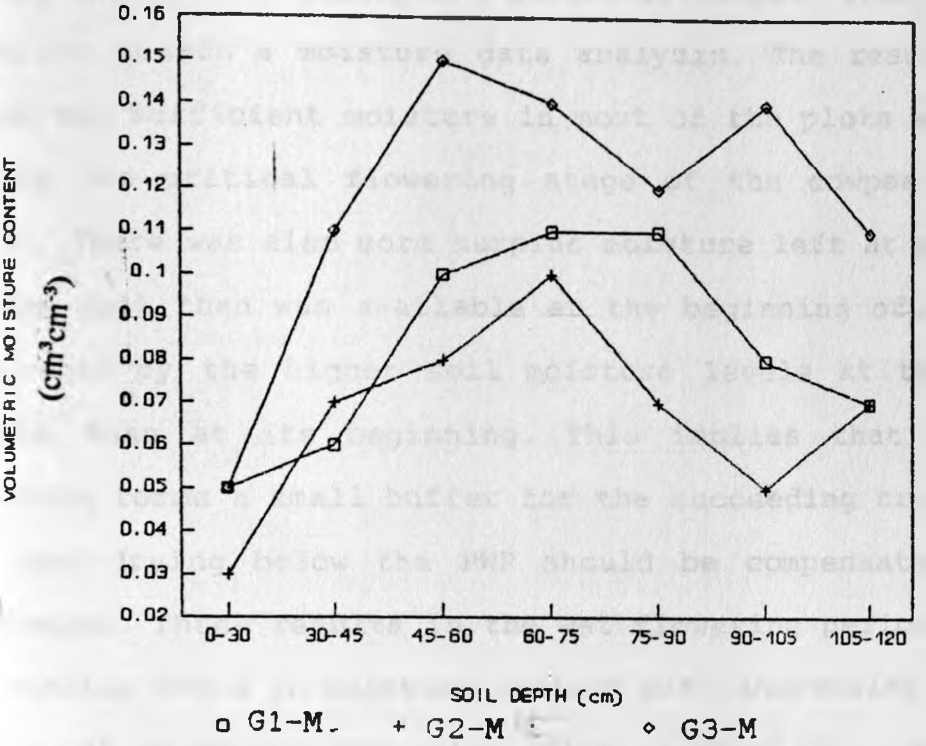


Figure 4.69. Seasonal mean soil moisture levels in grass, 1 m from grass and 2 m from grass. G-M plot, long rains of 1994.

4.5.6 Soil moisture for the short rains of 1994/95.

Figures (4.70-4.74) show the moisture content levels per depth in each plot during the initial dry planting period, the wet flowering period and the dry harvesting period of cowpea. This was extracted from the season's moisture data analysis. The results show that there was sufficient moisture in most of the plots at most depths during the critical flowering stage of the cowpea plant (4.70-4.74). There was also more surplus moisture left at all the depths in the soil than was available at the beginning of the season as indicated by the higher soil moisture levels at the end of the season than at its beginning. This implies that some of this moisture forms a small buffer for the succeeding crop next season as less drying below the PWP should be compensated for at its beginning. These results in the wet flowering period also show an increasing trend in moisture content with increasing soil depth of up to 105 cm before declining (figs. 4.70- 4.74). In the C and +M (figs.4.70. and 4.71) the soil moisture also roughly increased with increasing depths up to 105 cm during the other periods. In the H+M (fig. 4.72.), H-M (fig. 73), and G-M in (fig. 74), however, the soil moisture levels only increased with depth during the dry periods for up to 60 cm, before mildly declining or levelling off, with the exception of a continuing mild rise for the driest period in G-M.

In order to get the total soil moisture picture in the 120 cm soil profile in each treatment, the weekly mean soil moisture from the seasons moisture analysis was used and later on applied in a soil water balance as explained in section 4.5.5. The soil moisture storage results are shown in Table 4 below.

Table 4. Weekly moisture storage (mm) short rains 94/95

WEEK	C	+M	H+M	H-M	G-M
1	103.5	70.5	51.0	45.0	67.5
2	105.0	69.0	52.5	48.0	58.5
3	150.0	120.0	93.0	103.5	116.0
4	150.0	111.0	102.0	109.5	90.0
5	142.5	99.0	91.5	90.0	72.0
6	220.5	193.5	166.5	189.0	180.0
7	337.5	279.0	310.5	277.5	282.0
8	280.5	241.5	243.0	213.0	253.5
9	292.5	249.0	247.5	225.0	267.0
10	352.5	285.0	289.5	262.5	282.0
11	330.0	256.5	261.0	355.0	280.5
12	273.0	217.5	205.5	190.5	219.0
13	297.0	243.0	237.0	201.0	228.0
14	297.0	243.0	226.5	210.0	240.0
15	238.5	211.5	175.5	168.0	201.0
16	204.0	199.5	127.5	133.5	180.0
17	172.5	183.0	123.0	102.0	157.5
18	144.0	165.0	91.5	87.0	136.5

The seasonal mean soil moisture values from the six (that is three pairs of) measuring points for each treatment in the seasonal moisture analysis, showed that there was somewhat more moisture at the measuring points beneath the hedgerows than at the 1 and 2 m away from the hedgerows at 0-30 cm, 45-60 cm, 60-75 cm and 75-90 cm depths in H+M and in 0-30 cm, 75-90 cm and 90-105 cm depths in H-M (figs. 4.77 and 4.78), while there was more moisture at 2 m from grass strip than beneath the grass strip respectively, especially at the 30-45 cm, 45-60 cm and 60-75 cm depths (figs. 4.79). Although not particularly clear as to the pattern, this was most likely due to runoff water accumulating at the hedgerow barrier and infiltrating into the soil below in the H+M and H-M plots. For the G-M plot, severe competition for moisture by the grass roots at G1-M may be one of the reasons for higher moisture levels in the alley. There were the usual variations at the measuring points in the C and +M plots, with differences increasing with increasing depth as earlier found (figs. 4.75 and 4.76). On the whole, however, the pattern of moisture levels at the measuring points appear unclear for these two plots. When subjected to ANOVA, the average seasonal moisture differences (taken individually over depth in all plots) among treatments, and depths for the five plots and at the points of measurement were statistically significant at $P \leq 0.05$. CV = 36.8%.

Ranking these average seasonal means averaged over depth at the measuring points, via DMRT, showed that the positions 2 and 3 in the points of measurement were together ranked in second place and the 1st position was ranked 1st. The differences in moisture levels within treatments were statistically significant (LSD = 0.01; SE = 0.04) as shown in Table (xi) in appendix 4.5. From this table, the C plot had its 1st point of measurement between plant rows with more moisture ranked 1st, with the 2nd and 3rd points of measurement within plant rows with less moisture ranked together in second place. The +M plot had the 1st point of measurement (between plant rows) with less moisture ranked 2nd while the 2nd and 3rd points of measurement (within plant rows) with more moisture were ranked 1st. The H+M plot results have the position 2m from the hedge ranked 2nd, with less moisture than the positions 1m from the hedge and in the hedge, ranked 1st. The case for the H-M plot was that there were no differences among the three points of measurement. In the G-M plot, the position 1m from the grass strip (ranked 2nd) had less moisture than the positions 2m from the grass strip and within the grass strip, that were with more moisture, ranked 1st, together.

The average seasonal moisture levels at different depths over the five plots were statistically significantly different at $P \leq 0.05$, SE = 0.003, LSD = 0.007. When the individual means at each depth were separated and ranked, as earlier done, there was no clear cut picture, although layers nearer the surface and at the highest depth were often highest in moisture content, while there was similar medium level moisture content in the middle depths, where most of the cowpea/senna or grass roots are. These differences in moisture levels in depths within treatments at (LSD = 0.016 and SE = 0.006) are ranked and shown in Table (xii) in appendix 4.6. From this table also those moisture means which were ranked together had no statistically significant differences but there were statistically significant differences between different ranks. The general moisture levels for all depths in the five plots were generally high, with only exceptions at the 75-105 cm levels, as the season had above average rainfall.

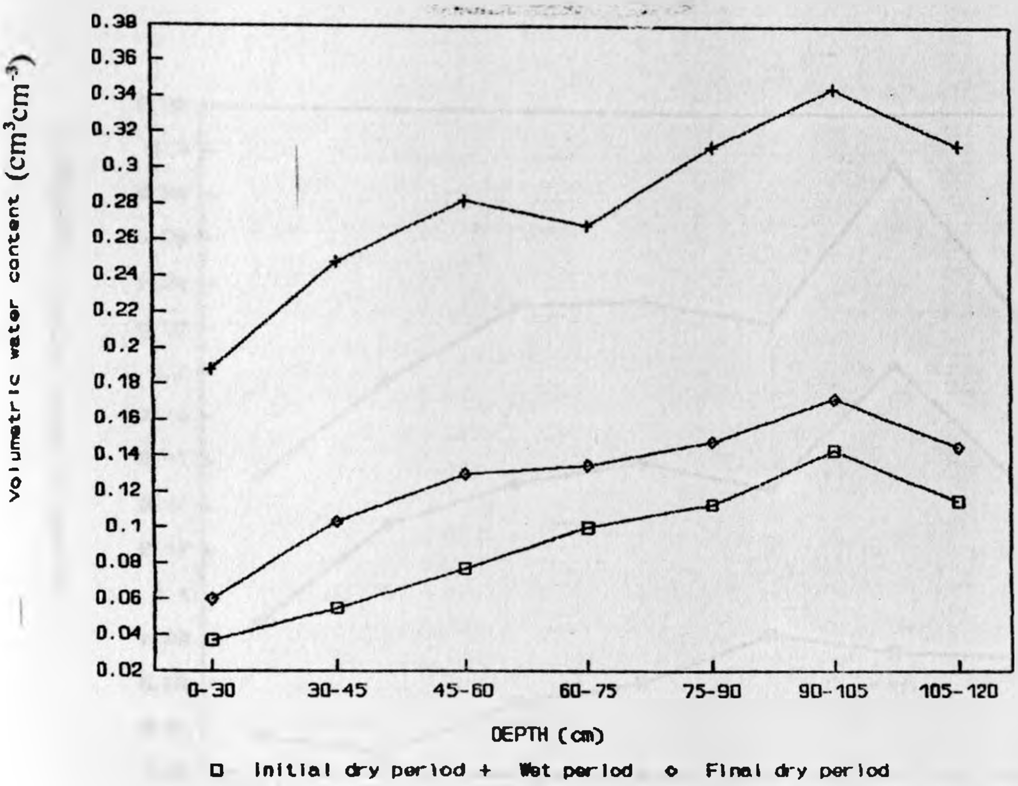


Figure 4.70. Soil moisture levels at planting, flowering and harvesting stages. C plot, short rains of 94/95.

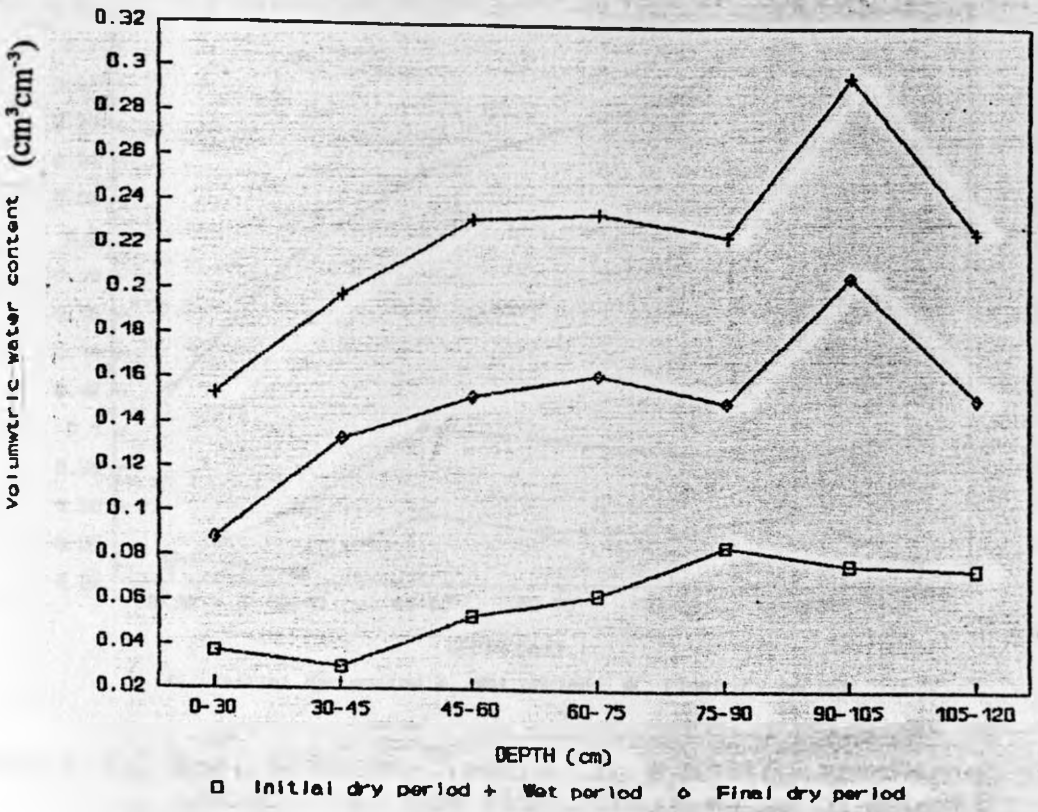


Figure 4.71. Soil moisture levels at planting, flowering and tasselling. +M plot, short rains of 94/95.

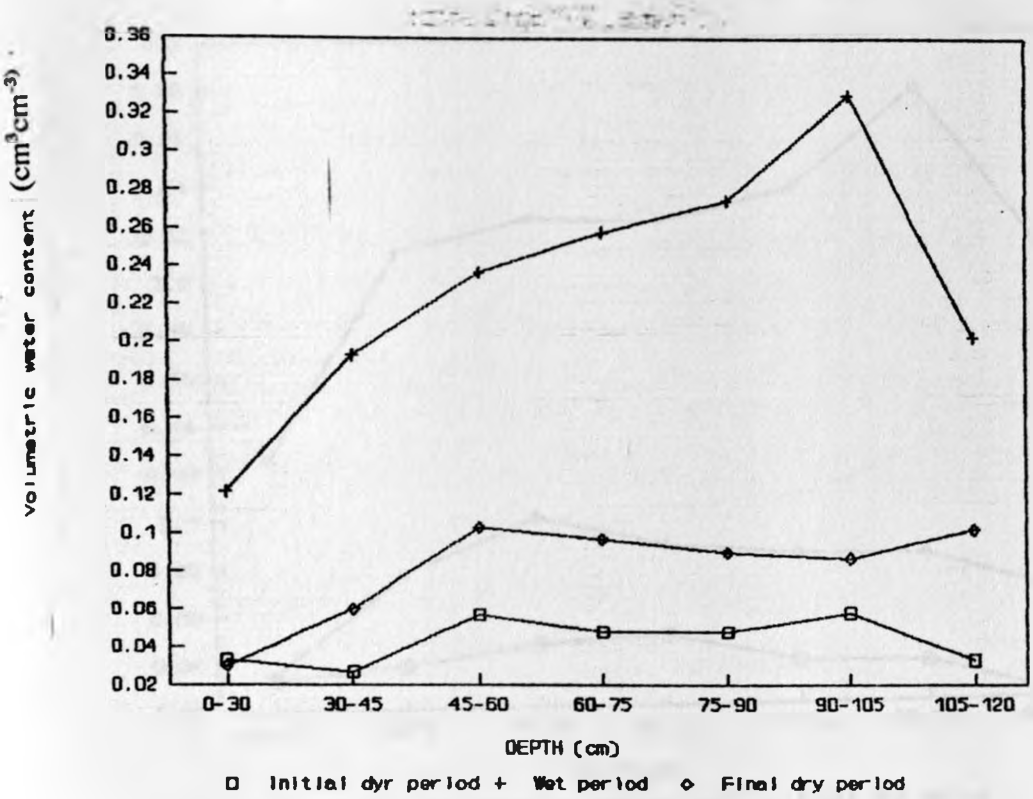


Figure 4.72. Soil moisture levels at planting, flowering and harvesting. H+M plot, short rains of 94/95.

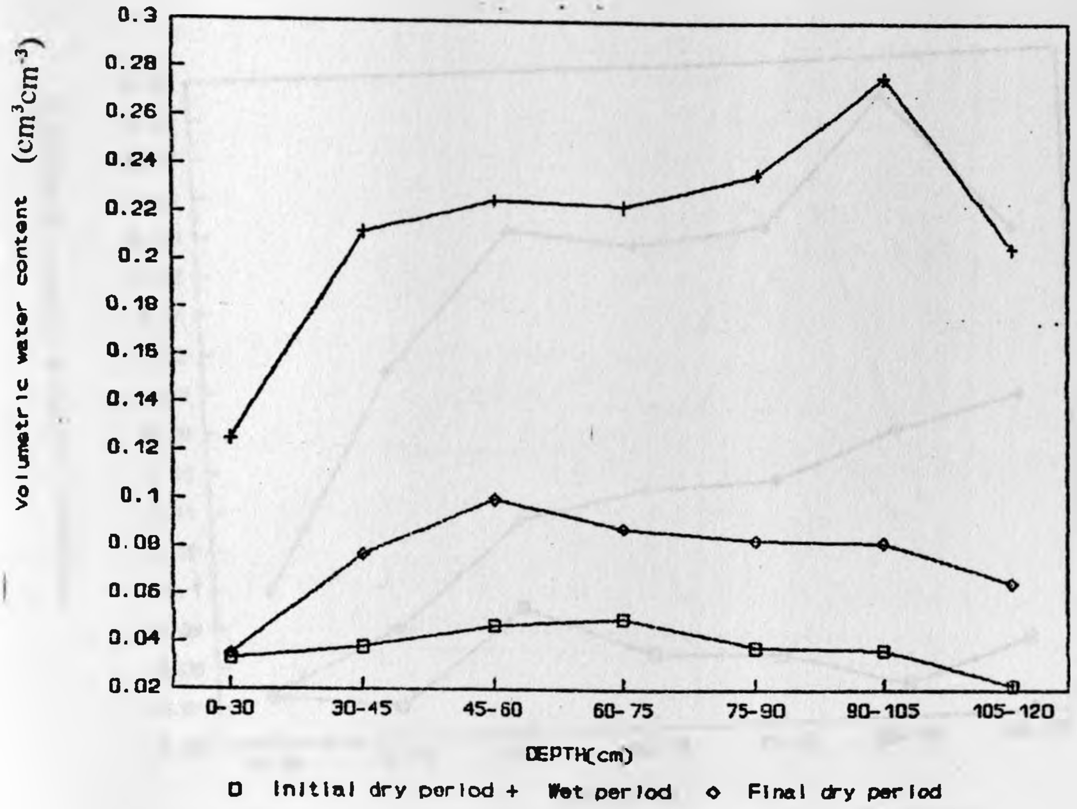


Figure 4.73. Soil moisture levels at planting, flowering and harvesting stages. H-M plot, short rains of 94/95.

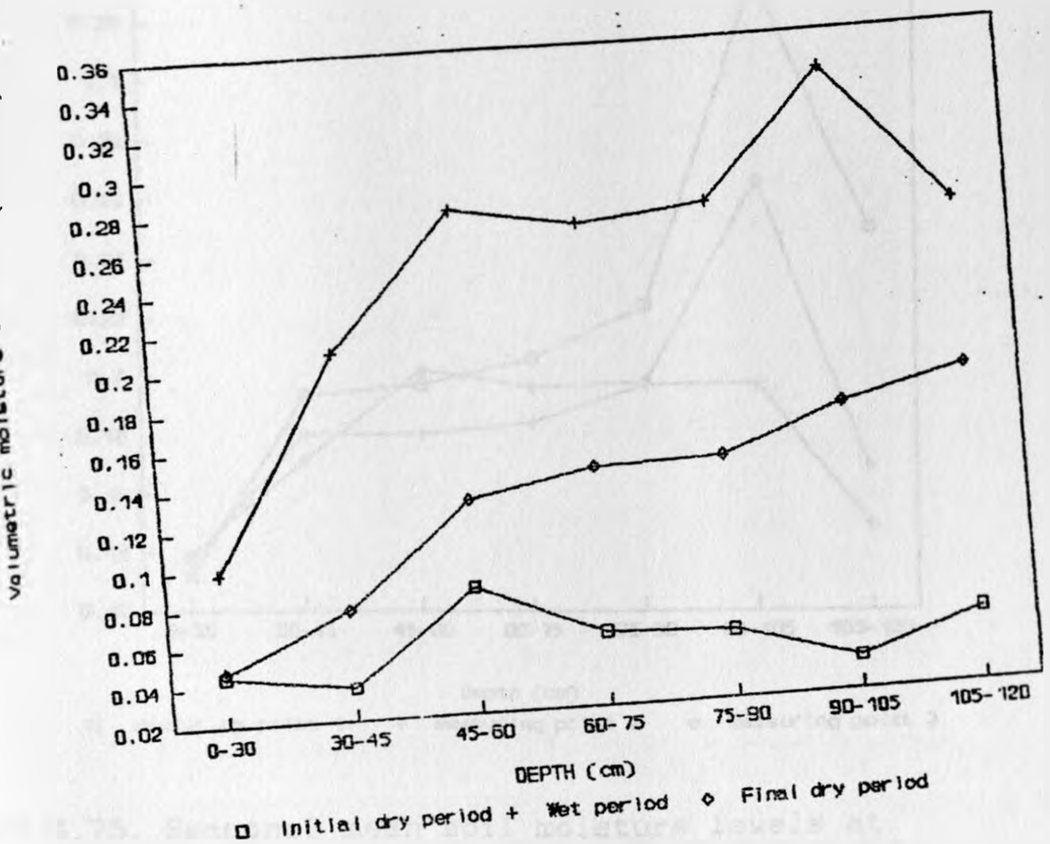


Figure 4.74. Soil moisture levels at planting, flowering and harvesting stages. G-M plot, short rains of 94/95.

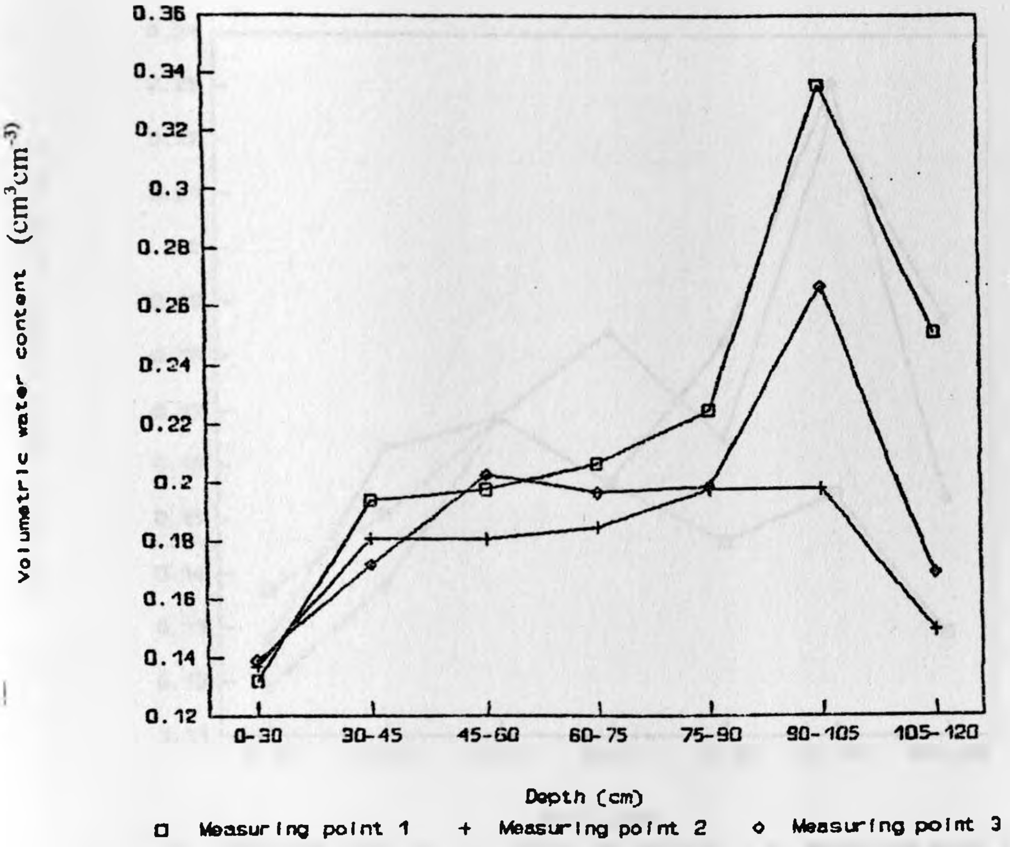


Figure 4.75. Seasonal mean soil moisture levels at three measuring points, C plot for the short rains of 1994/95.

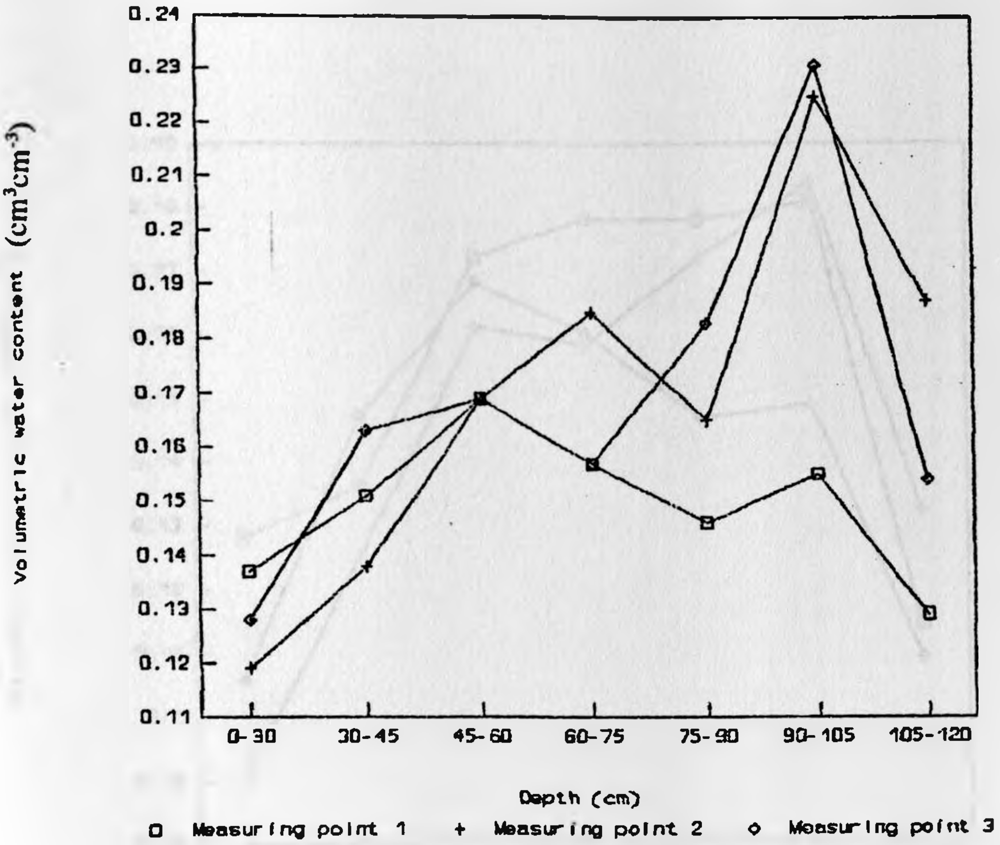


Figure 4.76. Seasonal mean soil moisture levels at three measuring points, +M plot for the short rains of 1994/95.

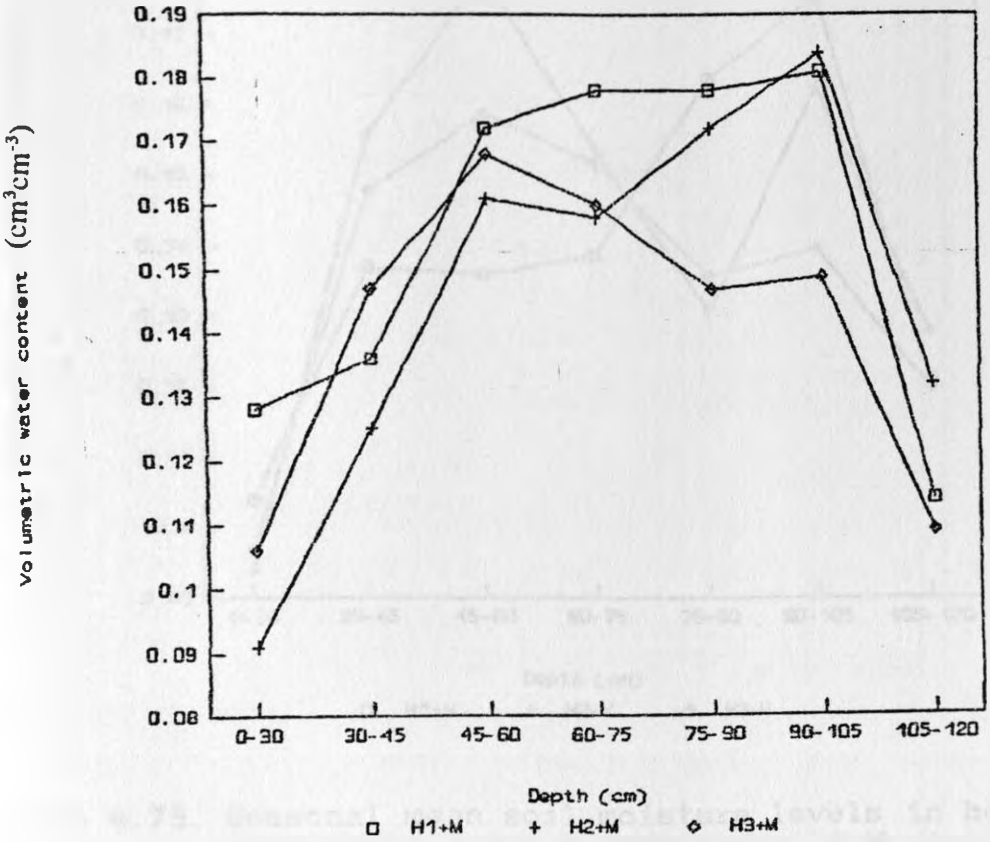


Figure 4.77. Seasonal mean soil moisture levels in the hedge, 1 m from the hedge and 2 m from the hedge. H+M plot, for the short rains of 1994/95.

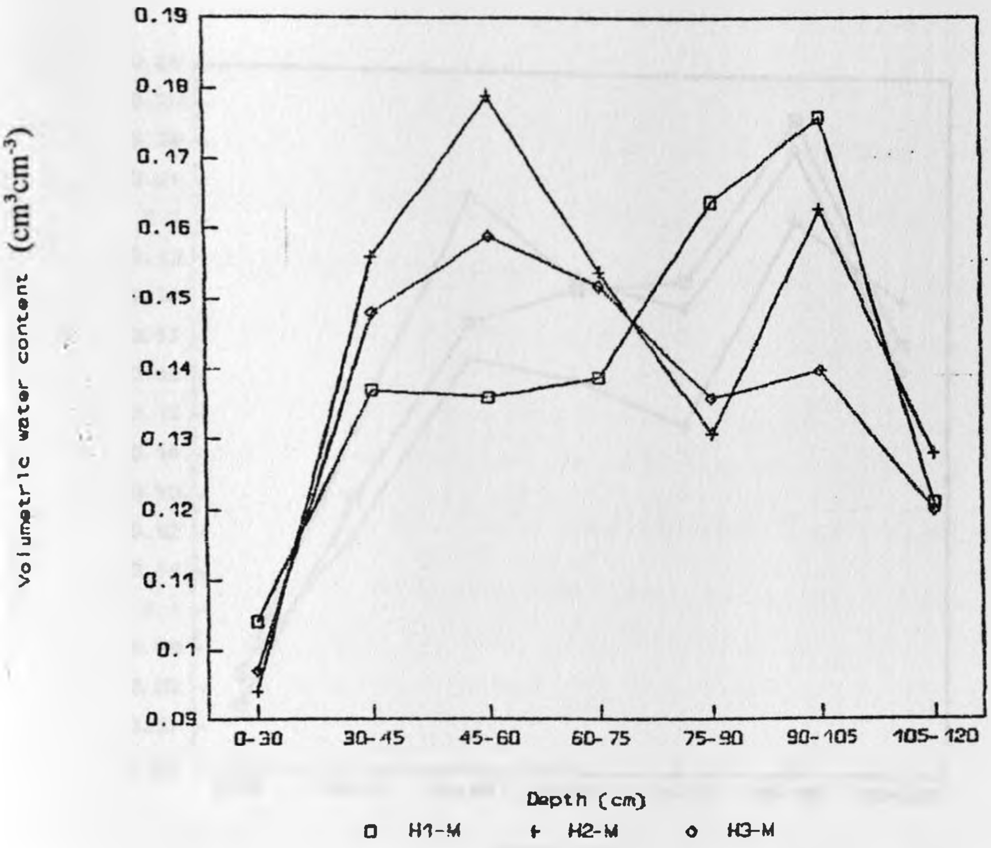


Figure 4.78. Seasonal mean soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H-M plot, for the short rains of 1994/95.

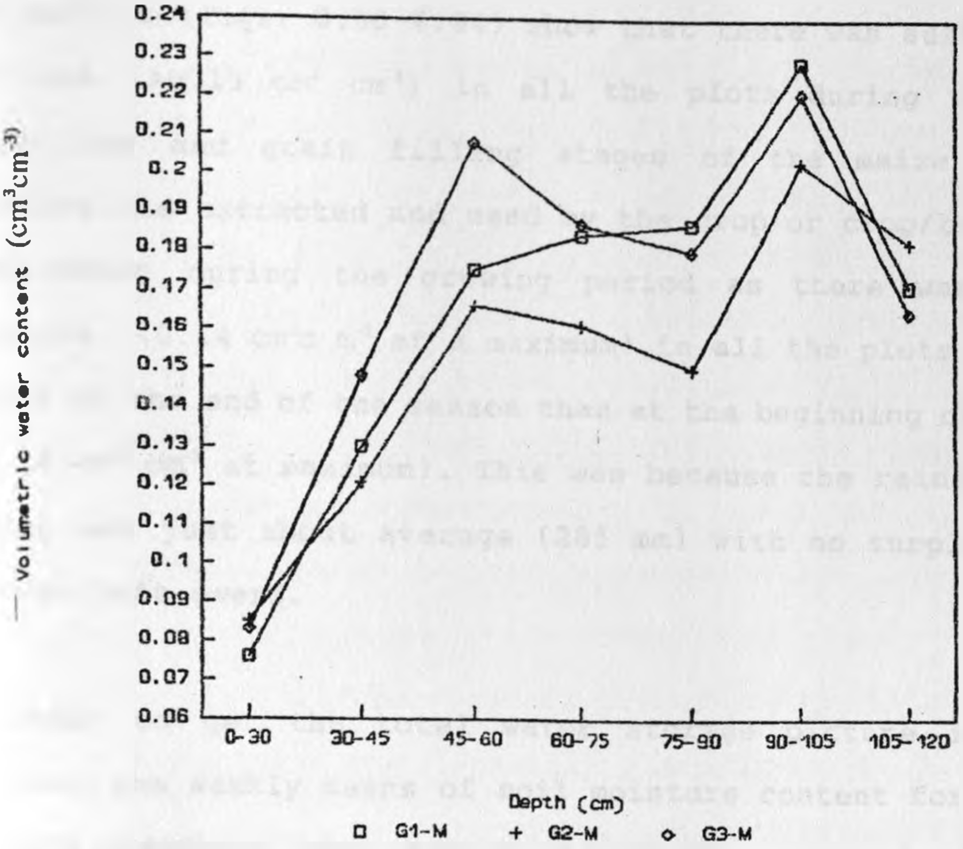


Figure 4.79. Seasonal soil moisture levels in grass, 1 m from grass and 2 m from grass. G-M plot, for the short rains 1994/95.

4.5.7. Soil moisture long rains, 1995.

Figures 4.80-4.84 depict a part of the extracted seasonal moisture data to show moisture levels at planting, flowering and harvesting. The results (figs. 4.80-4.84) show that there was sufficient soil moisture (>0.15 cm^3 cm^{-3}) in all the plots during the critical tasselling and grain filling stages of the maize crop. This moisture was extracted and used by the crop or crop/tree or grass combination during the growing period as there was less soil moisture (<0.14 cm^3c m^{-3} at a maximum) in all the plots at all soil depths at the end of the season than at the beginning of the season (<0.16 cm^3 cm^{-3} at maximum). This was because the rainfall for the season was just about average (285 mm) with no surplus for soil storage left overs.

In order to get the total water storage picture in the soil profile, the weekly means of soil moisture content for each depth in each treatment were multiplied by the appropriate depth and added together to get the seasonal soil moisture storage distribution in the 120 cm soil profile as in Table 5. To get water used for maize dry matter production in the season (Tr), the soil water stored in the profile was adjusted after adding measured weekly rainfalls, removing measured water losses via runoff, measured water losses via soil evaporation as well as calculated water losses via deep percolation (see also section 4.5.10). This value of (Tr) was then used to calculate water use efficiency for the maize crop (see section 4.7.7).

The seasonal moisture means were used to show moisture trends in each plot, depth and point of measurement. The moisture levels at the points of measurement indicate that there was somewhat more or equal moisture beneath the hedgerow barrier (at about 0-30 cm, 45-60 cm, 60-75 cm, 75-90 cm, 90-105 cm and 105-120 cm depths) than at 1 and 2 m from the hedgerow (figs. 4.87) and at 75-90 cm, 90-105 cm and 105-120 cm depth (fig. 4.88) in the H+M plot, most likely due to runoff water from the alleys accumulated at the hedgerow barriers. The points at 2 m away from the grass strip had generally more moisture than the point beneath the grass strip (fig. 4.89) as earlier observed. There were variations, rather wildly in the +M plot, at the points of measurements in the C and +M plot (figs. 4.85 and 4.86) as also earlier observed. These average seasonal soil moisture differences (taken individually over depth in all plots at the points of measurement, among treatments and depths for the five plots were statistically significant at $P \leq 0.05$. CV = 51.2%.

Separating and ranking these average seasonal overall plot values averaged over depth, at (statistically significantly different at at LSD = 0.05; SE = 0.002), using DMRT again, groups and ranks 1st the points at the 1st point of measurement and 2nd the 2nd and 3rd points of measurement together. The differences at the points of measurement within the treatments were found statistically significant (LSD = 0.012; SE = 0.004) as shown in Table (xiii) in appendix 4.6. This Table shows that the C plot had its 1st point of measurement (between plant rows), with appreciable more moisture, ranked 1st and the other two points with less moisture ranked 2nd. For the +M plot, the 1st point of measurement (between plant rows) with less moisture was ranked 2nd while the second two points of measurement (within plant rows) with more moisture were ranked 1st. For the H+M plot, the positions in the hedge and 1 m from the hedge had more moisture, jointly ranked 1st, than the position 2 m from the hedge ranked 2nd. The H-M plot had its first two points of measurement with more moisture ranked 1st and the 3rd measuring point with less moisture ranked 2nd. The G-M plot results showed that the moisture levels in the grass strip and 1 m from the grass strip were ranked 2nd together, with the 3rd point of measurement, with more moisture ranked 1st.

The differences in mean seasonal plot averaged moisture levels at individual depths over the plots were found statistically significantly different at $P \leq 0.05$, SE = 0.003, LSD = 0.008. Separation and ranking of the mean moisture levels at each of the seven individual depths showed, with little exception, again the two top layers and the layer sampled at highest depth to contain least moisture, while the middle layers had highest moisture, again with some exceptions or some differences in sequence. These differences in moisture levels at different depths within treatments are shown in Table (xiv) in appendix 4.6. They were found statistically significantly different (LSD = 0.019; SE = 0.007). Separation and ranking of the moisture means by DMRT is shown for each treatment also in Table (xiv) in appendix 4.6. The depths grouped together in one group and rank did not differ statistically significantly in their seasonal average moisture contents, while the depths placed in different ranks had statistically significant moisture differences. It was also clear from the above table that the C and +M plots had generally higher moisture levels than the AF and G-M plots, with somewhat more moisture in the G-M plot than in AF plots.

Table 5. Weekly moisture (mm) storage in the soil profile, long rains 1995

WEEK	C	M	H+M	H-M	G-M
1	147.0	153.0	67.5	91.5	118.5
2	210.0	193.5	118.5	160.5	175.5
3	220.5	193.5	138.0	168.0	172.5
4	202.5	177.0	138.0	132.0	159.0
5	265.5	253.5	195.0	201.0	219.0
6	244.5	208.5	184.5	168.0	166.5
7	240.0	228.0	201.0	181.5	199.5
8	276.0	241.5	226.5	199.5	222.0
9	238.5	222.0	201.0	165.0	201.0
10	226.5	207.0	178.5	144.0	193.5
11	216.0	198.0	172.5	142.5	181.5
12	198.0	189.0	142.5	115.5	162.0
13	159.0	159.0	114.0	103.5	124.5
14	147.0	129.0	99.0	84.0	105.0
15	141.0	126.0	82.5	82.5	108.0
16	123.0	108.0	73.5	63.0	103.5
17	118.0	91.5	64.5	54.0	99.0
18	115.5	96.0	55.5	46.5	91.5

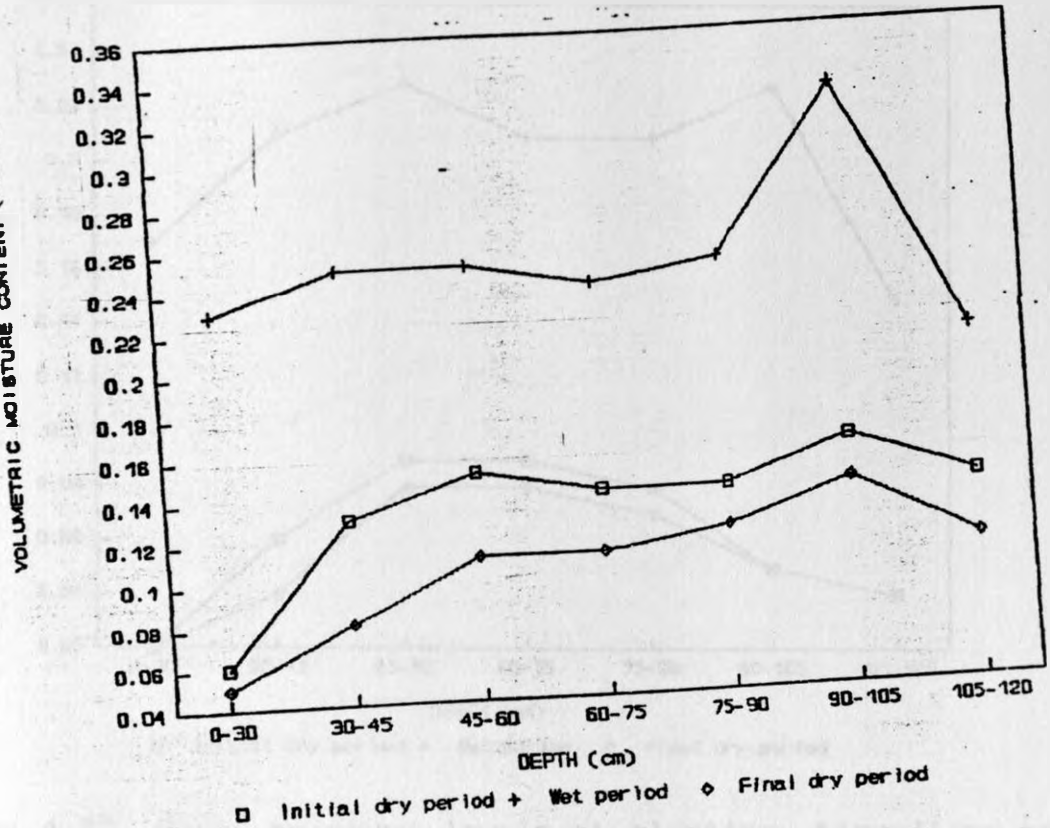


Figure 4.80. Soil moisture levels at planting, tasselling and harvesting. C plot, long rains of 1995 .

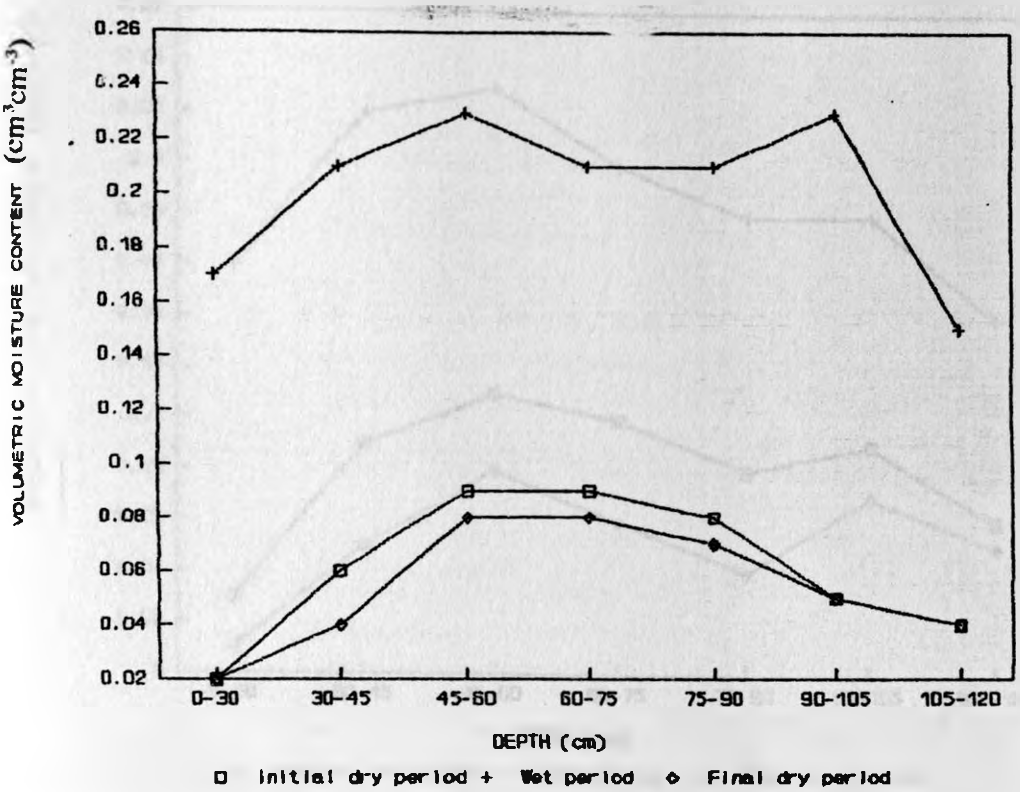


Figure 4.82. Soil moisture levels at planting, tasselling and harvesting stages. H+M plot, long rains of 1995.

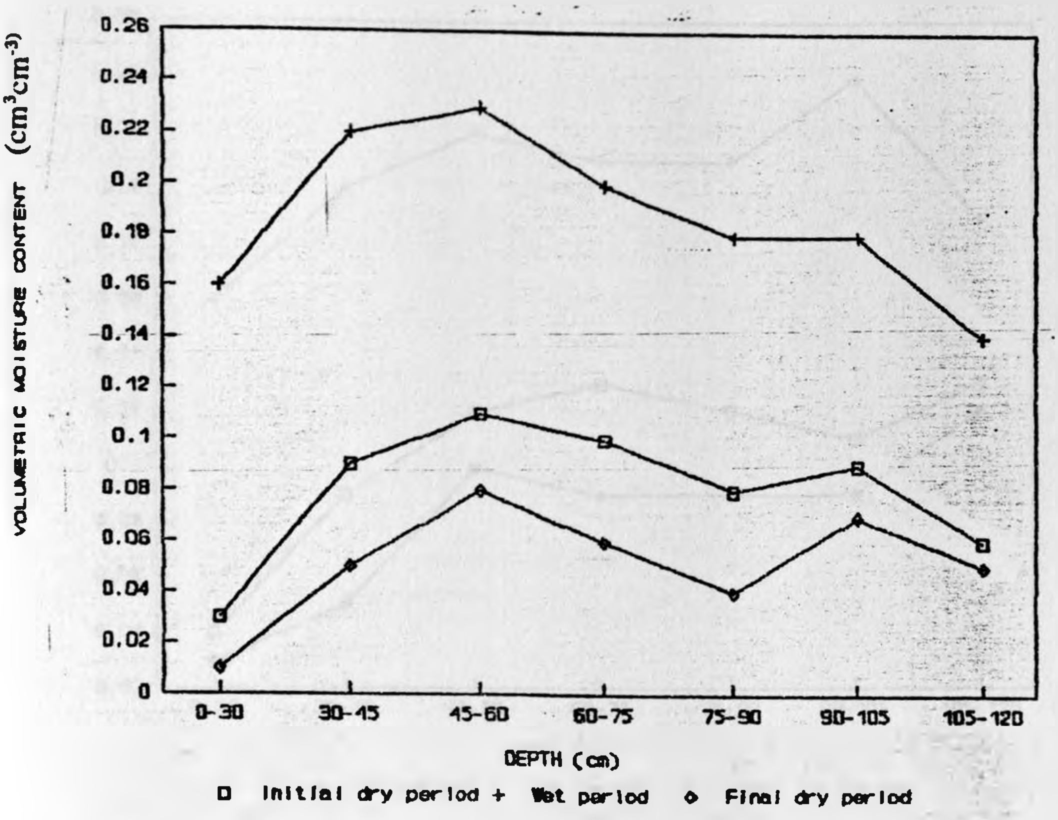


Figure 4.83. Soil moisture levels at planting, tasselling and harvesting stages. H-M plot, long rains of 1995.

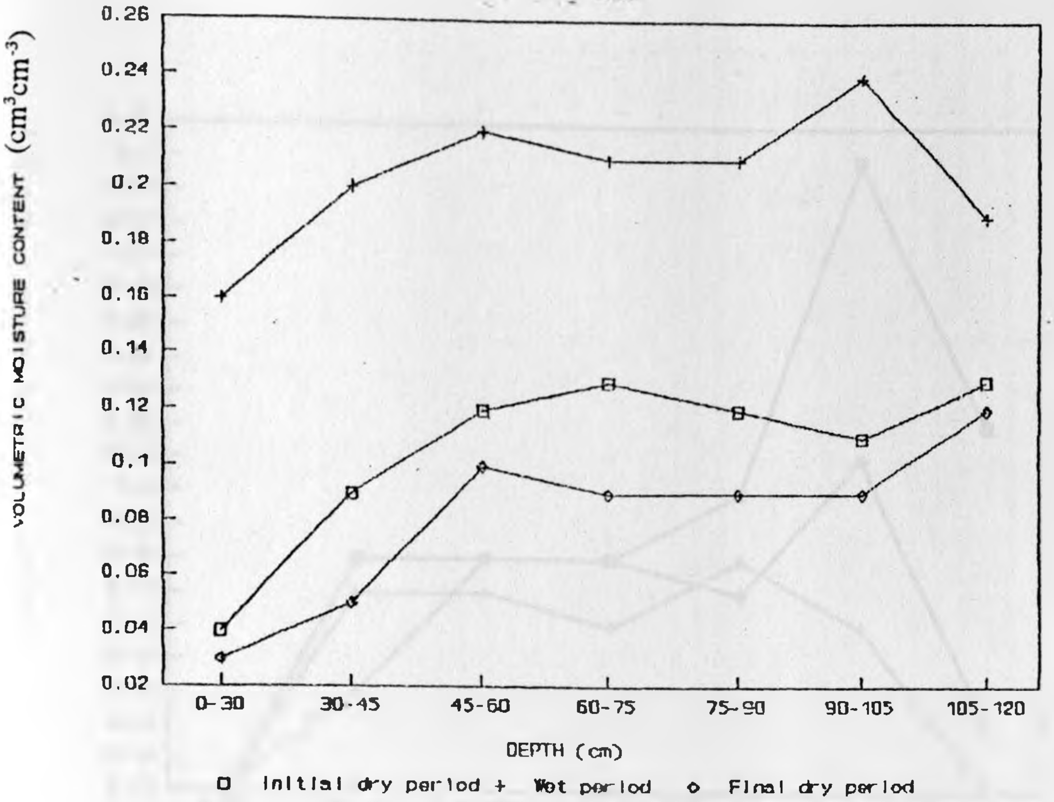


Figure 4.84. Soil moisture levels at planting, tasselling and harvesting stages. G-M plot, long rains of 1995.

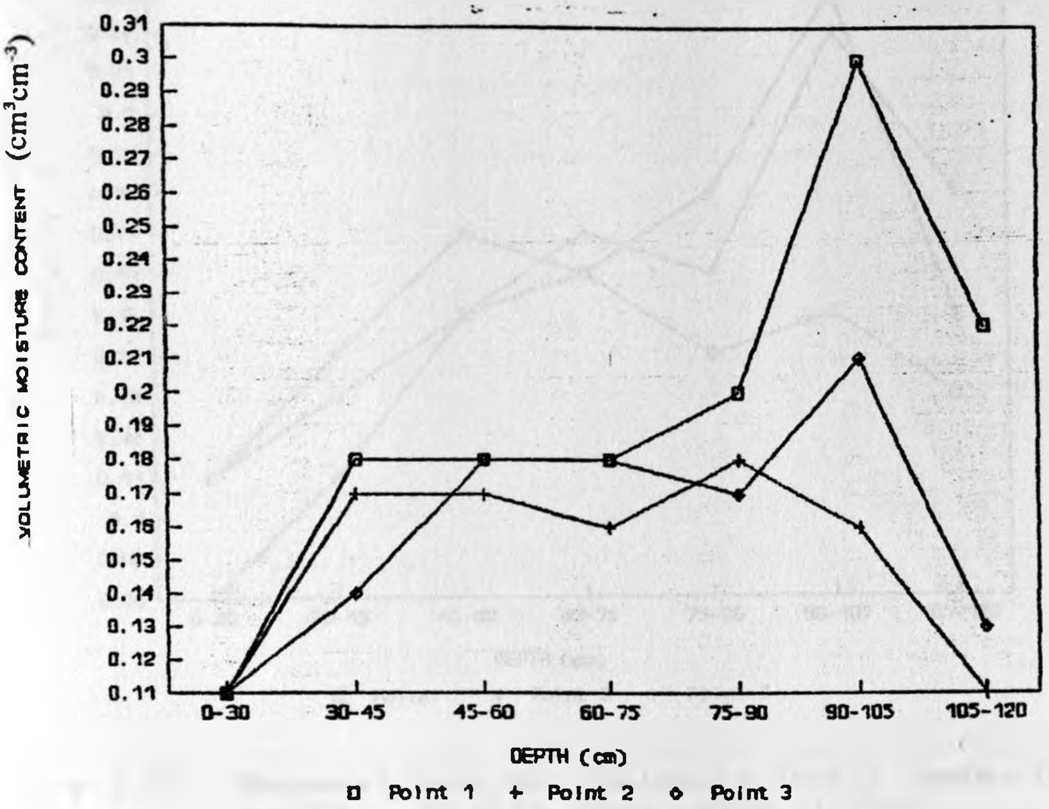


Figure 4.85. Seasonal mean soil moisture levels (at measuring points). C plot, long rains of 1995.

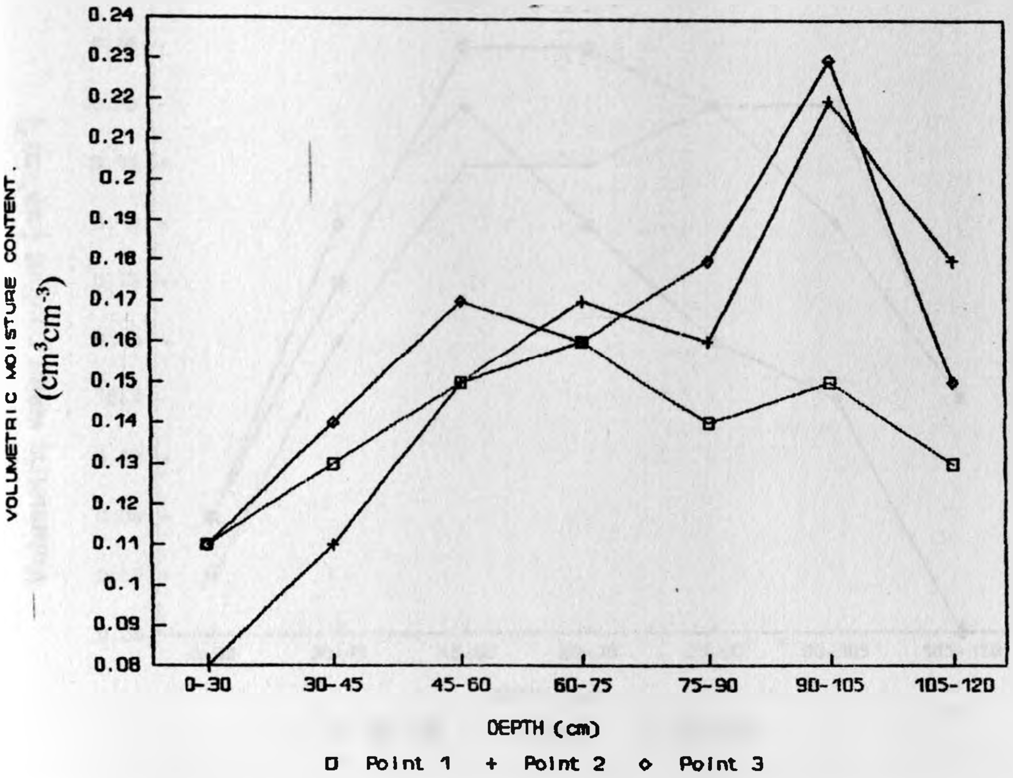


Figure 4.86. Seasonal mean soil moisture levels (measuring points). +M plot, long rains of 1995.

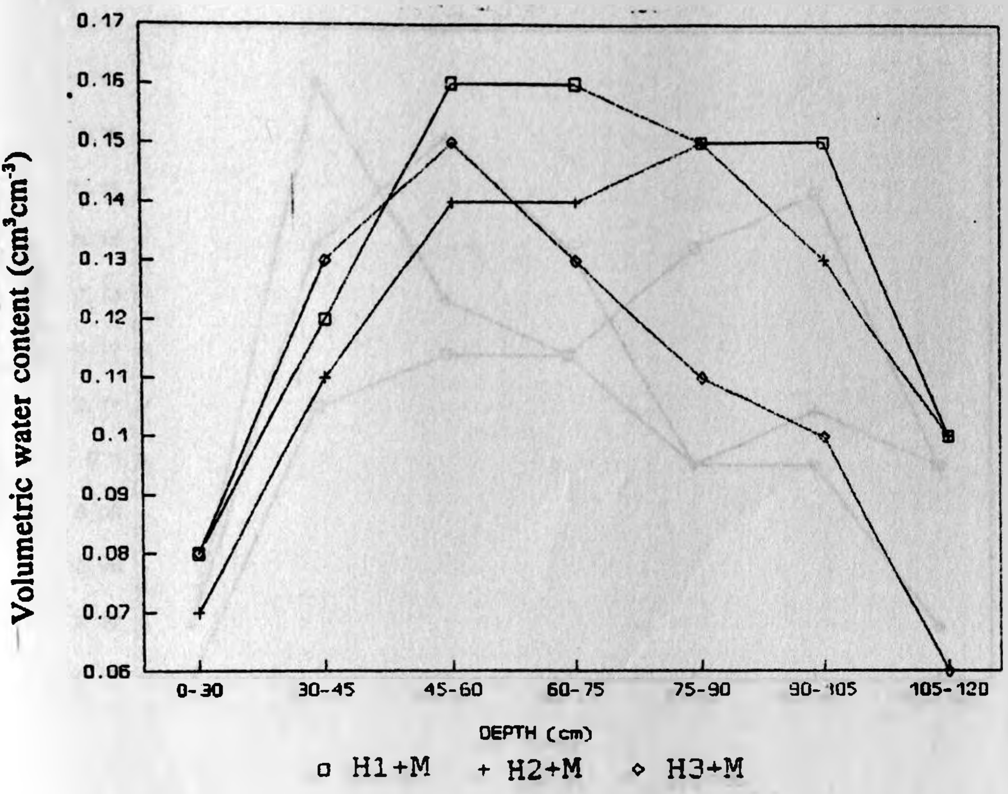


Figure 4.87. Seasonal mean soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H+M plot, long rains of 1995.

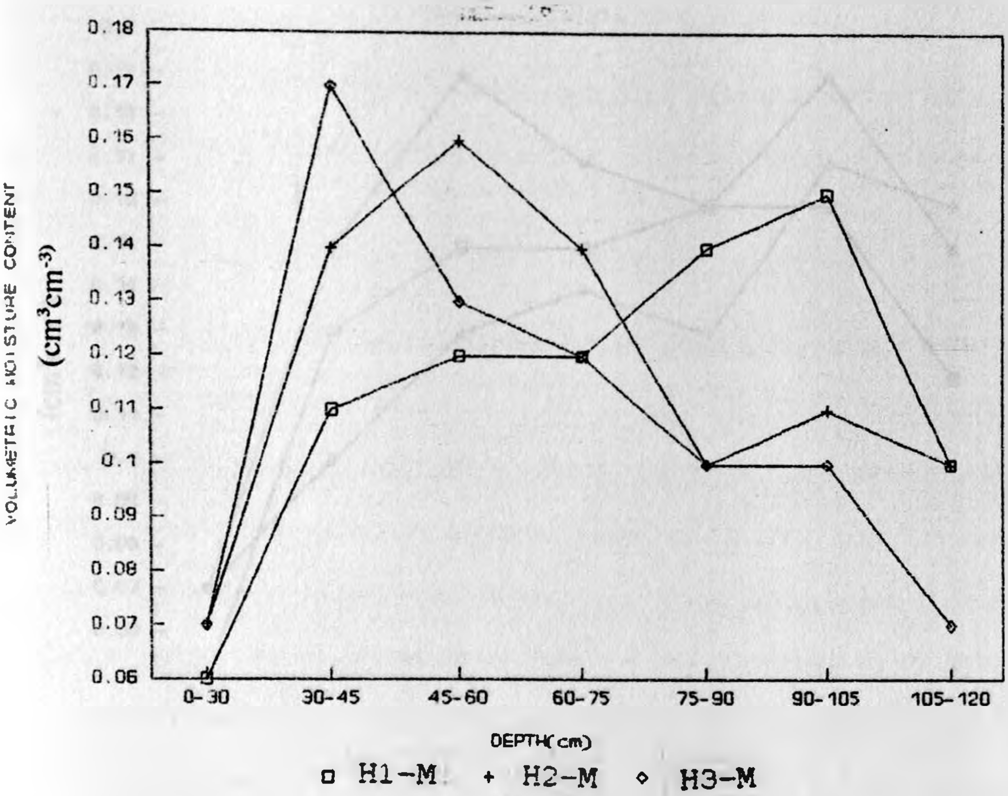


Figure 4.88. Seasonal mean soil moisture levels in hedge, 1 m from hedge and 2 m from hedge. H-M plot, long rains of 1995.

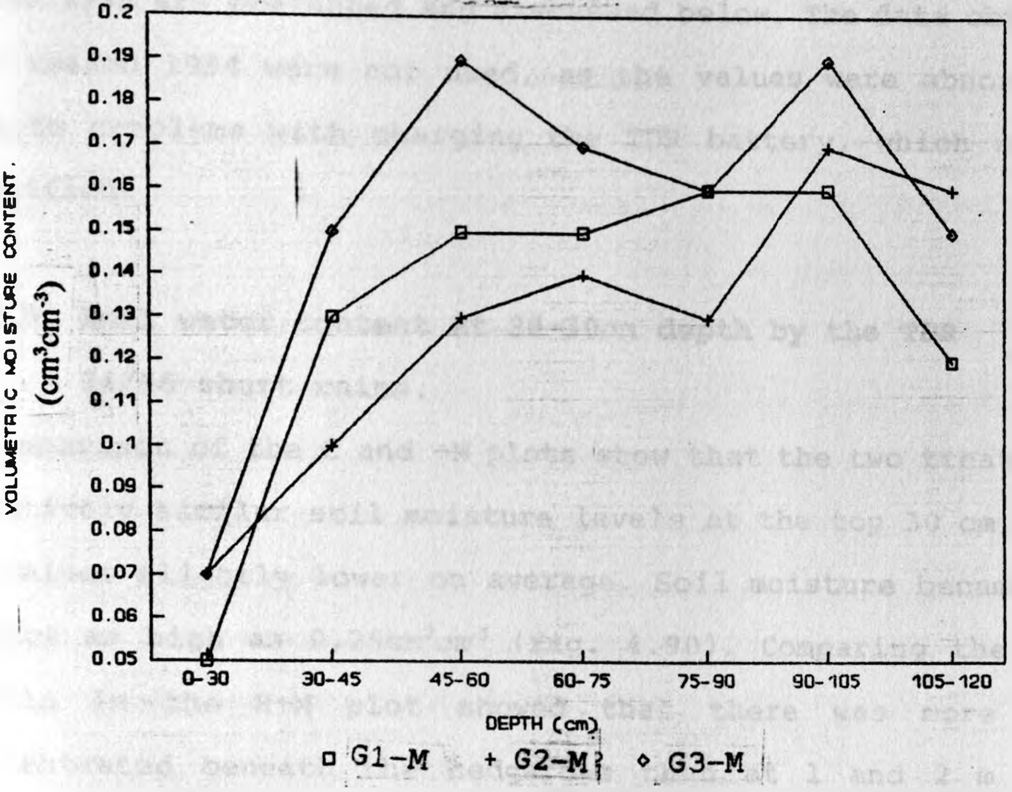


Figure 4.89. Seasonal mean soil moisture levels in grass, 1 m from grass and 2 m from grass. G-M plot, long rains of 1995.

4.5.8. TDR results.

The seasonal moisture distribution in the top 30 cm depth of the soil as measured by the TDR for the short rains 94/95 and the long rains 1995 are presented and discussed below. The data obtained for the season 1994 were not used, as the values were abnormally low due to problems with charging the TDR battery, which were later rectified.

4.5.9 Soil water content at 20-30cm depth by the TDR 94/95 short rains.

A comparison of the C and +M plots show that the two treatments had relatively similar soil moisture levels at the top 30 cm, with the +M values slightly lower on average. Soil moisture became for the C plot as high as $0.28cm^3cm^{-3}$ (fig. 4.90). Comparing the moisture levels in the H+M plot showed that there was more moisture concentrated beneath the hedgerows than at 1 and 2 m from the hedgerow (fig. 4.91). As we have seen in the previous sections, this was due to the barrier effect in the plot of holding runoff water and allowing it to infiltrate more beneath the hedgerow. This led to a decreasing moisture trend in the 1 and 2 m positions from the hedgerow barrier. There was also more moisture concentrated beneath the hedgerow in (H-M) plot than at 1 and 2 m from the hedgerow barrier (fig. 4.92) for the same reasons as explained for the H+M plot. The same trend of holding more water at the grass strip barrier than at 1 and 2 m from the barrier into the alley was as well portrayed (fig. 4.93).

When the average seasonal moisture results accumulated over the season for the different plots were subjected to ANOVA, there were statistically significant moisture differences between the treatments and at points of measurement at $P = \leq 0.05$, $CV = 20.69$. The overall moisture differences between treatments were statistically significant (at $LSD = 0.52$, $SE = 0.19$). The differences in moisture content among the points of measurement in all the treatments were also statistically significant ($LSD = 0.40$, $SE = 0.14$). Separation and ranking of the overall means at the points of measurement in the five plots shows that the first point of measurement with the highest moisture content of 0.13 $cm^3\ cm^{-3}$ (ranked 1st), and the second point of measurement with (0.11 $cm^3\ cm^{-3}$) moisture was ranked 2nd, with the third point of measurement having 0.10 $cm^3\ cm^{-3}$ moisture content ranked third. The within treatment values ($LSD = 0.90$; $SE = 0.33$) as shown in Table (xv) in appendix 4.7 show that the differences in moisture content in the C and +M were insignificant. The position in the H+M, H-M and G-M was that the H+M1, H-M1 and G-M1 positions, with more moisture, were ranked 1st, while the H+M2, H-M2 and G-M2 positions ranked 2nd and 3rd respectively. This confirms the fact that runoff water had collected beneath the hedgerows and grass strips, because of the water holding effects of these soil and water conservation barriers.

A comparison was made of soil moisture measurements at the 20-30 cm soil depth at three measuring points, throughout the season, using

TDR (figures 4.90, 4.91, 4.92 and 4.93) and neutron probe metre methods figures (4.94, 4.95, 4.96, 4.97 and 4.98). The results show that the C and +M plots had similar and very close moisture values by both instruments (figs. 4.90 and 4.94 and 4.95). This must be due to the uniformity of soil moisture at the measuring points in C and +M plots. For the H+M plot, the soil moisture values by the TDR were clear cut, as we discussed above, and showed a decrease from H1+M >H2+M and >H3+M (fig. 4.91). The picture shown by the neutron probe metre for the same measuring points, though in trends relatively similar to the ones by TDR, was not so clear cut among the points of measurement but had a wider scatter of the moisture levels (fig. 4.96). For the H-M plot, there was a similar trend of moisture level distribution at H1-M, H2-M and H3-M as in H+M plot throughout the season as well as a decreasing trend in moisture levels from H1-M> H2-M and >H3-M, particularly clearly for the TDR (fig. 4.97). For the G-M plot a similar trend in moisture levels distribution was noted as in the AF plots in the G1-M, G2-M and G3-M positions and also over the season (fig. 4.93).

The probe metre values were however somewhat lower than the TDR values, particularly at the G1-M positions during the wetter part of the season (figs. 4.93 and 4.98). Compared to the probe metre the results show that the TDR portrayed a better and clearer cut picture of the soil moisture levels and distribution at the hedgerows/grass strips and at 1 and 2 m away from them. The explanation for this is that the neutron probe metre has some of its neutrons escaping into the air which cannot be detected by the neutron detector and hence resulting in lower than the usual count rate ratios with consequent low moisture content. The dryer the soil, the larger the percentual error, because the sphere of importance that backscatters the neutrons is larger in a dryer soil. This does not happen with the TDR, which directly monitors soil moisture content at the surface depths where it is mounted. The moisture values by the neutron probe were also lower than the moisture values by the TDR, an indication that indeed the TDR values were more accurate than the neutron metre. The moisture levels as measured by the TDR in the C and +M were rather close even though there was mulch application in the +M plot. The mulch rates were rather low and may not have been effective enough in holding water for infiltration to show differences in moisture levels.

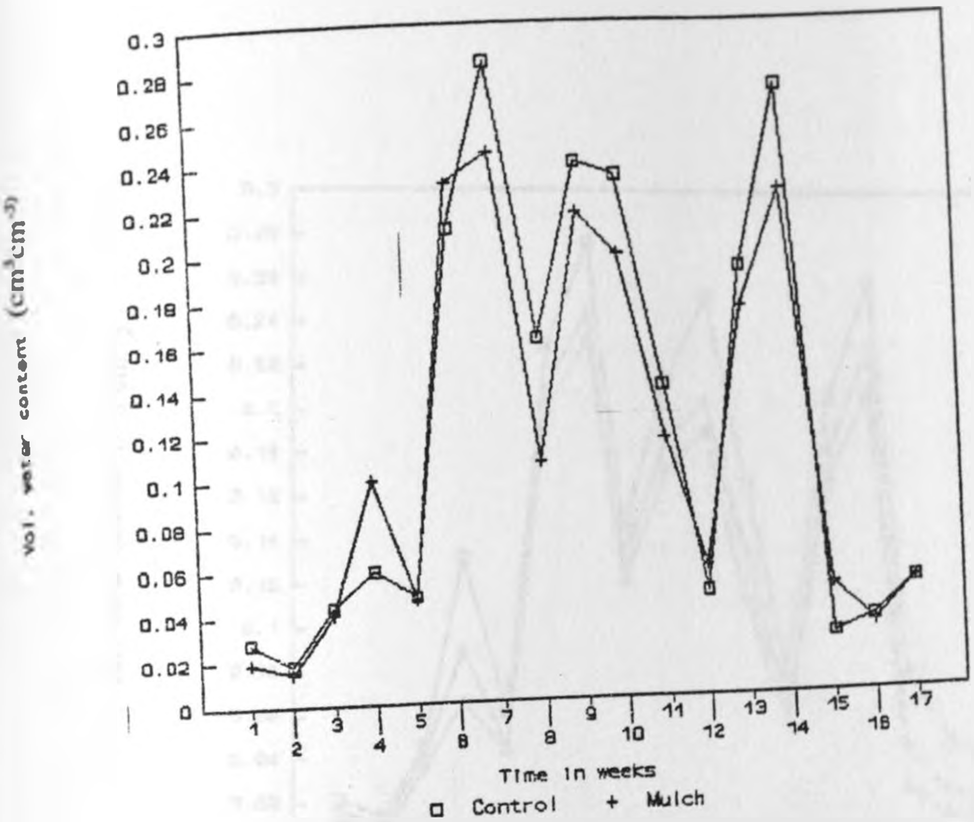
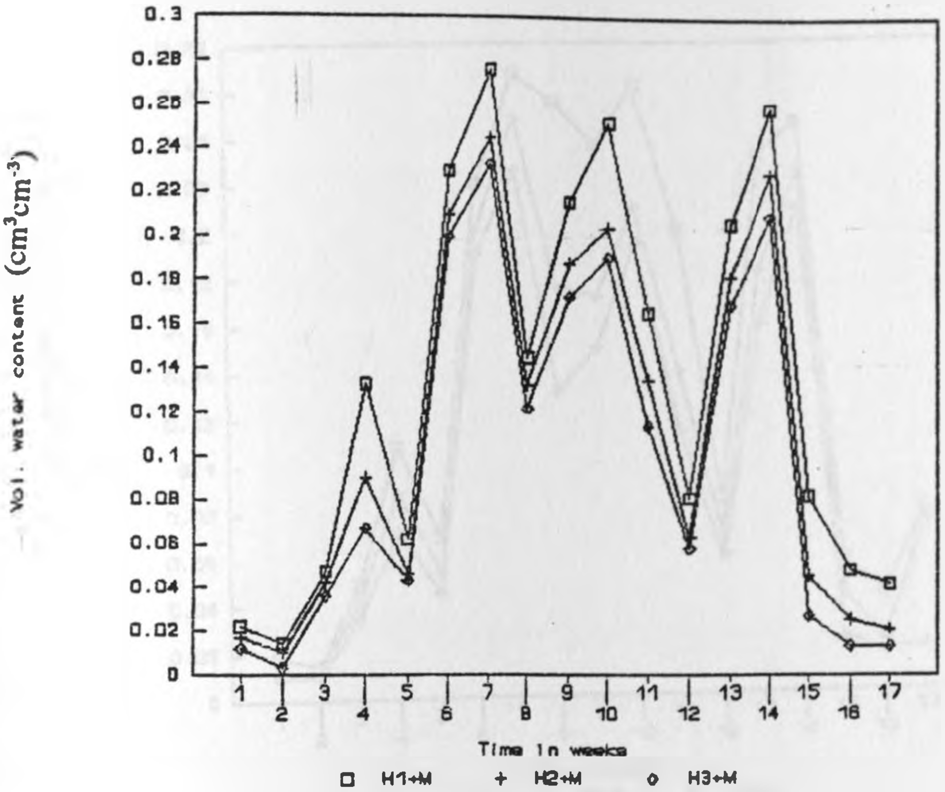


Fig. 4.90. Comparison of soil moisture by TDR (20-30cm depth) between the control and mulched plots for the short rains of 94/95.



Fi. 4.91. Comparison of soil moisture by TDR (20-30cm depth) in the hedge, 1m from the hedge and 2m from the hedge for the H+M plot, short rains of 94/95

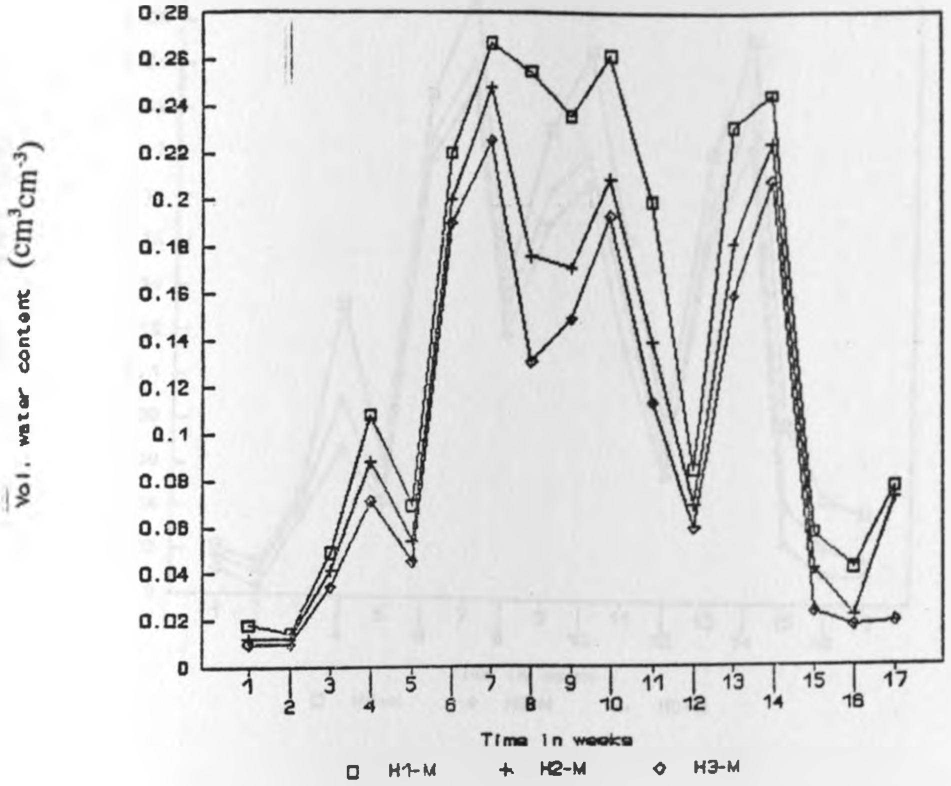


Fig.4.92. Comparison of soil moisture by TDR (20-30cm depth) in the hedge, 1m from the hedge and 2m from the hedge for the H-M plot, short rains of 94/95

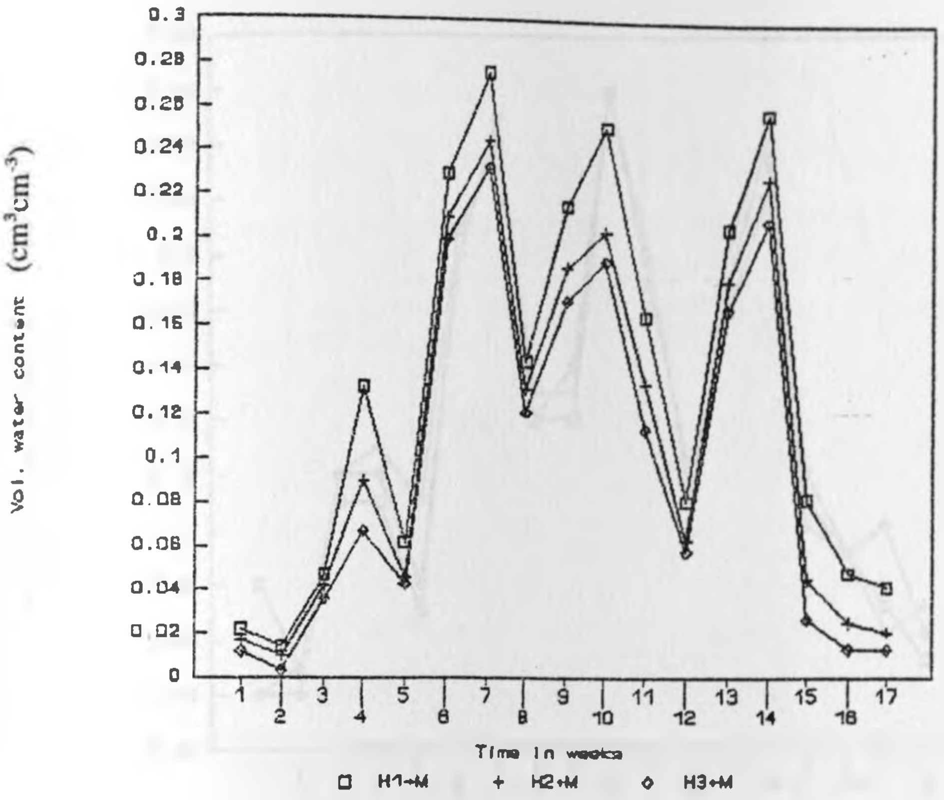


Fig. 4.93. Comparison of soil moisture by TDR (20-30cm depth) in grass strip, 1m from grass strip and 2m from the grass strip, G-M plot, short rains of 94/95.

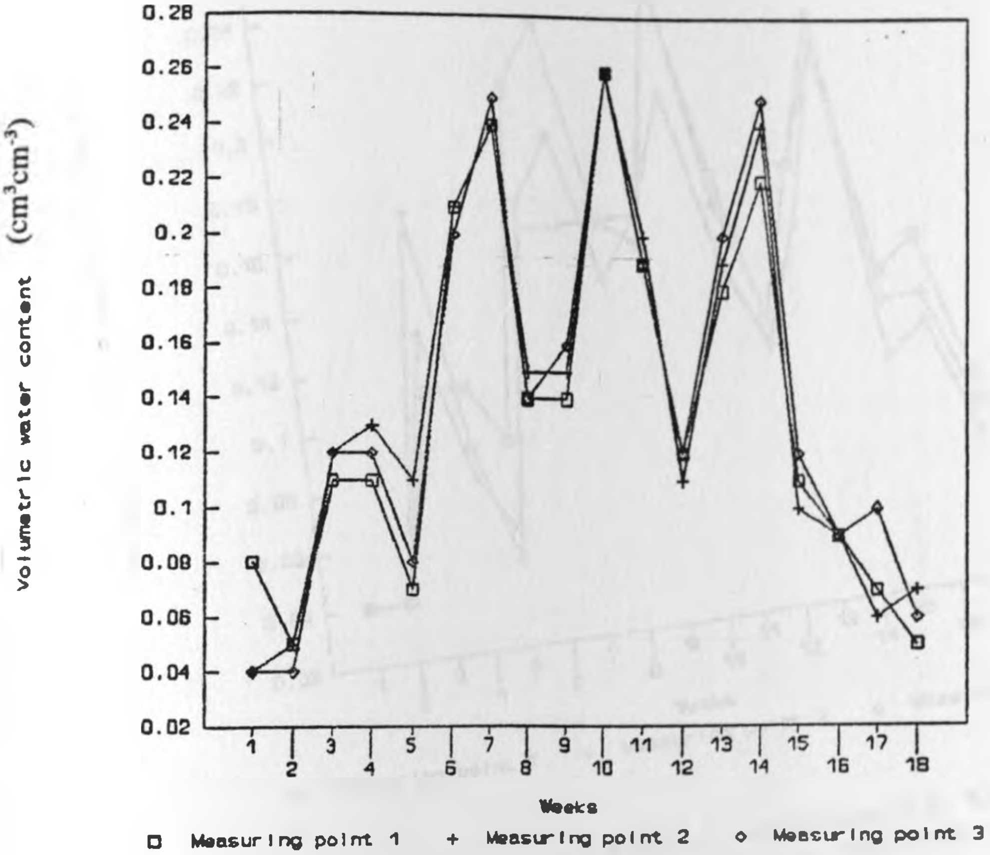


Figure 4.94. Comparison of soil moisture at the measuring points 0-30 cm depth by neutron probe, C plot, short rains 94/95.

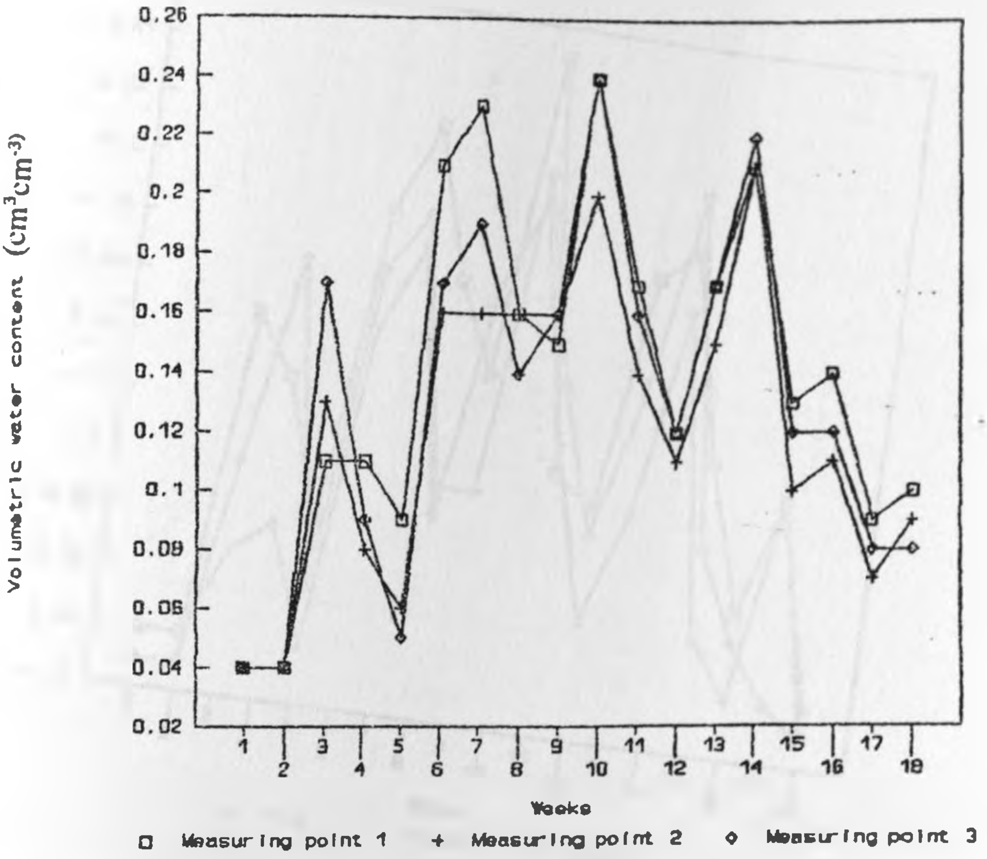


Figure 4.95. Comparison of soil moisture at the measuring points 0-30 cm depth by neutron probe, +M plot short rains of 94/95.

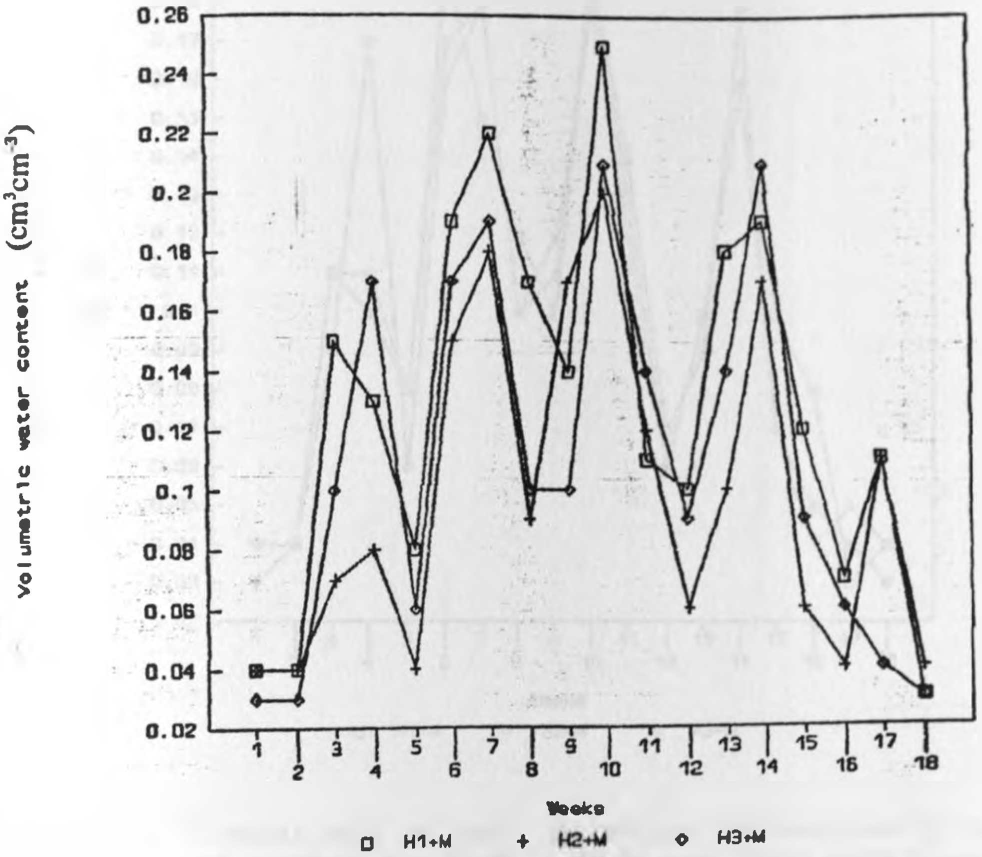


Figure 4.96. Comparison of soil moisture by neutron probe (0-30cm) depth at H1+M, H2+M and H3+M, for the H+M plot short rains of 94/95.

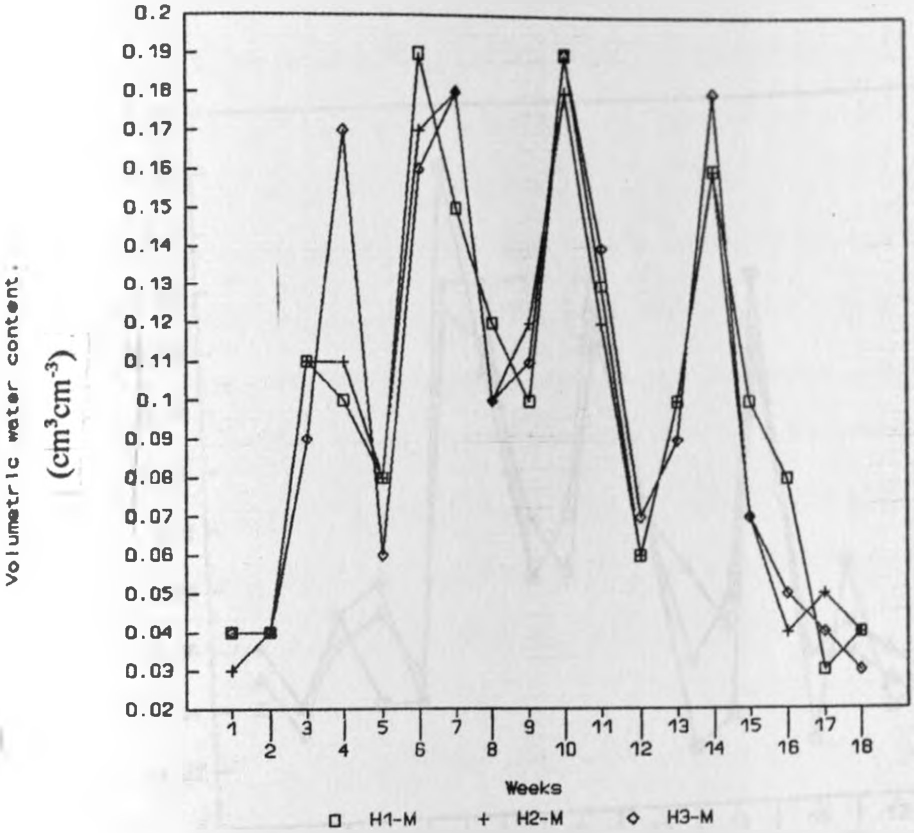


Fig.4.97. Comparison of soil moisture by neutron probe (0-30 cm depth) at H1-M, H2-M and H3-M positions. H-M plot for the short rains of 94/95.

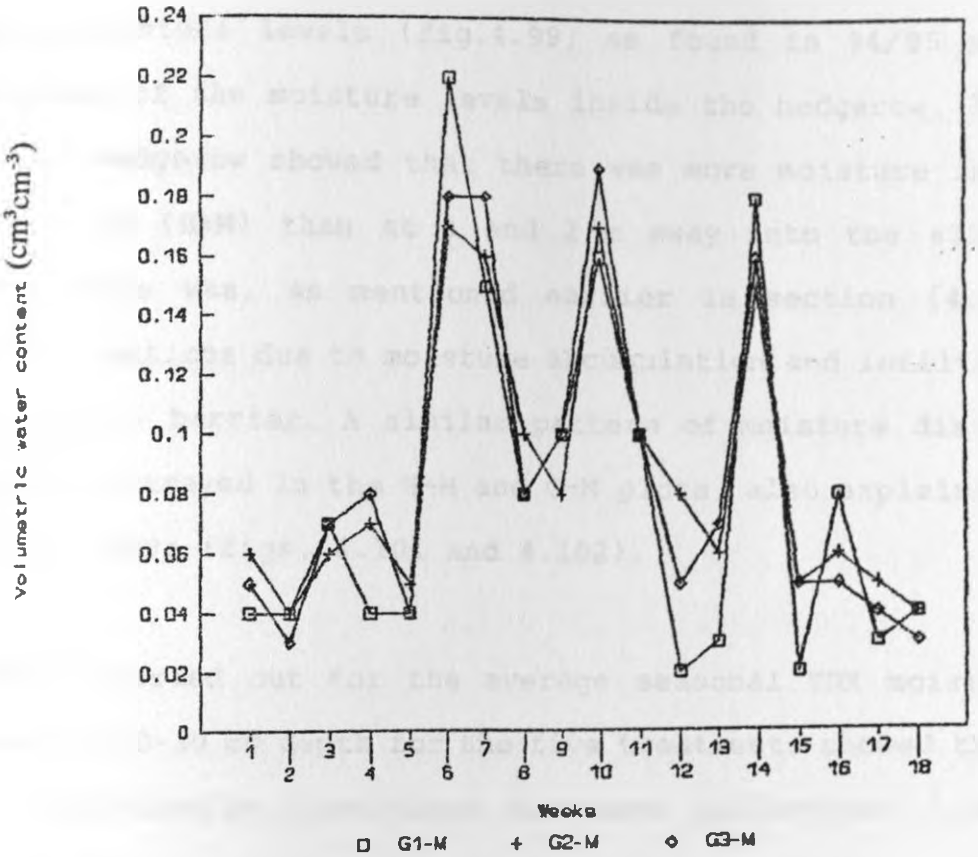


Figure 4.98. Comparison of soil moisture by neutron probe (0-30 cm depth) at G1-M, G2-M and G3-M for G-M plot, short rains 94/95.

4.5.10 Soil water content at 20-30cm depth by the TDR long rains 1995.

A comparison of C and +M plots show that they had relatively similar moisture levels (fig.4.99) as found in 94/95 season. A comparison of the moisture levels inside the hedgerow, 1 and 2 m from the hedgerow showed that there was more moisture inside the hedgerow in (H+M) than at 1 and 2 m away into the alley (fig. 4.100). This was, as mentioned earlier in section (4.5.9) and previous sections due to moisture accumulation and infiltration at the hedgerow barrier. A similar pattern of moisture distribution was also portrayed in the H-M and G-M plots, also explained as for H+M plot above (figs. 4.101 and 4.102).

An ANOVA carried out for the average seasonal TDR moisture data results at 20-30 cm depth for the five treatments showed that there were statistically significant treatment differences in moisture contents between treatments and points of measurement at $P \leq 0.05$; CV = 21.14. The moisture differences between treatments were statistically significant (LSD = 0.29; SE = 0.10). There were further statistically significant differences in the seasonal moisture contents among the overall points of measurement in all the plots at LSD = 0.37; SE = 0.13. Separation and ranking of the overall seasonal moisture means showed that the point of measurement in all the plots with highest mean moisture content of (0.11 cm^3 cm^{-3}) (rank 1) was in the 1st measuring position, the moisture content of (0.09 cm^3 cm^{-3}) in 2nd rank was in the second measuring position, while the last moisture content of (0.08 cm^3 cm^{-3}) in 3rd rank was in the third measuring position. A separation and ranking of the means within treatments (Table (xvi) in appendix 4.7) showed that there was more moisture in the H+M1, H-M1 and G-M1 positions (ranked 1st) in the AF and G-M plots than in H+M2, H-M2 and G-M2 positions ranked 2nd. The H+M3, H-M3 and G-M3 positions had the least soil moisture and were ranked 3rd (at LSD = 0.638; SE = 0.23). This confirms that most of the soil moisture was concentrated beneath the hedgerows or grass strips and this decreases with increasing distance into the alleys.

A comparison of the TDR (figs. 4.99, 4.100, 4.101 and 4.102) and neutron probe (figs. 4.103, 4.104, 4.105, 4.106 and 4.107) methods for soil moisture measurement at 20-30 cm depth was made. The results show that both the TDR and neutron probe metre show a rather similar trend of moisture levels throughout the season for the C and +M plots (figs. 4.99, 4.103 and 4.104) with minor variations as was the case in 94/95 season. These variations could be due to differences arising from soil heterogeneity in the plots. It is an indication that more sampling points would have increased the accurancy but is of course also caused by the non-sutability of neutron probe measurements near the surface. For the H+M plot, the picture on moisture levels is clearer with the TDR than with the neutron probe metre, with the moisture levels on average decreasing with increasing distance to the centre of the alley (fig. 4.100 and 4.105). There was also a tendency for the TDR to show higher moisture values, with higher absolute differences when the soils were wet than when they were dry. This was most likely because of neutrons escaping into the air (which percentually should be higher in dry soil) which could therefore not be detected by the neutron probe detector, resulting in rather lower moisture content obtained by the by the probe metre. For the H-M plot, the picture on moisture distribution is again clearer by the TDR than by the probe metre, with decrease in moisture levels at H1-M >H2-M and >H3-M actually only visible for TDR observation. This must be due to actual sampling differences over depth. The range of moisture levels by both instruments was, however, rather similar, with TDR showing a more clear pattern of moisture distribution than the probe (figs. 4.101 and 4.106). As in the H+M and H-M plots, the G-M plot had similar moisture pattern distribution by both the TDR and the probe metre over the season. Only the TDR showed a clear cut picture of moisture levels as G1-M >G2-M >G3-M respectively, with higher absolute moisture levels by the TDR than by the probe metre, especially during wet periods at the G1-M position (fig. 4.102 and 4.107). This was partly due to runoff water accumulation at the grass strip compared to the positions G2-M and G3-M in the alley. Why this is at least relatively again not shown by the neutron metre is not immediately clear. Possible reasons may be differences in sample volume, that is much larger for the neutron probe, that also samples therefore another horizon of the soil. This introduces biases. Actual differences between measuring points due to very local effects may be involved as well.

A comparison of the TDR and neutron probe methods for soil moisture measurement at 30 cm depth during this season has shown that the TDR was more reliable than the neutron probe metre as earlier explained in the 1994/95 rain season. In cases where high accuracy soil moisture is needed with minimum soil disturbance in the 30 cm top soil layer, TDR though also expensive, is recommended for use.

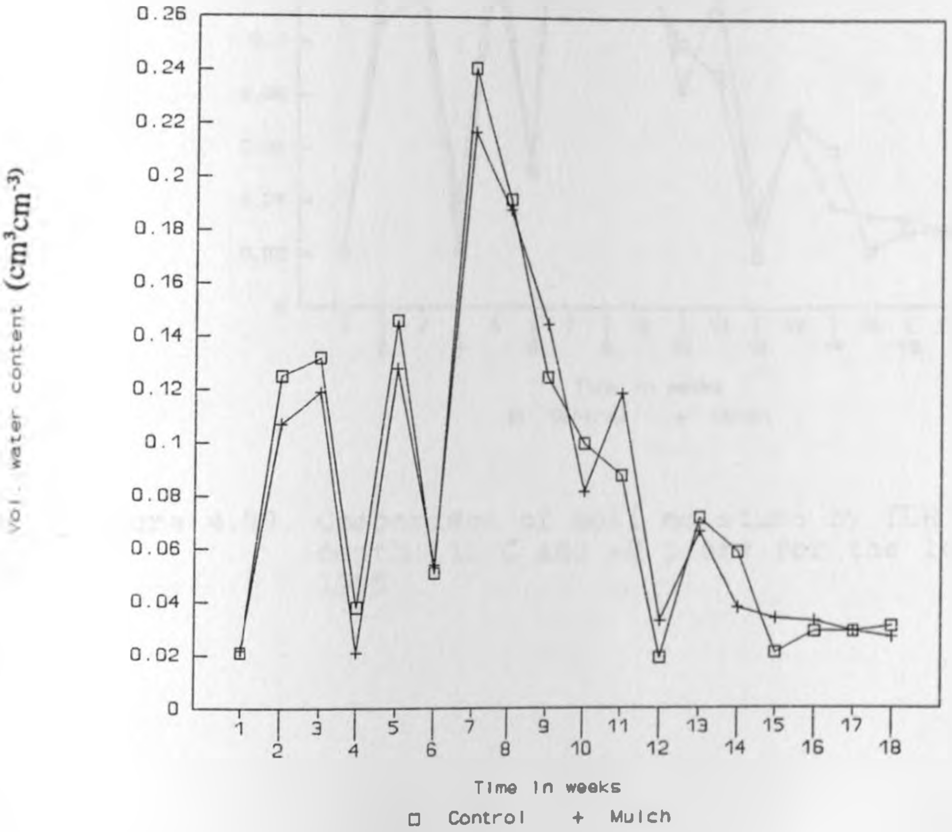


Fig. 4.99. Comparison of soil moisture by TDR (20-30cm depth) in C and +M plots for the long rains of 1995.

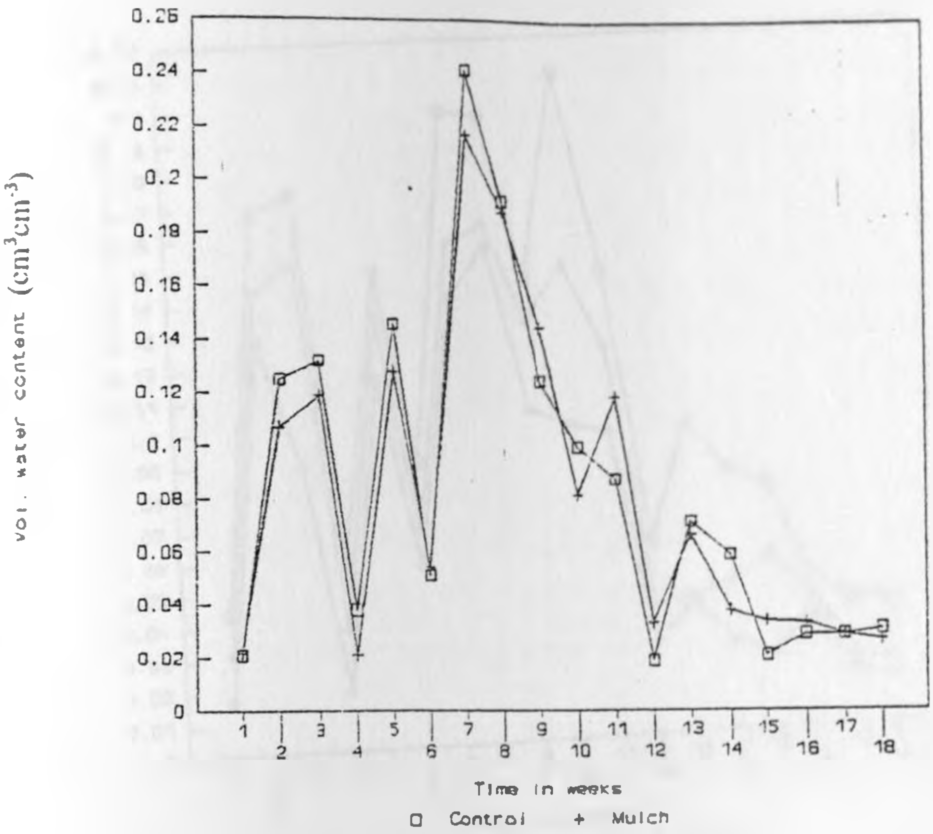


Figure 4.99. Comparison of soil moisture by TDR (20 - 30cm) depth) in C and +M plots for the long rains of 1995.

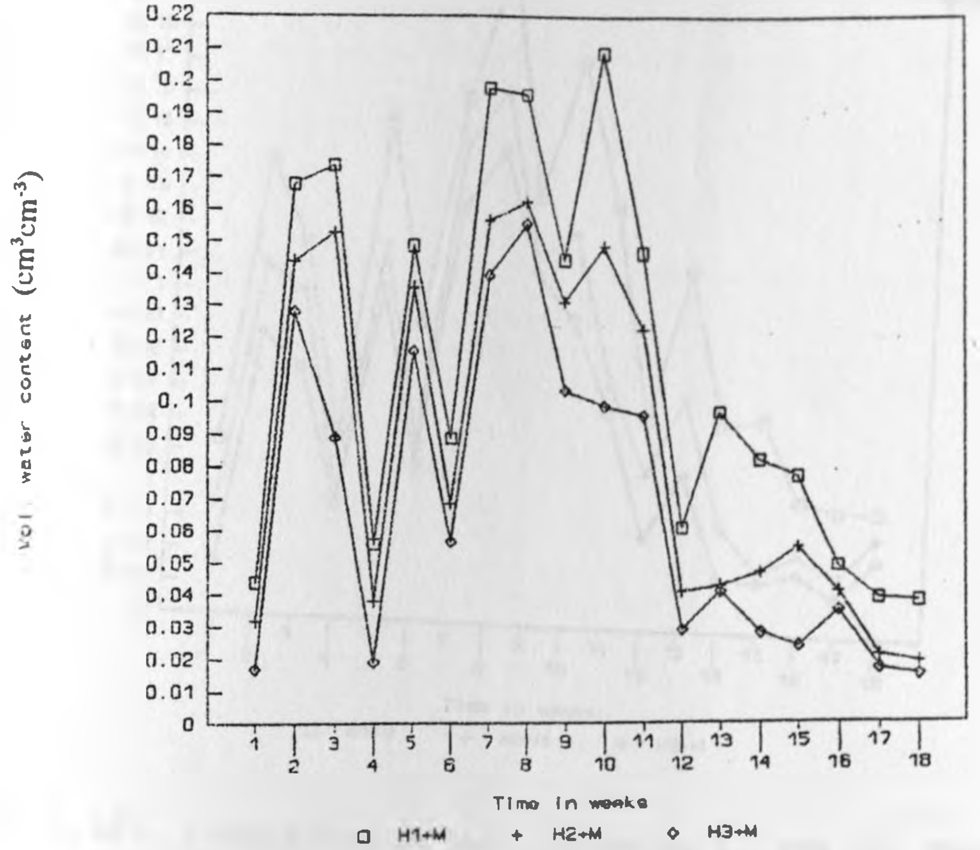


Figure 4.100. Comparison of soil moisture by TDR (20 - 30cm) depth) in the hedge, 1 m from the hedge and 2 m from the hedge in the H+M plot, for the long rains of 1995.

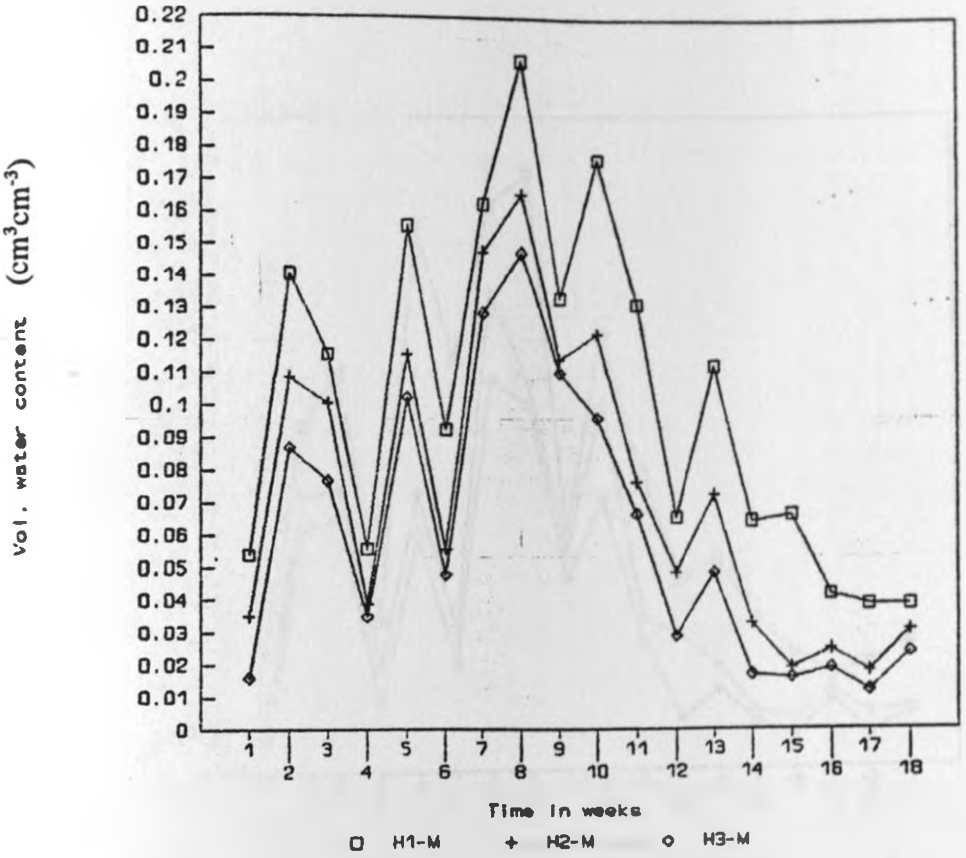


Figure 4.101. Comparison of soil moisture by TDR (20 - 30cm) depth) in the hedge, 1 m from the hedge and 2 m from the hedge for the H-M plot in the long rains of 1995.

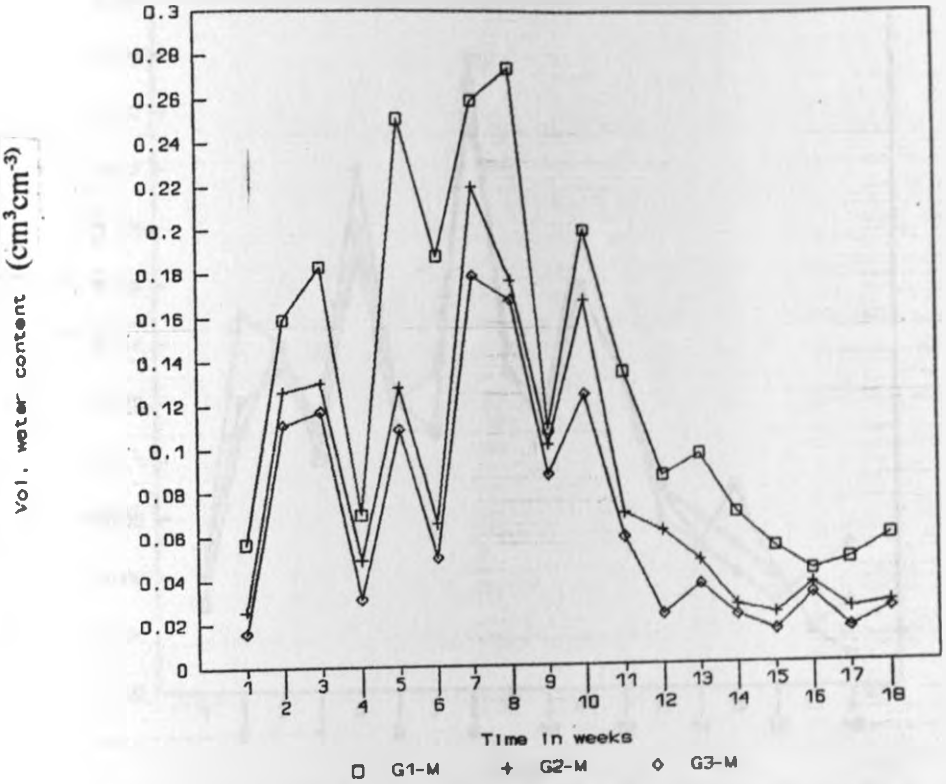


Figure 4.102. Comparison of soil moisture by TDR **20-30 cm** depth) in the grass strip, 1 m from the grass strip and 2 m from the grass strip for the G-M plot in the long rains of 1995.

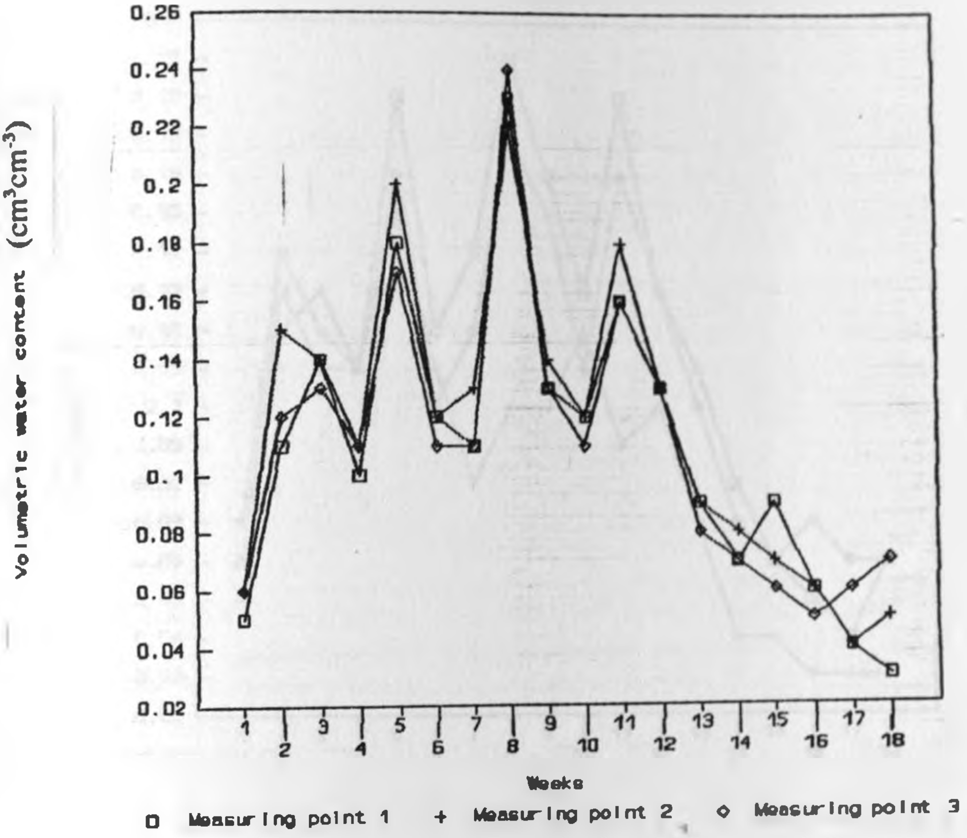


Figure 4.103. Comparison of soil moisture changes at three measuring points by neutron probe metre (0-30 cm depth), C plot long rains of 1995.

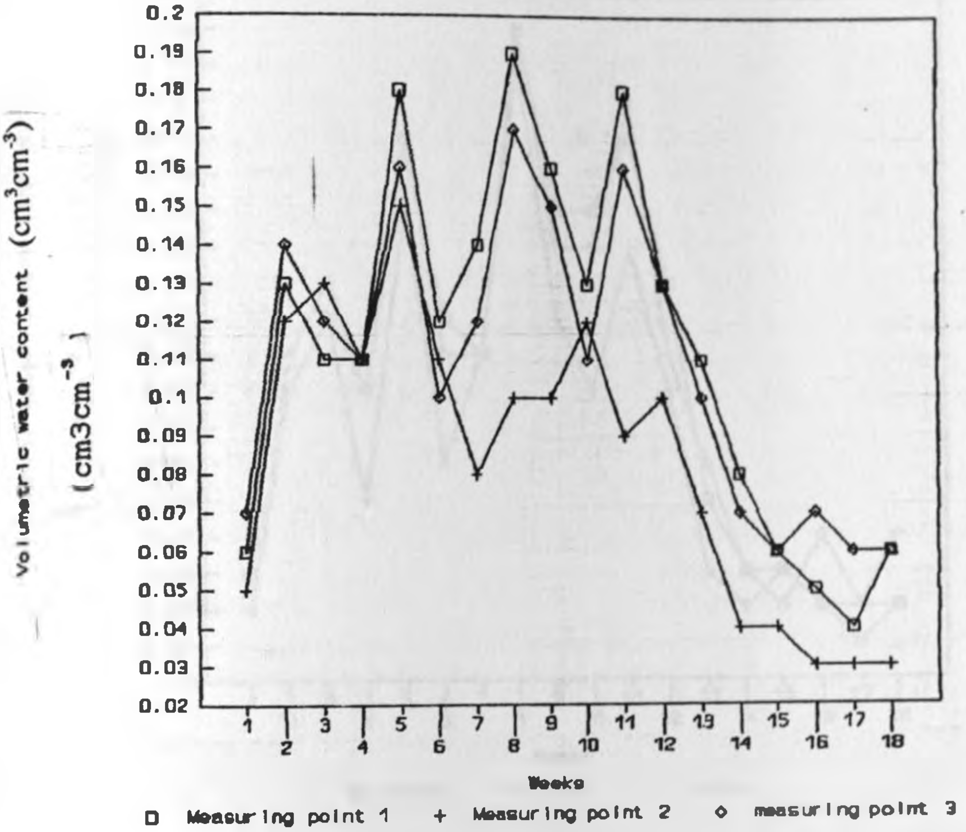


Figure 4.104. Comparison of soil moisture changes at three measuring points by neutron probe (0-30 cm depth). +M plot, long rains of 1995

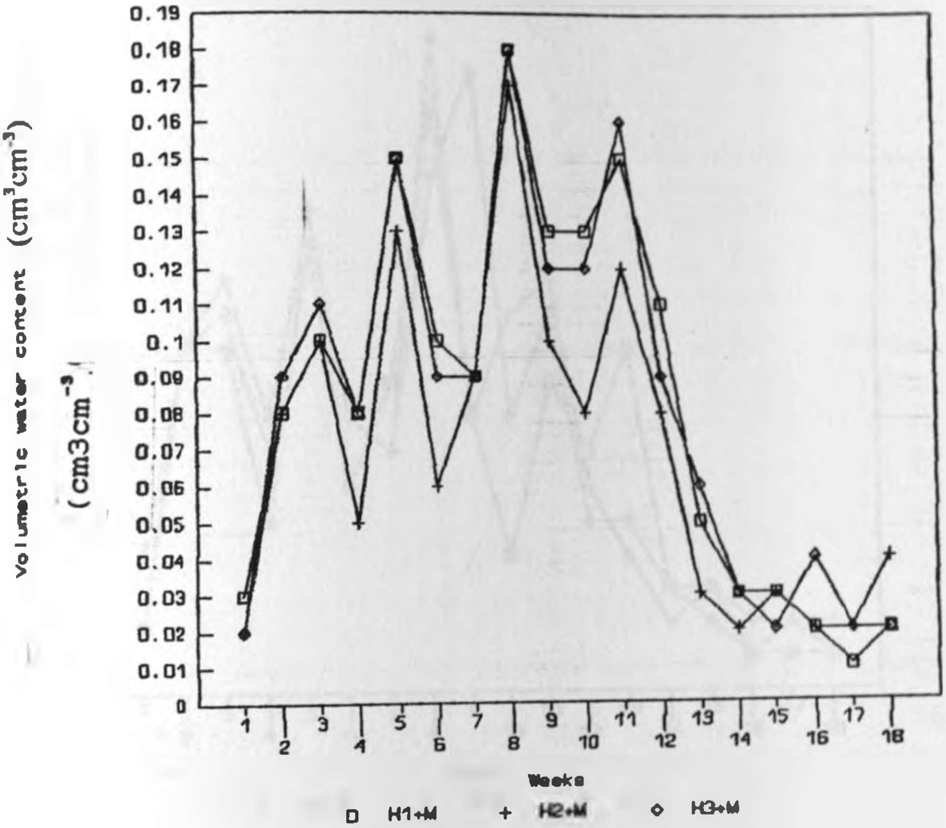


Figure 4.105. Comparison of soil moisture changes in the hedge, 1 m from hedge and 2 m from hedge, by neutron probe (0-30 cm depth). H+M plot, long rains of 1995.

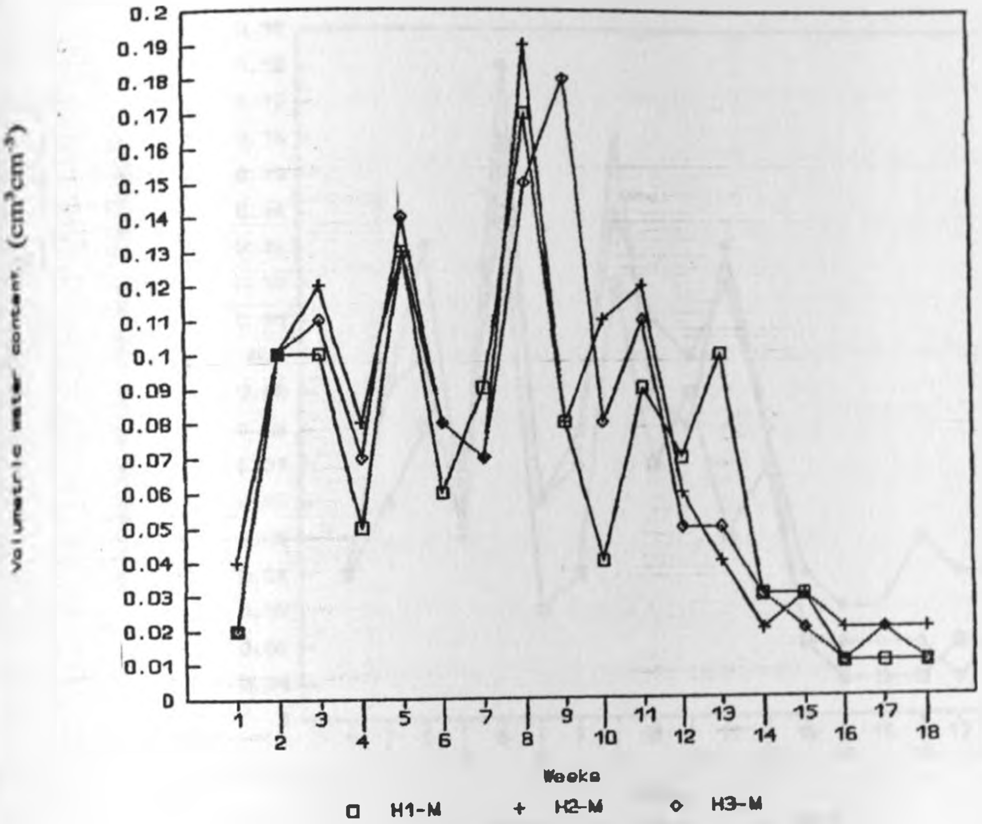


Figure 4.106. Comparison of soil moisture in the hedge, 1 m from hedge and 2 m from hedge by neutron probe (0-30 cm depth). H-M plot, long rains of 1995.

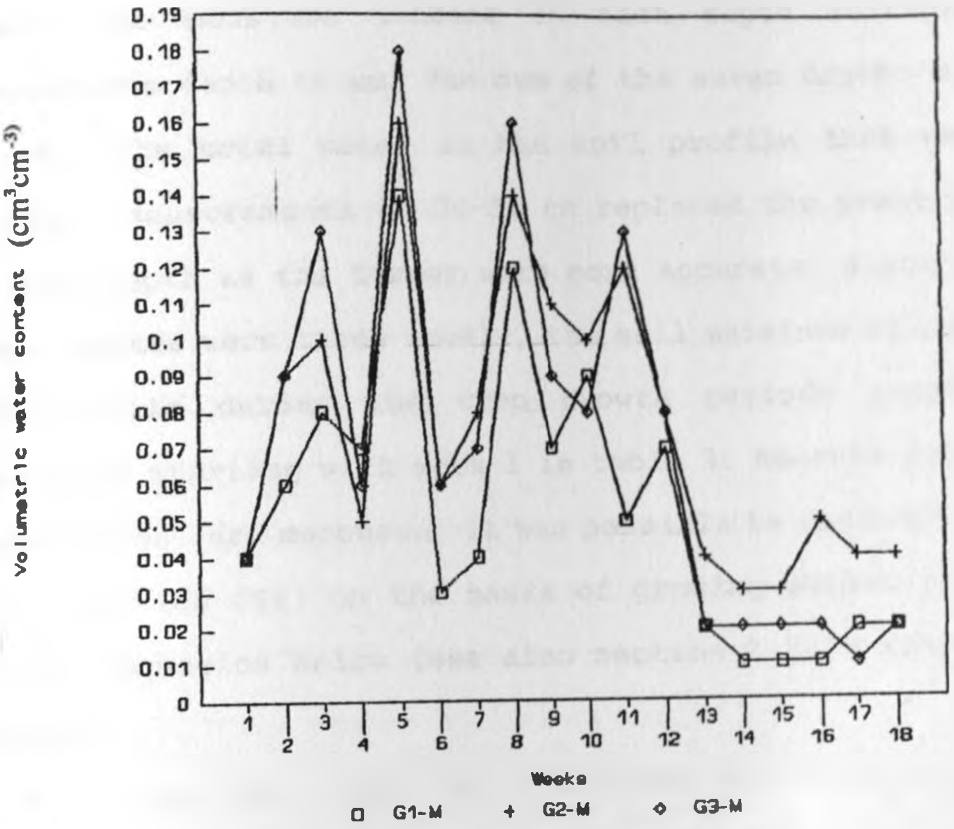


Figure 4.107. Comparison of soil moisture changes in grass, 1 m from grass and 2 m from grass. G-M plot, for the long rains of 1995.

4.5.11 Soil water balance.

The water storage in the entire soil profile for each treatment in each week of measuring season was computed as earlier stated by taking the moisture content in each depth multiplied by the appropriate depth in mm. The sum of the seven depths soil water in mm gave the total water in the soil profile that week. The TDR moisture measurements at 20-30 cm replaced the probe measurements at this depth as the former were more accurate. Since the moisture measurements were taken weekly, the soil moisture storage trends in the profile during the crop growth periods could be weekly monitored starting with week 1 in table 3. Because runoff and soil evaporation were measured, it was possible to estimate the value of transpiration (Tr) on the basis of growing season from the water balance equation below (see also section 2.5.3) where ▲S = 0 was assumed:

Tr = P - Rn - Es - Epl - ▲S - L, where Tr is transpiration, P is precipitation, Rn is runoff losses, Es is soil evaporation losses, Epl is evaporation from plant surfaces, ▲S is change in soil water storage and L is losses from deep percolation (All units in mm per season). This equation has been expanded from the one in section 2.5.3 so that calculated ET can be separated from Es and Epl (taken as zero) as well as allowing for the computation of water storage changes (▲S) in the soil profile due to moisture additions from rainfall. A calculation example for Tr is shown in Table (xvii) in appendix 4.7.

This transpiration value was used for the calculation of WUE in section (4.6.7). Using the moisture content for each soil depth per week also, it was further possible to know at what depth soil water exceeded field capacity and treat it as loss through deep percolation in the water balance equation. Permanent wilting point (PWP) is the water content at which plants remain wilted over night or in a humid chamber unless they are watered, while ins itu field capacity (FC) of a soil refers to the water content after downward drainage has become negligible and water content has become relatively stable (Kramer and Boyer, 1995).

The values for the FC and PWP for various field soil depths for the experimental plots were determined in the laboratory by Kibe et al. (1981). The FC for the first 30 cm depth was $0.26cm^3cm^{-3}$, it was $0.34cm^3cm^{-3}$ for the depths 30-105 cm and $0.32cm^3cm^{-3}$ for the 105-120 cm depth. The PWP values were $0.11cm^3cm^{-3}$ for the first 30 cm depth and $0.16cm^3cm^{-3}$ for the depths 30-120 cm. The maximum available water or water holding capacity was obtained from the difference between field capacity (FC) and the permanent wilting point (PWP). These were the values used to determine whether or not the soil had percolation losses over the seasons of experiment. The results show that except for the 94/95 rainy season, the soil water content in the 1.2 m soil depth in all the plots was between the determined FC and PWP at the moment of measuring and no percolation losses were assumed to have occurred since no soil water went beyond FC. We indicated earlier that with large shower(s) in the beginning of such a week, this assumption may not be correct and this way evaporation may be too high. For the 94/95 season the results obtained as seepage losses from a calculation example in table (xviii) in appendix 4.7 were: C plot 30 mm, +M plot 0 mm, H+M plot 1.5 mm, H-M 4.5 mm and G-M plot 0 mm. This was obtained as per the method described in section 4.5.5. These results were calculated as an example from table (xix) in appendix 4.8 which show the volumetric water content for seven depths in the C plot for the 94/95 rainy season. These table shows by inspection at which soil layers the soil moisture content was more than FC for percolation losses to occur. The procedure for the calculation of percolation losses is the one earlier used for 1994 long rains maize season.

4.6 Soil evaporation.

The results presented cover the long rains 1994, the short rains 94/95 and the long rains 1995. The results for 1993/94 were omitted as they had major errors made during the set up of the microlysimeters.

4.6.1 Soil evaporation results for the long rains of 1994.

Tables 6-9 show the 1994 seasonal soil evaporation losses from the five plots, as measured a maximum of up to seven days following rainfall events, as well as the estimates made during the rainy days and measurements taken after the representative measuring periods of up to seven days. This was done in order to get total soil evaporation taking place during the entire growing period of the crop. The results show that there were somewhat higher soil evaporation losses recorded in the non-mulched C, H-M and G-M plots as compared to the mulched plots +M and H+M respectively. This is shown in tables (6-9) for both the subtotals for each treatment as well as the daily trends within the treatments. This was as a result of less solar radiation reaching the mulched soil and less water vapour leaving it than for the non-mulched plots. There is indeed also an insulation aspect in which air movement is being reduced just above and within the mulch. Water vapour can leave less easily a mulched soil. The differences found are ,however, very small. At the same time, the areas at H2+M, H2-M and G2-M also showed on average somewhat lowered soil evaporation losses as compared to H3+M, H3-M & G3-M respectively, most likely because of the extended shading from the hedgerows and grass strip (Tables 6-9). The mulch in the +M plot showed a clear low soil evaporation loss as compared to the C plot throughout the season, while the soil evaporation at the H2+M was lower than in the +M plot, possibly due to the additional hedgerow shade at the H2+M. This was all confirmed by the periodical means and subtotals in different stages of crop growth in the season (Tables 6-9). The results further show that there were considerably higher daily evaporation losses in all the plots in the wetter parts of the month sampled in March, compared to the drier April and May. Those of May were lowest because the crop had developed fully its canopy, which further reduced the area of soil exposed to solar radiation. The month of June was quite dry, as the crop approached maturity and harvesting. This period was characterised by very small and negligible or no changes in the weight of microlysimeters as measured early and late in the day (see chapter. 3), and therefore showing no evaporation losses.

There was of course a marked tendency for higher evaporation losses to occur when the soils were wetter as compared to when they were drier following rainfall events (Tables 6-9). This was the case at least in the first drying day of taking measurements in all the plots. The values for the soil evaporation then would go down as the soil dried, approaching zero when no more water could be lost from the dry cropped soil. This was the case in the majority of cases as the seventh day and beyond was approached. The results have been obtained by assuming that maximum soil evaporation losses occurred not only in the wetter months of March and April but also for the month of May. It was assumed that evaporation was at maximum when it was raining or at first day of drying. There were rather high variations in the mean daily soil evaporation losses as indicated by the high ranges in evaporation losses from wetter to drier days. This pattern is illustrated in tables (6-9).

The final results in table 9 show the percentages of soil evaporation expressed as a percentage of total rainfall for the season. They show that, after averaging H2+M and H3+M respectively H2-M and H3-M as well as G2-M and G3-M, the mulched plots +M and H+M had lower soil evaporation by 8.8% and 9.8%, in absolute values, compared to the C plot, while the non-mulched plots, H-M and G-M, had lower soil evaporation by only 3.7 and 2% in absolute values respectively, compared to the C plot. As a fine structure of the above, because of the extended shading by the hedgerows and grass strips, up to 1 m from hedge or grass position, the soil evaporation losses at these positions were lower than at 2 m from the hedge or grass position (Table 9). The soil evaporation on the whole ranged from 56.5% in H+M, 57.5 in +M plot, 62.6% in H-M plot, 64.3% in the G-M to 66.3% in the C plot. This shows that mulches result in somewhat lower soil evaporation losses and it suggests that soil evaporation losses account for a very high (perhaps due to the above assumptions or below mentioned errors too high) proportion of water loss in the water balance equation in the semi-arid areas of Kenya, as long as soils are wet. Nevertheless, these findings are substantially higher than the also high findings in other semi-arid areas (see more in section 4.5.3). One reason for this high evaporation losses found may be due to assuming a maximum soil evaporation during rainy days while another reason could be due to suspected poor drainage of the microlysimeter soil core when it was sealed with a cellotape. Some of the losses detected could also have been due to soil water extraction by the plant/tree roots. They should be considered an upper limit.

It should be pointed out that to get the values of soil evaporation (mm) shown in Table 6, each microlysimeter weight in grammes was multiplied by the equivalent water depth (mm) of 0.12mm. A calculation example of soil evaporation is illustrated in Table (xx) in appendix 4.8.

Table 6. Soil evaporation losses long rains, 1994.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
18.3.94	5.8	5.7	5.4	5.7	5.9	5.8	5.7	5.9
19.3.94	3.9	3.8	3.7	3.8	3.8	3.8	3.9	3.9
20.3.94	4.2	4.0	4.0	4.1	4.3	4.2	4.3	4.4
21.3.94	4.0	3.8	3.7	3.9	4.0	4.1	4.0	4.1
22.3.94	3.9	3.7	3.6	3.7	3.9	4.0	3.8	3.7
23.3.94	3.0	2.4	2.1	2.2	2.5	2.7	2.6	2.8
Mean	4.1	3.9	3.8	3.9	4.1	4.1	4.1	4.1
Std	0.8	1.0	1.0	1.0	1.0	0.9	0.9	0.9
Sub total	24.8	23.4	22.5	23.4	24.4	24.6	24.3	24.8

24.3.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
25.3.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
26.3.94	3.2	2.5	2.4	2.5	2.6	2.8	2.9	3.0
27.3.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
28.3.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
29.3.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
30.3.94	3.6	3.2	3.1	3.2	3.4	3.4	3.5	3.5
31.3.94	3.3	2.9	3.0	3.2	3.3	3.3	3.4	3.4
1.4.94	2.8	2.5	2.4	2.4	2.6	2.7	2.6	2.8
2.4.94	1.9	1.4	1.3	1.4	1.6	1.7	1.8	1.8
3.4.94	1.5	1.3	1.2	1.0	1.4	1.5	1.4	1.5
4.4.94	1.0	0.5	0.3	0.4	0.7	0.8	0.8	0.9
Mean	3.1	2.9	2.8	2.8	3.0	3.0	3.0	3.1
Std	1.0	1.2	1.2	1.2	1.1	1.1	1.1	1.1
Sub total	37.3	34.3	33.7	34.1	35.6	36.2	36.4	36.9

Table 7. Soil evaporation losses long rains, 1994.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
5.4.94	0.8	0.4	0.3	0.5	0.6	0.7	0.8	0.8
6.4.94	0.5	0.2	0.1	0.3	0.4	0.4	0.5	0.5
7.4.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.4.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.4.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.4.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
12.4.94	3.0	2.4	2.1	2.2	2.5	2.7	2.6	2.9
13.4.94	2.2	1.8	1.6	1.7	1.9	2.0	1.8	2.0
14.4.94	1.5	0.8	0.6	0.7	0.9	1.1	1.3	1.3
Mean	1.2	1.0	0.9	0.9	1.0	1.1	1.1	1.2
Std	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3
sub total	12.0	9.6	8.7	9.4	10.3	10.9	11.0	11.5

15.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
16.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
17.4.94	3.1	2.4	2.1	2.3	2.7	2.8	2.7	2.8
18.4.94	2.3	1.6	1.3	1.5	1.8	1.9	1.8	2.1
19.4.94	1.4	0.8	0.6	0.7	0.9	1.0	1.1	1.2
20.4.94	0.8	0.4	0.3	0.4	0.6	0.8	0.7	0.8
21.4.94	0.3	0.0	0.0	0.0	0.2	0.3	0.3	0.3
22.4.94	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.3
Mean	2.0	1.7	1.5	1.6	1.8	1.9	1.9	1.9
std	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.4
sub total	16.2	13.2	12.3	12.9	14.2	15	14.8	15.5

Table 8. Soil evaporation losses long rains, 1994.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
23.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
24.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
25.4.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
26.4.94	2.8	2.2	2.1	2.3	2.6	2.8	2.7	2.8
27.4.94	2.0	1.4	1.2	1.3	1.7	1.9	1.8	2.0
28.4.94	1.4	0.8	0.6	0.7	0.9	1.0	1.1	1.2
29.4.94	0.8	0.4	0.2	0.3	0.6	0.8	0.7	0.7
30.4.94	0.5	0.2	0.1	0.2	0.4	0.4	0.5	0.5
Mean	2.4	2.1	2.0	2.1	2.3	2.4	2.4	2.4
std	1.4	1.6	1.6	1.6	1.5	1.4	1.4	1.4
subtotal	19.5	17	16.2	16.8	18.2	18.9	18.8	19.2

1.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
7.5.94	2.5	2.0	1.9	2.0	2.2	2.4	2.3	2.5
8.5.94	2.4	1.8	1.6	1.9	2.0	2.2	2.2	2.3
9.5.94	2.0	1.5	1.3	1.4	1.8	1.9	2.0	2.0
10.5.94	1.5	1.0	0.8	0.9	1.3	1.4	1.4	1.4
11.5.94	0.5	0.2	0.1	0.3	0.4	0.5	0.4	0.5
12.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	1.1	0.9	0.8	0.9	1.0	1.0	1.0	1.1
Std	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3
Sub total	12.9	10.5	9.7	10.5	11.7	12.4	12.3	12.7

Table 9. Soil evaporation losses long rains, 1994.

13.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.5.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.5.94	2.0	1.4	1.2	1.3	1.6	1.7	1.7	1.8
16.5.94	1.5	1.1	0.8	0.9	1.2	1.4	1.3	1.5
17.5.94	0.8	0.4	0.3	0.4	0.6	0.7	0.7	0.8
18.5.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
19.5.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
20.5.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
21.5.94	3.9	3.5	3.4	3.5	3.7	3.8	3.9	3.9
Mean	2.2	2.0	2.0	2.0	2.1	2.2	2.2	2.2
std	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Subtotal	20.2	18.4	17.7	18.1	19.1	19.6	19.6	20

22.5.94	3.8	3.4	3.5	3.6	3.7	4.0	3.6	4.0
23.5.94	3.2	2.7	3.0	3.0	3.2	3.5	3.1	3.7
24.5.94	3.0	1.9	2.4	2.3	2.5	2.6	2.0	2.9
25.5.94	2.0	1.6	1.5	2.0	1.8	1.9	1.8	2.3
26.5.94	2.0	1.5	1.4	1.8	1.4	1.5	1.0	1.9
27.5.94	1.5	0.9	0.8	1.1	1.3	1.3	1.4	1.4
28.5.94	1.0	0.4	0.3	0.5	0.7	0.8	0.8	0.9
29.5.94	0.6	0.3	0.2	0.4	0.5	0.6	0.5	0.5
30.5.94	0.4	0.2	0.1	0.2	0.3	0.4	0.3	0.4
31.5.94	0.2	0.0	0.0	0.0	0.2	0.2	0.2	0.2
Mean	1.8	1.3	1.3	1.5	1.6	1.7	1.5	1.8
Std	1.2	1.1	1.2	1.2	1.2	1.2	1.1	1.3
Sub total	17.7	12.9	13.2	14.9	15.6	16.8	14.7	18.2
Total	160.7	139.4	143.1	140.1	149.1	154.4	152.0	159.0
% of total rainfall	66.3	57.5	55.3	57.8	61.5	63.7	62.7	65.6

C = Control +M = Mulch H2+M = 1m from (H+M)
H3+M = 2m from (H+M) H2-M = 1m from (H-M) H3-M = 2m from (H-M)
G2-M = 1m from (G-M) G3-M = 2m from (G-M)

4.6.2 Soil evaporation for the short rains of 1994/95.

The results for the season are presented in tables 10-14. They indicate that in total there were somewhat higher evaporation losses in the non-mulched plots C, H-M and G-M than in the mulched plots (+M and H+M) (Tables 10-14), as in the former season and for the same reasons. The H2+M, H2-M and G2-M showed slightly lower soil evaporation losses compared to the C plot (for all) as well as H3+M, H3-M and G3-M respectively, which had no additional hedgerow or grass shading. The H3+M and +M plot had similar evaporation losses as both had no grass or hedgerow shading, but only crop and mulch shading as was seen in 4.6.1 for the maize crop. The microlysimeters, as stated in chapter 3, were placed between the rows of maize (4.6.1) as well as between the rows of cowpea (for this season). The results show that more evaporation occurred in all the plots during the months when it was quite wet (e.g. November and December Tables 11 and 12) compared to dry months (e.g January in Tables 13 and 14), as was the case for the 1994 maize season. This was as a result of the water available on the surface as well as of the low crop cover, which had little effect on solar radiation received by the soil.

Following the protocol of no interruption by the rain during the period of evaporation measurement (Allen et al, 1990), soil evaporation was sometimes only measured this way in only a few days in one month (during the days of 3rd, 9th and from 18th onward till 27th and on 30th in November) as shown in Tables 11 and 12. The rest of the measurements had rainfall interruptions, assuming maximum evaporation losses in all plots on rainy days. This caused more evaporation in the wet months. Despite this, differences in plots were still shown, for instance 83.6 mm in the C plot compared to the +M plot with 78.6 mm, as subtotals in Table 11. The relatively low evaporation losses recorded in January 1995, as compared to those in November and December, were as expected because (i) the soil was drier and losing less water through evaporation and (ii) less evaporation due to increased crop cover, less solar radiation penetrating to the soil in the plots.

The picture portrayed in this season was that the mulch in the +M and H+M plots lowered soil evaporation over the season by 3.9 % and 4.6 % in absolute values compared to the C plot, while the unmulched plots H-M and G-M with close to 48.5 and 49.5% had only a little less evaporation compared to the C plot, with 50% soil evaporation loss. On the whole, the soil evaporation losses expressed as a percentage of the total seasonal rainfall ranged from close to 45.5% and 46% in the mulched plots H+M and +M to close to 50% in the C, H-M and G-M plots (Table 14). The high proportion of soil evaporation, of up to 50% of the rainfall, being used by soil evaporation in our case of a semi-arid area points to the need to reduce evaporation with the use of mulches from senna shrubs. These differences are to be considered small when mulching is only a small barrier to evaporation, as in our case. The values found may be somewhat too high for reasons given at the end of section 4.6.1. They should be considered an upper limit.

Table 10. Soil evaporation losses short rains 94/95 season.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
13.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
14.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
15.10.94	3.7	3.4	3.2	3.5	3.6	3.7	3.7	3.7
16.10.94	3.3	3.1	3.0	3.2	3.2	3.3	3.2	3.3
17.10.94	3.0	2.7	2.6	2.7	2.8	2.9	2.8	2.9
18.10.94	2.8	2.5	2.4	2.6	2.8	2.7	2.8	2.8
mean	3.5	3.3	3.2	3.3	3.4	3.4	3.4	3.5
Std	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.5
sub total	20.8	19.7	19.2	20.0	20.4	20.6	20.5	20.7

19.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
20.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
21.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
22.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
23.10.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
24.10.94	3.5	3.0	2.8	2.9	3.1	3.3	3.2	3.4
25.10.94	3.2	2.5	2.3	2.3	2.6	2.8	2.7	2.8
26.10.94	2.7	2.0	1.9	1.7	2.1	2.3	2.5	2.6
27.10.94	2.2	2.0	1.9	1.0	2.0	2.1	2.0	2.1
28.10.94	2.0	1.3	1.2	1.4	1.7	1.9	1.9	2.0
29.10.94	1.8	1.0	0.9	1.1	1.6	1.8	1.7	1.8
30.10.94	1.0	0.9	0.8	1.0	0.9	1.0	1.0	1.0
31.10.94	0.6	0.4	0.3	0.5	0.6	0.4	0.5	0.6
mean	2.8	2.5	2.5	2.5	2.7	2.7	2.7	2.8
std	1.2	1.3	1.4	1.4	1.2	1.2	1.2	1.2
sub total	37.0	33.1	32.1	31.9	34.6	35.6	35.5	36.3

Table 11. Soil evaporation losses short rains, 94/95 season.

1.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.11.94	3.1	2.4	2.2	2.3	2.5	2.5	2.6	2.6
4.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
5.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
7.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
8.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
9.11.94	3.3	2.5	2.4	2.5	2.7	2.9	2.8	3.0
10.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
11.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
12.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
13.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
14.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
15.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
16.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
17.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
18.11.94	3.5	2.9	2.8	2.9	3.0	3.1	3.2	3.4
19.11.94	2.6	2.1	2.0	2.1	2.4	2.5	2.5	2.5
20.11.94	2.0	1.7	1.5	1.6	1.8	1.8	1.9	1.9
21.11.94	3.0	2.4	2.3	2.4	2.6	2.7	2.7	2.9
22.11.94	2.2	1.7	1.5	1.6	1.8	1.9	1.8	2.0
23.11.94	1.8	1.4	1.3	1.3	1.6	1.8	1.7	1.7
24.11.94	1.3	1.0	0.8	0.9	1.1	1.2	1.3	1.3
25.11.94	0.8	0.5	0.3	0.4	0.6	0.8	0.8	0.9
mean	3.3	3.1	3.1	3.1	3.2	3.2	3.3	3.3
std	1.0	1.1	1.2	1.2	1.1	1.0	1.0	1.0
sub total	83.6	78.6	77.1	78.0	80.1	81.2	81.3	82.2

Table 12. Soil evaporation losses short rains, 94/95 season.

Date	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
26.11.94	0.9	0.6	0.6	0.7	0.8	0.9	0.9	0.9
27.11.94	0.6	0.3	0.2	0.4	0.5	0.5	0.6	0.6
28.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
29.11.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
30.11.94	3.6	3.0	3.1	3.2	3.4	3.5	3.3	3.4
1.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.12.94	3.6	3.0	3.1	3.2	3.3	3.5	3.4	3.5
4.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
5.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
7.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
8.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
9.12.94	3.1	2.4	2.3	2.4	2.6	2.7	2.7	2.8
Mean	3.2	3.0	3.0	3.1	3.1	3.1	3.1	3.1
std	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4
subtotal	47.8	45.3	45.3	45.9	46.6	47.1	46.9	47.2
10.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
11.12.94	3.8	3.5	3.4	3.6	3.8	3.7	3.6	3.8
13.12.94	3.2	3.3	3.3	3.4	3.6	3.6	3.5	3.7
14.12.94	3.0	3.2	3.0	3.2	3.4	3.5	3.3	3.5
15.12.94	2.7	3.0	3.0	3.1	3.4	3.5	3.2	3.4
16.12.94	2.5	2.9	2.8	2.9	3.1	3.3	3.2	3.4
17.12.94	2.1	1.7	1.5	1.6	1.8	1.9	2.0	2.0
18.12.94	2.0	1.5	1.4	1.5	1.7	1.9	1.8	1.8
19.12.94	1.8	1.4	1.3	1.3	1.6	1.7	1.7	1.7
20.12.94	1.0	0.6	0.4	0.6	0.7	0.9	0.9	1.0
21.12.94	0.7	0.5	0.2	0.4	0.6	0.7	0.6	0.7
mean	2.4	2.3	2.2	2.3	2.5	2.6	2.5	2.6
std	1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.2
sub total	26.8	25.6	24.3	25.6	27.7	28.7	27.8	29.0

Table 13. Soil evaporation losses short rains, 94/95 season.

22.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
23.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
24.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
25.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
26.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
27.12.94	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
28.12.94	3.4	2.8	2.6	2.7	2.9	2.9	2.9	3.1
29.12.94	2.5	2.0	1.9	2.1	2.3	2.4	2.4	2.5
30.12.94	1.6	1.0	0.8	0.9	1.2	1.5	1.6	1.6
31.12.94	0.6	0.0	0.0	0.0	0.4	0.5	0.6	0.6
1.1.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	2.9	2.7	2.7	2.7	2.8	2.8	2.9	2.9
std	1.4	1.6	1.6	1.6	1.5	1.5	1.4	1.4
Subtotal	32.1	29.8	29.3	29.7	30.8	31.3	31.5	31.8

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
2.1.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.1.95	4.0	3.4	3.2	3.3	3.6	3.7	3.6	3.8
4.1.95	3.5	3.0	2.9	3.0	3.3	3.4	3.4	3.4
5.1.95	3.0	2.6	2.4	2.5	2.7	2.8	2.9	2.9
6.1.95	2.8	2.4	2.3	2.4	2.5	2.6	2.6	2.7
7.1.95	2.5	2.0	1.9	2.1	2.3	2.4	2.4	2.5
8.1.95	1.3	0.9	0.8	0.9	1.0	1.2	1.3	1.3
9.1.95	0.6	0.3	0.2	0.2	0.5	0.6	0.6	0.6
10.1.95	0.3	0.1	0.2	0.3	0.2	0.2	0.3	0.3
11.1.95	0.2	0.0	0.0	0.0	0.1	0.2	0.2	0.2
12.1.95	0.4	0.2	0.2	0.2	0.4	0.3	0.3	0.4
Mean	2.1	1.7	1.6	1.7	1.9	1.9	2.0	2.0
std	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Sub total	22.6	18.9	18.1	18.9	20.6	21.4	21.6	22.1

Table 14. soil evaporation losses short rains, 94/95 season.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
13.1.95	1.7	1.2	1.0	1.1	1.5	1.6	1.6	1.6
14.1.95	1.3	0.8	0.6	0.7	1.1	1.2	1.1	1.1
15.1.95	0.8	0.4	0.3	0.4	0.6	0.7	0.6	0.8
16.1.95	0.4	0.0	0.0	0.0	0.3	0.4	0.4	0.4
17.1.95	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.1.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.1.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.1.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
mean	0.6	0.3	0.2	0.3	0.4	0.5	0.5	0.5
std	0.6	0.4	0.4	0.4	0.5	0.6	0.6	0.6
Sub total	4.4	2.4	1.9	2.2	3.5	3.9	3.7	3.9
Total	275.1	253.4	247.3	252.2	264.3	269.8	268.8	273.2
% of total rainfall	50.1	46.2	45.0	45.9	48.1	49.1	48.9	49.8

C = Control +M = Mulch H2+M = 1m from (H+M) H3+M = 2m from (H+M)
H2-M = 1m from (H-M) H3-M = 2m from (H-M) G2-M = 1m from (G-M)
G3-M = 2m from (G-M)

4.6.3 Soil evaporation for the long rains of 1995.

The results for this season are presented in tables 15-19. They are in a relative sequence close to what was earlier explained in 1994 long and 1994/95 short rainy seasons.

There was again a marked and logical tendency for the days when soils were wet to depict higher soil evaporation losses compared to days with already drying soils (Tables 15-19). There was virtually no soil evaporation recorded in May/June because, with exceptions in early May, the soil, covered with a well established maize canopy, was quite dry and the microlysimeters registered no weight differences. The bulk of soil evaporation therefore occurred during the wet periods of March, April and early May. Apart from rainy days, the maximum soil evaporation per day recorded by the microlysimeter is always the first day after rains. This was 3.8 mm day^{-1} in Table 16. The minimum soil evaporation was 0 mm day^{-1}, mostly on days in May and June (Table 17 and 18). There was one late April (Table 16).

The total soil evaporation losses were expressed, as a percent of the total rainfall for the season, in Table 18. This table shows that the mulched plots +M and H+M had reduced soil evaporation in absolute values by 5.9% and to 6.8% compared to the C plot. The unmulched plots, H-M and G-M had only lowered soil evaporation by 2.8% and 2.4% in absolute values over the season compared to the C plot. There were minor differences in soil evaporation between the points of measurements at H2+M & H3+M, H2-M & H3-M and at G2-M & G3-M respectively. On the average the seasonal soil evaporation losses ranged from roughly 45-49% of rainfall in the nonmulched plots to around 41-43% in the mulched plots. This shows that mulch had helped reduce seasonal soil evaporation by in the order of 4-6% (Table 18). As rainfall limits crop and pasture production in the semi-arid areas of Kenya, efforts in soil and water management should be geared towards reducing the substantial quantities of water loss via soil evaporation, in order to increase the amount of water from rain going to transpiration. Our soil evaporation results may be somewhat too high for reasons given at the end of section 4.6.1. They should be considered an upper limit.

Table 15. Soil evaporation results long rains, 1995.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
18.3.95	3.5	2.9	3.1	3.4	3.4	3.3	3.2	3.0
19.3.95	3.0	2.9	2.8	2.9	3.0	3.2	3.0	2.8
20.3.95	2.9	2.9	2.7	2.7	2.9	3.0	2.9	2.7
21.3.95	2.9	2.8	2.8	2.7	2.8	2.8	2.4	2.5
22.3.95	2.9	2.8	2.6	2.6	2.4	2.5	2.0	2.5
23.3.95	1.8	1.3	1.0	1.2	1.4	1.7	1.5	1.8
mean	2.8	2.6	2.5	2.6	2.7	2.8	2.5	2.6
Std	0.5	0.6	0.7	0.7	0.6	0.5	0.6	0.4
Sub total	17.0	15.6	15.0	15.5	16.0	16.6	15.0	15.3

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
24.3.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
25.3.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
26.3.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
27.3.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
28.3.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
29.3.95	3.2	2.4	2.5	2.6	2.7	2.8	2.7	2.9
30.3.95	2.8	2.2	2.1	2.2	2.5	2.6	2.4	2.5
31.3.95	2.1	1.8	1.7	1.7	1.9	2.0	1.9	2.0
1.4.95	2.0	1.6	1.7	1.8	1.7	1.8	1.8	1.8
2.4.95	1.8	1.5	1.4	1.6	1.7	1.8	1.7	1.8
3.4.95	1.5	1.3	1.2	1.3	1.4	1.5	1.5	1.5
4.4.95	1.0	0.6	0.4	0.5	0.7	0.7	0.8	0.9
mean	2.9	2.6	2.6	2.6	2.7	2.8	2.7	2.8
Std	1.1	1.2	1.3	1.2	1.2	1.2	1.2	1.1
Sub total	34.4	31.4	31.0	31.7	32.6	33.2	32.8	33.4

Table 16. Soil evaporation losses long rains, 1995.

DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
5.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
7.4.95	3.8	3.3	3.0	3.1	3.6	3.7	3.8	3.8
8.4.95	2.5	2.1	2.0	2.2	2.4	2.5	2.3	2.5
9.4.95	1.8	1.0	0.9	1.3	1.7	1.7	1.8	1.8
10.4.95	0.4	0.2	0.2	0.3	0.2	0.4	0.3	0.4
mean	2.8	2.4	2.4	2.5	2.7	2.7	2.7	2.8
Std	1.3	1.5	1.5	1.4	1.4	1.3	1.4	1.3
Sub total	16.5	14.6	14.1	14.9	15.9	16,3	16.2	16.5
DATE	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
11.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
12.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
13.4.95	3.5	3.3	3.3	3.2	3.4	3.5	3.6	3.6
14.4.95	3.0	3.0	3.1	3.0	3.5	3.4	3.5	3.5
15.4.95	2.8	2.9	2.8	2.9	3.2	3.2	3.1	3.5
16.4.95	2.4	2.6	2.4	2.5	2.7	2.9	2.8	3.0
17.4.95	1.1	0.8	0.7	0.8	0.9	1.0	0.8	1.0
18.4.95	1.0	0.5	0.4	0.3	0.6	0.7	0.5	0.7
mean	2.7	2.6	2.6	2.6	2.8	2.8	2.8	2.9
Std	1.1	1.2	1.3	1.3	1.2	1.2	1.3	1.2
Sub total	21.8	21.1	20.7	20.7	22.3	22.7	22.3	23.3
19.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
20.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
21.4.95	2.8	2.4	2.0	2.2	2.5	2.6	2.5	2.8
22.4.95	1.6	1.2	1.1	1.3	1.4	1.5	1.4	1.6
23.4.95	1.0	0.6	0.5	0.7	0.8	0.9	0.8	0.8
24.4.95	0.7	0.3	0.2	0.3	0.4	0.6	0.5	0.7
25.4.95	0.3	0.1	0.0	0.2	0.3	0.3	0.2	0.3
26.4.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.4.95	0.5	0.2	0.1	0.2	0.4	0.5	0.3	0.5
28.4.95	0.6	0.3	0.2	0.2	0.3	0.5	0.4	0.4
29.4.95	0.6	0.5	0.4	0.5	0.6	0.8	0.7	0.8
mean	1.5	1.2	1.1	1.2	1.3	1.4	1.3	1.4
Std	1.4	1.5	1.5	1.4	1.4	1.4	1.4	1.4
Sub total	16.1	13.6	12.5	13.6	14.7	15.7	14.8	15.9

Table 17. Soil evaporation losses long rains, 1995.

Date	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
30.4.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1.5.95	3.5	3.0	2.5	2.9	3.2	3.4	3.2	3.3
2.5.95	2.7	2.6	2.4	2.7	2.6	2.8	2.6	2.9
3.5.95	2.7	2.4	2.2	2.6	2.1	2.4	2.5	2.2
4.5.95	2.6	2.2	2.0	2.4	1.9	2.0	2.0	2.0
5.5.95	1.2	0.6	0.4	0.5	0.7	0.8	0.8	0.9
6.5.95	0.4	0.0	0.0	0.0	0.1	0.1	0.1	0.2
7.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.5.95	0.5	0.1	0.1	0.1	0.3	0.4	0.4	0.5
Mean	1.6	1.3	1.2	1.4	1.3	1.4	1.4	1.5
std	1.5	1.4	1.4	1.5	1.4	1.4	1.4	1.4
Subtotal	17.7	14.8	13.7	15.2	14.8	15.9	15.6	16.0

Date	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
11.5.95	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
12.5.95	2.6	2.2	2.1	2.3	2.5	2.7	2.6	2.7
13.5.95	1.2	0.7	0.6	0.7	0.8	0.8	0.8	0.9
14.5.95	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.5.95	1.0	0.6	0.5	0.6	0.7	0.7	0.7	0.8
16.5.95	1.3	0.9	0.8	0.8	1.0	1.1	1.0	1.0
17.5.95	1.8	1.2	1.0	0.9	1.4	1.5	1.4	1.6
18.5.95	0.7	0.3	0.2	0.2	0.4	0.6	0.5	0.6
19.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	1.1	0.8	0.8	0.8	0.9	1.0	0.9	1.0
Std	1.2	1.1	1.1	1.2	1.2	1.2	1.2	1.2
Sub total	12.9	9.9	9.2	9.5	10.8	11.4	11.0	11.6

Table 18. Soil evaporation losses long rains, 1995.

23.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.5.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.5.95	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.5.95	0.6	0.2	0.1	0.1	0.3	0.4	0.5	0.6
30.5.95	1.0	0.6	0.4	0.4	0.7	0.8	0.9	1.0
31.5.95	0.7	0.3	0.3	0.4	0.5	0.5	0.6	0.6
Mean	0.3	0.1	0.1	0.1	0.2	0.2	0.2	0.2
std	0.4	0.2	0.1	0.2	0.3	0.3	0.3	0.4
subtotal	2.5	1.1	0.8	0.9	1.5	1.7	2.0	2.2

Date	C	+M	H2+M	H3+M	H2-M	H3-M	G2-M	G3-M
1.6.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.6.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.6.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.6.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.6.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	138.8	122.1	117.0	122.0	128.6	133.4	129.6	134.3
% of total rainfall	48.7	42.8	41.1	42.8	45.1	46.8	45.5 0	47.1 0

C = Control +M = Mulch H2+M = 1m from (H+M) H3+M = 2m from (H+M)

H2-M = 1m from (H-M) H3-M = 2m from (H-M) G2-M = 1m from (G-M)

G3-M = 2m from (G-M)

The amount of water evaporated from the five plots in the experiment were used in the water balance equation for the calculation of transpiration by the growing crops and hence for calculation of water use efficiency in section (4.7).

4.6.4. Discussions.

Determination of soil evaporation leads to the separation of the transpiration of plants from the total evapotranspiration of a crop. The soil evaporation values were used for the determination of the water use efficiency of the plants, using the water balance equation. This is important as it leads to the knowledge of the actual water use by the crop for dry matter or economic yield production. In managing the water balance mentioned earlier, soil and water management techniques can therefore be used to minimise the losses arising from soil evaporation and maximise available water for transpiration in the semi-arid areas of Kenya.

Soil evaporation losses reported from other semi-arid areas have been shown to be quite high. Results from semi-arid Niger (Wallace, 1991) show that soil evaporation can dominate the crop water balance or become insignificant, depending on the soil wetness. Direct soil evaporation from millet has been determined as between 35-45 % of the total rainfall, the higher proportions occurring in low rainfall (Wallace et al., 1988; Bley et al., 1991; Fetcher et al. 1991). One third of the rainfall was lost as soil evaporation for wheat grown in Syria, with even greater losses (50-60% of rainfall) in dryland barley (Cooper et al. 1983). As mentioned in Chapter 1, also soil evaporation under a wheat canopy in Australia was found to be 48% of the total rainfall (Pleuning et al. 1994). Soil evaporation has been estimated via modelling, using maize and cowpeas, as between 42-58% of the total estimated evapotranspiration at Machakos, Kenya (McIntyre et al., 1996). Our values are very much in line with the above.

The soil evaporation losses from maize/senna or /grass strip cropping for the seasons 1994 and 1995 were high but within the ranges mentioned above. The soil evaporation losses, as percentage of the total rainfall, from below the cowpea crop, though still high, were appreciably lower in the season 1994/95 than that of the maize crop in 1994 but slightly higher than in the 1995 seasons (tables 9, 14 and 18 respectively). Actual evaporation losses were highest in the cowpea season and among the two maize seasons it was highest in the first. One reason for the high evaporation losses in all seasons may have been due to assumed maximum soil evaporation losses during rainy days. A second reason may be that the microlysimeters may have suffered from poor drainage, as they had been sealed at the bottom by cellotape to minimise water losses. This may have created wet conditions in the microlysimeter which enhances more soil evaporation.

Treatment differences were mainly due to (i) mulch applications and differences in the crop cover to the ground, which reduce radiation penetration to the soil, thereby reducing soil evaporation, (ii) insulation effects where air movement is reduced within and below the mulch and water vapour can leave less easily and (iii) shading effects of the hedgerows and grass strips. Additionally, wind movement can lead to asymmetrical shading of the rows near the hedge or grass(e.g.Mungai, 1991). Because the mulch rates were low in all the seasons, they managed to lower soil evaporation by absolute amounts of 8.8-9.8% in 1994, 5.9-6.8% in 1995 for maize crop and also 3.9-4.6% for the cowpea crop of 94/95 between the mulched and nonmulched plots respectively. These percentages slightly less 1994 respectively slightly more than double 94/95 and 1993) when relative percentages are used to express differences.

4.7. Photosynthetically active radiation (PAR) interception.

Except for the long rains of 1993, when no data were obtained because of a severe drought, the results for the short rains 92/93, 93/94, long rains 1994, short rains 94/95 and long rains 1995 for PAR (%) interception are presented and discussed.

4.7.1 PAR (%) interception for the cowpea/Senna siamea hedgerow cropping, for the short rains of 1992/93.

The actual PAR results from 30 DAS through flowering and grain filling to harvesting, for the short rains of 92/93 are shown in Table 19 and figures (4.108-110).

The results show that there was a general increase in PAR interception in the C, +M, H+M, H-M and G-M plots from generally below 20% as at 30 DAS, reaching a peak of between 60 and 90 %, mostly at 60 DAS. PAR then in most cases levelled off or fell slightly towards harvest as the crop reached senescence. The above was as a result of the increase in the leaf area index with increase in hedge/crop canopy growth and hence increase in PAR interception. The combination of shade in the hedge/cowpea interface canopy near the hedgerow resulted in more canopy shade and an increase in PAR interception compared to the crop at 1 m from the hedge in the plot with mulch, H2+M (fig. 4.108). The PAR interception was however slightly more at 2 m from the hedge, H3+M, than at 1 m, H2+M, because there was no hedge shading at 2 m from H+M and the cowpea had a healthier canopy compared to the poorer canopy crop at H2+M, somewhat shaded by the Senna canopy near it.

The results also show that the H-M plot had a rather similar relative PAR interception as the H+M plot, for similar reasons (fig. 4.109). Also the results from the G-M plot (fig. 4.110) show that while the interface canopy at the grass/cowpea interface showed increased PAR interception at 60 DAS and beyond, mainly due to grass, at 1 m from grass strip G2-M had slightly lower PAR interception from 60 DAS onwards than G3-M at 2 m from the grass strip. This may have been partly because the cowpea row at 1 m from the grass strip was still seriously affected by not only the grass shading but also by the lateral grass roots. This resulted in stunted small leaved cowpea plants, which intercepted very little PAR compared to the middle big leaved cowpea plant rows, that had less competition for light, water and crop nutrients than the rows nearer to the grass strip. The cowpea in the middle rows of the G-M plot intercepted less PAR than those in the C and +M plot (fig.4.110), as the latter had no competition for light and other growth resources.

An additional analysis of variance (ANOVA) was carried out for the PAR interception averaged for the whole season, which showed that there were generally statistically significant differences in the five treatments in PAR interception at the points of measurement, among treatments and within treatments at $P \leq 0.050$; CV = 32.6%. Because of this, the next step in the analysis was to separate and rank the PAR means at these points of measurement using Duncan's Multiple Range Test (DMRT) as described in chapter 3. As an example, separating and ranking the PAR means at the points of measurement for the overall treatments is illustrated in Table (xxi), in appendix 4.8. After separating the means for the five treatments, the PAR means of points ranked 1st and the other 2 positions were ranked 2nd after the first point of measurement at LSD = 2.6 and SE = 0.95. From the ANOVA, it was also shown that there were significant differences among treatments at $P \leq 0.05$, LSD 3.4 and SE = 1.2. The DMRT ranked the H+M, H-M and G-M treatment PAR means together while the C and +M treatment PAR means followed jointly in a descending order. This separation and ranking of the treatment means is illustrated as an example in table (xxii) in appendix 4.8. The ranking confirms the fact that alley cropping results in on average increased PAR interception by the intercrop, as differences between ranks are statistically significant. The differences within treatments LSD 5.9; SE = 2.1 are shown in Table (xxiii) in appendix 4.9. In this Table the differences in PAR at the three points of measurement in the C and +M plots were statistically significantly different (position 2 ranked 1st and positions 1 and 3 ranked 2nd. The H+M1, H-M1 and G-M1 positions with more intercepted PAR (1st rank) were also statistically significantly different from H+M2, H+M3, H-M2, H-M3 and G-M2 & G-M3 positions with less PAR (2nd rank) respectively. This statistically confirms that there was more PAR interception at the hedge/cowpea and grass/cowpea interface close to the hedge/grass than at 1 or 2 m from the hedge or grass strip.

Table 19. Mean PAR interception cowpea senna hedgerow cropping short rains 92/93

DAS	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
30	12.7	15.5	18.0	15.5	12.5	11.0	7.5	4.5	26.6	25.0	18.0
40	30.2	31.2	45.5	44.0	31.5	55.7	50.5	53.8	42.5	35.0	36.4
50	73.8	74.5	78.0	67.0	76.5	76.5	65.0	72.5	66.0	60.3	59.0
60	80.2	74.3	91.4	76.0	90.0	80.1	71.2	79.4	74.5	61.2	65.1
70	80.0	71.8	87.0	73.2	87.4	88.4	73.4	80.3	72.3	62.3	67.4
80	76.8	68.2	82.4	80.4	82.6	83.7	71.9	81.2	70.7	63.3	65.8
90	73.5	70.1	83.7	79.3	81.9	90.3	72.4	80.2	74.1	67.5	68.5

C = Control +M = Mulch H1+M = Mean (crop/H+M) H2+M = 1m from (H+M)

H3+M = 2m from (H+M) H1-M = Mean (crop/H-M) H2-M = 1m from (H-M)

H3-M = 2m from (H-M) G1-M = Mean (crop/G-M) G2-M = 1m from(H-M)

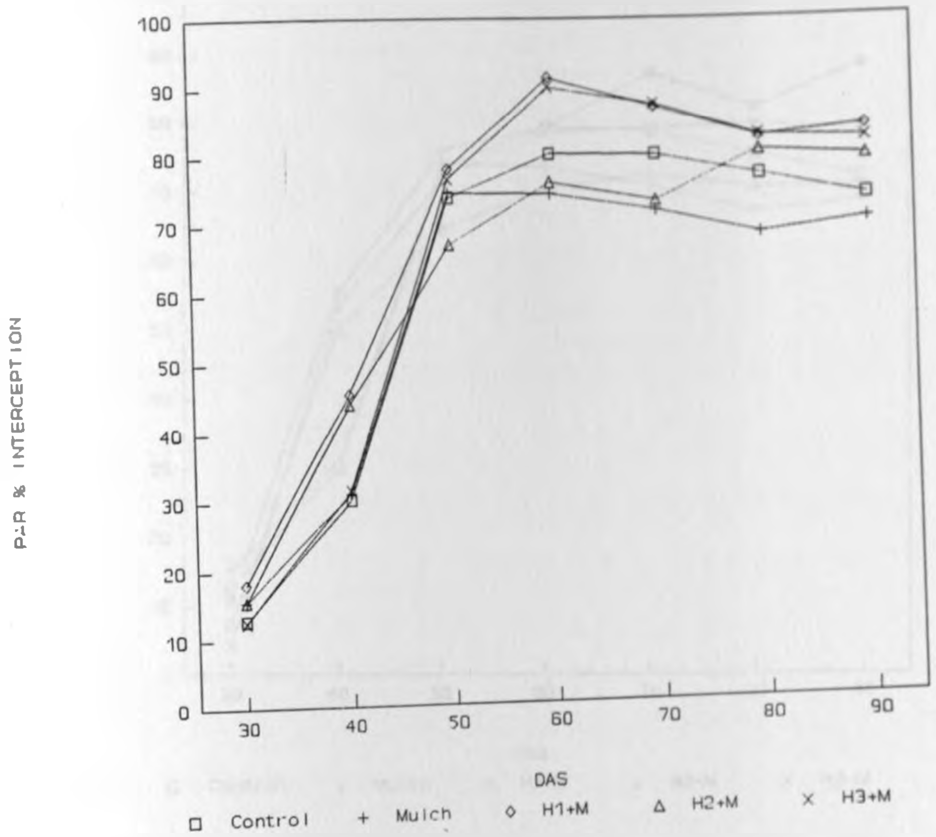


Fig.4.108. PAR interception. Comparison between control, mulch, hedge+mulch, 1 m from hedge+mulch and 2 m from hedge+mulch. Cowpea, short rains of 1992/93.

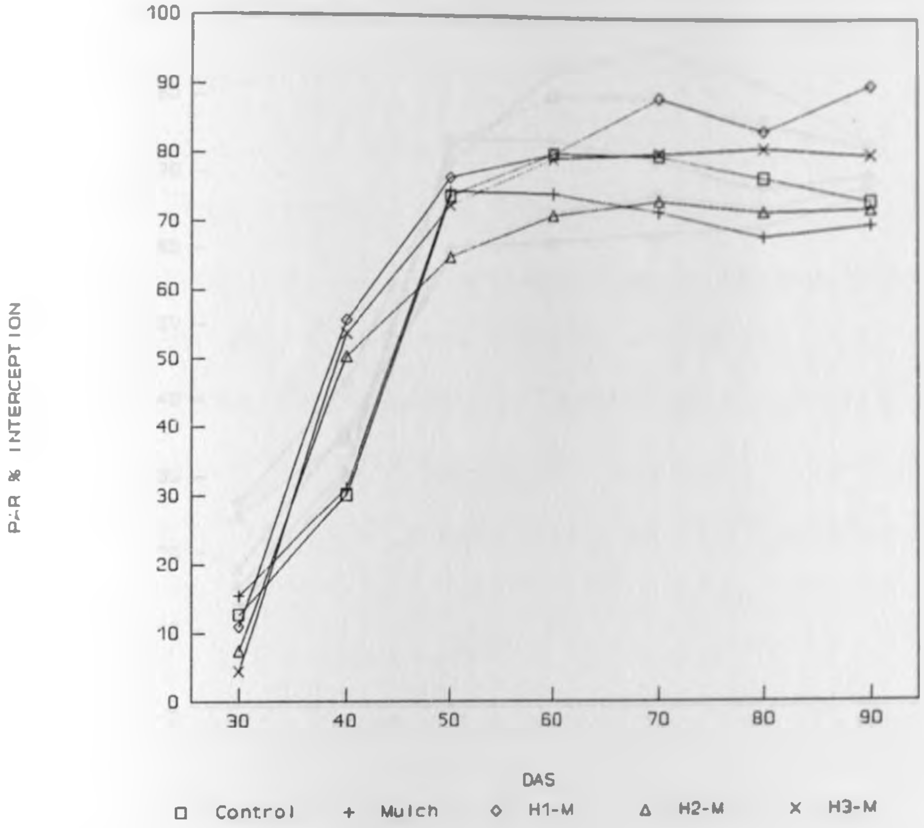


Fig.4.109. PAR interception. Comparison between control, mulch, hedge+crop, 1 m from hedge+crop and 2 m from hedge+crop. Cowpeas, short rains of 1992/93.

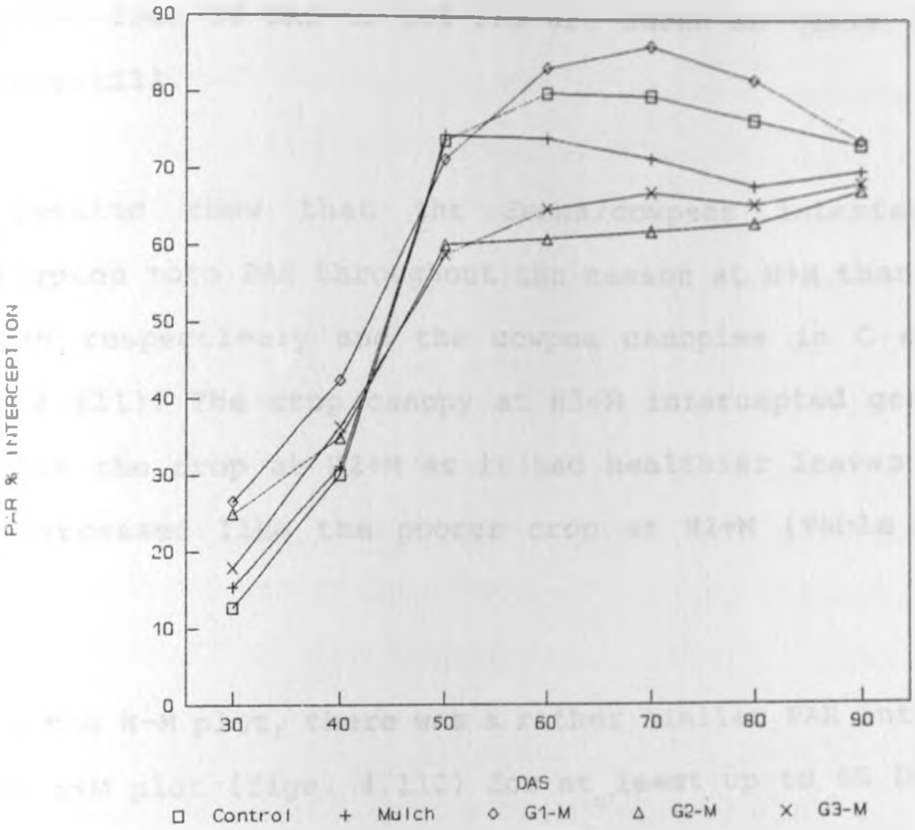


Fig.4.110. PAR interception. Comparison between control, mulch, grass+crop, 1 m from grass and 2m from grass. Cowpeas, short rains of 1992/93.

4.7.2 PAR interception by the cowpea/Senna siamea hedgerow cropping for the short rains of 1993/94.

The results for the actual PAR interception for the short rains of 1993/1994 from 20 DAS to 101 DAS are shown in table 20 and figs. (4.111-4.113).

The results show that the *Senna*/cowpeas interface canopies intercepted more PAR throughout the season at H+M than at H2+M and at H3+M respectively and the cowpea canopies in C and +M plots (fig. 4.111). The crop canopy at H3+M intercepted generally more PAR than the crop at H2+M as it had healthier leaves and was not shade stressed like the poorer crop at H2+M (Table 20 and fig. 4.111).

As for the H-M plot, there was a rather similar PAR interception as in the H+M plot (figs. 4.112) for at least up to 65 DAS, although the cowpea crop in H+M plot appeared somewhat healthier. This can be seen from comparisons in 1 m and 2 m from the hedges in table 20. This could have been due to release of nutrients by the decomposing mulch in the H+M as opposed to H-M with no mulch or to another beneficial mulch factor.

In the G-M plot, there was also a similarity in PAR interception with that in the H+M plot. The middle rows (G3-M) in the G-M plot generally intercepted slightly more PAR between 35 and 80 DAS than the cowpea rows nearer the grass strip (G2-M) for the reasons given earlier in the 92/93 season (fig. 4.113).

Additionally, an ANOVA carried out showed that seasonally averaged there were statistically significant differences in PAR interception in all the plots at the points of measurement, between treatments and within treatments at $P \leq 0.05$ and) CV = 23.9%. Separation and ranking of the overall PAR means at the points of measurement in all treatments using DMRT, as applied in 92/93 season, clearly showed that position one with higher PAR (1st rank) was statistically significantly different from positions two and three of PAR measurement ranked 2nd and 3rd respectively (LSD = 2.63, SE = 0.95). The C and +M plots showed no within treatment PAR differences while the AF and G-M plots had significant differences (LSD = 5.9; SE = 2.1) as shown in Table (xxiv) in appendix 4.9. In this table, the H+M1, H-M1 and G-M1 (jointly with G-M3) positions with more PAR interception (1st rank) were statistically significantly different from H+M2 (3rd rank), H-M2 and G-M2 (both 2nd rank) and H+M3, H-M3 (2nd rank) positions which had less PAR. This means the crop/hedgerows and crop/grass strip interfaces together with G-M3 had highest PAR interception (ranked 1st) followed by the other points in the middle of the alley together with H-M2 (ranked 2nd and jointly second) and then the other in between ones (ranked last, 3rd and jointly second. There were also statistically significant differences among treatments. Separating the seasonal PAR means over the treatments and ranking them in a descending order showed that the H+M and H-M plots (jointly ranked earlier in the 92/93 season (fig. 4.113).

Additionally, an ANOVA carried out showed that seasonally averaged there were statistically significant differences in PAR interception in all the plots at the points of measurement, between treatments and within treatments at $P \leq 0.05$ and) CV = 23.9%. Separation and ranking of the overall PAR means at the points of measurement in all treatments using DMRT, as applied in 92/93 season, clearly showed that position one with higher PAR (1st rank) was statistically significantly different from positions two and three of PAR measurement ranked 2nd and 3rd respectively (LSD = 2.63, SE = 0.95). The C and +M plots showed no within treatment PAR differences while the AF and G-M plots had significant differences (LSD = 5.9; SE = 2.1) as shown in Table (xxiv) in appendix 4.9. In this table, the H+M1, H-M1 and G-M1 (jointly with G-M3) positions with more PAR interception (1st rank) were statistically significantly different from H+M2 (3rd rank), H-M2 and G-M2 (both 2nd rank) and H+M3, H-M3 (2nd rank) positions which had less PAR. This means the crop/hedgerows and crop/grass strip interfaces together with G-M3 had highest PAR interception (ranked 1st) followed by the other points in the middle of the alley together with H-M2 (ranked 2nd and jointly second) and then the other in between ones (ranked last, 3rd and jointly second. There were also statistically significant differences among treatments. Separating the seasonal PAR means over the treatments and ranking them in a descending order showed that the H+M and H-M plots (jointly ranked

1st) had higher PAR interception than the G-M plot (ranked 2nd) and C and +M plots (ranked 3rd) respectively at $P \leq 0.05$, LSD = 3.4 and SE = 0.6. This ranking of the PAR interception means, both between the points of measurement and between treatments, again confirms statistically that cowpea/senna and cowpea/grass systems increased overall PAR interception but Table (xxiv) of course shows where exactly this increase took place.

Table 20. Mean PAR interception cowpea senna hedgerow cropping short rains 93/94.

DAS	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
20	22.6	26.4	37.9	19.7	27.9	42.2	20.9	24.1	39.9	21.3	21.3
27	25.8	28.3	44.4	25.2	30.5	46.5	24.8	29.5	44.8	26.2	25.7
35	33.6	33.7	53.7	37.0	38.6	53.7	32.3	34.9	55.6	33.6	36.0
42	40.2	43.1	62.5	43.3	48.6	64.8	42.5	45.1	64.6	44.1	45.1
51	42.3	44.6	64.8	46.0	49.3	66.1	43.6	46.6	66.7	45.3	49.6
58	44.3	46.2	66.6	47.6	51.3	68.1	45.6	48.6	60.4	48.3	47.6
65	51.1	51.9	69.4	49.1	54.3	70.4	49.7	50.1	63.2	53.2	57.0
72	50.0	50.0	68.2	57.4	60.3	75.0	57.6	47.6	64.5	43.6	54.6
80	34.0	33.0	55.6	36.2	34.0	58.3	30.9	20.0	57.4	32.6	38.5
87	34.1	33.0	56.5	36.6	34.8	47.7	25.8	24.4	43.0	31.9	30.3
94	33.5	32.0	52.5	22.8	32.6	47.8	25.5	19.1	41.0	30.6	29.7
101	32.6	30.0	45.1	19.4	24.4	51.9	22.5	25.3	40.9	24.2	26.6

C = Control   +M = Mulch   H1+M = Mean(Crop/H+M)   H2+M = 1m from (H+M)   H3+M = 2m from (H+M)

H1-M =Mean(Crop/H-M)   H2-M = 1m from (H-M)   H3-M = 2m from (H-M)

G1-M = Mean(Crop/G-M)   G2-M = 1m from (G-M)   G3-M = 2m from (G-M)

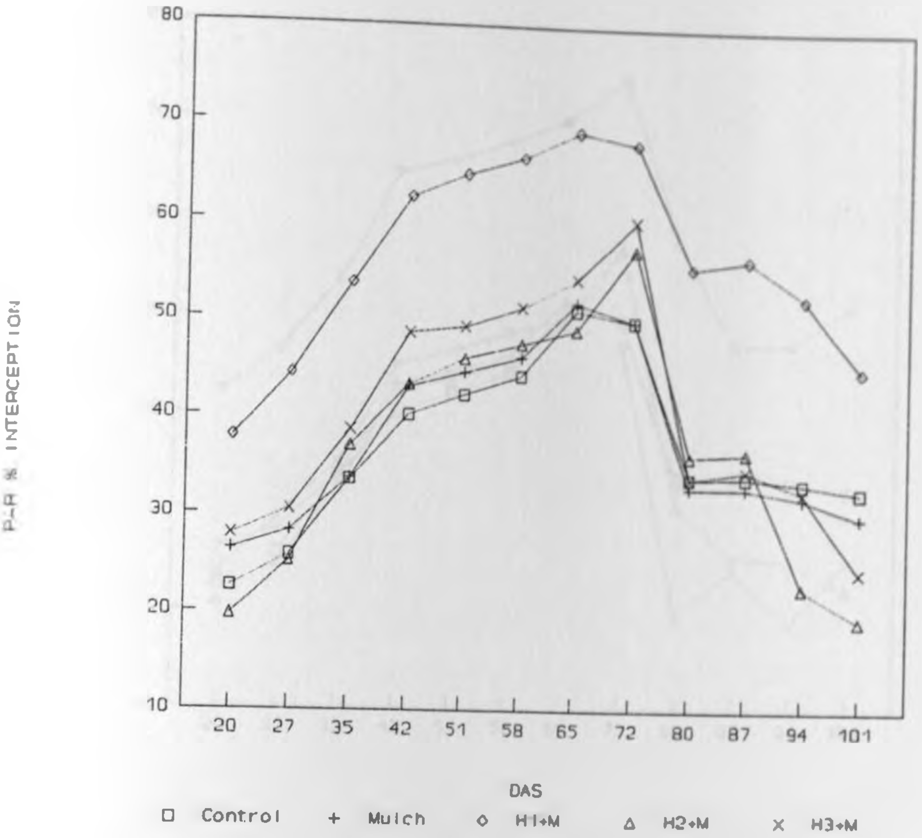


Fig. 4.111. PAR interception. Comparison between control, mulch, hedge+mulch+crop, 1 m from hedge+mulch+crop and 2m from hedge+mulch+crop. Cowpea, short rains of 1993/94.

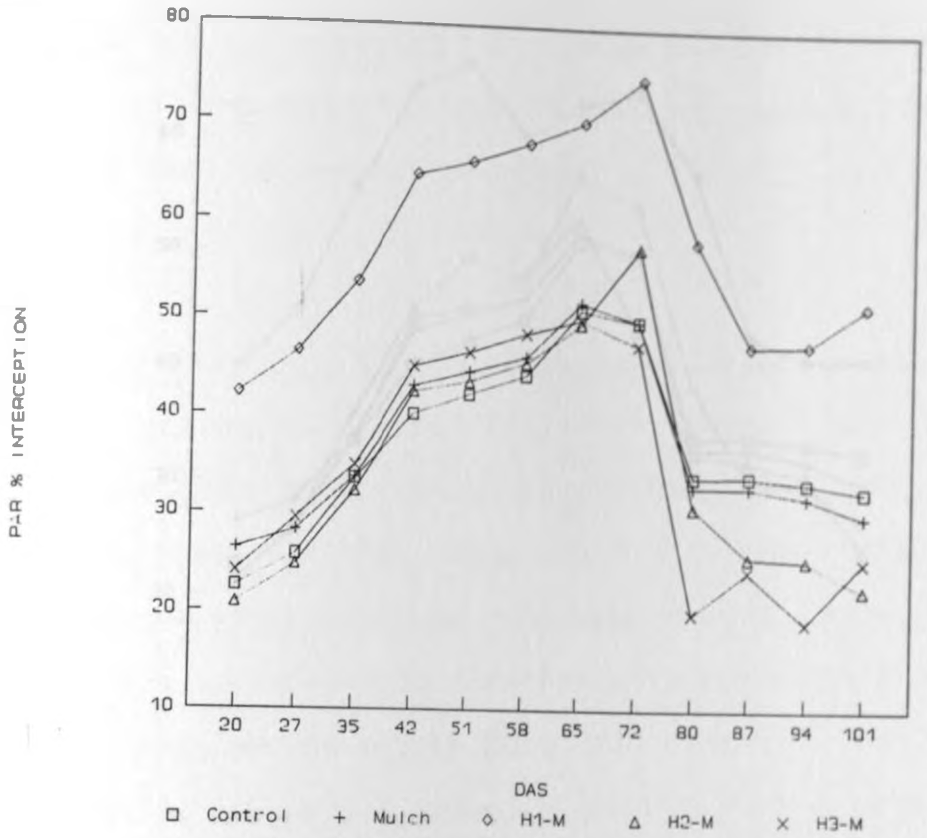


Fig. 4.112. PAR interception. Comparison between control, mulch, crop/hedge, 1 m from hedge and 2 m from hedge. Cowpea short rains of 1993/94.

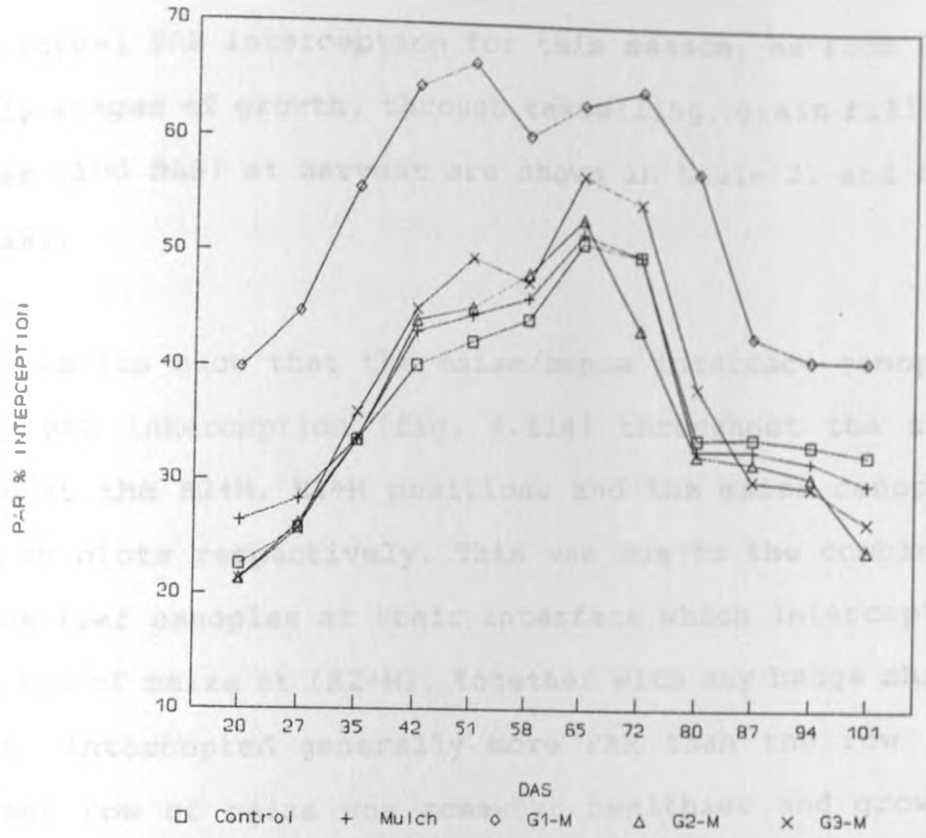


Fig.4.113. PAR interception. Comparison between, control, mulch, grass+crop, 1m from grass and 2m from grass. Cowpeas, short rains of 1993/94.

4.7.3 PAR interception by the maize/Senna siamea hedgerow cropping, for the long rains of 1994.

The actual PAR interception for this season, as from 30 DAS at the early stages of growth, through tasselling, grain filling stage and later (100 DAS) at harvest are shown in table 21 and figs. (4.114-4.116).

The results show that the maize/senna interface canopies realised more PAR interception (fig. 4.114) throughout the season at H+M than at the H2+M, H3+M positions and the maize canopies in the C and +M plots respectively. This was due to the combined maize and senna leaf canopies at their interface which intercepted more PAR. The row of maize at (H2+M), together with any hedge shade influence left, intercepted generally more PAR than the row at H3+M. The former row of maize was somewhat healthier and growing somewhat more vigorously and was observed to have more leaf area than the latter. This was possibly due to partial beneficial shading of the first mentioned maize row till the maize plant grew taller than the senna hedgerow and also due to more moisture concentrated beneath the hedgerows (section 4.7) than in the middle of the alley. The roots of senna have been shown to extend to the middle maize rows where they depressed somewhat more the yields in the maize rows compared to the rows nearer the hedges through competition for water and other growth resources on flat ground Mungai (1992). This depressed maize growth contributed to lower PAR interception.

The PAR interception pattern in the H-M plot was similar to the pattern in the H+M plot, save the fact that the PAR levels were lower than in H+M (be it very variably so for the H2 position), possibly due to the absence of the mulch, as the crop appeared less healthy and more stressed (Fig. 4.115). In the G-M plot, the maize/grass interface canopies also intercepted higher PAR than the maize canopies at G2-M and G3-M respectively. The crop generally intercepted somewhat more PAR (Table 21) at G3-M than at G2-M, that may have included some shading, although they were often close. Competition for water and other nutrients by the lateral grass roots extended to G3-M as well (figs. 4.116).

An ANOVA performed for the PAR interception over the season showed that there were statistically significant differences in seasonally averaged PAR interception between the points of measurement in all the treatment plots, among and within treatments at $P \leq 0.05$(, CV = 46.4. Ranking the overall means among the treatments (LSD 4.0 and SE = 1.4) for the PAR interception indicated that the first point of measurement had significantly higher PAR (1st rank) than the second point of measurement (3rd rank) and the third point of measurement (2nd rank). The C and +M treatments showed no statistically significant differences in PAR interception within the points of measurements but there were differences in the AF and G-M plots as shown in Table (xxv) in appendix 4.9 (LSD = 8.86; SE = 3.19). From this table, the H+M1, H-M1 and G-M1 & G-M3 positions had more PAR interception (1st rank), H+M2, position (3rd rank) had least PAR interception together with H-M2 (jointly ranked 2nd) and G-M2 (ranked 2nd and last) while H+M3, (ranked 2nd) and H-M3 (jointly ranked 2nd) positions had intermediate PAR interception. There were also statistically significant PAR interception differences between treatments. Separating the seasonal average PAR interception means for the five treatments using DMRT at $P \leq 0.05$, LSD = 5.1 and SE = 1.8 showed a decreasing order for agroforestry H+M plot (ranked 1st), H-M and G-M plots (ranked 2nd) and C and +M plots (ranked 3rd and last). This confirms, as found in earlier seasons of cowpea, that also Senna/maize and grass/maize systems result in increased PAR interception, but as in the former season Table xxv indicates where exactly this increase occurs. Adding the hedge/strips to the maize is not compensated for by equally less maize biomass.

Table 21. Mean PAR interception maize/senna hedgerows cropping long rains 1994.

DAS	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
30	13.6	14.5	27.5	10.1	7.4	25.2	19.4	8.7	17.8	5.2	9.7
37	18.7	16.3	39.1	18.8	14.0	36.6	20.0	9.5	29.4	7.0	14.6
44	19.5	22.3	42.3	28.8	19.2	40.5	21.0	17.0	32.0	9.3	18.8
51	21.9	30.2	45.7	29.7	20.5	48.0	32.8	22.4	33.3	31.0	29.4
58	49.2	50.7	66.2	54.3	48.6	57.1	42.6	36.0	48.2	43.3	45.0
65	53.9	57.2	70.0	64.0	53.0	59.1	42.0	36.6	56.8	49.3	51.6
72	53.8	52.9	63.6	49.6	44.3	58.2	51.3	38.7	56.0	48.0	43.6
79	53.3	56.6	62.1	40.0	51.6	59.6	48.0	40.3	59.0	48.6	45.00
86	44.3	36.5	60.7	45.6	42.3	53.5	43.3	40.6	43.8	27.3	37.00
93	39.2	38.5	46.7	28.6	25.6	38.5	30.0	20.6	40.3	25.0	25.30
100	39.0	35.5	47.1	29.0	25.8	38.7	30.1	19.7	41.0	25.4	25.40

C = Control +M = Mulch H1+M = Mean (crop/H+M) H2+M = 1m from (H+M) H3+M = 2m from(H+M)

H1-M = mean(crop/H-M) H2-M = 1m from (H-M) H3-M = 2m from (H-M)

G1-M = mean(crop/G-M) G2-M = 1m from(G-M) G3-M = 2m from(G-M)

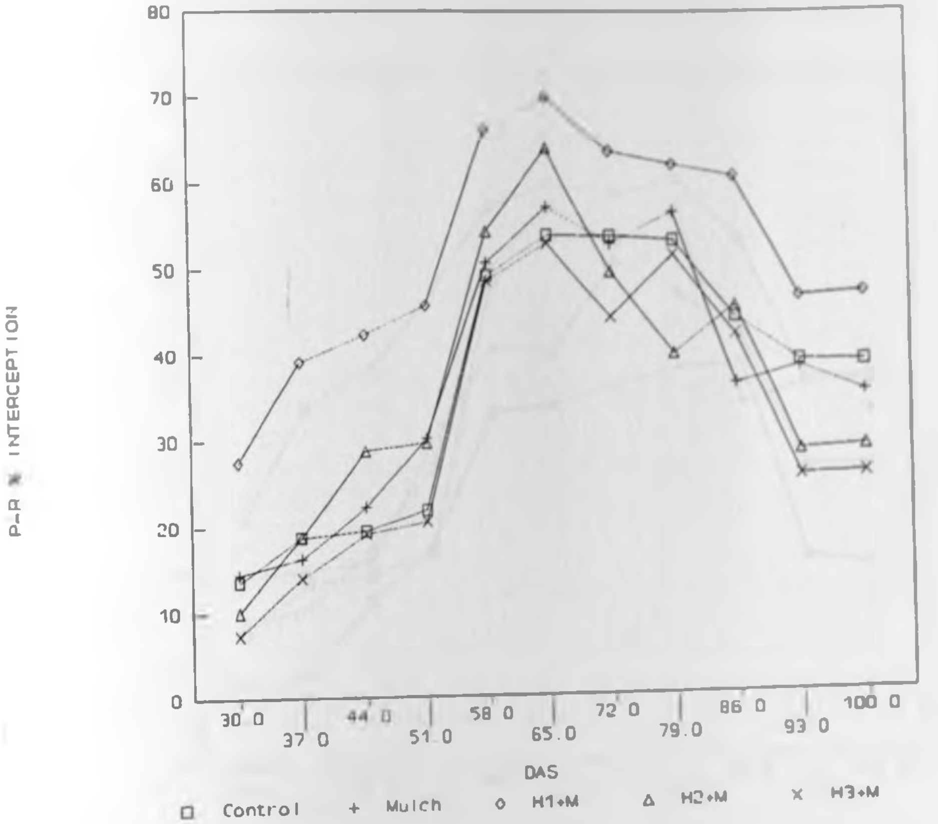


Fig. 4.114. PAR interception. Comparison between control, mulch, hedge+mulch+crop, 1 m from hedge+mulch+crop and 2 m from hedge+mulch+crop. Maize, long rains of 1994.

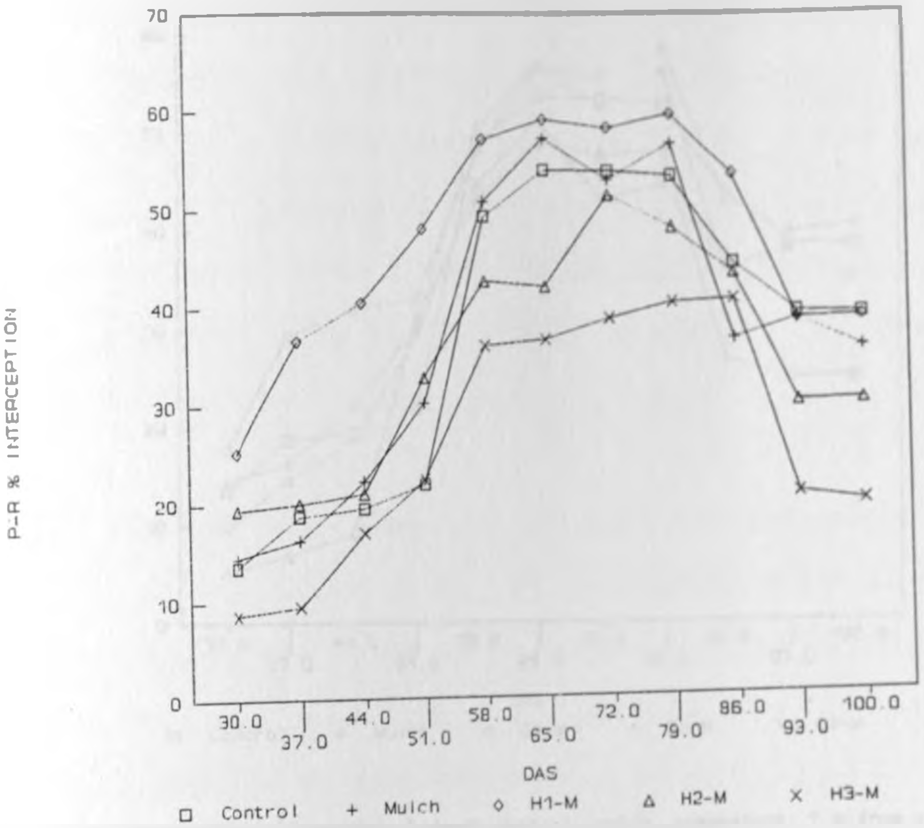


Fig.4.115. PAR interception. Comparison between control, mulch, hedge+crop, 1m from hedge+crop and 2 m from hedge+crop. Maize, long rains of 1994.

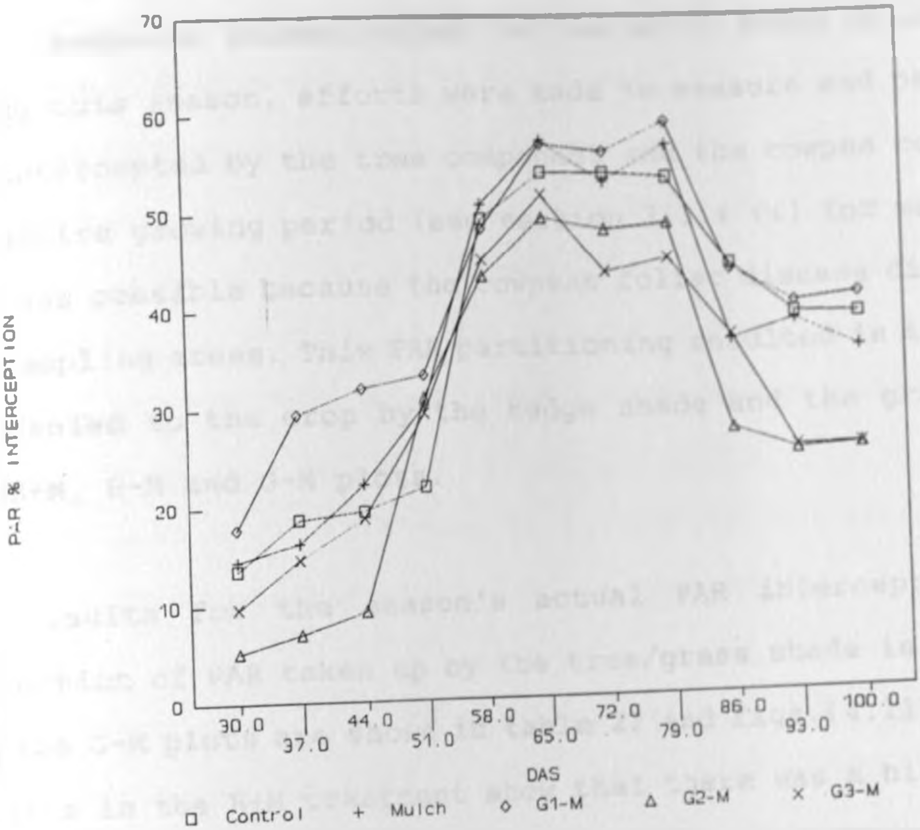


Fig.4.116. **PAR interception.** Comparison between control, mulch, grass+crop, 1 m from grass+crop and 2 m grass+crop. Maize, long rains of 1994.

4.7.4 PAR interception by the cowpea/Senna siamea hedgerow intercropping for the short rains of 1994/95.

During this season, efforts were made to measure and partition the PAR intercepted by the tree component and the cowpea component for the entire growing period (see section 3.3.4 (i) for methodology). This was possible because the cowpeas foliar disease did not affect the sampling areas. This PAR partitioning resulted in isolating the PAR denied to the crop by the hedge shade and the grass shade in the H+M, H-M and G-M plots.

The results for the season's actual PAR interception and the proportion of PAR taken up by the tree/grass shade in the H+M, H-M and the G-M plots are shown in table 22 and figs.(4.117-4.119). The results in the H+M treatment show that there was a high proportion of PAR interception by the combination of tree/crop interfaces H1+M as shown earlier in 92/93 and 93/94 cowpea seasons. When PAR interceptions by crop and tree were separated, it became clear that shading by the tree only occupied a small proportion of the total PAR intercepted by the combination of the tree and the crop (table 22 and fig.4.117). Except for 19, 31 and 38 DAS, when the PAR interception was 17 % or below, tree shade in H+M remained between 21 and 24 % from 45 DAS to 122 DAS (Table 22). This was the period when the tree had fully developed its canopy. The PAR taken up by the tree was far less than that taken up by the crop at 2 m from the hedge (fig. 4.117 and Table 22). Because the cowpea plants next to the hedgerow were depressed, it can be deduced that the cowpea plants were sensitive to the hedgerow competition for light, water and nutrients which affected their growth and hence their final yields, as shown later in section 4.10.

As for the H-M plot, from 45 DAS to 108 DAS there was a lower tree+crop as well as cowpea PAR interception than for the H+M case but a similar increase in PAR interception as in the H+M plot through combination of hedge and crop canopies (Table 22). Compared to the tree/crop PAR interception, the PAR taken up by the tree was relatively low, with values below 20 % from 19-38 DAS and above 20 % but below 25 % from 45 DAS to the end of the season. This suggests, also in fig. 4.118, that cowpea may have been sensitive to the tree shading and this may partly account for the poor state of the cowpeas at the row next to the hedgerow, which explain the lower yields shown in section 4.10 of this study.

In the G-M plot, a comparable pattern of increased PAR interception was realised in the grass/crop interface, with the percentages of g/c generally closer to t/c (H-M) than to t/c (H+M). The portion of PAR intercepted by the grass remained generally between 18 and 24 % from 31 DAS (Table 22 and fig. 4.119). This PAR interception by the grass may have affected the growth of cowpeas growing next to the grass strip, which as earlier noted above in H+M and H-M plots may be sensitive to shading. The effect of the grass competition to the cowpea was so severe, like in the H-M case, that the combined PAR interception by grass and cowpea at their interface became even less than that found in C and M plots, where there was no competition for growth resources.

At the same time, however, the total PAR amounts intercepted by the crop in the C and +M plots were nearly the same. PAR intercepted by both the trees in H+M, H-M and the grass in the G-M plots was nearly the same, showing that the degree of additional row shading by trees in the agroforestry and by grass in the Panicum plots was nearly the same. An ANOVA contacted for 94/95 season, showed that there statistically significant differences for the overall points of measurements among treatments at (P= 0.05, CV = 16.6%). As was done before for the other seasons, DMR was used to separate treatment means among treatments at (LSD = 4.7; SE = 1.5). This picture is clearly shown in Table (xxvi) in appendix 4.10. The table shows that there were no statistically significant differences at the points of measurement in C and +M plots but there were statistically significant differences between point H1+M and 1 and 2 m from the H1+M position. The same was the case for the H-M and G-M plots where the H1-M and G1-M positions (1st rank) were statistically significantly different from the positions 1 and 2m from hedge and grass respectively.

Table 22. Mean PAR interception by cowpea/Senna hedgerow and their separation for the short rains of 1994/95.

DAS	C	+M	ts(H+M)	mc(H+M)	t/c(H+M)	ts(H-M)	mc(H-M)	t/c(H-M)	gs(G-M)	mc(G-M)	g/c(G-M)
19	2.2	10.5	13.9	5.5	13.7	9.1	4.8	10.8	16.6	5.4	10.7
31	24.7	24.4	15.5	16.1	25.8	17.3	14.8	20.0	20.9	16.5	22.4
38	36.7	36.1	17.0	17.7	28.1	19.7	25.8	35.8	22.4	27.9	36.1
45	53.7	54.4	22.5	44.5	59.4	22.7	39.0	50.8	22.7	39.3	54.0
52	61.3	67.0	23.1	49.4	69.6	22.4	42.9	63.0	22.8	39.5	54.2
59	70.7	67.5	23.9	63.3	82.7	22.0	42.1	60.8	22.5	51.0	63.3
66	87.6	92.4	24.2	68.8	91.2	23.7	60.9	81.2	24.2	62.0	80.6
73	90.9	91.5	24.2	68.6	91.0	24.3	65.4	87.0	22.0	59.1	80.2
80	83.1	84.6	21.8	62.9	82.8	21.6	54.9	72.2	19.2	53.6	62.6
87	72.9	70.4	22.5	56.7	73.1	22.3	42.7	58.4	18.6	53.2	62.3
94	47.9	50.6	21.1	39.0	53.0	20.9	26.7	38.7	20.6	36.3	45.5
101	54.0	41.0	22.2	37.2	50.5	24.1	23.8	37.1	18.7	38.9	50.9
108	45.0	39.5	24.3	30.5	41.7	23.0	25.7	37.0	22.5	25.6	34.4
115	44.4	40.9	22.7	28.0	41.6	24.5	31.5	43.0	20.9	28.2	38.1
122	38.3	34.2	23.9	23.9	34.4	23.5	21.8	31.3	23.7	26.2	36.7

C = Control +M = Mulch ts(H+M) = tree shade PAR (H+M) mc(H+M) = cowpea crop PAR (H+M) or H3+M

t/c(H+M) = tree+crop PAR (H+M) or H1+M ts(H-M) = tree shade PAR (H-M) mc(H-M) = cowpea crop PAR (H-M) or H3-M

t/c(H-M) = tree+crop PAR(H-M) or H1-M gs(G-M) = Grass shade PAR(G-M) mc(G-M) = cowpea crop PAR (G-M) or G3-M

g/s(G-M) = grass+crop PAR (G-M) or G1-M

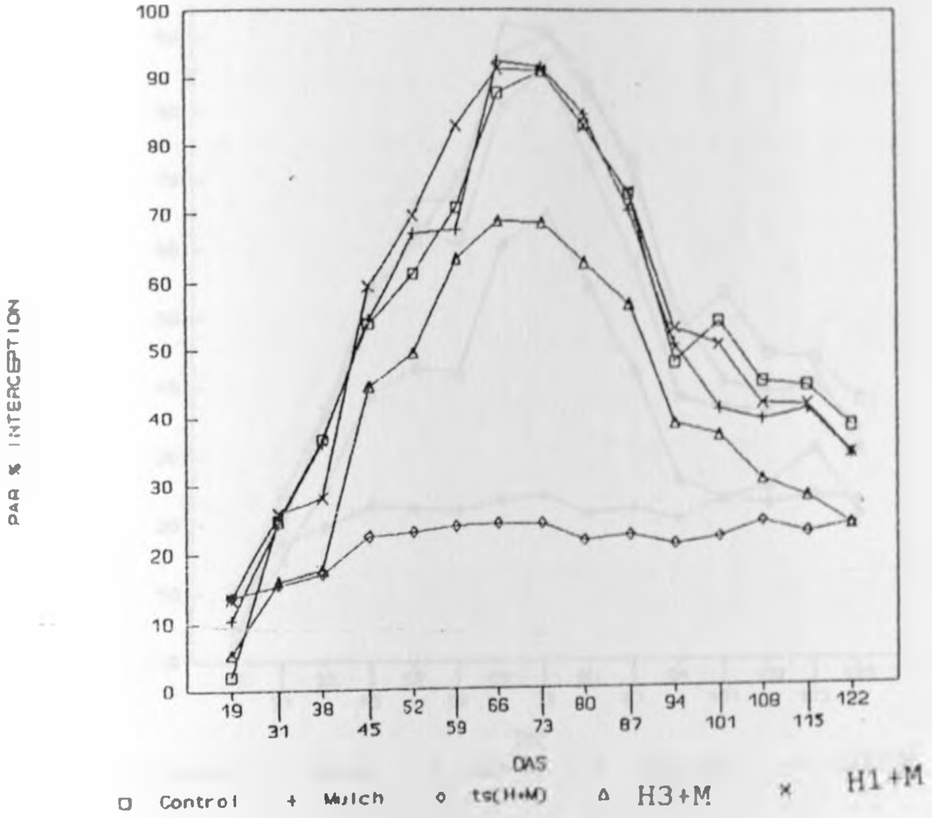


Figure 4.117 PAR interception/partitioning. Comparison of PAR interception by control, mulch. tree shade, crop at H3+M and H1+M. Cowpea, short rains of 1994/95.

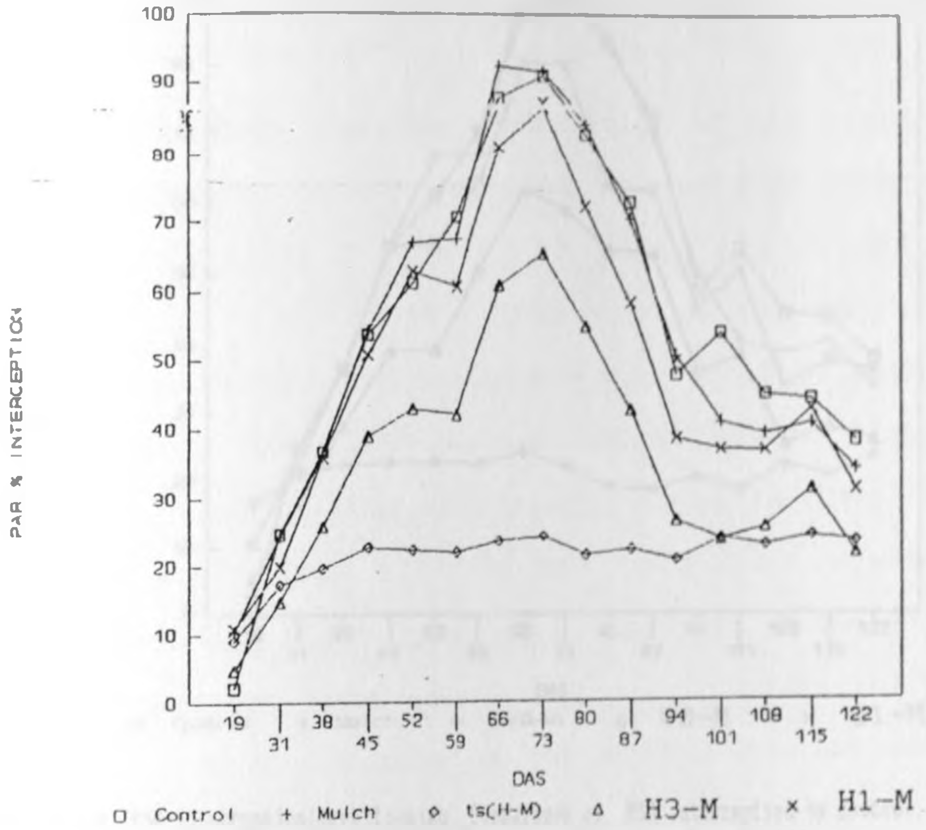


Figure 4.118 PAR interception/partitioning. Comparison of PAR interception by control, mulch, tree shade, crop at H3-M and by H1-M. Cowpeas, short rains of 1994/95.

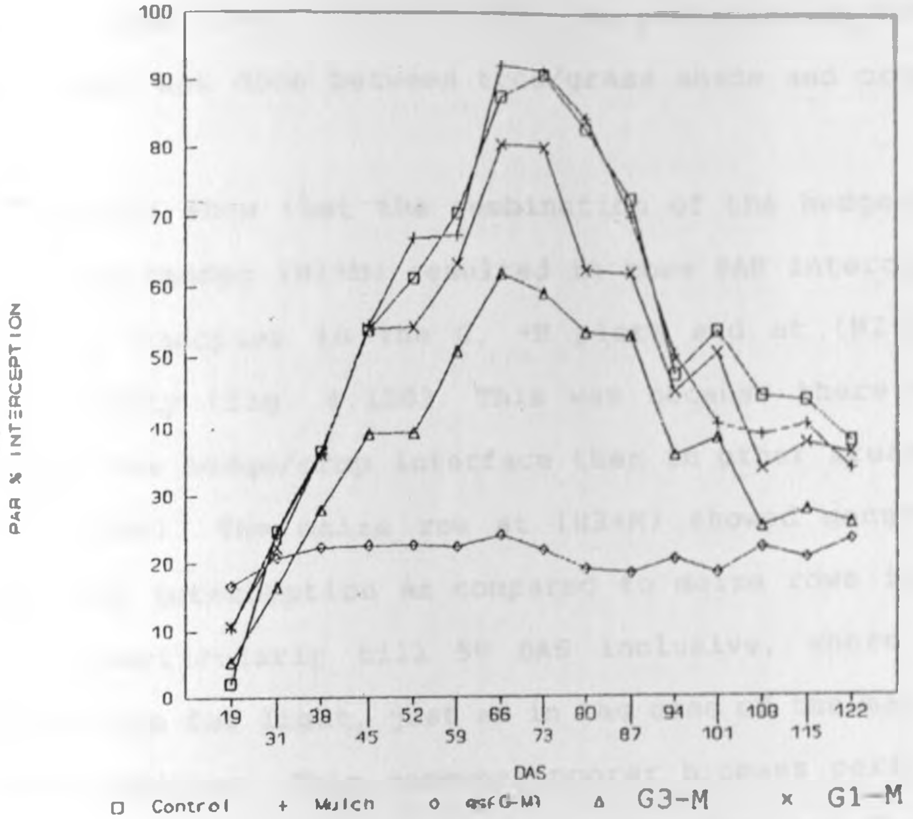


Figure 4.119 PAR interception/partitioning. Comparison of PAR interception by control, mulch, grass shade, crop at G3-M and by G1-M. Cowpeas, short rains of 1994/95.

4.7.5 PAR interception by the maize/Senna siamea hedgerow cropping for the long rains of 1995.

The seasonal results for the actual PAR interception are shown in table 23 and figs. (4.120-4.122). No partitioning for any part of the season was done between tree/grass shade and crop shade.

The results show that the combination of the hedgerow canopy and maize row canopy (H1+M) resulted in more PAR interception than by the crop canopies in the C, +M plots and at (H2+M) and (H3+M) respectively (fig. 4.120). This was because there was more leaf area at the hedge/crop interface than in other areas (Table. 23 & fig. 4.120). The maize row at (H3+M) showed generally slightly lower PAR interception as compared to maize rows in the C and +M plots, particularly till 59 DAS inclusive, where there was no competition for light, just as in the case of the maize rows at the (H3+M) position. This somewhat poorer biomass performance in the first part of the season of the middle row was due to the senna roots which extend to the middle of the tree alley, as earlier explained in section 4.6.3.

The H-M showed similar PAR interception trends as the H+M plot compared to C and +M plots, now for H3-M till 80 DAS inclusive and also from 101 DAS and beyond for similar reasons (Table 23 and fig. 4.121). This trend was generally also shown in the case of the G-M plot (fig. 4.122). The row of maize next to the grass strip was visually very stressed to the extent that it must have intercepted less PAR than middle rows, which were only slightly stressed by the extending lateral shallow grass roots. Table 23 shows that the actual PAR amounts intercepted at both crop/hedgerows and crop/grass interfaces were higher than those in the middle rows H3+M, H3-M; G3-M.

An ANOVA performed as in the previous seasons (apart from 94/95) for the average PAR interception over the season showed that there were statistically significant differences among PAR interception at the points of measurement in all plots among and within treatments at $P \leq 0.05$; CV = 10. The ranking of the overall means in the five treatments (LSD = 1.2, SE = 0.4), using DMRT as earlier done at these points of measurement, showed that the first point of measurement had more PAR interception (1st rank) than the second and third points of measurements with less PAR interception ranked 2nd and 3rd respectively. The C and +M plots showed no statistically significant differences within the treatments at the points of measurements, while those in AF and G-M plots were (LSD = 2.7; SE = 1.0), as shown in Table (xxvii) in appendix 4.10. This table shows that the H+M1, H-M1 and G-M1 positions with more PAR interception (1st rank) were statistically significantly different from the H+M2, H-M2 & G-M2 as well as H+M3, H-M3 & G-M3 positions with less PAR interception (ranked 2nd and 3rd) respectively. This confirms that the hedgerow/crop and grass/crop interfaces had a higher PAR % interception close to the hedge/grass than at 1 and 2 m away from hedge respectively. Separating the seasonal treatment means by DMRT showed further that the H+M and H-M had the highest means (ranked 1st) followed by G-M plot (ranked 2nd) and finally the +M and C plots (ranked 3rd) respectively. This confirms statistically that alley cropped plots and grass stripped plots resulted in higher PAR % interception than found in the sole cropped plots. Table xxvii shows exactly where these differences occurred.

Table 23. Mean PAR interception maize/Senna hedgerow cropping long rains 1995.

DAS	C	M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
30	14.6	16.5	40.3	22.9	17.7	29.8	21.8	13.1	42.7	21.2	14.4
38	32.9	35.8	67.9	40.6	28.1	64.2	35.3	27.2	58.1	33.2	30.4
45	58.7	61.2	72.6	55.2	52.7	75.6	56.6	55.5	76.5	61.5	54.1
52	48.8	49.5	72.1	45.4	45.2	73.0	48.5	47.5	73.5	50.3	45.1
59	60.9	57.5	76.6	56.7	57.5	75.1	54.0	51.3	72.3	52.1	45.5
66	60.1	54.4	81.2	63.9	57.9	78.0	58.6	52.0	78.1	63.5	54.5
73	60.8	59.8	80.0	61.7	59.9	80.8	63.0	57.1	74.3	58.3	54.5
80	59.4	60.1	80.6	63.3	60.1	78.5	58.5	57.9	76.3	65.0	59.8
87	46.6	49.5	78.9	59.6	60.5	82.0	65.8	64.3	77.1	57.0	51.8
94	44.2	49.0	75.2	50.8	44.9	75.0	54.8	50.7	74.1	50.7	41.0
101	46.0	48.5	72.6	49.2	48.7	72.0	49.2	43.2	68.9	47.2	46.0
108	39.2	41.0	71.2	47.2	39.8	71.7	46.8	35.8	65.2	38.4	30.8
115	38.5	43.7	71.9	45.6	35.5	71.6	45.0	34.3	66.3	41.7	37.4

C = Control   +M = Mulch   H1+M = Mean(crop/H+M)   H2+M = 1 m from (H+M)

H3+M = 2 m from (H+M)   H1-M = mean(crop/H-M)   H2-M = 1 m from (H-M)

H3-M = 2 m from (H-M)   G1-M = Mean(crop/G-M)   G2-M = 1 m from (G-M)

G3-M = 2 m from (G-M)

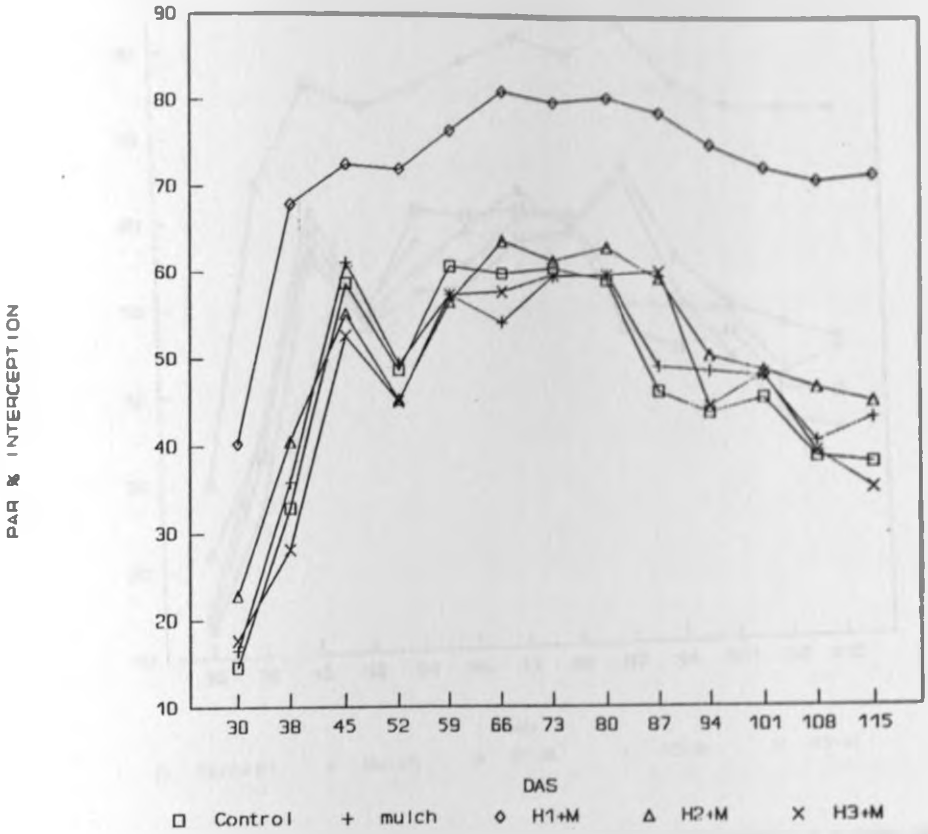


Fig.4.120. PAR interception. Comparison between control, mulch, hedge+mulch+crop, 1 m from hedge+mulch and 2 m from hedge+mulch. Maize, long rains of 1995.

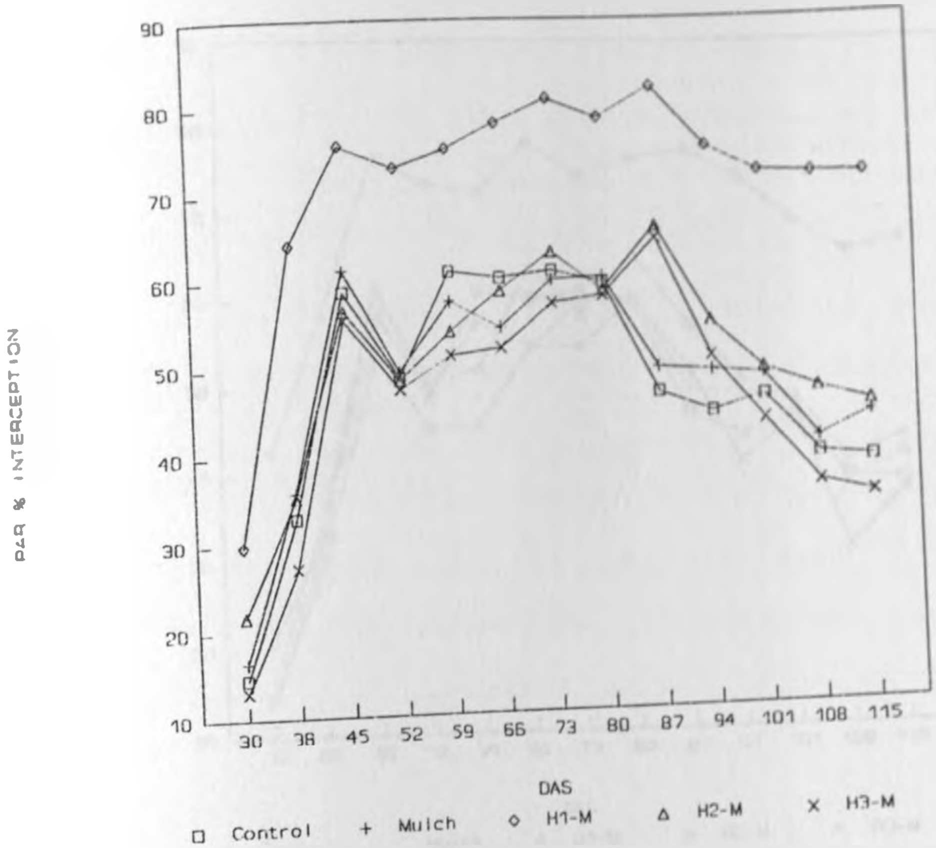


Fig.4.121. PAR interception. Comparison between control, mulch, hedge+crop, 1 m from hedge+crop and 2 m from hedge+crop. Maize, long rains of 1995.

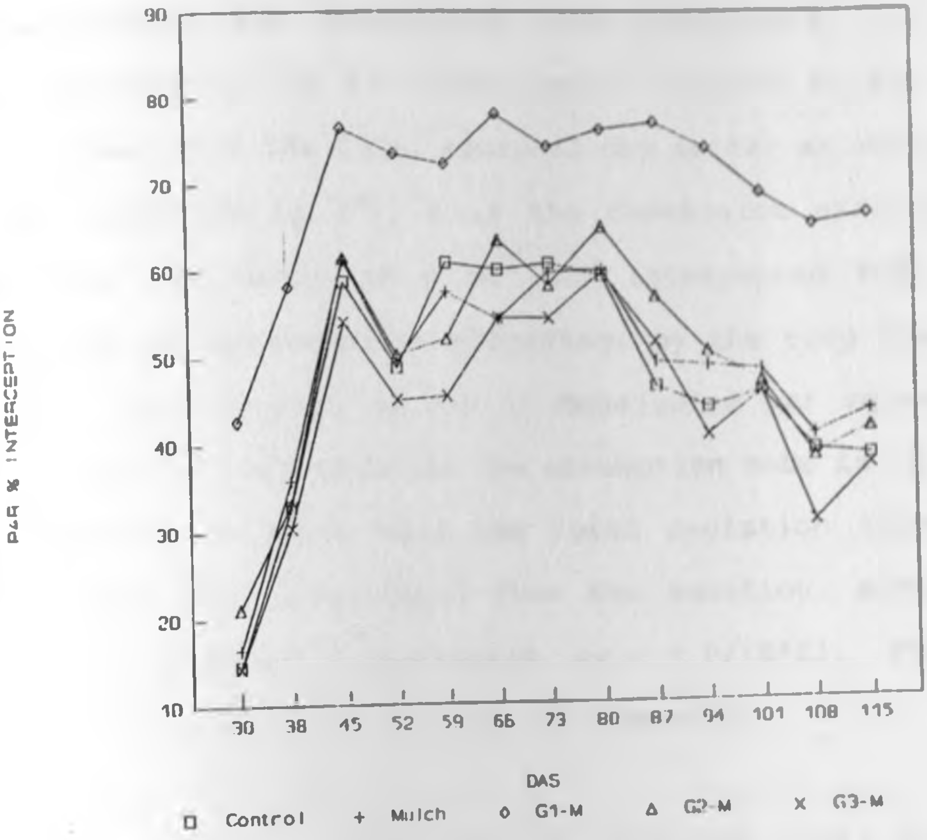


Fig.4.122. PAR interception. Comparison between control, mulch, grass+crop, 1 m from grass+crop and 2m from grass+crop. Maize, long rains of 1995.

4.7.6 Light use efficiency (e).

To put the results in this section 4.7 in proper perspective, light use efficiency was determined using Monteith's (1977) equation given in section 2.6 for crop growth analysis of the form: P = e*f*S, where P is the total seasonal dry matter or above ground dry biomass produced (g m^{-2}), e is the conversion efficiency or the light use efficiency in g MJ^{-1} (of intercepted PAR), f is PAR absorption or interception percentage by the crop for the season and S is flux density of PAR in Megajoules per square metre per season. To use this equation one assumption made is that the total incoming PAR is about half the total radiation incoming in the season. Now e is calculated from the equation, since the other values are measured or estimated, as e = P/(S*f). Table (xxviii) in appendix 4.10 shows how (e) was computed.

4.7.6.(a). Light use efficiency for the long rains 1994.

Table 24 compares the results for the calculated efficiency with which the PAR intercepted was used for the above ground biomass formation in the five plots. This above ground biomass includes the harvested Senna hedgerows biomass and grass biomass from the grass strips respectively, because measured PAR did not distinguish between them during the season. The results show that the C and +M plots with sole maize crop canopies had higher e (1.8± 0.1, 1.8± 0.1) than the H+M (1.5± 0.4), H-M (1.2± 0.3) and G-M (1.1± 0.9) plots with maize and tree or grass canopies respectively. This means that although the agroforestry and grass/maize canopies had intercepted more PAR, they were less efficient in its use, for the increased PAR interception did on average produce less above ground biomass per unit of PAR intercepted. The reason for this is that maize as a C4 pathway photosynthetic plant is more efficient in the use of intercepted PAR than the C3 *Senna siamea* tree in the hedgerows (e.g. Squire, 1993). In the G-M plot there was still lower (e), comparable to the H-M case, although both the maize and grass are C4 plants. This was due to the extreme competition not only for water but also for nutrients and other resources by the grass lateral roots, which nearly wiped out the rows of maize adjacent to the grass strip.

Sole maize, therefore, without the competing C3 trees and C4 grass, was more efficient in the use of light. Drought and too low nutrient supply have been shown to affect (e) (e.g. Squire, 1979, Muniafu, 1991). As such, the 1994 rainy season was just below average (242.4 mm) and no fertilizer was used and these two factors may have limited the value of (e). The (e) values obtained from sole maize in the C and +M non-agroforestry plots were somewhat higher than values reviewed elsewhere for C4 plants of 1.5-1.7 (e.g Russel et al. 1989). However, Howard et al. (1995) also obtained a higher (e) value, of 2.2, for sole maize at Machakos, Kenya.

Table 24. Light use efficiency long rains 1994.

Treatment	g m^{-2} P	g MJ^{-1} e	(%) f	MJ m^{-2} S
C	400±4	1.8	37	590
+M	380±3	1.7	37	590
H+M	380±3	1.5	43	590
H-M	290±2	1.2	40	590
G-M	230±8	1.1	36	590

PAR was estimated with an error of 6%.

4.7.6.(b) Light use efficiency short rains 94/95.

Table 25 compares the results for the (e) of the five treatments. The results show that the C and +M plots, with sole cowpea canopies having an (e) of 0.9± 0.2 and 0.7± 0.2, appear slightly lower in the efficient use of intercepted PAR compared to the agroforestry/cowpea canopies in H+M and H-M plots which had an (e) of 1.0± 0.5 and 1.1± 0.5 respectively. The G-M plot had an (e) of 0.8 ± 0.7. The combined canopies of cowpea/trees in the agroforestry plots intercepted less PAR but produced more or nearly the same biomass (in total as well as per unit of PAR intercepted) compared to the sole cowpea canopies in the C and +M plots. This could be because of the poor performance of the shaded cowpea near the hedge. Stress conditions influence the outcome. The (e) by the cowpea/grass canopies in the G-M plot was equally low or lower compared to other plots, although grass is a C4 plant. As explained earlier, the grass was very competitive with the first rows of cowpeas for water and nutrients as well as for light and other growth resources and this resulted in low PAR interception by the crop as well as low above ground biomass formation by the crop and hence low (e). The combination of Senna hedgerow/cowpea and grass/cowpea strip intercropping did in this study not result in much improved (e) compared to sole cowpea. Competition accounts for this poor performance. For the G-M plot, this was even worse.

Table 25. Light use efficiency, short rains 1994/95.

	$g\ m^{-2}$	$g\ MJ^{-1}$	(%)	$MJ\ m^{-2}$
TREATMENT	**P**	**e**	**f**	**S**
C	**480± 1**	**0.9**	**53**	**1050**
+M	**380± 1**	**0.7**	**53**	**1050**
H+M	**510± 4**	**1.0**	**47**	**1050**
H-M	**470± 4**	**1.1**	**41**	**1050**
G-M	**350± 7**	**0.8**	**42**	**1050**

PAR was estimated with an error of 6%.

4.7.6.(c) Light use efficiency for the long rains 1995.

Table 26 compares the results for the five treatments. The results show that the C and +M plots with C4 sole maize crop canopies had higher (e) than the Senna/maize and grass/maize canopies in the H+M and H-M, C3+C4 plants combination and G-M C4 plants combination plots respectively (Table 26). The H+M and H-M plots had higher (e) than the G-M for reasons explained earlier for the long 1994 rains maize season. Sole maize was, as in 1994 more efficient in the use of PAR than Senna/maize or grass/maize for reasons also explained earlier in (4.7.6.(a)), but overall their efficiency came out somewhat lower than in 1995, although only in C nd +M the error limits do not overlap, the error limits in Table 26 being comparable to those in Table 24. Although the 1995 (285 mm) season was slightly wetter on the whole than the 1994 (242.4 mm) season and much more runoff occurred in 1995, the resulting above ground biomass yield productions were appreciably higher, due to a better use of effective rainfall and higher PAR, as well as PAR interception. Stronger competition for resources must have spoiled (e).

Table 26. Light use efficiency long rains, 1995.

	$g\ m^{-2}$	$g\ MJ^{-1}$	(%)	$MJ\ m^{-2}$
TREATMENT	**P**	**e**	**f**	**S**
C	530±3	1.7	46	690
+M	530±4	1.6	48	690
H+M	580±2	1.3	63	690
H-M	500±3	1.2	62	690
G-M	340±6	0.8	59	690

The error involved in PAR estimation is about 6%.

4.7.6.(d) Discussion.

It should be noted here that not all PAR intercepted by the plant is directly used for dry matter production. Of the PAR incident on a crop, 5-6% is lost by reflection and transmission, while inactive absorption by the cell wall cytoplasm and non-photosynthetic tissues, which include trunks and flowers, also account for losses estimated to be between 2 and 5. (Hall, 1979, Ling and Robertson, 1982, Beadle and Long, 1985). Some PAR losses may also result from the death of some of the plant parts during the measuring period as well. The PAR therefore available for active absorption, taking into account the above losses, is only 38-43% of incident global radiation (Beadle and Long, 1985).

In our calculations of (e) ineffective absorption was not considered. In calculating (e), in all the plots for 1994, 94/95 and 1995 seasons, to obtain absorbed instead of intercepted radiation, a 6% loss in reflection (see section 2.6) of the total seasonal PAR was deducted from all the plots, which had the same effect for all plots calculated.

PAR affects the rate of photosynthesis and consequently the (e). Normally a linear response of growth to absorbed PAR is expected as long as the unstressed canopy is not exposed to saturatory irradiations for significant parts of the growing season (e.g. Russel et al. 1989). Shortage of water has been shown to be the cause of reduction in (e) in a number of plant species. This has been the case for barley plants (Legg et al, 1979) and also for chickpea (Hughes et al, 1987). In this study, however, (e) for the two maize seasons of rather comparable rainfall from 1994 (242.4 mm) to 1995 (285 mm) remained comparable if anything, somewhat lower in 1995) as shown in tables 24 and 26. This was the case because, although the rainfall amounts were different by over 40 mm, and were well distributed over the two seasons and runoff and soil loss were alot higher in 1995, the higher production of biomass used same or more PAR per unit of biomass in 1995, due to increased competition, if differences have to be explained. The low (e) values associated with leguminous species (Gosse et al, 1986) may be partly attributable to the demands of the nitrogen fixing rhizobia in the root nodules. This could also be the case in this study, where (e) for cowpea is found to be lower than that of maize, but the influence of other stresses complicates this picture.

4.7.7 Water use efficiency (WUE).

The results for the WUE for the long rains 1994, short rains 1994/95 and long rains 1995 are presented in tables (27-29). The values for transpiration (Tr) are obtained from the calculated values in section (4.5.11) from the water balance equation. WUE is obtained by dividing the total biomass per hectare of the plots from each treatment by the value of (Tr). The value of WUE has an ccumulated error of 16% accruing from the determination of Tr in Table xvii in appendix 4.7. See Table (xxix) in appendix 4.10 for a calculation example.

4.7.7.(a) Water use efficiency (WUE) long rains 1994.

The results for water use efficiency in 1994 show (Table 27) that except for the H+M plot, which had slightly higher WUE (33.5), the sole maize in the C plot was most efficient in the use of water for above ground biomass yield production. The maize/senna and maize/grass systems in the H-M and G-M plots were also lower. Competition for water and other nutrients, with the exception of the H+M plot, lowered the water use efficiency of the agroforestry and grassed plots respectively. Where there was more competition, especially for water in the G-M plot, the WUE was lowest.

Table 27. Water use efficiency, long rains of 1994.

Treatment	Total biomass yield t ha^{-1}	Transpiration (Tr) mm	Water use efficiency (WUE) Kg ha^{-1} mm^{-1}
C	4.0	150	26.7
+M	3.8	170	23
H+M	3.8	115	33.5
H-M	2.9	120	24
G-M	2.3	110	21

N.B. The error from the determination of ET from soil moisture values was 5%, that from the estimation of soil evaporation from the lysimeter use protocol was 10%, the error from runoff data was 5% while error arising from estimating percolation losses was 5%. The total cumulative error in estimating WUE is therefore about 2%.

4.7.7.(b) Water use efficiency for the short rains of 94/95.

The WUE for the 94/95 season show that the sole cowpea in the C plot was more efficient in the use of water for above ground biomass yield production than the +M plot as well as the cowpea/senna and cowpea/grass systems in the H+M, H-M and G-M plots respectively (Table 28). For the intercrops this was due to competition for water and/or other growth resources. The differences in WUE in C and +M plots were partly due to differences in total above ground biomass in the season as a result of observed slow germination in +M plot, for reasons as such unknown. We will come back to this issue, forwarding several possible reasons, among which lower temperatures in H+M and other reasons for differences in root growth. The cowpea/tree system in the H+M, H-M and G-M plots had relatively small differences in WUE, falling in a range of 21 ± 2.5 kg ha^{-1} mm^{-1}. Any of such maximum differences may be differences in observed severity of competition for water and nutrients, that for example in the G-M plot nearly wiped out the rows of cowpea next to the grass strip. These results show that the senna/cowpea or grass/cowpea system resulted in using more water from the soil profile than the sole cowpea in C and +M plots, as shown by the value of Tr in Table 28, but this did not result in more biomass production per unit of water used when compared to the C plot. Apparently the trees evaporated water without giving much additional biomass in return and to the grass this applies as well but less: it gave much less biomass with slightly higher Tr. As earlier indicated competition effects must also have been involved.

Table 28. Water use efficiency, short rains of 94/95.

Treatment	**Total biomass yield**	**Transpiration (Tr)**	**Water use efficiency (WUE)**
	t ha^{-1}	**mm**	**Kg ha^{-1} mm^{-1}**
C	4.8	160	31.5
+M	3.8	175	22
H+M	5.1	215	23.5
H-M	4.7	230	20.5
G-M	3.5	190	18.5

4.7.7.(c) Water use efficiency for the long rains of 1995.

The picture for this season was bearing some similarity with 1994, particularly in the ranking, but the values were on average 45% higher, due to somewhat better rainfall. Due to the absence of competition for water, light and nutrients, the WUE (Table 29) for 1995 for the sole maize C plot was now highest, but this did again not apply to the +M plot. The G-M plot was lowest of the intercrops and again the H+M was strangely highest in WUE. The presence of mulch in the +M plot, as well as the presence of hedgerow and grass strip barriers resulted in higher (Tr) values. Lower WUE values for the H-M and G-M plots are explained from lower biomass. The exception of the H+M plot, because of high biomass, is not immediately explainable either, particularly because +M fails to high but inefficient transpiration. The WUE for the G-M plot for 1995 was only 23, due to severe competition between the grass and crop components.

Compared to the (242.4 mm) 1994 rainfall season, the WUE for maize in 1995 (285 mm) rainfall improved by 10.5 (about 30%) and 5 (about 20%) kg ha^{-1} mm^{-1} for sole maize in the C and +M plots respectively. Also despite the competition there were increases in the WUE of 2.5 (<10%) and (25%) kg ha^{-1} mm^{-1} in H+M and H-M plots respectively. There was also an increase in the WUE in the grass/maize system of 2 (10%) kg ha^{-1} mm^{-1} in 1995 over 1994. These differences were due to increase in moisture in the soil profile, as 1995 was wetter than 1994. This of course agrees with the fact that the actual rate of transpiration of a canopy depends on the potential rate, dictated by meteorological conditions, and on the availability of water in the rooted soil profile (e.g. Van Keulen et al, 1990). Some explanations are, however, needed for both seasons as to +M, H+M and H-M behaviour, whether equal or different for both seasons.

Table 29. Water use efficiency long rains of 1995.

Treatment	Total biomass yield t ha^{-1}	Transpiration (Tr) mm	Water use efficiency (WUE) Kg ha^{-1} mm^{-1}
C	5.3	130	41.5
+M	5.3	190	28
H+M	5.8	160	36
H-M	5.0	165	30
G-M	3.4	150	23

4.7.7.(d). Discussion.

Gregory (1989) showed that WUE can be increased via use of fertilizer in millet in West Africa. It is therefore likely that it is possible to raise the WUE of maize in Eastern Kenya, since no fertilizer was used in this study. Sole maize was shown to be better in WUE than the maize/senna or grass/maize systems (Tables 27 and 29), for understandable reasons of low WUE of Senna and grass and, for the grass more than for Senna, strong competition effects.

The best maize crop had a somewhat better WUE than the cowpea crop although the latter had more rainfall than maize in this best case (in tables 28 and 29 above respectively). It is worth noting here again that runoff was influenced by the diseased cowpea while the biomass figures were not. Increased runoff and decreased transpiration (or increased soil evaporation) due to diseases may lower the value of Tr in the water balance equation and lead to increased WUE, which even was a possibility in the 94/95 season. Because of the use of sealed microlysimetres for estimating soil evaporation (Es) in our study, it was expected that the values of (Es) were possibly somewhat lower and this could lead to higher Tr values and hence lower the values of WUE. WUE of monocropped sorghum has been shown to be more than that of monocropped cowpea (Morris et al, 1990). They also observed that the WUE of sorghum was influenced by the rainfall pattern. This is also confirmed in this study, where the WUE for maize increased with increase in rainfall amount (tables 27 and 29). In line with the results shown, WUE is known to be higher in C4 plants than in C3 plants, and water stress, particularly during grain filling stage, affects it (e.g Angus et al, 1983). Also Fajemisin and Olaniyan (1976) indicated that the C4 group of plants are known to be more efficient in water utilisation than the C3 plants. They further noted that C4 plants are generally less drought tolerant than C3 plants. C4 plants normally have cells which are specialised to fix carbon dioxide at higher rates and usually lower stomatal conductance (Gifford, 1974). This combination of higher rates of CO_2 and lower conductance leads to a lower intercellular CO_2 concentration in C4 than in C3 plants and thus a steeper CO_2 gradient from the air to the intercellular spaces. As stomatal conductance controls water loss, C4 plants lose less water per unit of CO_2 fixed and thus have a higher WUE based on either photosynthesis or dry matter accumulation (Pearce and Ehleringer, 1984). The higher concentration of CO_2 in bundle sheath cells also allows C4 plants to utilise N more efficiently in CO_2 assimilation. For these reasons, C4 plants are better than C3 plants in using water efficiently as also confirmed in this study.

Management practices such as soil erosion control, which minimise water loss via runoff reduction and enhanced infiltration, may lead to enhanced WUE by increasing the value of (Tr), when more water indeed carries more nutrients. Despite the reduction in runoff by the +M plot (section 4.3.1-4.3.3), WUE value remain low. Given our visual observations, this could partly be due to suboptimal temperatures and reaction of root and shoot growth induced by the mulch, which may affect germination and final biomass yields.The difference with H+M, that has comparatively low or even lower temperatures must then be the addition of the hedge, influencing biomass as well as water use. Mulches also harbour microbes which can cause diseases to the crop and affect its performance, hence lowering final biomass which may also affect (Tr). Our fields, especially cowpea, showed that the fields with mulch had more disease than non-diseased plots from observations. Mulching may also induce shallower roots of maize and cowpea, that later on suffer from stress more. This would affect the performance of the crop, especially in drier seasons. Given that the number of measuring places for soil moisture was rather low, some biases of the measuring places cannot be excluded. Not all the above factors explain the higher (Tr) values in the two maize years, which cause the low the low WUE values.

At the same time, the use of mulches and hedgerows in alley cropping, which increases infiltration and reduces soil evaporation, may also tilt the water balance equation towards (Tr) and a decrease in WUE. Our H+M plot was quite effective in the control of runoff (section 4.3.1-4.3.4) which was possibly used effectively by the crop and tree to enhance (Tr), particularly for cowpea, and WUE. This available conserved moisture may have lowered the competitiveness for moisture between the crop and Senna and resulted in increase in biomass production and an increase in WUE. There is also the possibility that the stressed plants near the hedgerows compete less for moisture, nutrients and light in their poor condition. This may lower WUE. The water nearer the Senna/grass is better infiltrating but just that water may not effectively be used by tree and grass and by shaded crops that also have to fight for nutrients and this will affect WUE. In the H+M plot the stress is more severe in the middle maize rows by the Senna roots. The cowpea row near the hedgerow is more stressed than the middle rows.

It is worth noting here that the error arising from the determination of (Tr) values is as a result of errors accruing from (i) the estimation of soil evaporation, (ii) runoff water and (iii) from soil moisture determination by neutron probe may finally induce errors in the value of (Tr) and hence affect WUE. These errors have been estimated as shown in the calculation example for Tr in Table (xxx) appendix 4.11.

4.8 Soil temperature.

4.8.1 Soil temperature calibration results

The results for the eleven resistance platinum thermometers are presented by the eleven regression equations in table 30 below.

Table 30. Soil temperature calibration equations.

X = temperature of the platinum thermometer and Y = corrected resistance platinum thermometer temperature after calibration.

Platinum thermometers	Regression equation	Regression coefficient (r^2)
1	$Y = 4.7 + 0.84 X$	0.98
2	$Y = 2.67 + 0.90 X$	1.0
3	$Y = 3.59 + 0.88 X$	1.0
4	$Y = 2.23 + 0.94 X$	1.0
5	$Y = 0.50 + 0.97 X$	1.0
6	$Y = 0.95 + 0.93 X$	0.99
7	$Y = -0.27 + 0.96 X$	1.0
8	$Y = -0.66 + 0.97 X$	1.0
9	$Y = 0.47 + 0.95 X$	0.99
10	$Y = 1.01 + 0.95 X$	1.0
11	$Y = 0.27 + 0.97 X$	1.0

These equations show that there was a very high correlation between the temperature of the sensors and the temperature of the calibration chamber. The platinum resistance thermometers therefore accurately measured soil temperatures near 7.5cm depth, depending on the accuracy of the placement of the thermometers, which is also influenced by differences in slope. The estimated accuracy in weekly average temperature is ±0.5^{0}C.

The results were obtained by averaging the hourly temperatures per day and then taking these daily means for the week to get the weekly mean near surface soil temperatures measured at 7.5 cm depth for the short rains of 92/93, long rains of 1993, short rains of 93/94, long rains of 1994, short rains of 94/95 and the long rains of 1995 are presented and discussed.

4.8.2 Weekly mean near surface soil temperatures, short rains 1992/1993.

The results for the season are presented in table 31 and figs. 4.123, 4.124 and 4.125. The results show that the mulch in the +M plot had slightly modified the average soil temperatures, by less than 1^0 C for the most part of the season as compared to the C plot (Table 31 and fig. 4.123). On the other hand, the mulch and hedge shade in the H+M plot had depressed the average soil temperatures more than the mulch and crop shade in +M (>1^{0}C plot and even more (up to more than 2^{0}C) compared to the C plot (fig. 4.123). This temperature depression decreased as from H1+M, H2+M and H3+M respectively (fig. 4.125). This was due to tree shading which decreased with increasing distance to the centre of the alley.

As for H-M plot, there was more temperature depression by the hedgerow shade (H1-M) (of >1^{0}C), compared to the crop and mulch shadings in the C and +M plots (fig. 4.124). The +M plot had depressed the soil temperatures by nearly the same degree as by the crop and tree shade at H2-M (fig. 4.126). This was associated with extended tree shade and increasing crop shade with the advancing season. The H3-M had similar temperatures to the C plot but this became higher towards crop maturity fig. (4.124). This could be explained by the fact that the crop at H3-M shed its leaves and dried earlier than that in the C plot where the crop had not shed its leaves and was still providing some shade.

In the G-M plot, there was more temperature depression (of up to >2^{0}C) in the G1-M compared to the C plot while there was a clear cut temperature increase (apart from week 1) in G2-M and G3-M respectively fig. (4.125). This was due to a decrease in grass shading away from the grass strip. The temperatures at G3-M compared generally well with those in the C plot as the two had only crop shading.

On the whole, however, seasonally averaged as well as weekly the shading by the grass strip in the G-M plot at G1-M was equally most effective in temperature depression as compared to the shading by both the mulch and tree in the H+M plot at H1+M. Also on average for the three measuring points in G-M and H+M this appears true. It shows that mulch has indeed only a small influence. This was followed by G2-M, H1-M and H2-M even before +M. This trend is clear from the seasonal soil temperature means in Table 31.

Table 31. Near surface average soil temperatures short rains 92/93.

WEEK	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
1	19.5	19.5	19.0	19.3	19.3	19.2	19.2	19.2	19.1	19.0	19.0
2	22.2	21.7	20.8	21.5	22.0	20.7	21.7	22.0	20.9	21.3	21.7
3	21.3	21.0	20.0	20.6	21.1	20.7	20.8	21.0	20.0	20.3	21.0
4	22.6	22.5	20.7	22.0	23.0	21.6	22.4	23.1	20.5	22.0	23.5
5	23.0	22.6	20.6	21.8	22.8	21.5	23.0	23.3	20.5	21.8	23.5
6	20.9	20.7	19.5	19.9	20.5	19.7	20.5	21.3	19.3	19.4	20.9
7	20.8	20.7	19.8	20.5	20.6	20.3	21.0	21.5	19.6	19.9	21.8
8	21.1	20.1	19.3	20.3	20.8	20.3	20.6	20.9	19.3	19.4	21.3
9	21.2	20.8	19.5	20.9	21.3	21.0	21.6	21.7	19.6	20.0	22.6
10	20.9	20.5	19.0	20.7	21.3	20.9	21.0	21.3	19.0	21.3	21.3
mean	21.3	21.0	19.8	20.7	21.3	20.6	21.2	21.5	19.8	20.3	21.5

C = Control +M = Mulch H1+M = In (H+M) H2+M = 1m from (H-M)

H3-M = 2m from (H-M) G1-M = In (G-M) G2-M = 1m from (G-M) G3-M = 2m from (G-M)

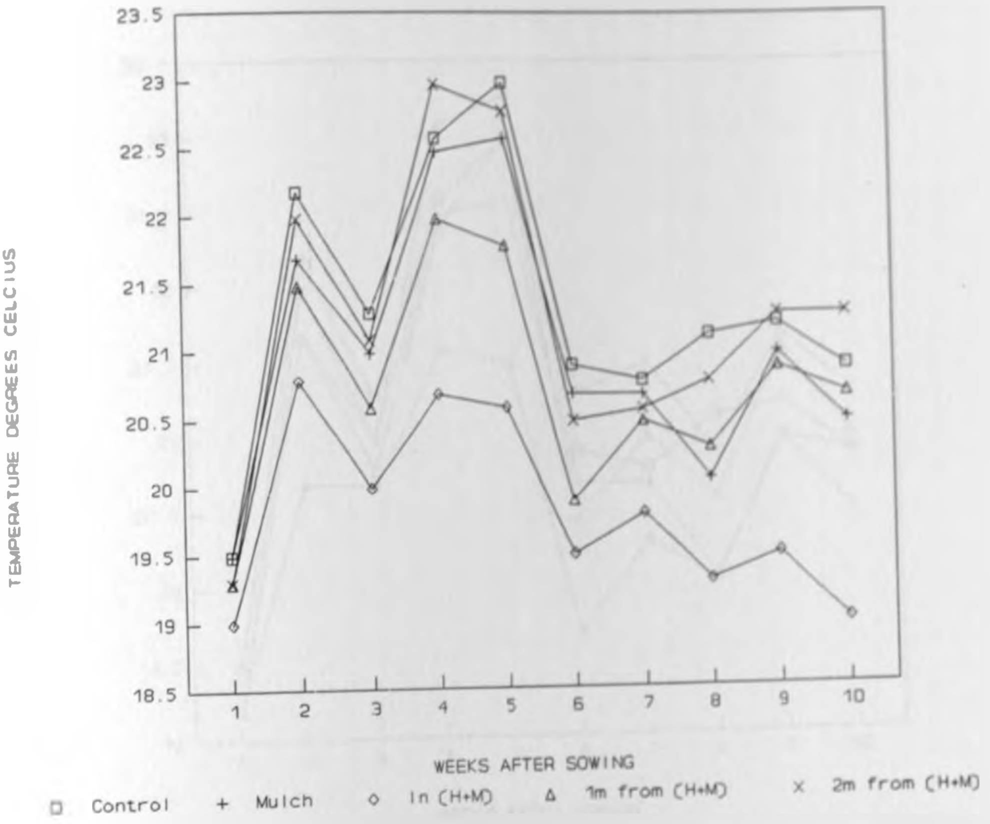


Fig.4.123: Near surface average soil temperature temperatures taken at 7.5 cm depth in the C,+M, H1+M, H2+M and H3+M positions. Short rains of 92/93.

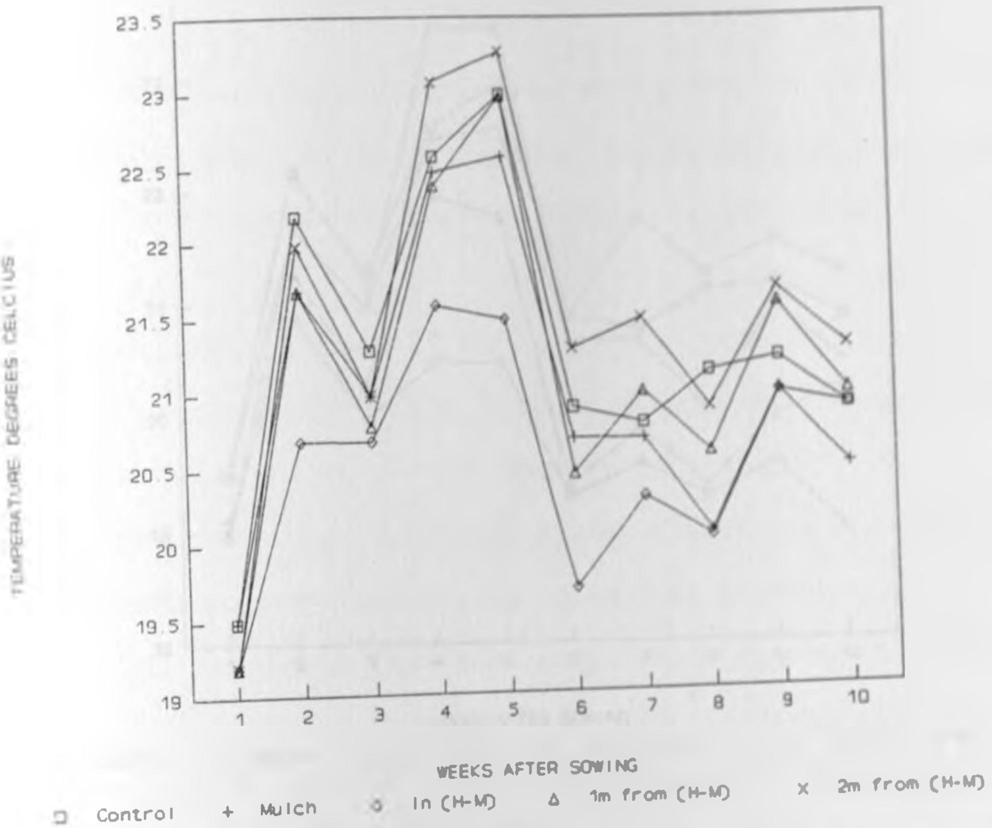


Fig. 4.124. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Short rains of 92/93.

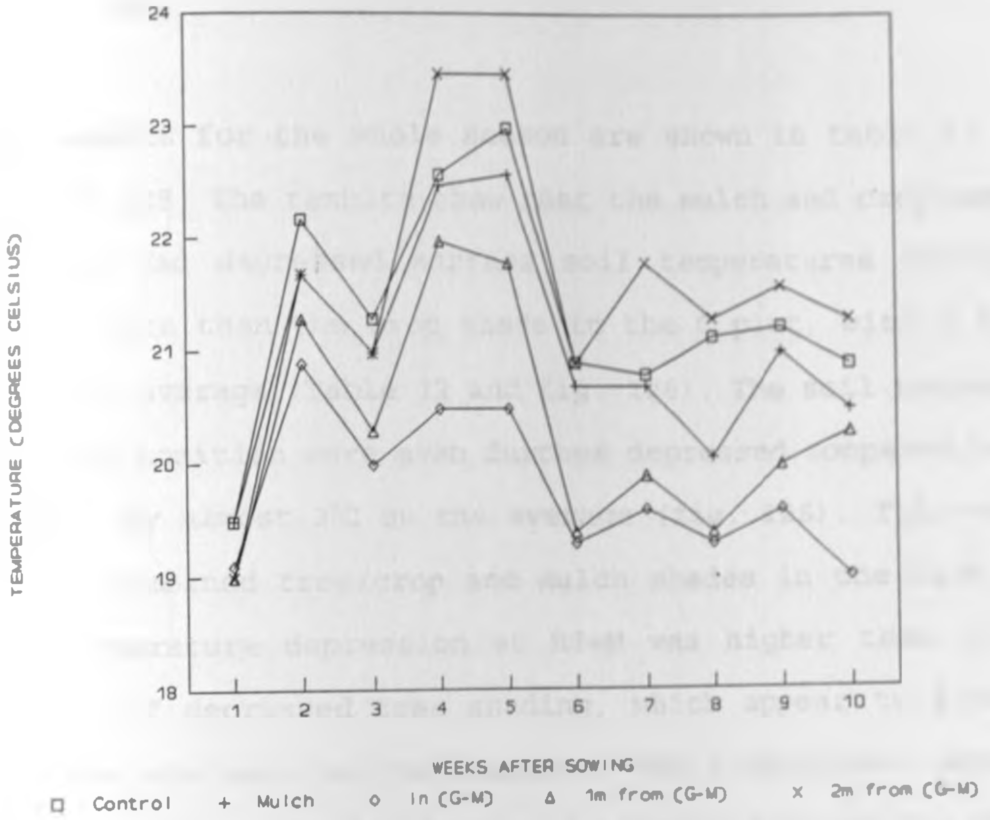


Fig.4.125. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, G1-M, G2-M and G3-M positions. Short rains of 92/93.

4.8.3 Weekly mean near surface soil temperatures, long rains 1993.

The results for the whole season are shown in table 32 and figs. 4.126-4.128. The results show that the mulch and crop shade in the +M plot had depressed surface soil temperatures throughout the season more than the crop shade in the C plot, with 0.65^{0}C as the seasonal average (Table 32 and fig. 126). The soil temperatures in the H1+M position were even further depressed compared to those in C plot, by almost 3^{0}C on the average (fig. 126). This was because of the combined tree/crop and mulch shades in the H1+M position. The temperature depression at H2+M was higher than in the H3+M because of decreased tree shading, which appear to affect mainly the crop row next to the hedgerow. The temperature depression at H2+M was rather similar to that in the +M plot as the crop in the former was poorer than in the latter. The soil temperature depression in the H3+M was similar to that in the C plot as there was a far better crop in the C plot compared to the poor miserable crop at the H3+M position.

As for the H-M plot, a pattern of decreasing temperature depression from H1-M to H3-M was noted, due to decreasing shade to the centre of the alley fig. (4.127). As compared to the C plot, the H2-M had more depressed soil temperatures, partly due to hedgerow shading, while the temperatures at H3-M more closely compares with those in the C plot. The C plot had healthier plants, providing better shading, than those poor stressed plants at H3-M, providing poor shading. This stress was partly due to the competition for mostly moisture between the tree/crop component roots in the H-M plot.

In the G-M plot, there was a similar temperature depression to that in the H-M plot, decreasing from G1-M to G2-M and G3-M respectively. This was because of decreasing shade by the grass towards the centre of the alley fig. (4.128). The temperature depression by the crop and grass shading at G2-M was higher than at the C plot and almost identical to that of the +M plot, while the temperature depression at G3-M was slightly higher than that at C, but this remained within the accuracy limits.

Generally although the crop was very poor during the season, the combination of mulch and hedge shade had the greatest average soil temperature depression, of near 3^0C, compared to the C plot. This was followed by grass shade in the G-M plot and hedge shade in the H-M plot, with average temperature depressions for G1-M of 2.9^0C and for H1-M of 1.9^0C compared to the C plot respectively. The crop and mulch shade in the +M plot had depressed temperatures least, by 0.6^0C compared to the C plot, but H2+M, H2-M and G2-M were not different from +M, within the accuracy limits.

Table 32. Weekly mean near surface soil temperatures long rains, 1993

WEEK	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
1	26.6	25.0	21.4	24.7	25.4	24.2	26.5	27.3	22.1	25.9	26.6
2	26.4	25.5	21.8	25.0	25.3	23.6	26.0	26.7	22.1	25.5	26.4
3	26.4	25.9	21.8	25.7	25.9	23.1	26.1	27.1	21.8	26.2	26.7
4	26.4	25.7	22.9	25.5	25.5	23.4	26.1	27.2	22.9	26.7	27.2
5	25.2	24.6	23.8	23.8	24.9	22.6	25.1	25.6	23.4	25.5	25.6
6	27.0	25.9	25.0	25.9	26.0	25.3	26.6	27.0	24.9	26.1	26.3
7	25.6	25.1	24.4	25.0	25.0	25.0	25.2	25.6	23.9	24.5	25.3
8	26.4	26.0	24.3	25.5	25.6	25.1	26.2	26.6	24.3	25.2	25.5
9	27.0	26.3	24.6	26.0	26.0	25.6	26.8	27.3	24.6	26.1	26.3
10	27.3	26.7	24.5	26.2	26.3	26.0	26.8	27.7	24.4	26.1	26.3
11	24.7	24.2	22.3	24.1	24.0	23.4	24.2	24.8	21.8	24.2	24.2
12	24.9	24.1	21.5	23.9	24.0	22.4	23.4	24.2	21.3	23.4	23.7
13	24.6	24.1	21.8	24.0	23.8	22.6	23.0	24.7	21.7	24.0	24.0
14	23.7	23.4	21.2	23.3	23.6	22.1	22.8	24.0	21.0	23.1	23.2
15	23.0	22.6	20.8	22.6	22.9	21.9	22.1	23.1	20.6	22.3	22.5
16	22.9	22.6	20.5	22.7	22.8	21.7	22.0	23.2	20.2	22.2	22.5
Mean	25.5	24.9	22.7	24.6	24.8	23.6	24.9	25.8	22.6	24.8	25.1

C = Control +M = mulch H1+M = In (H+M) H2+M = 1m from (H+M) H3+M = 2m from (H+M)

H1-M = In (H-M) H2-M = 1m from (H-M) H3-M = 2m from (H-M)

G1-M = In (G-M) G2-M = 1m from (G-M) G3-M = 2m from (G-M)

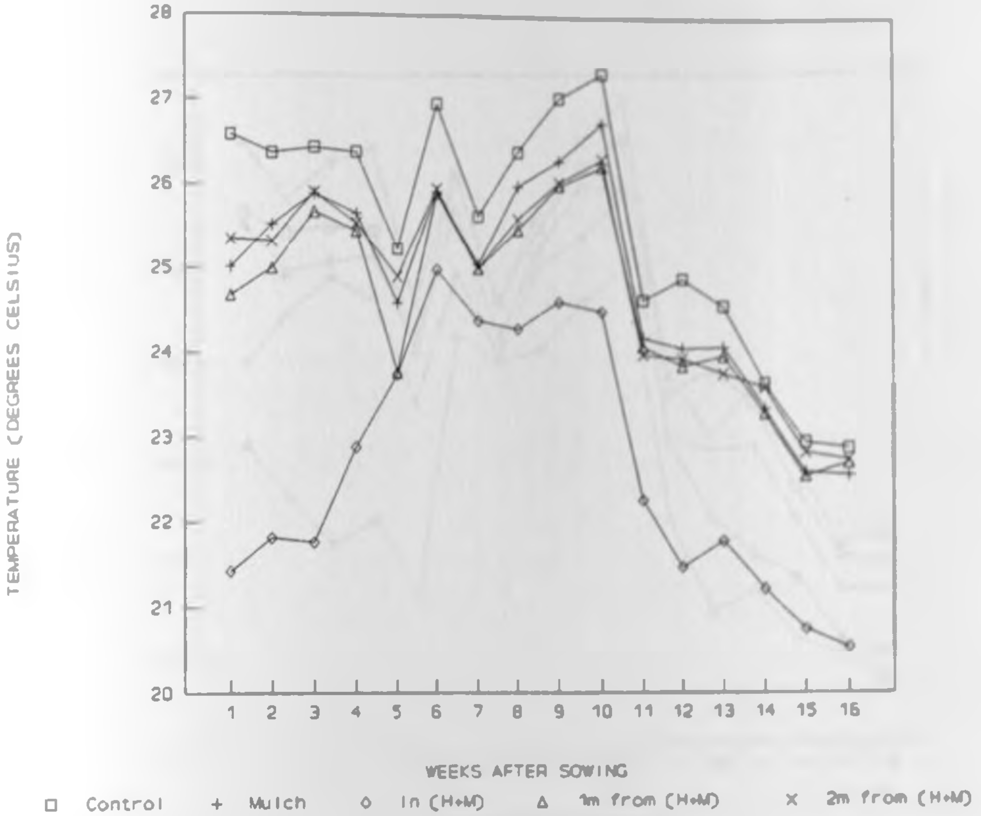


Fig.4.126. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1+M, H2+M and H3+M positions. Long rains of 1993.

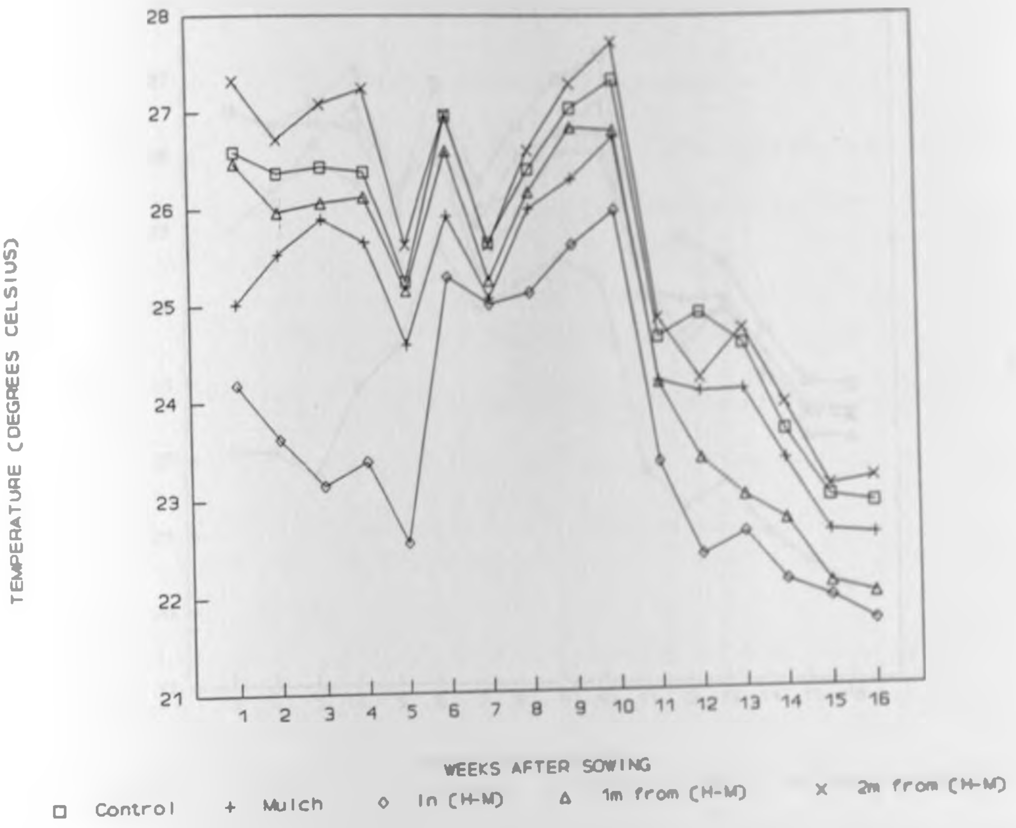


Fig.4.127. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Long rains of 1993.

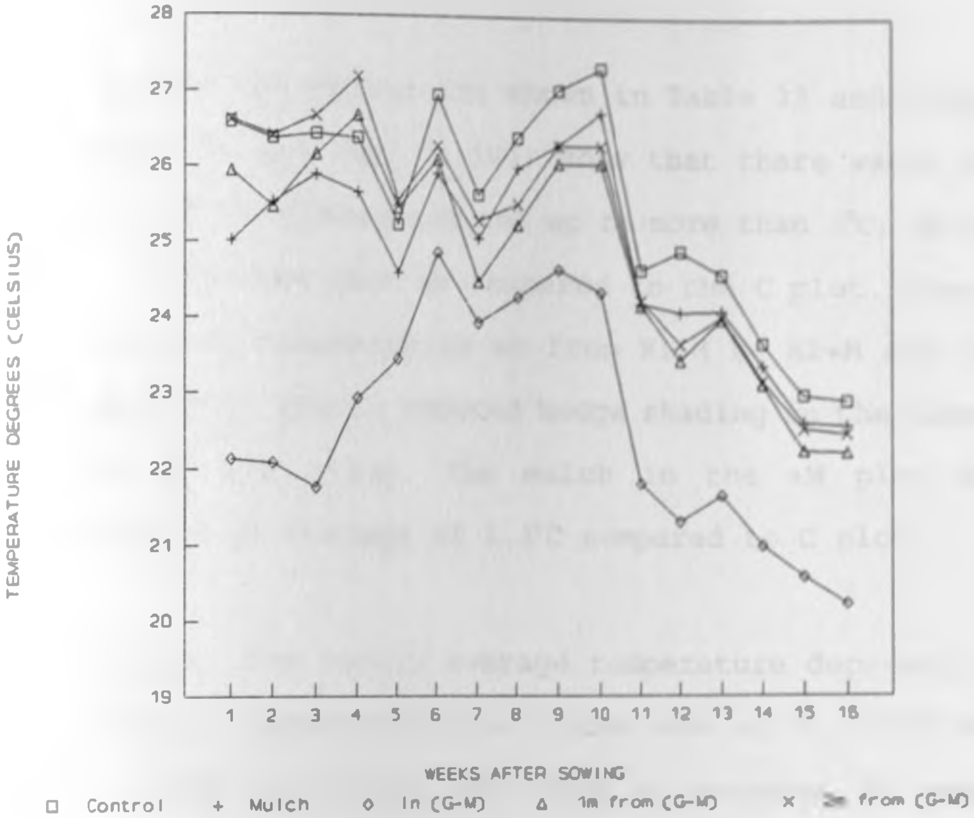


Fig.4.128. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, G1-M, G2-M and G3-M positions. Long rains of 1993.

4.8.4 Weekly mean near surface soil temperatures, short rains 93/94.

The results for the season are shown in Table 33 and figs.(4.129-4.131). Table 33 and fig. (4.129) show that there was a clear cut decrease in soil temperatures, of up to more than 3^0C, by the hedge and mulch in the H+M plot as compared to the C plot. There was an increase in soil temperatures as from H1+M to H2+M and (smaller) H3+M respectively, due to reduced hedge shading in the direction of the centre of the alley. The mulch in the +M plot depressed temperatures by an average of 1.3^0C compared to C plot.

In the H-M plot, the weekly average temperature depression by the hedge (H1-M) as compared to the C plot was up to 2.5^0C while the seasonal average was about 2^0C, with a decrease in temperature depression towards the centre of the alley where shading was only by the crop alone fig. (4.130). The same trend of temperature depression as in the H-M plot occurred in the G-M plot (Fig. (4.131); Table 33). The weekly average temperature depression by the grass strip (at G1-M) as compared to the C plot was up to almost 4^0C, and the seasonal average was 3^0C. There was further again a marked temperature increase towards the centre of the alley due to decreased grass shading from the grass strip. Although there were temperature variations found within and between treatments, the seasonal soil temperatures (Table 33) show clearly that the mulch and hedge shade in the H+M treatment was the strongest in terms of temperature reduction. The grass shade in the G-M plot was the second, hedge shade in the H-M plot was third and mulch in the +M plot among the last in their effectiveness for soil temperature reduction respectively.

Table 33. Weekly mean near surface soil temperatures short rains 1993/94.

WEEK	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M
1	26.5	24.2	23.9	24.1	24.7	24.4	25.6	25.9	24.8	25.4	25.6
2	23.1	22.1	22.1	21.4	22.9	20.9	22.6	23.0	21.6	21.9	22.4
3	23.1	22.2	20.9	22.5	22.6	20.9	22.4	22.4	21.2	21.8	22.3
4	24.0	22.8	21.0	23.4	23.7	22.4	22.5	23.8	21.4	23.1	24.0
5	25.8	24.3	21.7	24.3	24.3	23.3	24.0	25.5	22.0	25.0	25.7
6	25.6	24.4	21.8	24.2	24.3	23.6	23.8	25.4	21.8	24.3	25.0
7	24.1	23.2	20.8	23.5	23.7	22.5	23.4	24.3	20.4	22.6	23.5
8	26.2	25.0	22.0	24.3	24.4	24.6	25.2	26.3	22.3	24.5	25.6
9	26.4	25.1	22.3	24.8	24.8	24.8	25.6	26.5	22.6	25.0	25.9
mean	25.0	23.7	21.7	23.7	24.1	23.1	23.9	24.8	22.0	23.8	24.5

C = Control

+M = Mulch

H1+M = In (H+M)

H2+M = 1m from (H+M)

H3+M = 2m from (H+M)

H1-M = In (H-M)

H2-M = 1m from (H-M)

H3-M = 2m from (H-M)

G1-M = In (G-M)

G2-M = 1m from (G-M)

G3-M = 2m from (G-M)

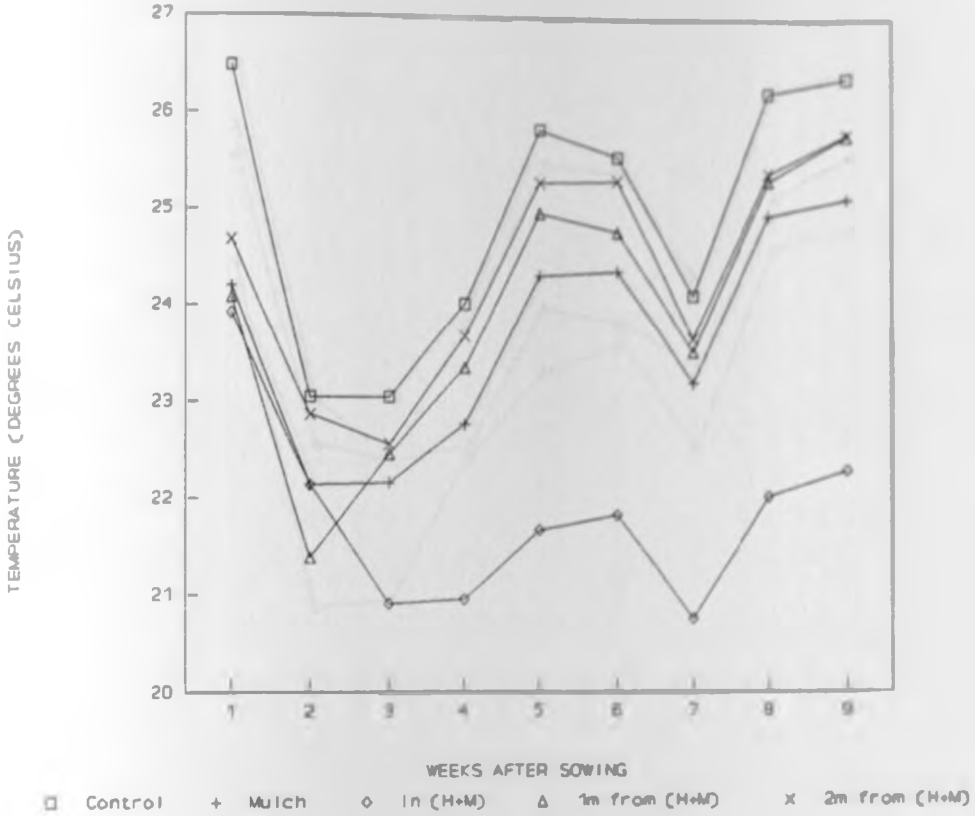


Fig.4.129. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1+M, H2+m and H3+M at positions. Short rains of 93/94.

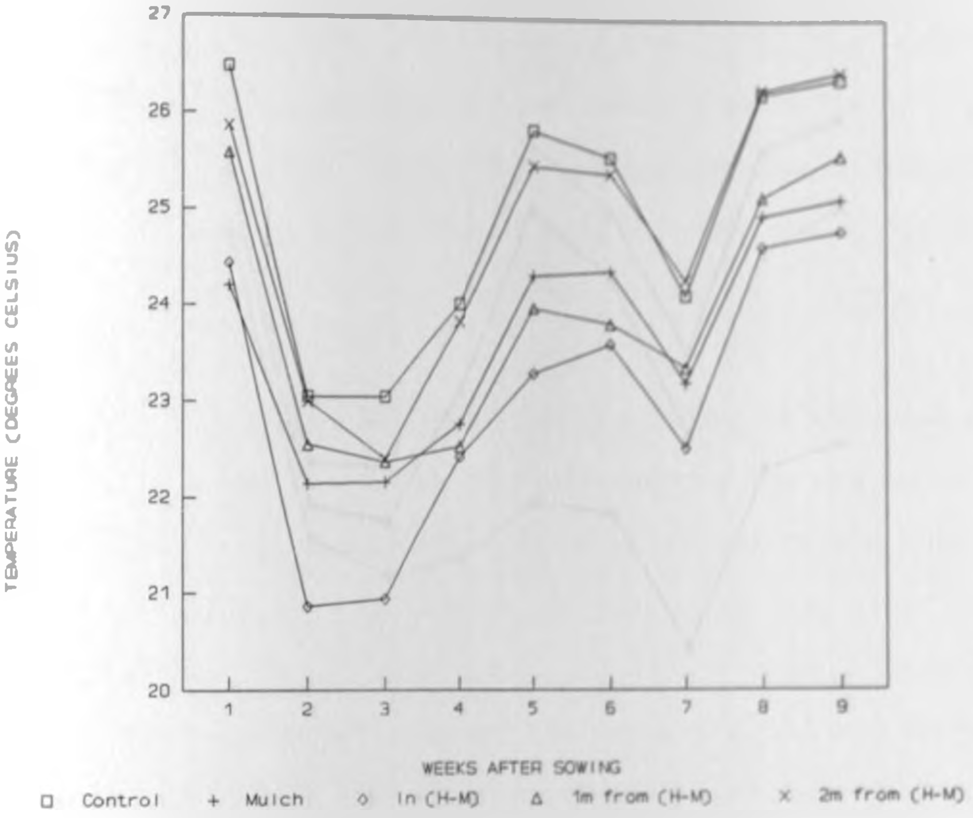


Fig.4.130. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Short rains of 93/94.

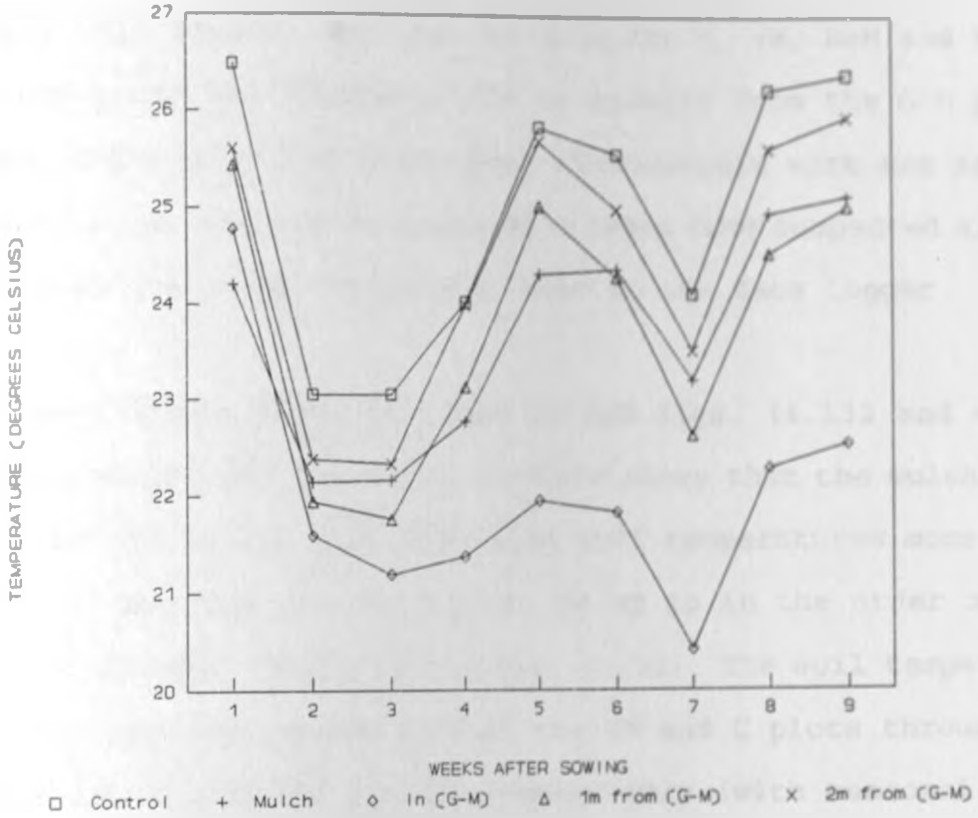


Fig.4.131. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, G1-M, G2-M and G3-M positions. Short rains of 93/94.

4.8.5 Weekly mean near surface soil temperatures, long rains 1994.

During this season, the results from the C, +M, H+M and H-M plots are presented and discussed for no results from the G-M plot were given as the platinum resistance thermometers were not in working condition for there were problems arising from suspected electrical faults in the wires connecting them to the data logger.

The results are shown in table 34 and figs. (4.132 and 4.133). A comparison between the C and +M plots shows that the mulch and crop shade in the latter plot depressed soil temperatures more than the shade by the crop in the C plot, by up to in the order of 1°C and 0.6°C on average (Table 34 and fig. 4.132). The soil temperature at H1+M was more depressed than at the +M and C plots throughout the season by up till 3°C and 4°C respectively (with seasonal averages of 1.9°C and 2.5°C). This was because of the combined effect of the tree shade and mulch at the hedgerow plot (H1+M). The other results were as expected within these ranges.

Table 34. Weekly mean near surface temperatures for the long rains 1994.

WEEK	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M
1	26.5	25.6	23.9	24.3	24.6	26.2	26.6	26.9
2	27.7	26.9	24.7	25.5	26.6	26.5	27.1	27.3
3	26.0	25.5	23.1	24.2	25.8	24.5	25.2	26.6
4	23.7	23.2	21.2	22.0	23.4	22.0	22.9	24.1
5	24.2	23.1	20.8	22.1	23.9	21.4	22.8	25.0
6	25.0	23.9	21.0	23.4	24.4	22.8	24.4	26.1
7	22.8	22.3	20.2	21.6	22.3	20.9	22.1	23.5
8	21.3	20.8	19.2	20.7	21.1	19.6	20.8	23.0
9	21.7	21.1	18.9	20.9	22.0	20.0	21.3	24.0
10	21.4	21.0	19.2	20.8	22.1	20.3	21.5	23.4
11	21.2	20.9	19.4	20.5	21.5	20.3	21.2	22.6
12	21.7	21.2	19.6	20.5	21.8	20.4	21.4	22.9
13	21.9	21.4	19.7	20.7	22.0	20.6	21.7	23.1
14	21.0	20.6	19.2	19.8	20.6	19.7	20.6	21.4
15	21.5	21.0	19.3	20.3	21.5	20.1	21.0	22.5
16	20.8	20.4	19.2	19.8	20.8	19.9	20.6	21.6
mean	23.0	22.4	20.5	21.7	22.8	21.5	22.6	24.0

C = Control   +M = Mulch   H1+M = In (H+M)   H2+M = 1m from (H+M)

H3+M = 2m from (H+M)   H1-M = In (H-M)   H2-M = 1m from (H-M)

H3-M = 2m from (H-M)

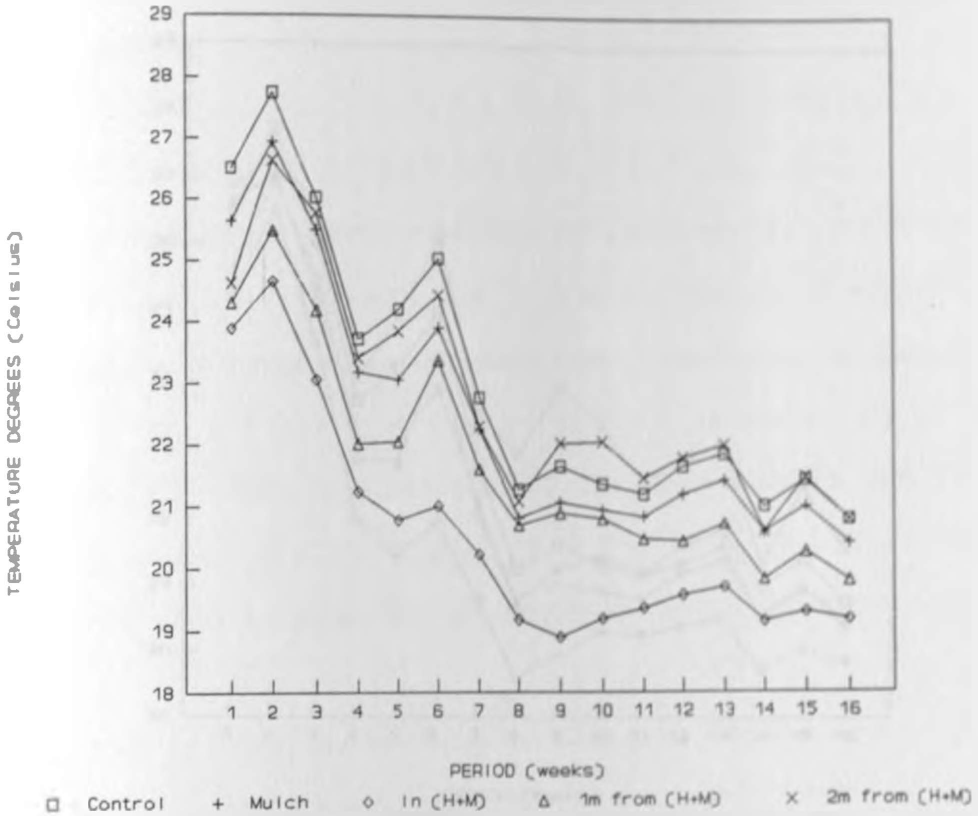


Fig.4.132. Near surface average soil temperatures taken at 7.5 cm in C, H1+M, H2+M and H3+M positions. Long rains of 1994.

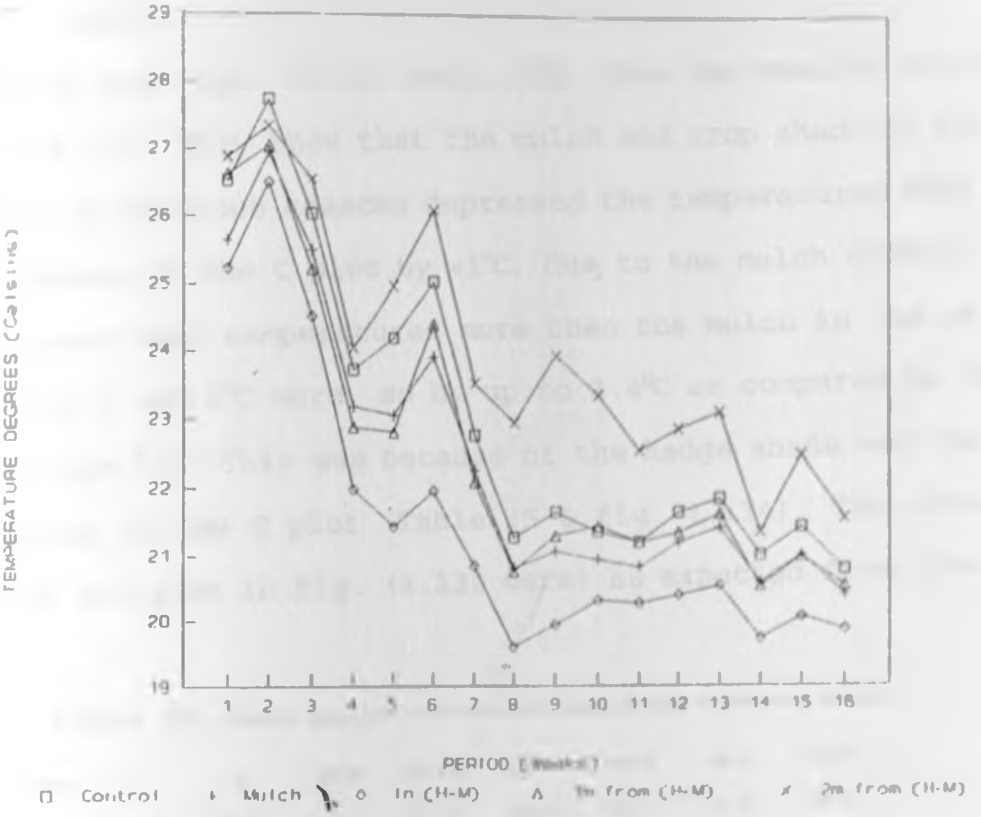


Fig.4.133. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Long rains of 1994.

4.8.6 Weekly mean near surface soil temperatures, short rains 94/95.

Table 35 and figs. (4.134 and 4.135) show the results for the short rains 94/95. They show that the mulch and crop shade in the +M plot had as in previous seasons depressed the temperatures more than the crop shade in the C plot by <1^{0}C, due to the mulch effect. The H1+M depressed soil temperatures more than the mulch in the +M plot, by between 1 and 2^{0}C more, so by up to 2.4^{0}C as compared to the C plot (for week 12). This was because of the hedge shade and the mulch as compared to the C plot (Table 35 & fig. 4.134). The other results in the H-M plot in fig. (4.135 were) as expected from this picture.

Table 35. Weekly mean near surface soil temperatures 94/95 rain season.

WEEK	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M
1	24.6	23.9	23.1	23.7	24.5	23.7	24.2	24.9
2	25.6	24.9	23.7	24.4	25.2	23.7	24.2	24.9
3	26.8	26.1	24.7	25.2	26.0	24.4	24.9	25.5
4	27.3	26.8	24.8	25.2	25.8	25.7	26.0	27.6
5	24.4	23.7	22.6	23.1	24.6	22.6	22.9	23.4
6	23.3	22.9	22.5	22.7	23.0	22.6	22.9	23.3
7	24.5	24.0	23.9	24.1	24.6	24.0	25.2	25.6
8	20.9	20.5	19.0	19.3	20.0	20.3	20.9	21.6
9	21.3	20.7	19.4	20.0	20.8	20.2	21.2	22.4
10	20.6	20.4	19.3	19.4	19.9	20.1	20.3	20.9
11	21.9	21.6	19.7	20.2	20.6	21.2	21.4	21.7
12	22.5	22.2	20.1	20.4	21.0	21.8	22.0	22.3
mean	23.6	23.1	21.9	22.3	23.0	22.5	23.0	23.7

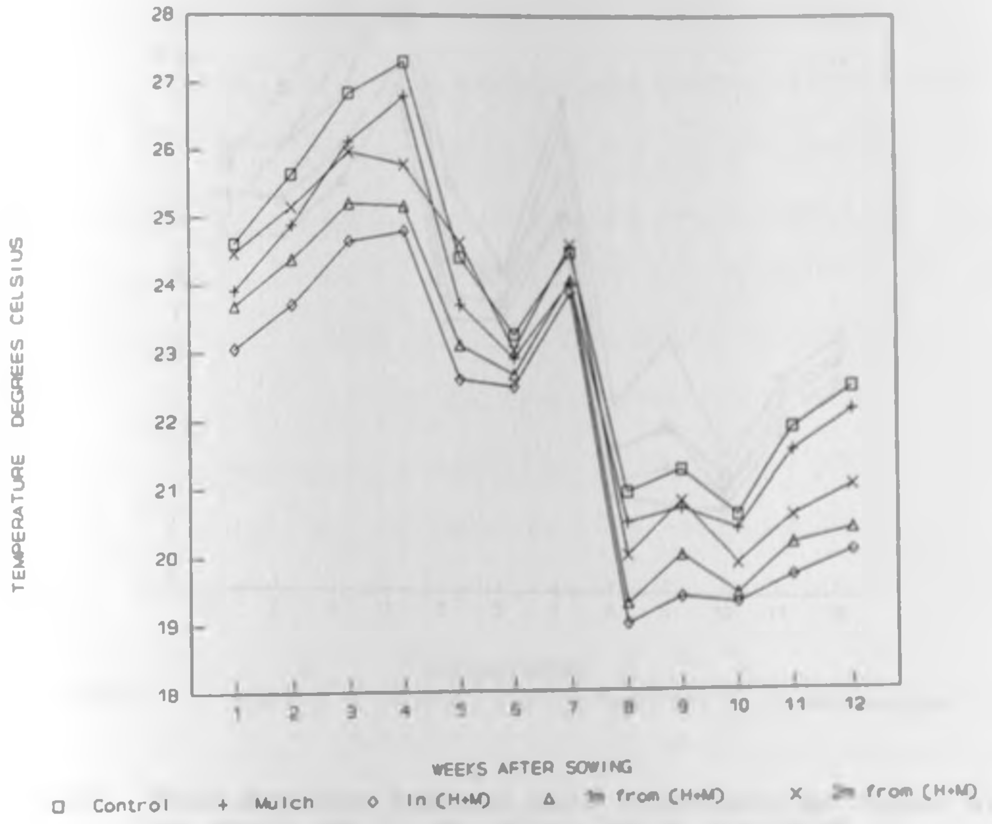


Fig.4.134. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1+M, H2+M and H3+M positions. Short rains of 94/95.

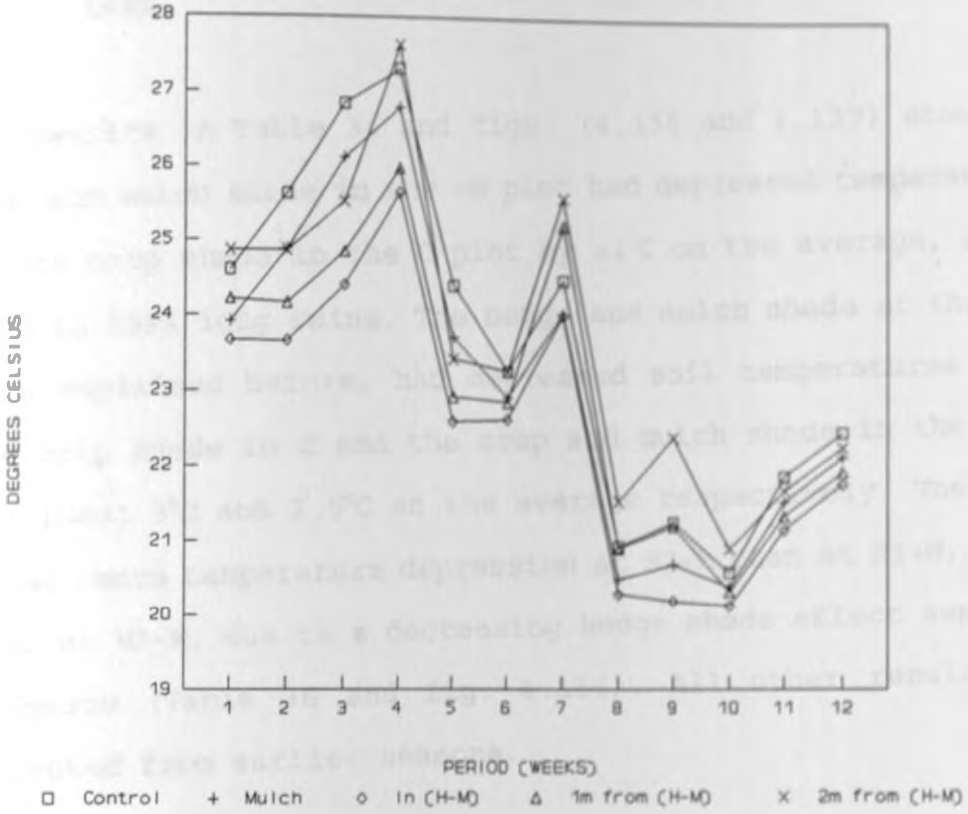


Fig.4.135. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Short rains of 94/95.

4.8.7 Weekly mean near surface soil temperatures, long rains 1995.

The results in Table 36 and figs. (4.136 and 4.137) show that the crop and mulch shade in the +M plot had depressed temperatures more by the crop shade in the C plot by >1^{0}C on the average, as earlier seen in 1994 long rains. The hedge and mulch shade at the H1+M, as also explained before, had depressed soil temperatures more than the crop shade in C and the crop and mulch shade in the +M plots, by almost 3^{0}C and 1.5^{0}C on the average respectively. There was, as usual, more temperature depression at H2+M than at H3+M, as at H2-M than at H3-M, due to a decreasing hedge shade effect away from the hedgerow (Table 36 and fig. 4.136). All other results were as expected from earlier seasons.

Table 36. Weekly mean near surface soil temperatures long rains 1996.

Week	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M
1	25.1	24.9	22.8	23.9	24.4	22.8	24.4	25.4
2	25.6	24.2	22.3	23.4	24.0	23.0	24.0	25.3
3	24.8	24.0	22.1	23.4	23.6	23.0	24.0	24.1
4	24.0	22.3	21.1	22.2	23.0	21.0	22.6	23.6
5	23.2	21.1	20.5	21.0	21.0	20.5	22.0	23.0
6	22.9	21.6	20.0	21.0	22.0	20.6	22.0	22.8
7	22.9	20.9	19.7	20.8	21.8	20.0	22.4	22.7
8	22.8	21.7	20.2	21.6	21.8	20.5	22.7	23.0
9	23.7	22.0	20.1	21.9	22.0	20.5	22.7	23.5
10	23.5	22.5	21.0	22.3	22.6	21.4	23.1	23.6
11	23.0	22.4	20.9	22.2	22.3	21.0	22.9	22.9
12	22.9	21.2	20.1	21.0	22.1	20.5	22.3	22.9
13	23.0	21.7	20.5	21.6	21.7	20.5	22.0	22.6
14	22.9	21.6	20.9	21.3	21.4	21.0	22.1	22.9
15	22.7	21.0	20.5	21.1	21.3	20.9	21.7	22.6
16	22.8	21.3	20.0	21.0	21.0	20.1	21.8	22.5
17	23.2	21.4	19.6	20.4	21.3	20.0	21.7	22.7
18	22.8	21.2	19.8	20.0	21.0	19.8	21.6	22.3
19	22.8	21.0	19.5	20.1	20.5	19.7	21.5	22.1
20	22.5	21.1	19.4	20.1	20.8	19.6	21.5	22.3
Mean	23.4	21.9	20.5	21.5	22.0	20.8	22.4	23.1

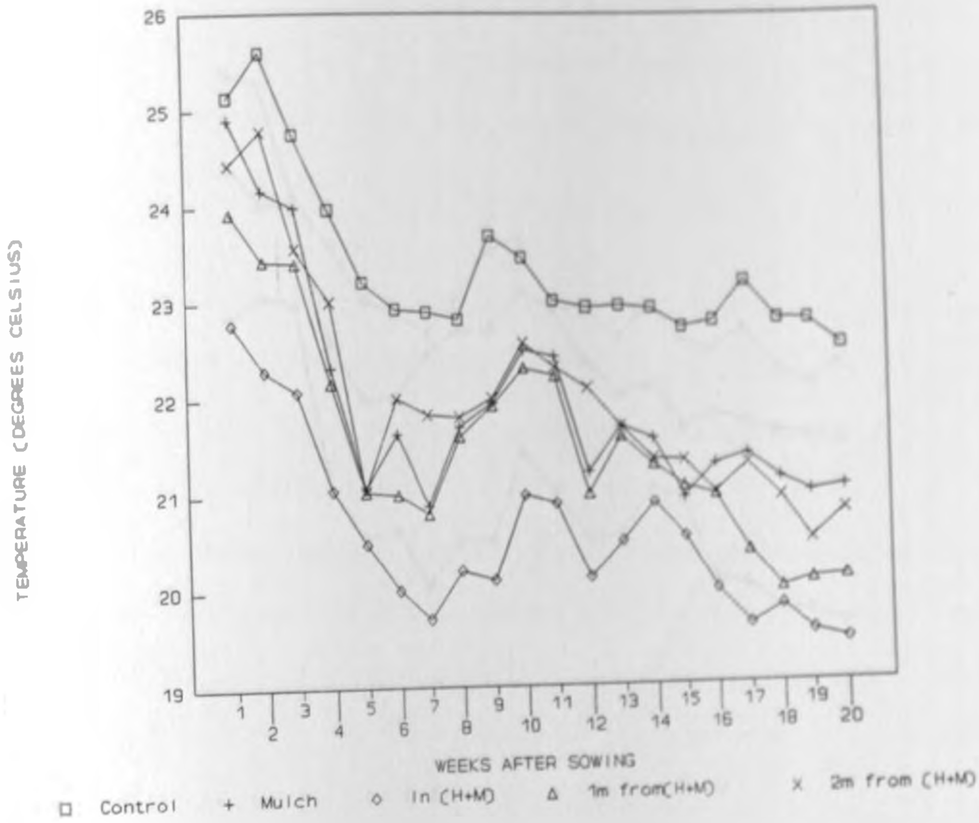


Fig.4.136. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1+M, H2+M and H3+M positions. Long rains of 1995.

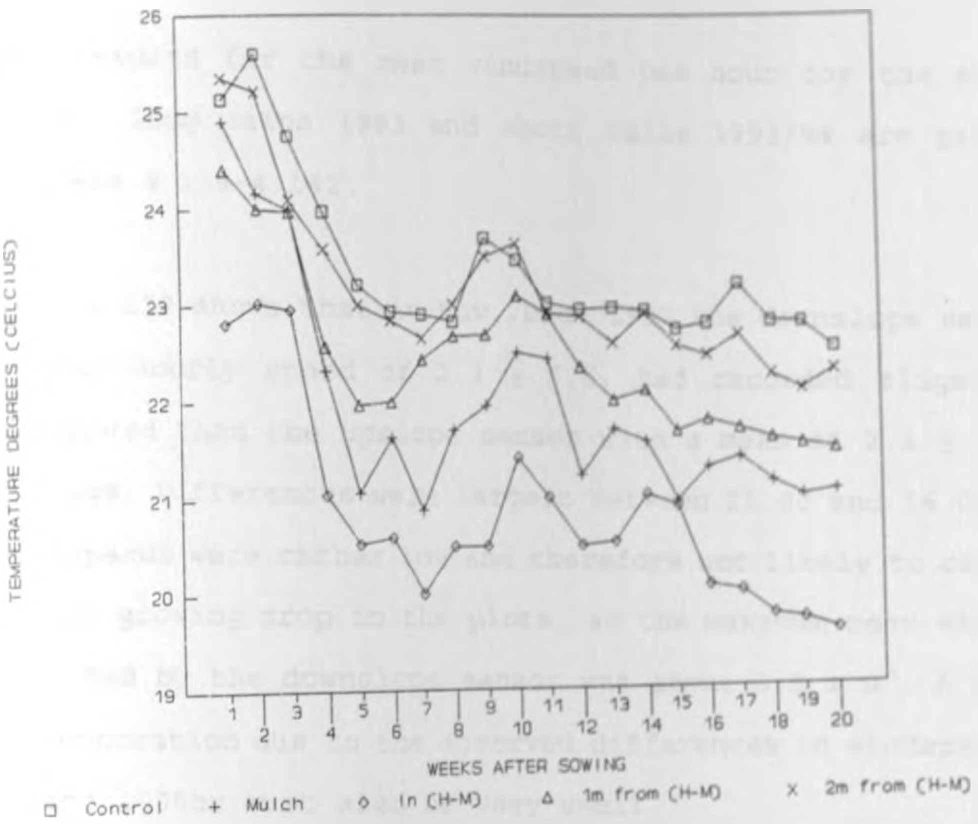


Fig.4.137. Near surface average soil temperatures taken at 7.5 cm depth in C, +M, H1-M, H2-M and H3-M positions. Long rains of 1995.

4.8.8 Conclusion.

This section on soil temperature has shown that weekly average temperatures at 7.5 cm depth remain below 28^0C and above 18^0C. For germination the lowest temperatures may therefore be sub-optimal, negatively influencing germination under mulch as well as in places heavily shaded by the grass strips and under combination of hedgerow shade and mulch (Van Wijk and DerKsen, 1966). Such examples will be discussed in section 4.10, when talking about final yields.

4.9 Windspeed and direction results and discussions.

The results for the mean windspeed per hour for the short rains 92/93, long rains 1993 and short rains 1993/94 are presented in figures 4.138-4.142.

Fig. 4.138 shows that in Nov./Dec. 1992 the downslope sensor, with a mean hourly speed of 2.3 ± 0.8, had recorded slightly higher windspeed than the upslope sensor with a mean of 2.1 ± 0.4 on the average. Differences were largest between 11.00 and 16.00hr. These windspeeds were rather low and therefore not likely to cause damage to the growing crop in the plots, as the maximum mean windspeed as recorded by the downslope sensor was about 3.5 m s'. A difference in evaporation due to the observed differences in windspeed between 06 and 1800hr must also be very small.

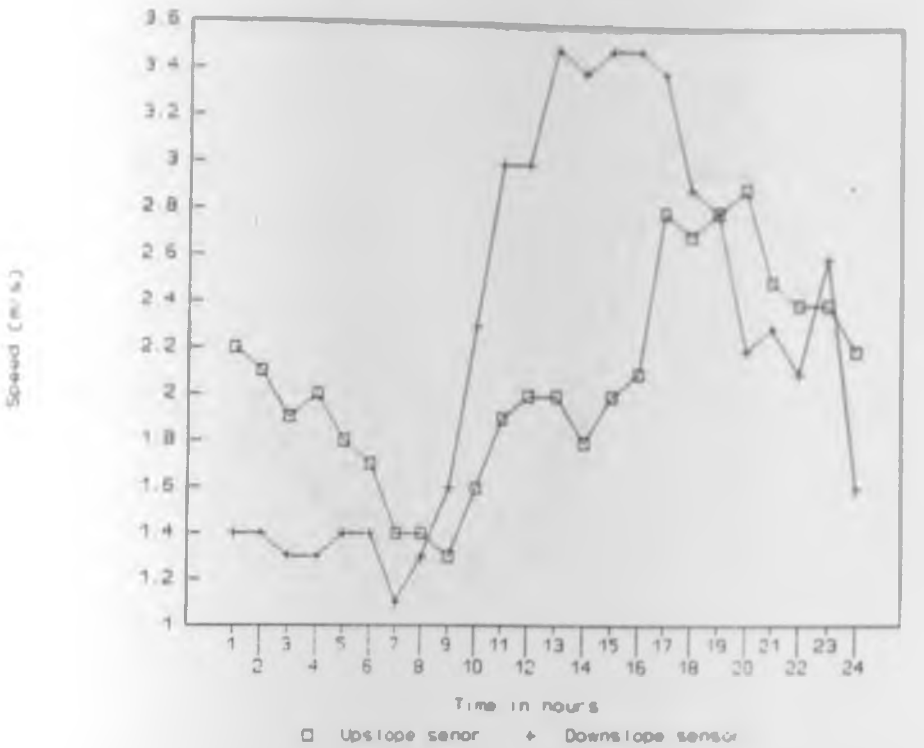


Fig. 4.138. Comparison of upslope and downslope diurnal windspeed on a steep slope, Nove./Dec.1992.

Fig. 4.139 shows negligible windspeed differences between the positions for the period Dec. 1992/Jan. 1993. These mean windspeeds were 1.9± 0.8 and 1.8± 0.6 respectively and the maximum windspeed of 3.2 m s^{-1} was still too low to cause damage to the surrounding crop, while evaporation differences were negligible.

Fig.4.140 shows that for March/April 1993 the downslope sensor had recorded somewhat higher mean windspeed than upslope sensor,

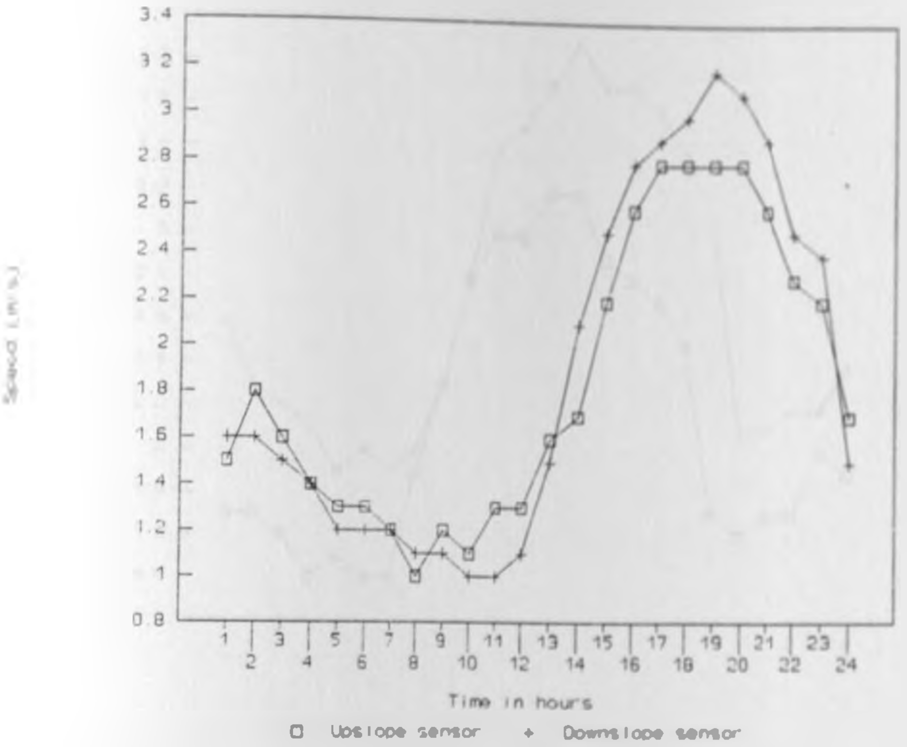


Fig. 4.139. Comparison of upslope and downslope diurnal windspeed on a steep slope, Dec.'92/Jan.'93.

of on average 2.7 ± 0.7 and 2.1 ± 0.7 m s^{1} respectively. Early morning differences were smallest. Such differences will have overall little consequences.

Fig. 4.141 for April/May, 1993, also shows that the mean windspeeds recorded by the downslope sensor were slightly higher than those recorded by the upslope sensor and these were on average 2.5 ±0.6 and 2.0 ±0.7m/s respectively. Differences were small from 9.00-

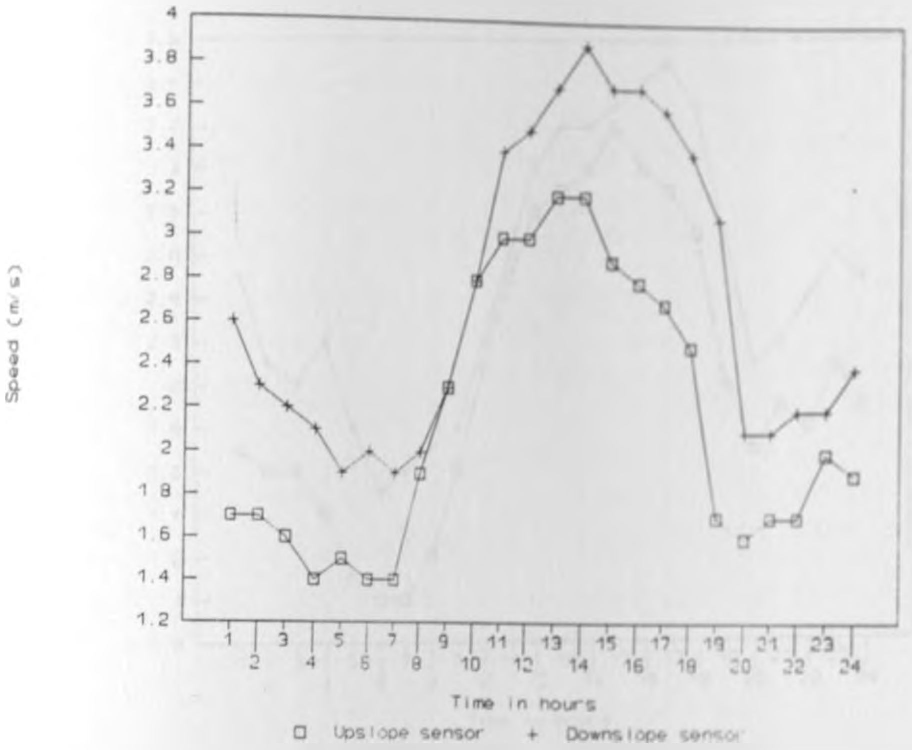


Fig. 4.140. Comparison of upslope and downslope diurnal windspeed on a steep slope, March/April 1993.

13.00hr.

During May/June, fig. 4.142, the windspeeds recorded were 2.4 ± 0.7 and 1.9 ± 0.6 for the downslope and upslope sensors respectively, with an overall almost similar difference, throughout the day.

In fig. 4.143, the tendency of having slightly higher downslope than upslope mean hourly windspeeds was portrayed for some parts of

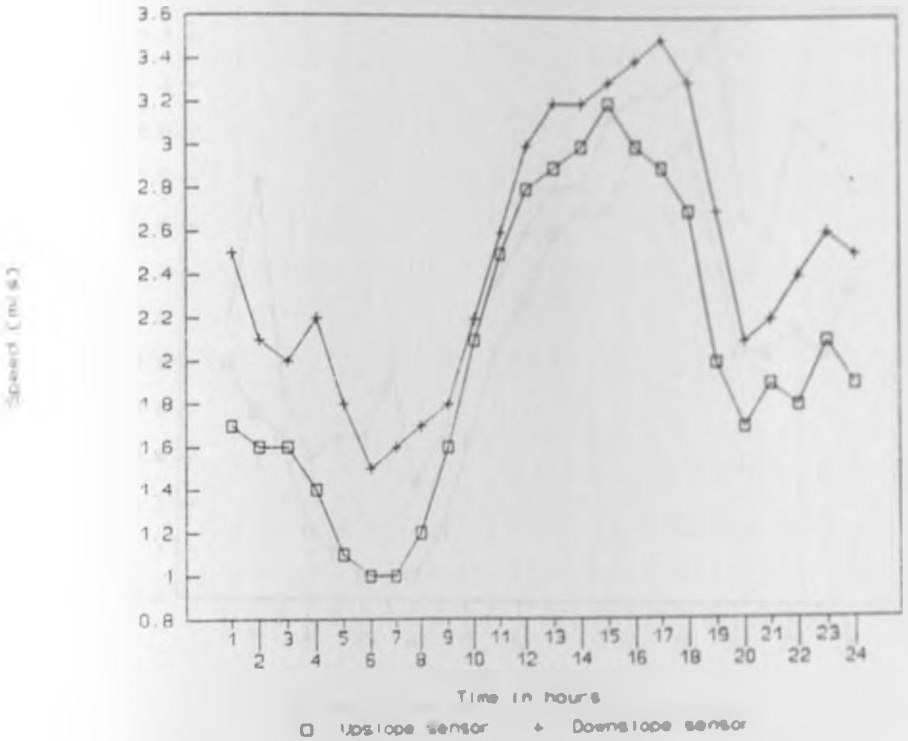


Fig. 4.141. Comparison of upslope and downslope diurnal windspeed on a steep slope, April/May 1993.

the day. The mean hourly windspeeds were recorded on average as 3.2 ± 0.7 and 2.7 ± 0.6m/s for downslope and upslope sensors respectively. Although the maximum hourly windspeed recorded was up to 5m/s, this was still too low to cause damage to crops. For large parts of the day the differences remained negligible.

Fig. 4.144 shows that for Nov./Dec. 1993 the hourly mean windspeeds for the downslope and upslope sensors were 2.7 ± 0.7

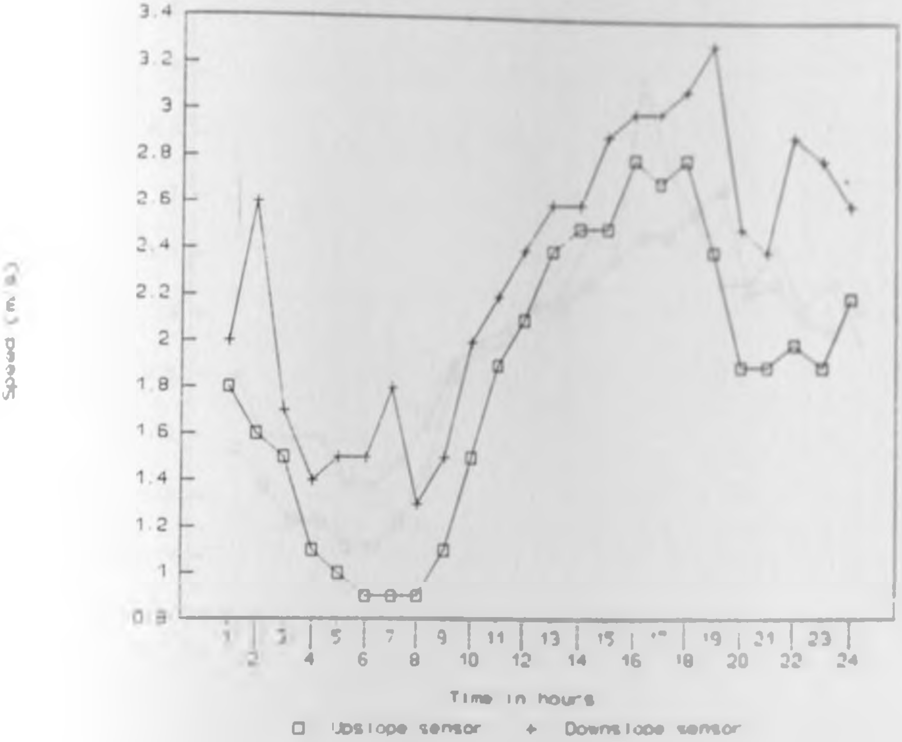


Fig. 4.142. Comparison of upslope and downslope diurnal windspeed on a steep slope, May/June 1993.

and 2.0 ± 0.7 respectively, with the downslope sensor again showing higher windspeeds than the upslope sensor, rather equally distributed over the day. The highest recorded windspeed for the period was now 4 ms^{-1}.

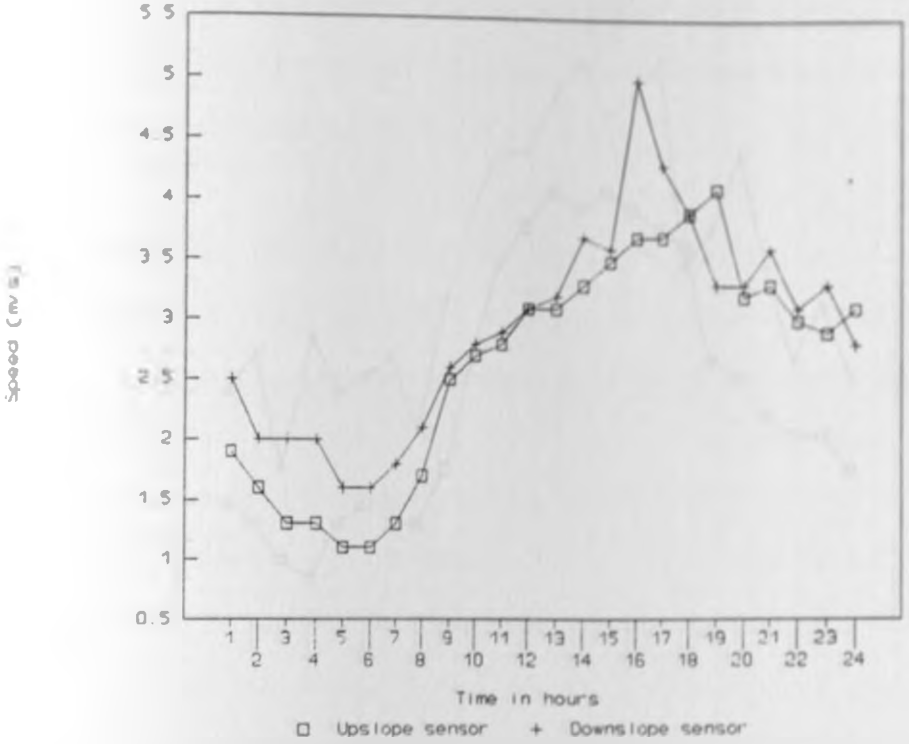


Fig. 4.143. Comparison of upslope and downslope diurnal windspeed on a steep slope, Oct./Nov. 1993.

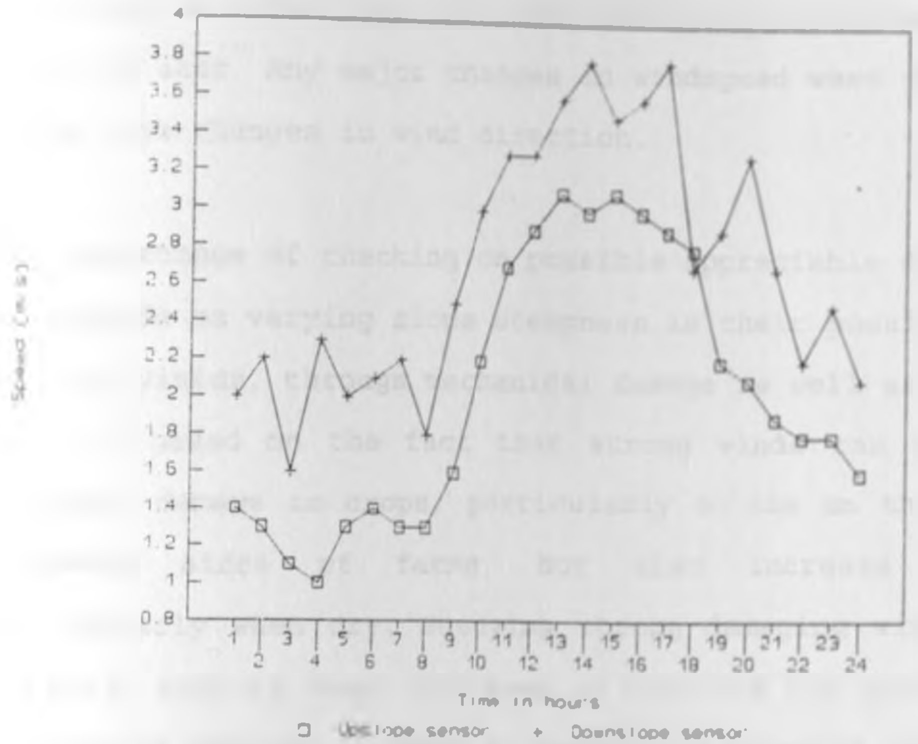


Fig. 4.144. Comparison of upslope and downslope diurnal windspeed on a steep slope, Nov./Dec. 1993.

4.9.1 Discussion.

It should be noted here that the winds were predominantly blowing from the east. Any major changes in windspeed were occurring when there were changes in wind direction.

The importance of checking on possible appreciable differences in windspeeds on varying slope steepness is their possible influence on crop yields, through mechanical damage as well as desiccation. This is based on the fact that strong winds can cause serious physical damage to crops, particularly on the on the unprotected windward sides of farms, but also increase evaporation, particularly when dry. Studying strong damaging winds, or blown material such as sand, can lead to planning for establishment of protective devices in order to reduce the expected risks on crops. These devices may include belts or other grown windbreaks (including scattered trees) which are traditionally well known everywhere to provide shelter for crops, animals and human dwellings (Stigter, 1985b). From a world wide questionnaire, Stigter (1986) noted that wind protection was the most widely known form of traditional techniques of microclimatic modification. In agroforestry, the tree components inter alia act as protective barriers against strong winds when used under parkland conditions, as forest strips, or as shelter belts near growing food crops (Stigter, 1985). However, in our case the results for the three seasons show that the windspeeds were small and differences between upslope and downslope negligible. They were not likely to pose any damage to the surrounding crops and hedges, nor to the soil, while influence on evaporation must also have been rather similar over the sloping land.

4.10. Grain and biomass yield results.

The results for the long rains 1993, the short rains 93/94, the long rains 1994, the short rains 1994/95 and finally the results for the long rains 1995 are presented and discussed on both per row and per hectare basis. Since the short rains of 92/93 were a familiarisation trial season, the yield results for this season will be discussed only on a per hectare basis.

4.10.1. Cowpea yield results, short rains 1992/93.

Table 37. shows the grain and biomass yield in kgs per hectare for the 92/93 season. Because representativety of data may be estimated at ±0.2 t ha^{-1}, there were insignificant differences in grain yields between +M and H+M and between H-M and +M. The difference between H+M and H-M is possibly due to enhanced reduction in soil and nutrient loss resulting from the combination of mulch and hedgerow erosion control effects. The G-M had the lowest grain and biomass yield/hectare, because of the severity of competition between cowpea and grass lateral roots, also already when compared to the grain yields in the H-M plot with cowpea/senna root competition. The low grain yields in the C plot may have been due to increased runoff and increased (accumulated) nutrient loss through this runoff as compared to other plots, with erosion control measures. The C plot was observed to have rather more vegetative growth than the pods after all filling from, suggesting that plant assimilates went to the build up of vegetation that could not be mobilised for grain formations. This is seen in the high biomass yields and low

grain in Table 37 and is responsible for the low H.I in the C plot compared to the other plots. In a comparison with the 93/94 season we will later on suggest that the far above average rainfall for this season (662mm) and below 2 t ha' mulch are responsible for the differences observed. Whether the fertility status of the soil plays a role, via nutrients taken out in the previous season, availability of nitrogen, influenced not only by the normal balance but also by previous cowpeas, via nitrogen fixing and availability, itself determined by soil conditions (Norman et al., 1995) will remain unknwon until the soil fertility status is quantified in experiments like ours as well.

Table 37. Cowpea yields (t ha^{-1}) short rains 92/93.

Treatment	Grain	Biomass	Harvest Index (%)
C	0.32	3.9	8.3
+M	0.43	2.3	18.3
H+M	0.46	3.2	14.4
H-M	0.39	2.2	17.7
G-M	0.30	2.1	14.4
mean	0.38	2.7	14.6
Std(±)	0.06	0.8	3.6
cv (%)	16	25	24

4.10.2 Maize yield results, long rains 1993.

The results in mean grain/biomass per row in kg in Fig. (4.145) show that the mean yields per row were higher in the C plot than in the +M plot. This was because there was observed suppressed germination in the *Senna* mulched (+M) plot, possibly as a result of mulch trapping light rainfall experienced in March 1993 before reaching the soil and causing temporary moisture shortage for the germinating seed. This is confirmed by the soil moisture pictures (Fig. 4.40 and Fig. 4.41), which are for example different from that of the previous year (Fig. 4.30 and Fig. 4.31)

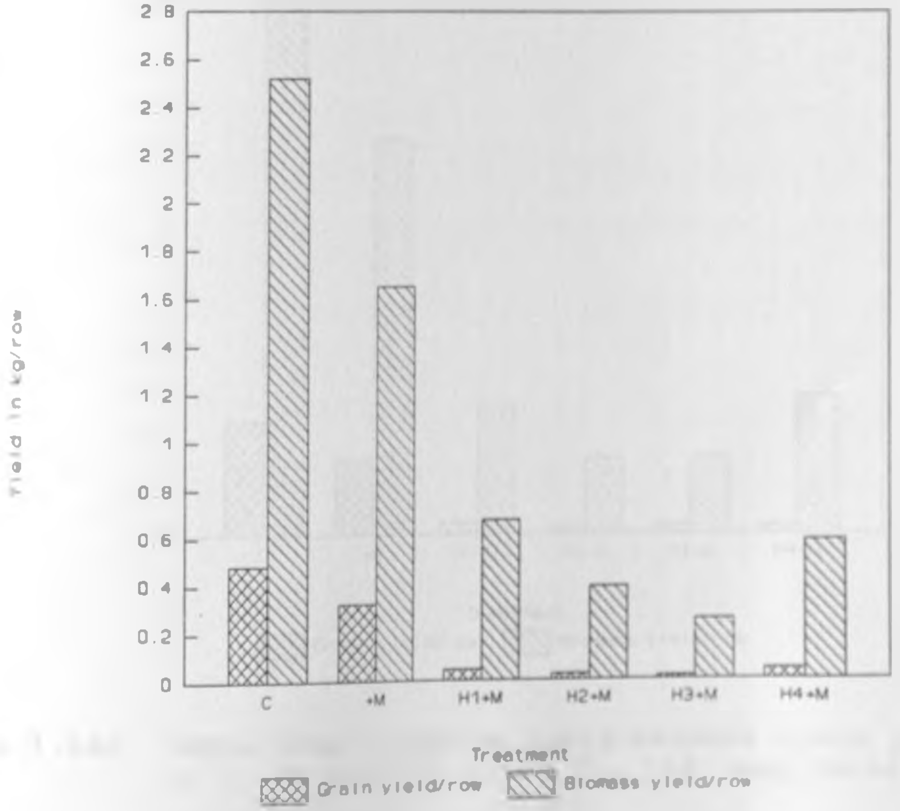


Fig. 4.145. Comparison of maize grain/biomass yield/row in C, +M and H+M plots, for the long rains 1993.

The high cover may also have intercepted much light. Figure 4.145 and figure 4.146 also show that the grain and biomass yields per row in the H+M and H-M plots were appreciably lower than those in the C and +M plots respectively. This has to be attributed to the (for H+M additional) root competition of the *Senna* trees and the maize plants for nutrients and water in the H+M and H-M plots.

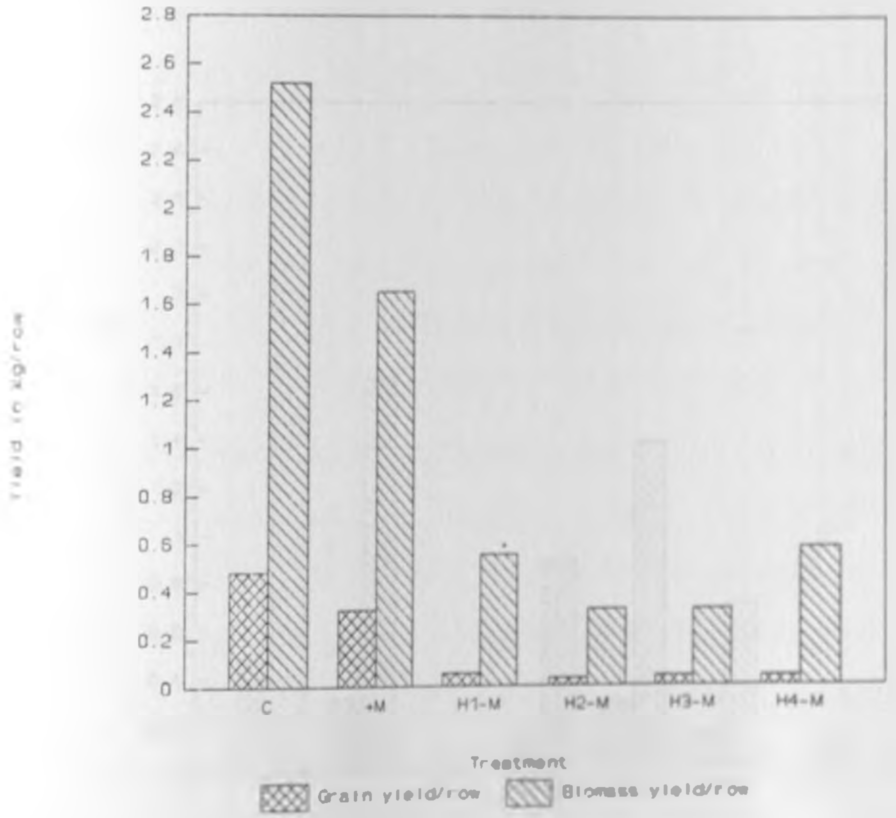


Fig.4.146. Comparison of maize grain/biomass yield per row in C, +M and H-M plots for the long rains 1993

The yields in the middle rows of maize were more depressed compared to the rows near the hedgerows in both the H+M and H-M plots figs (4. 145) and (4.146). This was partly because the rows of maize near the hedgerows had more moisture accumulated and had less soil eroded and even soil nutrients deposited at the hedgerow barrier. Those in the middle were somewhat more affected by Senna/maize root competition particularly at shallow soil depths where most of the smaller roots for nutrient uptake occur (e.g Mungai, 1991 and Mungai et al. 1996b). On the other hand, it is

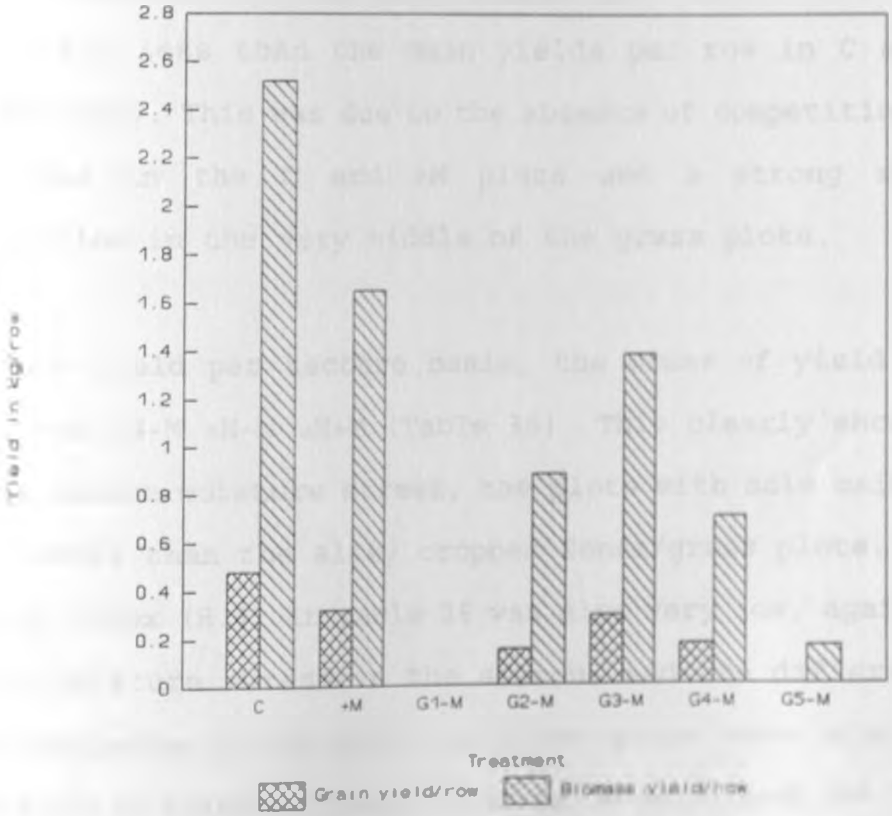


Fig.4.147. Comparison of maize grain/biomass per row in C, +M and G-M plots for the long rains 1993.

also near the hedgerows where near soil surface temperatures were more depressed by shade and this could have influenced the development of the crop near the hedgerows differently.

The mean grain/biomass yields per row in the G-M plot, in figure (4.147), show that the yields were much more depressed near the grass strip compared to those in the middle rows. This was because of the competition for water and nutrients between the lateral grass and maize roots and possibly the effect of shading. The yields per row in the middle rows of maize in the G-M plot were higher compared to the mean yields per row in the H+M and H-M plots, but less than the mean yields per row in C and +M plots respectively. This was due to the absence of competition for growth resources in the C and +M plots and a strong reduction of competition in the very middle of the grass plots.

On grain yield per hectare basis, the order of yield performance was C >+M >G-M >H-M >H+M (Table 38). This clearly showed that due to the severe moisture stress, the plots with sole maize performed much better than the alley cropped Senna/grass plots. The overall harvest index (H.I) in table 38 was also very low, again due to the severe moisture stress in the season, and the differences of the Senna hedgerow plots with the other plots were also higher. In normal maize seasons, the H.I for maize is around 50% (e.g. Howard et al. (1995) and sections 4.10.4 and 4.10.6 in this thesis). The low H.I for this season, with 108 mm, rainfall shows (table 38) that most of the plant assimilates that could be taken up went to the build up of the low vegetative maize biomass. The maize was already stressed at tasselling time and hence the formation of few very tiny grains. Of course means etc. do not have much meaning here anymore, when differences are that large.

Table 38. Maize yields (t ha^{-1}) Long rains 1993.

Treatment	Grain	Biomass	H.I (%)
C	0.48	2.5	18.8
+M	0.32	1.7	19.2
H+M	0.032	0.48	6.7
H-M	0.042	0.44	9.5
G-M	0.12	0.63	19.6
Mean	0.20	1.15	14.8
std (±)	0.17	0.82	5.5
Cv (%)	87	71	37

4.10.3 Cowpea yield results, short rains 93/94.

Because of cowpea infection by *Fusarium* and *Pseudomonas* during the growth period, harvesting was done in complete cowpea rows in areas and in the alleys which were not damaged by the disease, while retaining the sampling procedure.

Figure 4.148 shows that both the mean grain and biomass yield per row were higher in the C and +M plots than in the H+M, H-M and G-M

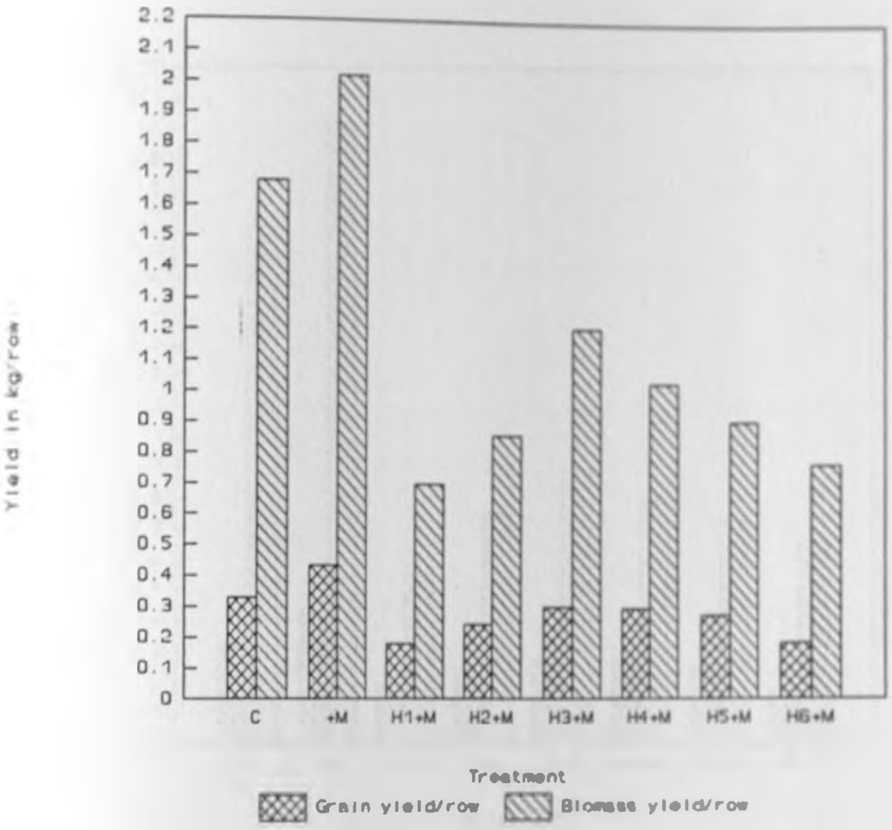


Fig.4.148. Comparison of cowpea grain/biomass yield per row in C, +M and H+M plots for the short rains 93/94.

plots respectively. The mean grain and biomass yields per row were higher in +M than in the C plot Fig. (4.148). This may possibly be attributed to some conserved moisture and reduced soil loss in +M as compared to more loss of nutrients and water in the C plot. The effect is opposite to what was found in the 92/93 season, possibly due to use of a new cowpea variety, within average rainfall (288.5 mm), within range of optimal (2.4 t ha^{-1}) mulch rate, which resulted in low erosion losses (less than the T value of 5 t ha^{-1}) as well as

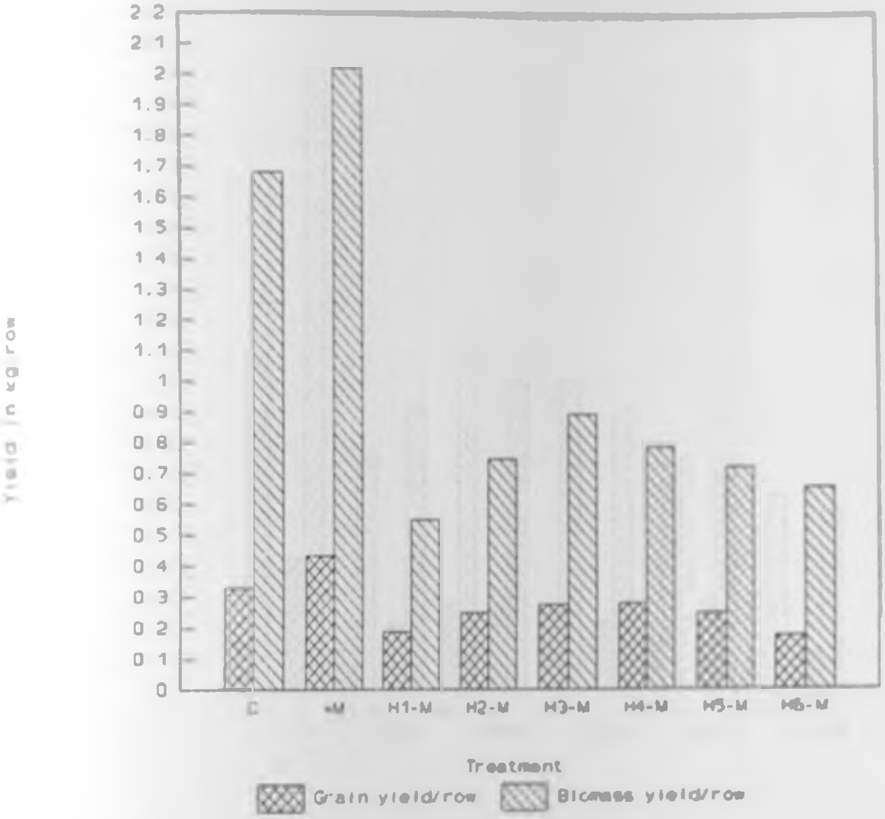


Fig.4.149. Comparison of cowpea grain/biomass yield per row in C, +M and H-M plots for the short rains of 93/94.

low runoff. The season 1992/93 had far above average rainfall (662 mm) while the mulch rate was below 2 t ha^{-1} which may have favoured soil loss and runoff, resulting in nutrient losses and consequently reducing the cowpea yields. The cowpea rows in the middle of the alley in H+M (Fig. 4.148), H-M (fig 4.149) and G-M (Fig. 4.150) had better yields than the rows near the contour hedgerows and grass strip respectively. In the H+M and H-M plots figs. (4.148 and

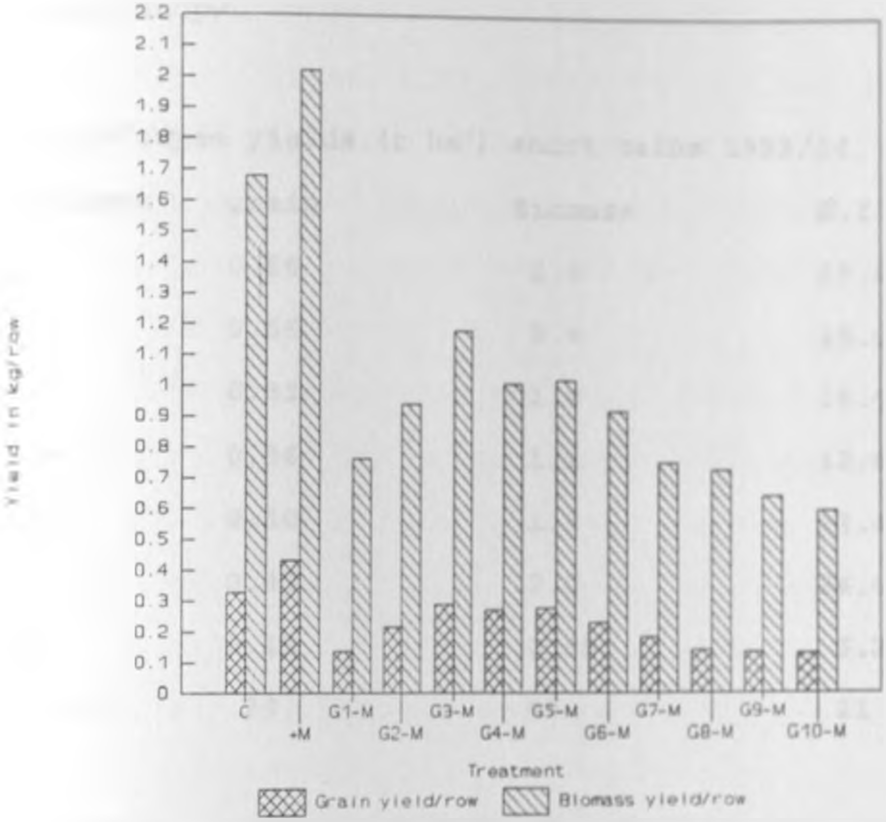


Fig.4.150. Comparison of cowpea grain/biomass yield per row in C, +M and G-M plots for the short rains 93/94.

4.149), the yield differences are as a result of shading of the cowpea plants by the *Senna* trees and of moisture accumulation of hedgerows which did not seem to sufficiently favour cowpea growth and development to compensate for nutrient and water competition and the shading. In the G-M plot, the yields were depressed near the grass strip and quite improved in most middle rows (fig. 4.150). This was as a result of diminishing competition for water and nutrients by the grass and cowpea roots, which was less pronounced in most middle rows, as well as diminishing shading by the grass canopy.

Table 39. Cowpea yields (t ha^{-1}) short rains 1993/94.

Treatment	grain	Biomass	H.I
C	0.56	2.9	19.6
+M	0.65	3.4	18.9
H+M	0.39	1.4	28.4
H-M	0.36	1.1	32.6
G-M	0.30	1.3	23.4
avg	0.45	2.0	24.6
Std	0.13	0.95	5.2
cv (%)	29	47	21

As for the grain/biomass yields per hectare, the grain yields arranged in a descending order gave +M >C >H+M =H-M >G-M plots respectively (Table 39). The differences between the seasons 92/93 (Table 37) and 93/94 (Table 39) must in first instance be due to better water relations in 93/94 because 1992/93 was an extremely wet year for cowpea. This apparently particularly favoured low quality biomass growth in the wetter year, 1992/93, contributing to low H.I. The mulched plot, however, benefitted most in the driest of these seasons (1993/94), in grain as well as in biomass yields. For grain this also applies to the control that almost doubled the 1992/93 yields. Partly, however, as already said, more nutrient loss through soil erosion, which was more in 92/93 than in 93/94, may have been involved and the cowpea variety difference. The biomass yields per hectare were in the same descending order, apart from not very different tail values for G-M and for H-M plots changing place respectively (Table. 39). The harvest index for the five plots showed that compared to maize they were low, ranging from 18.9 in the +M plot (same order of magnitude as in 1992/93) to 32.6 in the G-M plot (appreciably higher than in 1992/93, which is true for all plots other than +M (Table. 39). These lower values for cowpea were expected, as the harvest index for legumes are low (e.g Jain, 1975). The difference between the seasons in H.I are due the earlier mentioned factors. This distribution is economically not very important because the cowpea is grown both for grain and for leaves, that are used as vegetable in eastern semi-arid Kenya (Shakoor et al. 1984).

4.10.4. Maize yield results, long rains 1994.

The results in (fig. 4.151) for the mean grain/biomass yield in kg per row show that the C plot had similar yields per row as the +M plot (with a yield difference of less than 5%). The mean yields per row were lower in the H+M than in the C and +M plots (fig. 4.151). This was due to competition for moisture, light and nutrients between the *Senna trees and* maize plants in the H+M plot. A closer look at the mean yields per row in the H+M shows that there were again, as in 1993, yield depressions in the middle rows compared to the outer rows near the hedgerows (fig 4.151). This was expected as the runoff water from the alleys collects and infiltrates beneath

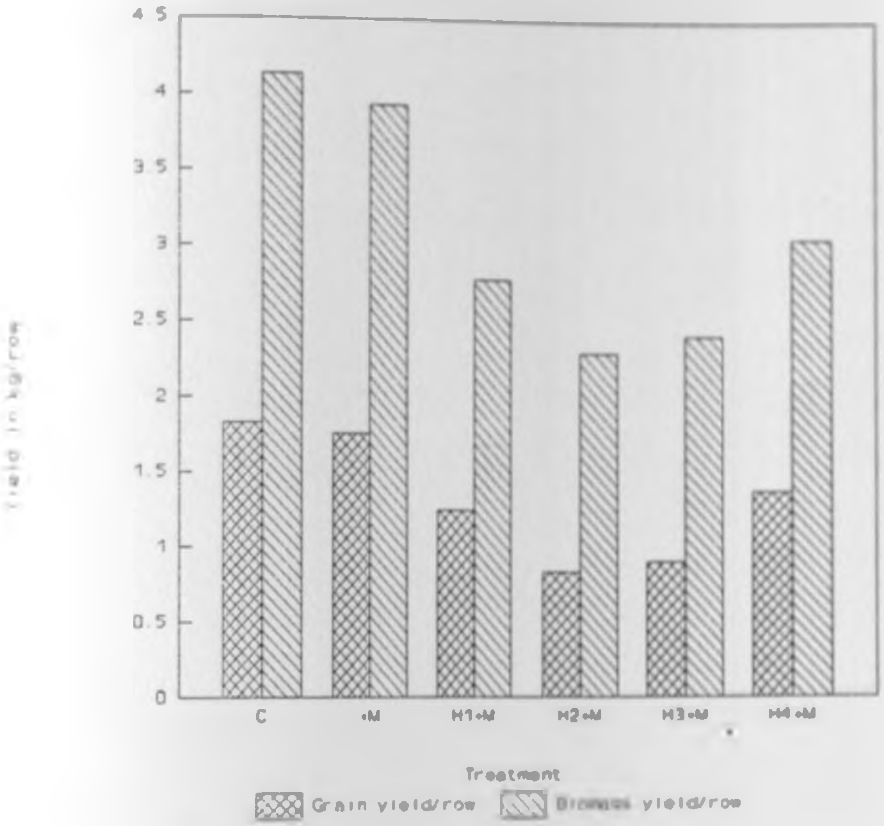


Fig.4.151 Comparison of maize grain/biomass yield per row in C, +M and H+M, for the long rains of 1994.

the hedgerow, resulting in more moisture and some soil deposition beneath the alley which in turn benefits the maize rows close to it. The yield depression in the middle rows may also have been due to increased *Senna*/maize competition for nutrients, and moisture and perhaps a temperature component is somewhere involved (Mungai, 1992). The yield depression in the middle rows was also found in the H-M plot (fig 4.152), obviously for similar reasons as explained for the H+M plot, all in line with the results in 1993.

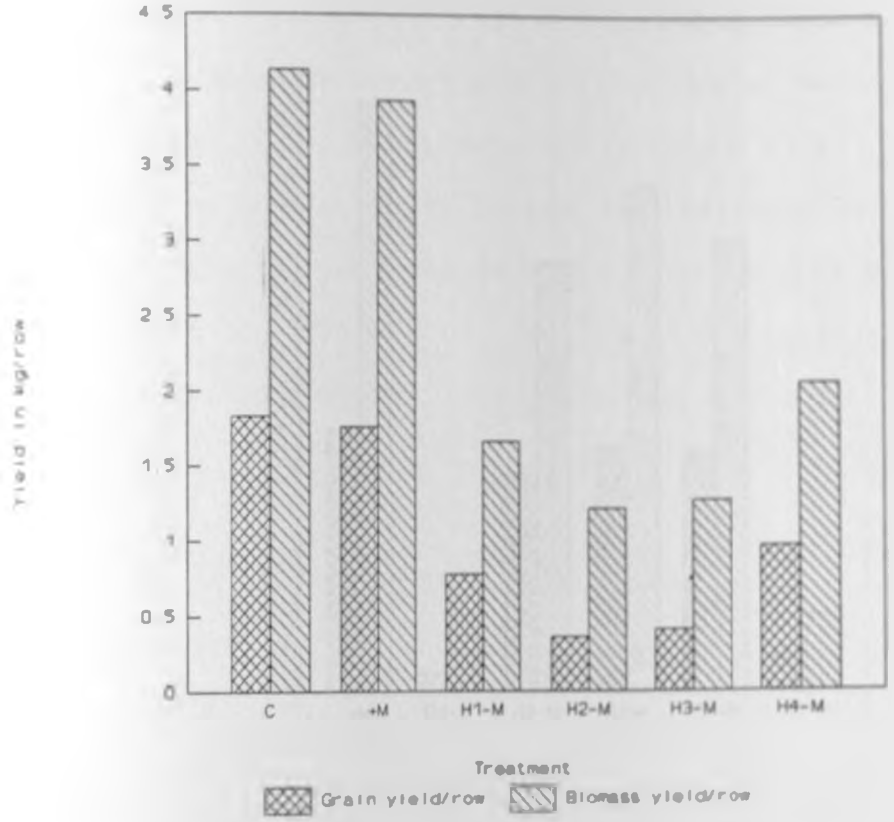


Fig.4.152. Comparison of maize grain/biomass yield per row in C, +M and H-M plots, for the long rains of 1994.

The yields per row were however appreciably lower in the H-M plot than in the H+M plot (fig.4.151 and 4.152) due to the effects of the mulching, conserving more water and possibly due to some release of nutrients by the decomposing mulch to benefit the maize crop.

In the G-M plot, however, the yield depression was at the rows close to the grass strip barrier (fig. 4.153), while the rows in

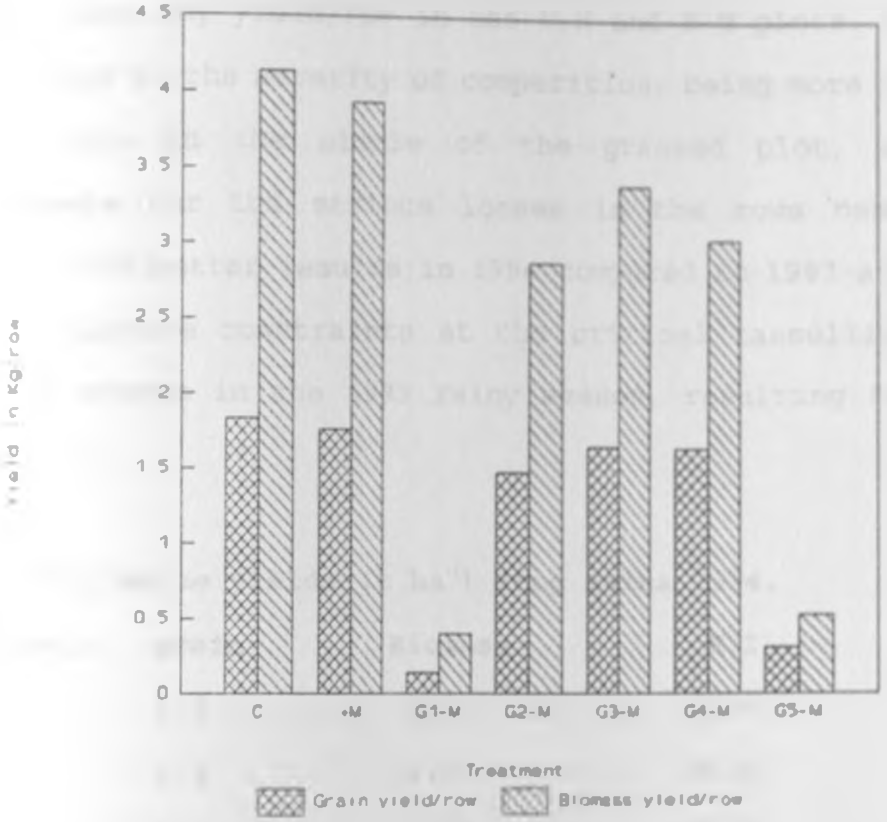


Fig.4.153. Comparison of maize grain/biomass yield per row in C, +M and G-M plots, for the long rains of 1994.

the middle of the grass alley had rather high yields. This was because of severe competition for moisture and nutrients between the lateral grass roots and the maize roots, which were apparently appreciably less in the middle maize rows. Additionally, the grass shade may also have affected the yields through competition for light. The yields per row in the middle rows of maize in the G-M plot were higher than the yields per row in at least the middle rows of the H+M plot and even much more in the H-M plot respectively. Grain yields in the middle of the grass plots are higher than any yield/row in the H+M and H-M plots. This must be attributed to the severity of competition, being more in the hedged plots than in the middle of the grassed plot, and it does compensate for the serious losses in the rows near the grass strips. The better results in 1994 compared to 1993 are due to the major moisture constraints at the critical tasselling and grain filling stages in the 1993 rainy season, resulting from very low rainfall.

Table 40. Maize yields (t ha^{-1}) long rains 1994.

Treatment	grain	Biomass	H.I
C	1.8	4.0	45.4
+M	1.8	3.8	45.8
H+M	1.1	2.6	42.8
H-M	0.63	1.4	44.1
G-M	0.79	1.6	49.4
avg	1.22	2.7	45.5
Std(±)	0.49	1.09	2.2
cv (%)	40.16	40.5	4.8

Table 40 shows the mean grain/biomass yields in t ha^{-1} for all the five plots. The results show that the C and +M plots had higher yields than the other plots and these decreased in the order C = +M >H+M >G-M = H-M respectively. Compared to 1993, particularly H+M has a very different position and all yields are very much higher.

This must be due to the higher amounts of rainfall (242.4 mm) in 1994 than the low amounts (108.5 mm) in 1993. The high H+M results must have been due to the mulch effects resulting in more moisture conserved than in the H-M and G-M plots. The H.I as shown in table 40 ranges from 43 to 49.5 (46 ± 7.5%) in all plots. These values are much higher than the values for 1993 and this was again due to the higher and well distributed 1994 rainfall, while 1993 had serious moisture stress which consequently affected grain yields and H.I.

4.10.5 Cowpea yield results, short rains 94/95.

Due to again *Fusarium* and *Pseudomonas* disease attacks on the cowpea during the season, the yield results were obtained from carefully selected sampling areas, where the plant populations remained uniform during the season and where complete cowpea rows were dominant. This minimises disease influences on the reported yield results. These population losses in each plot were quantified as a percentage of the total original population as 43, 56, 44, 42 and 58 % in the C, +M, H+M, H-M and G-M plots respectively. They therefore must have influenced erosion figures, which must have been relatively higher in +M and G-M plots. This is confirmed by fig. (4.9). The results in figure (4.154) show that the mean grain and biomass yield in kg per row, on average of comparable order of magnitude as in 93/94, were slightly higher in the C than in the +M plot just opposite from the results in 93/94, particularly due to a bit less than 25% higher C yields. The reason

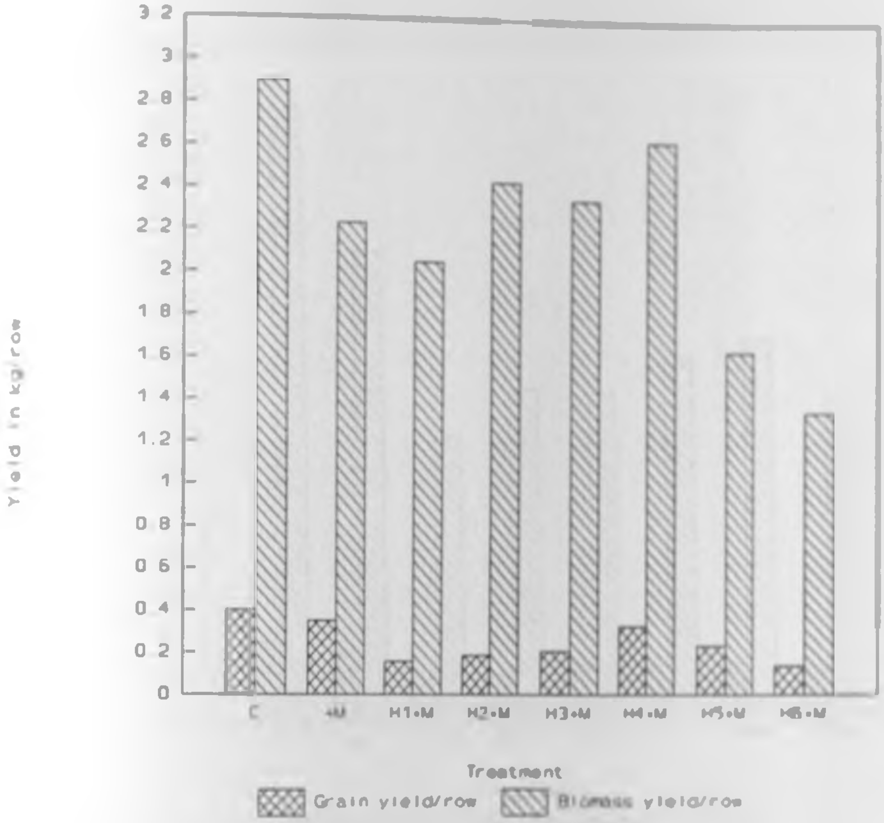


Fig.4.154. Comparison of cowpea grain and biomass yield in C, +M and H+M plots, for the short rains of 94/95.

for this may have been a rather slower germination noted in the +M plot due to the mulch, for reasons indicated below. Gapping was done to make the plant population uniform. The mean yields per row in the two rows closest to the hedges in the H+M and H-M plots were (most often slightly) depressed. In the H+M this was true for one more row (figs. 4.154 and 4.155). For the rows of H-M the depressions were less significant and this may have had the same reasons as the somewhat depressed yield in the +M plot, depressing

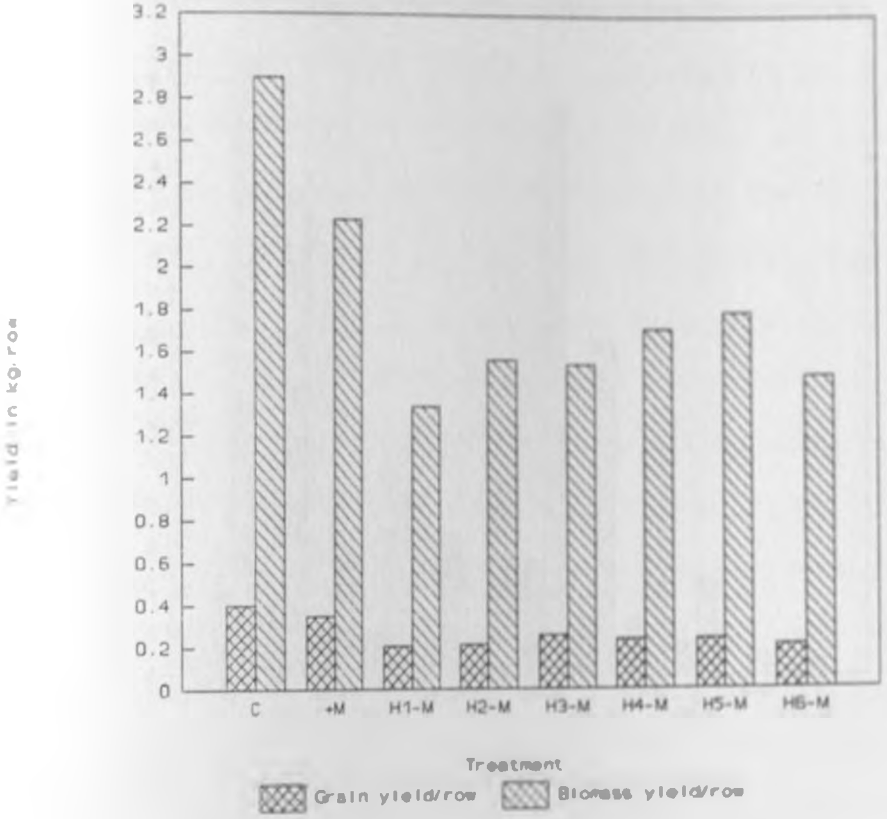


Fig.4.155. Comparison of cowpea grain/biomass yield in C, +M and H-M plots, for the short rains of 1994/95.

also H+M yields. The existing differences must further have been due to shading and perhaps some moisture concentration by the barrier hedgerows which, as earlier found, do not seem to sufficiently favour the growth of cowpea plants near them.

In the G-M plot, however, the yield depression was particularly at the rows near the grass strip, while peak and near peak yields per row were in only two middle rows (fig. 4.156). This was, for reasons earlier stated.

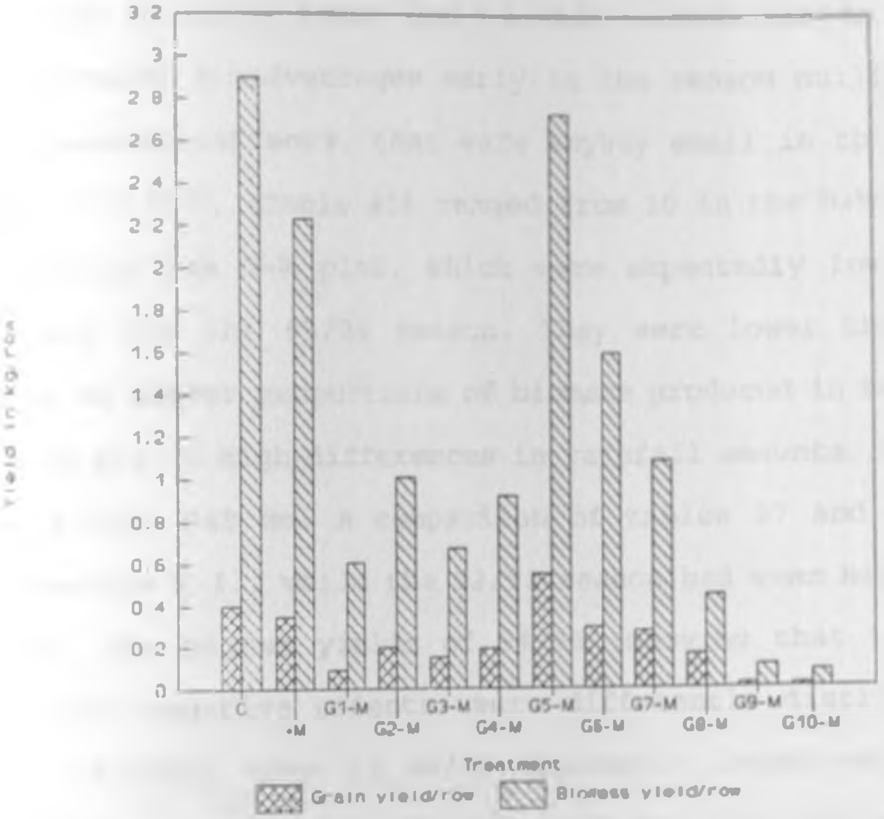


Fig.4.156. Comparison of cowpea grain/biomass yield per row in C, +M and G-M plots for the short rains of 1994/95.

The mean yields in kg per hectare, in Table 41, confirms that the C plot had slightly (less than 1 std) higher yields than the +M plot, most likely due to less light at germination and because of some lowered near soil surface temperatures and some early inefficient rain entrapment (see fig. 4.5), confirmed by the soil moisture figures 4.70 and 4.71, due to mulch, which may have negatively affected the germinating cowpea seeds at the beginning of the season. Though the yields were lower in the H+M and H-M plots compared to C and +M plots, the H-M plot had similar grain yields but slightly lower (half a std) biomass yields than H+M. In general mulch disadvantages early in the season nullified any later possible effects, that were anyway small in this good rainy season. The H.I. (Table 41) ranged from 10 in the H+M plot to less than 19 for the G-M plot, which were expectedly low, as earlier explained for the 93/94 season. They were lower than in 93/94, because of higher proportions of biomass produced in 94/95 compared to 93/94 due to high differences in rainfall amounts, that in 94/95 being a high 549 mm. A comparison of tables 37 and 41 shows the same average H.I., while the 92/93 season had even higher rainfall (662mm). The higher yields of 94/95 (showing that too much rain indeed has negative effects) were differently distributed. Still higher rainfall than in 94/95 apparently negatively influenced grain yields, and H.I in C, H+M, G-M and also grain and biomass yields in +M but positively influenced biomass production in C, grain yield and H.I in H+M and a bit everything in H-M. Mutifactorial effects are difficult to explain more precisely than we have done here.

Table 41. Cowpea yields (t ha^{-1}) 94/95 season.

	Grain	Biomass	H.I
C	0.69	4.8	13.9
+M	0.60	3.8	15.8
H+M	0.31	3.1	10.0
H-M	0.34	2.6	12.9
G-M	0.39	2.1	18.6
avg	0.47	3.3	14.2
Std	0.15	0.99	2.8
cv (%)	32	30	20

4.10.6 Maize yield results long rains, 1995.

The results of mean grain/biomass yields per row in (figs. 4. 157 and 4.158) show that there were similar high grain/biomass yields in the C and +M plots, while the yields per row in the H+M and H-M plots were lower overall and also again depressed in the middle rows, for reasons explained in the maize yields/row for the long rains 1994. These yields were however higher in the H+M plot than in the H-M plot, as in 1994, possibly because of moisture conservation and release of nutrients by the decomposing mulch, although this nutrient effect did not work at the +M compared to the C plot, suggesting that the hedge effect is the more important one.

In this best yields season for maize for all plots, the yields per row in hedgerow intercropping were again lower than in the C and +M

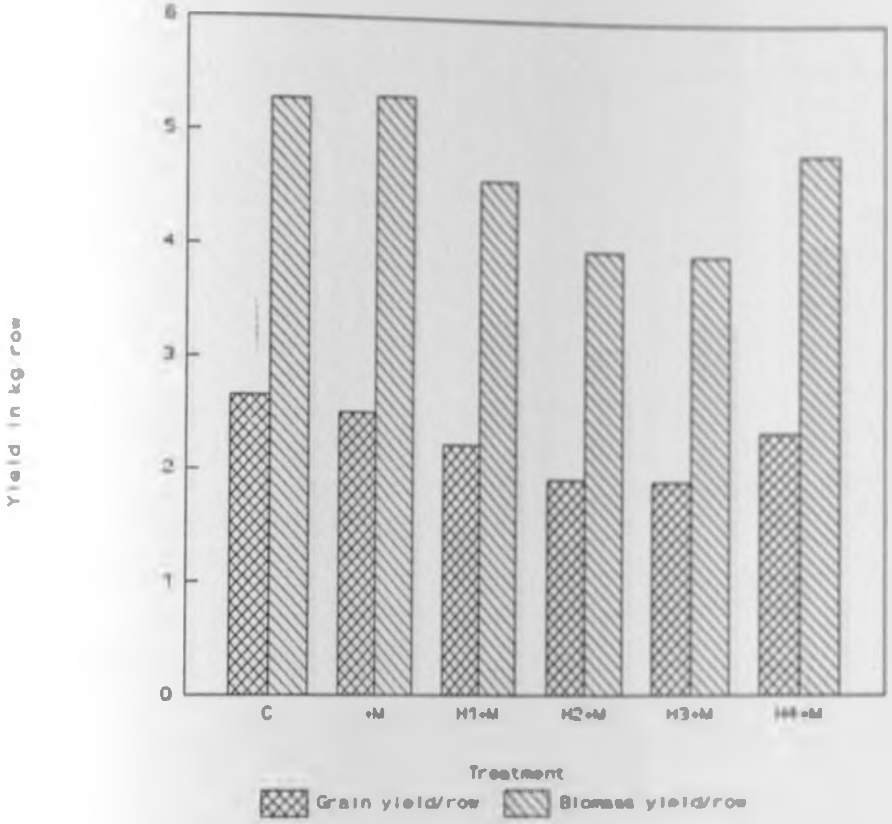


Fig.4.157. Comparison of maize grain/biomass yield in C, +M and H+M plots, for the long rains of 1995.

plots, again due to the absence of competition in the C and +M plots, compared to H-M and H+M plot. As found in the G-M plots in the 1994 maize crop, there were again serious yield depressions within the overall t ha^{-1} yield in the outer rows of maize next to the grass strips, and the best yields per row were still lower than those in C and +M plots, where there was sole maize, although the very middle row came close.

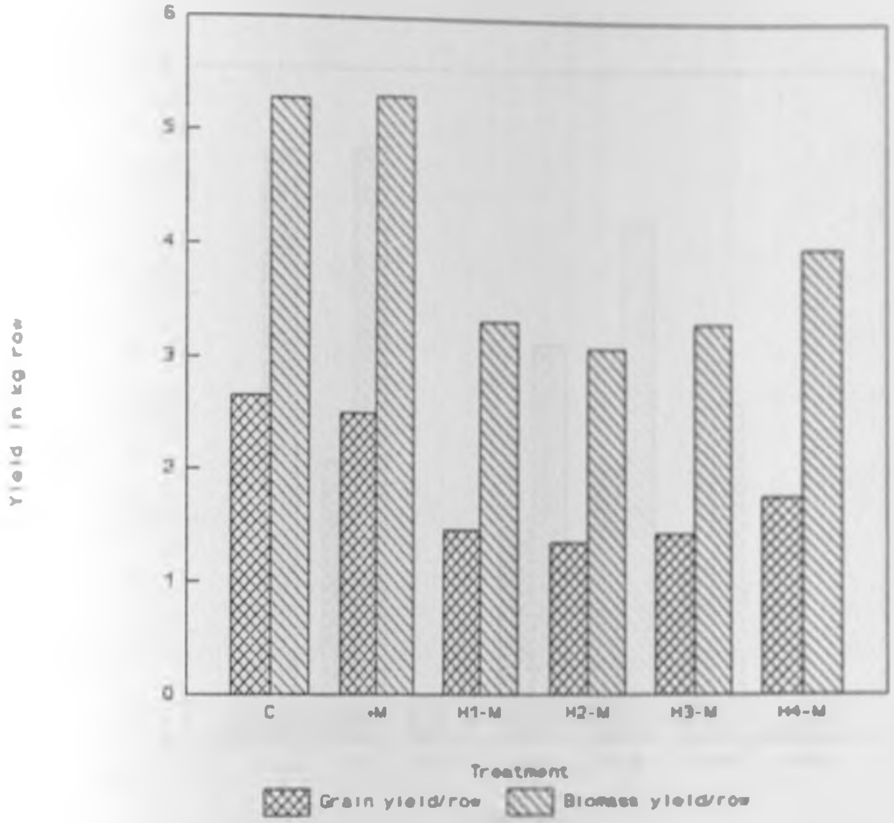


Fig.4.158. Comparison of maize/biomass yield per row in C, +M and H-M plots, for the long rains of 1995.

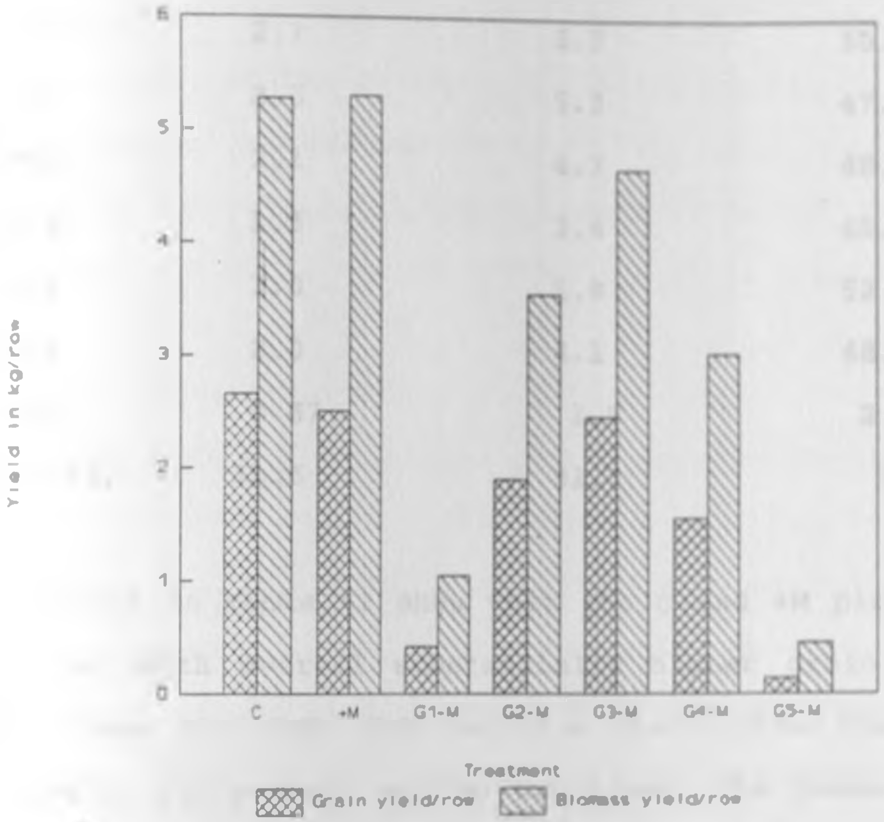


Fig.4.159. Comparison of maize/biomass yield per row in C, +M and G-M plots, for the long rains of 1995.

Table 42. Maize yield (t ha^{-1}) long rains 1995.

Treatment	Grain	Biomass	H.I
C	2.7	5.3	50.6
+M	2.5	5.3	47.3
H+M	2.1	4.3	48.7
H-M	1.5	3.4	43.9
G-M	1.0	1.9	52.1
avg	2.0	4.1	48.5
Std	0.67	1.3	2.6
cv (%)	31.6	31.3	5.5

The results in Table 42 show that the C and +M plots with sole maize had both overall substantially higher grain and biomass yields than the H+M, H-M and G-M plots with tree and grass components, for reasons earlier explained. The yields per hectare were lower in the H-M plot and lowest in the G-M plot, where there was no mulch. In fact, the grain yield in the G-M plot was only about half that in the H+M plot.

The H.I. ranged from 44 in the H-M plot to 52 in the G-M plot, with an overall mean of 48.5 % (with a range of ± 8%), which appears very alright for maize, of the same order of magnitude as in 1994 and much higher than in 1993, because the season was within the average rainfall (285 mm), appreciably more than in 1993, which favoured maize growth and development and hence grain yield, also with respect to the somewhat lower rainfall season of 1994 (242mm).

4.10.7. Summarising discussion.

This discussion on crop yields will further compare the three short rainy seasons of cowpeas and the three long rainy seasons of maize. The yields per treatment over the seasons can be read from the review tables that follow for cowpea and maize separately.

4.10.7.(a) Cowpea yields.

As regards cowpea grain yields per hectare in review (Table 43) below, variations were not only found within the treatments but also from season to season, particularly with respect to the first season relative to the other two. This was due to rainfall variations from season to season and cowpea varietal differences between the first and last two cowpea seasons. Except for the wet 94/95, where rainfall was too abundant early in the season and where there was a yield decrease of 100 kg ha^{-1} between C and +M plots, due to mulch disadvantages at germination and less than optimal mulch rate (1.2 t ha^{-1}) advantages throughout the season, the presence of mulch in +M as protective cover on sloping lands gives some cowpea grain yield increase compared to the C plot (Table 43). Although for 93/94 and 94/95 the grain yields were similar in the H+M and H-M plots, the mulch appears to give grain yield benefits in H+M compared to H-M in 92/93 and particularly G-M in 92/93 and 93/94 but not in 94/95. Except for the 92/93 season when C and +M grain yields were lower than in the other seasons, due to the serious wetness throughout the season and perhaps differences in variety, the C and +M plots have clear grain and biomass yield advantages over the H+M, H-M and G-M plots (in 93/94 and 94/95 seasons), as seen in table 43 below.

Table 43. Comparison of cowpea yields (t ha^{-1}) over the seasons

	92/93		93/94		94/95	
	grain	biomass	grain	biomass	grain	biomass
C	0.32	3.9	0.56	2.9	0.69	4.8
+M	0.43	2.3	0.65	3.4	0.60	3.8
H+M	0.46	3.2	0.39	1.4	0.31	3.1
H-M	0.39	2.2	0.36	1.1	0.34	2.6
G-M	0.30	2.1	0.30	1.3	0.39	2.1

There was a clear increase in grain yields in C, and a clear decrease in grain yields for H+M over the years, while there was an increase in grain yields only in 94/95 in G-M, which effects were mostly due to negative and beneficial trends in rainfall and its distribution and their effects (Table 43).

These results show that competition for growth resources such as water, light and nutrients by the *Senna* trees and grass with the cowpea plants were responsible for reduced yields in the hedgerow intercropped plots. Surprisingly, the cowpea yield in the C plot remained high with advancing seasons, a too wet too disastrous nutrient leaching and runoff in 92/93 apart, and also the yields only seriously decreased for H+M for reasons pertaining to hedge behaviour, even without the use of fertilizers on these steep slopes. This can for 93/94 and 94/95 partly be associated to carry over effects of the fixation of nitrogen by the cowpea from the atmosphere into the soil through symbiosis with rhizobia. The cowpea uses some of this fixed nitrogen and leaves some in the soil for the succeeding crop (Shakoor et al, 1984).

The overall grain yields in all plots were however still low compared to the yields from optimal conditions at KARI'S Dry Land Research Centre, Katumani, because the cowpea used had been bred specifically for economic use (here food) of both grain and leaf yields. From Table 43, it is shown that except for the +M plot, where the biomass yield increase was rather small, there was a large increase in biomass yield in the other treatments between 93/94 and 94/95 seasons. This was partly due to the higher rainfall amounts in the 94/95 compared to the 93/94 season which favoured this higher biomass formation. At the same time, except for the +M plot where there was a decrease in biomass yield in 92/93 due to negative mulch quantities and conditions, there was a clear cut lowest biomass yield in the 93/94 season. This can be attributed to the lower rains (288.5 mm) in this season. Except for the 92/93 season, when biomass yield in the +M plot was low (2.3 t ha^{-1}), for the reasons given, the biomass yields were generally lower in the Senna/cowpea and grass/cowpea treatments than in the C and +M plots (Table 43). This is attributed to the absence of competition for light, water and nutrients in these latter plots. The appreciably higher quantities of biomass produced over the seasons are fitting the feeding habits of the people in eastern Kenya of eating the leafy part of cowpea as a vegetable and this explains why multi-purpose cowpea varieties are popular with the farmers in this region of Kenya.

Cowpea grain yields under experimental conditions at Katumani, Machakos, on gently sloping land with similar soils, average rainfall and using fertilizers show values of more than 1.5 and 1.3 t ha^{-1} per season for the two commonly bred local varieties K80 and M66 respectively (Shakoor et al. 1984). Still higher grain yields, of up to almost 2.5 t ha^{-1}, were recorded at optimal field conditions in Australia (Ikombo, 1989).

The harvest index was low for cowpea during the three seasons and this must be due to the low H.I. found in many grain legumes (Jain, 1975), particularly in this case where the legume is used as both grain and leaf vegetable. In normal circumstances, where grain yield is the main wanted part of total above ground biomass yield, H.I. can be as high as 50%, when the cowpea breeder goes for high yielding grain cowpea varieties.

Cowpea is one of the main three main grain legumes used in the Eastern part of Kenya, and even though on-farm lower yields, of 0.35-0.45 t ha^{-1}, are obtained in East Africa under low management and 0.7-0.9 t ha^{-1} under good husbandry (Acland, 1971), there is a potential for its use in alley cropping (hedgerow intercropping), especially given the advantages of the build up of terraces of good soil near hedges and the provision of mulch for erosion control in the farmers' fields. A main problem to be solved is the susceptibility of cowpea for diseases and the strong competition with the grass or the somewhat less strong competition with hedges for growth resources. Of course the latter problems are compensated for if the hedges would also be economically sufficiently beneficial.

4.10.7.(b). Maize yields.

As shown from Table 44 in a maize yields review, the mean grain yields in tons per ha, of <0.50, for the long rainy season 1993 were extremely low, due to a very low rainfall of 108.5 mm. The study also shows that there was an increase in grain yields in all the plots (Table 44) with increase in rainfall amount in 1994 (242.4 mm) and even more in 1995 (285 mm).

Table 44. **Comparison of maize yields (t ha^{-1}) over the seasons.**

	1993		1994		1995	
	grain	biomass	grain	biomass	grain	biomass
C	0.48	2.5	1.8	4.0	2.7	5.3
+M	0.32	1.7	1.8	3.8	2.5	5.3
H+M	0.03	0.48	1.1	2.6	2.1	4.3
H-M	0.04	0.44	0.63	1.4	1.5	3.4
G-M	0.12	0.63	0.79	1.6	1.0	1.9

There were yield variations both among treatments as well as from season to season, 1995 being the best. These variations between seasons were due to rainfall and its distribution, and the variations between treatments were due to competition for water, nutrient and light between the *Senna* trees/grass and maize. These competition effects were also abundantly shown in the low yields of 1993, where there was about 10 times more grain yield in the non-agroforestry compared to agroforestry plots (Table 44).

The mean grain yields for the 1995 season of the C and +M plots were over 2.5 t ha^{-1}. This was one and a half times and more than double the average yields in the H-M and G-M plots respectively and about 25% higher than in the H+M plot. In 1994, the lower mean grain yields (about 1.8 t ha^{-1}) in C and +M plots were more than double the mean yields in H-M and G-M plots (about 0.7 t ha^{-1}) but 60% more than that in the H+M plot (Table 44). This was for the case of the hedgerows clearly due to the effects of the combination of hedge and mulch in the release of nutrients for the maize crop as well as in better moisture and soil conservation. In fact, the presence of mulch in H+M in 1994 resulted in an increase of 470 kg and 310 kg of grain yield compared to H-M and G-M plots respectively. In 1995, there was an increase of 600 kg and more than 1100 kg in the H+M plot compared to H-M and G-M plots respectively. Surprisingly, the mean yields in the C and +M plots were rather high, especially when taking into account that the plots have been under cultivation for a long time without erosion control measures (other than mulch for +M) and without the use of fertilizers. A reason for this could be the residual N fixed and left in the soil by the cowpea in rotation with maize. The presence of hedgerows and grass strips seems to lower grain yields because of competition by the *Senna* trees and grass with maize for water, light, and nutrients.

In the 1994 season, the amount of runoff reduction in water as well as in soil loss was appreciably higher in H+M than in the H-M plot. This additional soil and moisture conservation in the H+M plot, because of the hedge and mulch combination, may reduce the crop/tree moisture competition, resulting in more yield compared to the H-M plot. The case for 1993 is rather different, because in both H+M and H-M cases, there was not enough moisture to be conserved (fig 4.2). This meant that the presence of mulch had very little effect on moisture conservation.

The grain yields of Katumani composite maize under optimal conditions in Machakos district, under adequate rainfall, have been shown as being more than 3 t ha^{-1}, becoming about 0.65 t ha^{-1} for drought years on average (Nadar and Faught 1984a; 1984b). This is in contrast to the yields in farmers' fields which range from 0.25-0.75 t ha^{-1}, with an average low plant population of 20,000 plants ha^{-1} (Nadar, 1984). The present maize yield study shows that when mulch was added to the hedgerow barrier (H+M), as an additional protective cover on the steep slopes, the grain yields were close to 65 % and 40 % more compared to the H-M plot for both 1994 and 1995 maize seasons respectively (Table 44). At the same time, the presence of mulch as protective cover in the H+M plot also more than doubled and nearly doubled the grain yields compared to the G-M plot in 1994 and 1995 respectively. As for the C and +M plot, there were only appreciable yield differences between the two plots in 1993 an extremely low rainfall year with mulch working the wrong way through rainfall interception. There may however be yield differences in the long run when the effects of soil erosion above the T value are most likely to be felt in the C plot by yield reduction.

4.11. Kakuyuni catchment on-farm surveys results and discussions.

These results cover the short rains 93/94, the short rains 94/95 and the long rains 1995. The long rains of 1994 were a complete failure and are not discussed in this study, for no rainfall records were kept, as noted, at Kakuyuni site. Also no data on rainfall were collected during the 93/94 rains.

4.11.1. Rainfall distribution.

An idea of rainfall pattern in the catchment was obtained from only one rain gauge at Kakuyuni. The rainfall distribution in time for the 94/95 short and 1995 long rains seasons are shown in figures 4.160 and 4.161 respectively. The total amount of rainfall for 94/95 season was 378 mm, which is above average for the semi-arid areas of Kenya.

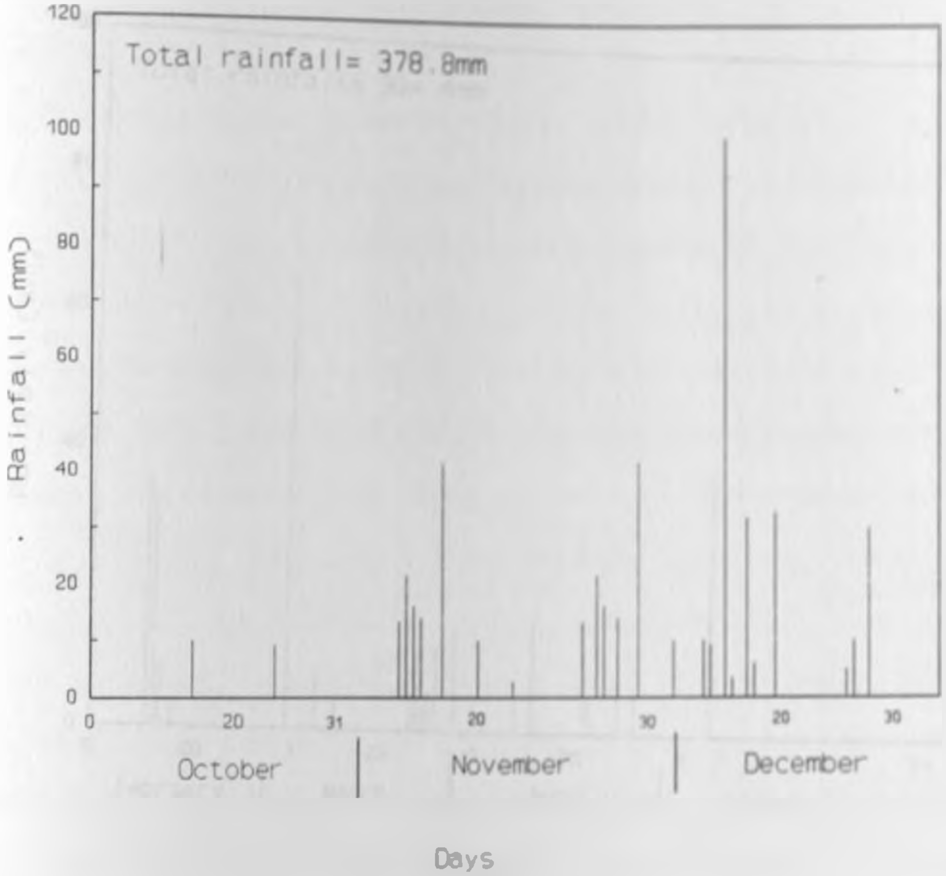


Fig.4.160. Short rains distribution 1994/95, Kakuyuni catchment.

The next (1995) long rains (304.4 mm) because of rainfall distribution nearly resulted in a crop failure, as the rains started off season, in February, continued into March (with the day of most rainfall already on 3/3), when the long rains normally come, and disappeared all together in May. The rain was so poorly distributed (46% fell on only three days) that maize suffered heavy losses. This rainfall could, however, support the more drought tolerant crops such as sorghums and millets, as shown in table 47.

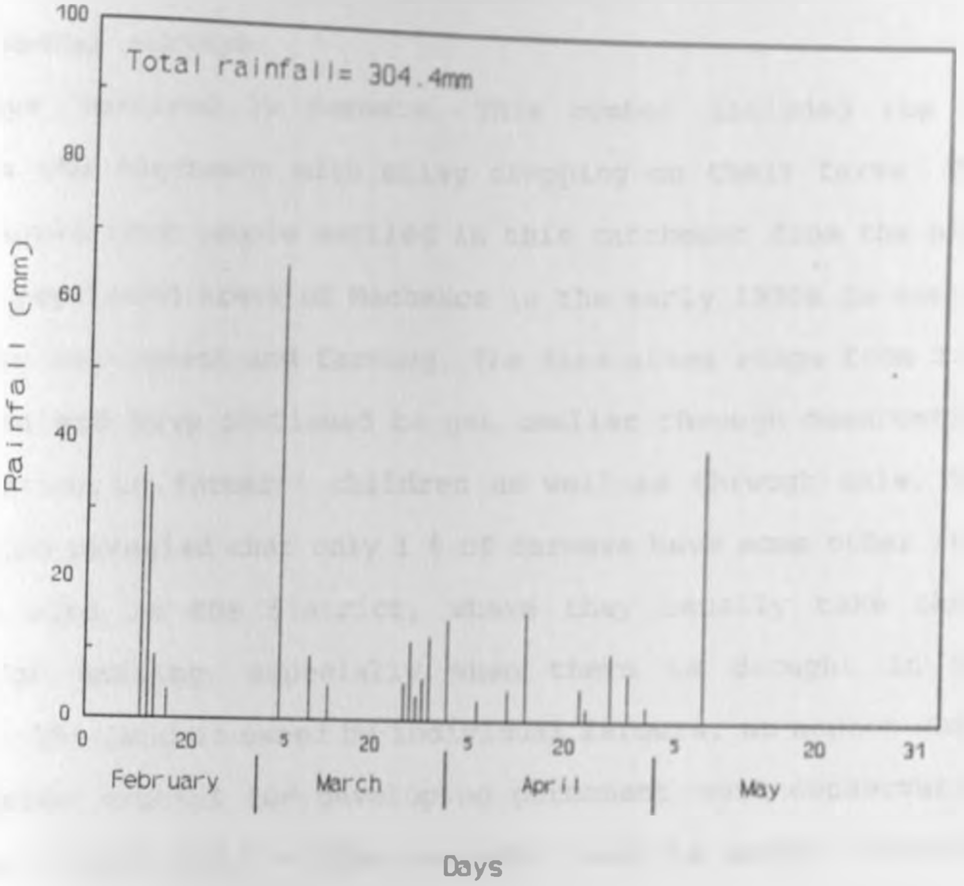


Fig.4.161. Long rains distribution 1995. Kakuyuni catchment.

A few farmers here planted in February, because of early rains, before the actual long rains started in March. Their strategy, from their experience, was to use some soil moisture for the short duration crops, like sorghums and millets, in February. When a risky season then started in March, these crops would have at least enough moisture, combined with their drought escaping (short) maturing mechanism, to reach harvesting.

4.11.2. General surveys.

The surveys involved 30 farmers. This number included the 10 farmers in the catchment with alley cropping on their farms. The surveys showed that people settled in this catchment from the high potential populated areas of Machakos in the early 1950s in search of land for settlement and farming. The farm sizes range from 2 to 50 hectares and have continued to get smaller through demarcation and allocation to farmers' children as well as through sale. The surveys also revealed that only 1 % of farmers have some other land somewhere else in the district, where they usually take their animals for grazing, especially when there is drought in the catchment. The land is owned by individual farmers, an aspect which is considered crucial for developing permanent soil conservation structures. About half of the farmers' land is under livestock production and the other half under crop production.

The topography of the catchment ranges from rolling (<5% slope), via moderately sloping land (6-10%) to steep slopes (>10%). Although soil erosion had declined over the years (1930s to 1990s) through increased soil erosion measures (Tiffen et al, 1994), our surveys showed that new cultivations were often being carried out on steep slopes without carrying out erosion control measures, despite the knowledge for soil conservation. The reason for doing this could be that the steep sloping lands are normally fertile, when newly opened for cultivation for up to about 3-4 years before crop yields start declining. The sign of declining yields will then make it necessary for the farmers to construct terraces for erosion control to reduce the declining yields.

4.11.3. General agricultural practices in Kakuyuni catchment.

The farm surveys conducted in the catchment revealed several agricultural practices. In the first place, farmers practise mixed farming, in which crops are grown and livestock is kept by the farmer on the same farm. The reason given by the farmers for this mixed farming practice is that of minimising risks in the event of disease outbreak, such as of foot and mouth disease in cattle and charcoal rot in millets. Intercropping also helps in reducing chances of crop failure when short maturing crops are included in the cropping systems. At the same time, this system also provides the farmers with a balanced food nutritionally, when legumes are mixed with cereals. The farm animals also provide the farmer with a source of income when they are sold or hired for ploughing, provide manure for sale or use on the farm to improve on soil fertility and they help in land preparation, sowing and even weeding. The crops, on the other hand, provide the farmers with food for their subsistence needs as well as cash whenever there is surplus for sale. The animals kept by the farmers include cattle, goats, sheep and poultry. The main crops grown by the farmer include maize, beans, cowpeas, pigeon peas, sorghums, bulrush millets, finger millets, sweet potatoes and cassava. They also grow fruit trees such as mangoes, citrus fruit, pawpaws, bananas and guavas.

The surveys showed that over 80% of the farms surveyed had mixed cropping (growing two or more crops simultaneously, with no distinct row arrangement) and intercropping practices (the growing of two or more crops simultaneously where one or more crops are planted in a row (Palaniappan, 1988). The rest of the farmers practised monocropping or had crop rotations. The farmers' reasons for these cropping practices were that while intercropping may enhance land productivity compared to monocropping (e.g Baldy and Stigter, 1997), it also reduces the risk of crop failure as the intercrops mature at different times. This is for example in agreement with the findings of Bryan and Pera (1988) that intercropping increases availability of N when a legume is one of the intercrops. They also advance the reason that intercropping may reduce and save the labour on weeding as opposed to monocropping. In cases where creeping crops like cowpeas and sweet potatoes are in intercrops, there is a possibility of reduction of soil erosion through interception of rainfall energy as well as control of runoff.

Crop rotations, farmers argue, reduce the incidences of soil borne diseases which occur when crops are continuously grown in one plot for a long time, because rotations break this continuity and the disease may disappear. It was also argued that when legumes are included in rotations they help in fixing atmospheric nitrogen in association with rhizobia, which improve soil fertility and enhance the yields of the proceeding crop. About 10% of the farmers use commercial fertilizers and these happen to be well off farmers. The main sources of farmers' income included sale of livestock, charcoal, wood for carvings and building poles, sale of sand from riverbeds, surplus millets, sorghums, cowpeas, beans, pigeon peas and fruits. There are also off-farm sources of income from those employed off-farm in the family.

It was also established from the surveys that rainfall was insufficient and poorly distributed over the years resulting in frequent crop failures to the point of having the government to intervene by famine reliefs. Experience shows that one out of every four years there are crop failures resulting from inadequate soil moisture from insufficient rainfall and food shortages are solved through the provision of food by the government. From the history of rainfall over many years (1894-1990) in the district, it was identified that droughts characteristically occur in runs of two or more seasons, and this amplifies their social, economic and environmental consequences (Tiffen et al, 1994; Mutiso 1991). What is very clear is that only a small proportion of the district can expect more than 250 mm in either the long or short season in six or more years out of ten (Jaetzzold and Schmidt, 1983), which is the barest minimum for producing a crop of maize, assuming a satisfactory distribution within the season. There has been a 70-100% versus 0-55% probability chance of success in growing maize in both the long rains and short rains in eastern Kenya, when the maize was planted at the onset and late after rains respectively (Stewart and Kashasha, 1984). This stresses the importance of timeliness in planting in eastern Kenya.

4.11.4. Traditional techniques of soil and water conservation.

Soil erosion was also identified as one of the serious problems facing farmers in the catchment. Farmers have used traditional soil and water management techniques to combat it. These traditional techniques were:

(a) "Fanya-juu" terraces which were the main structural erosion control practices but found expensive to construct. The terrace embankments were stabilised by growing grasses on them, to strengthen them and to minimise repair costs. Because of the communal "Myethya groups" farmers have made use of them to effect terracing despite the high labour costs.

(b) Stone terraces found with some farmers, where stones are collected from the farm and aligned along the contour so that bench terraces can naturally form with time along these stones on the contour, without incurring extra cost of terrace construction. Though effective in erosion control, they require labour for stone collecting and alignment (on the contour) but are cheaper than the

"Fanya juu" terraces.

(c) Trashlines, where crop residues from harvest are collected and aligned along the contour so that they can act as a barrier to breakdown the length of the slope, trap runoff and hence reduce soil erosion. They have the disadvantage that they reduce trash availability for livestock, that use these crop residues as feed during the dry period.

(d) Grass strips, which are established along the contour, with the purpose of forming earthen banks with time for the control of runoff water.

(e) Mulching, where crop residues were left on the farm after harvest so that they can decompose with time to release plant nutrients for the next crop as well as acting as rainfall interceptors, reducing the risk of soil removal and transportation.

(f) Cut-off ditches, which are normally constructed at the top of farms to intercept water, entering it from outside the farm and causing erosion through runoff water, by diverting it in a non-erosive manner into the natural water ways.

(g) Water harvesting techniques. This involves diverting runoff water from the roads into the farms in such a way that it can be stored in the ditches created during "Fanya juu" terrace construction, for especially fruit growing such as bananas, oranges and pawpaws.

(h) Ploughing along the contour. This is a conservation practice which has the advantage of directing runoff water to move along the contour and allowing it time for infiltration, without concentrating it at points where it can cause erosion.

(i) Early land preparation and early planting. Due to the limited amount of rainfall in the catchment, ploughing early ensures that the soil has time to weather and become well aerated, and remains cloddy to facilitate more water infiltration, for enhanced crop production. It also allows time for other farm operations such as planting and weeding.

(j) Scattered trees, which diminish water and wind erosion. Traditionally trees are placed along the homesteads, not only for shade, wood and fuel purposes but also for protection of the homestead against wind erosion damage by strong winds. Some of the trees found in the catchment were *Acacia albida*, *Acacia seyal*, *Acacia tortilis*, *Commifora ssp*, *Balanitis aegyptiaca* and *Terminalia spp.*, well known for the provision of wood used in wood carvings.

In 60% of the farms surveyed there were scattered trees grown in the grazing areas, mainly for the purposes of shade to the animals but also for provision of charcoal to the household or for sale.

There were also other soil and water conservation techniques found on the grazing lands. These included:
(i) A series of runoff retention ditches constructed along the contour to cut down the slope length and to trap water and allow runoff more time to infiltrate reducing, the chances of soil erosion. These are stabilised by growing grasses inside them so that they can last longer and minimise repair costs. (ii) Constructing interlocking semi circular micro catchments using wooden branches or stones, which trap runoff and soil sediments and attract grasses and other forms of vegetation in them and establish a protective cover in denuded areas. (iii) Check dams, for which pieces of wood and other small tree branches have been tied together and placed in gullied areas to trap both water and sediment and eventually attract vegetation growth, which finally stabilises the gulley walls and checks soil erosion. (iv) Tree establishment on denuded areas with the purpose of putting these denuded areas back original cover. These included *Acacia albida*, *A. tortilis*, *A. seyal* and *A. prosopis*.

The DARP project introduced alley cropping to the farmers, primarily to assist in soil erosion control, fertility improvement via mulching and provision of fodder and other production on cropped land. It was done using multi-purpose trees/shrubs, mainly *Leucaena leucocephala*, *Gliricidia sepium* and *Senna siamea*. More farmers appear keen to have these multipurpose trees for fodder, mulch and erosion control. The surveys showed that alley cropping was fixed at 4 m and that this was introduced while the farmers got improved seeds and tree seedlings as incentives. Farmers would not plant the AF plots until seeds had been brought to them, which caused delays in germination and planting and hence other farm activities. The farmer would prefer to weed other fields before weeding the AF, pointing to the fact that the plot "belonged to the researcher".

4.11.5. Grain and biomass yields.

The results in table 45 for the 93/94 short rains season show that the "Fanya juu" terraces had somewhat better grain/biomass yield compared to the agroforestry (AF) and grass stripped plots, with the exception of grain for Gliricidia.

Table 45. On-farm maize yield (t ha^{-1}) 93/94.

Control Structure	Grain yield	Std (±)	Biomass yield	Std (±)
Sole maize	1.2	>0.05	2.50	<0.05
Senna/maize	1.05	0.1	2.2	0.1
Leucaena/maize	1.0	>0.05	2.1	0.05
Gliricidia/maize	1.1	0.1	2.2	0.1
"Fanya juu"/maize	1.15	0.05	2.55	>0.05
Stone terrace	1.25	>0.05	2.35	<0.05
Grass strip/maize	1.0	>0.05	2.3	0.10
Trashline/maize	1.2	0.15	2.15	<0.05

N.B. 4 plots were used to determine yields.

This must be due to the competition of the tree canopies, for light, nutrients and moisture, with the maize canopy. The "Fanya juu" terraces appear as effective for moisture conservation as the trashlines, stone terraces and the control, while the latter was better than the AF plots and grass strip due to the absence of competition for moisture and other growth resources in the control. The other small differences are attributed to differences in management from one farm to the other and also in plant population. For this season, it can be concluded that moisture conservation by erosion control structures was not suufficient enough to show yield differences, as sole maize gave nearly equal grain yields and even greater biomass yields than all methods but "Fanya juu" without competive effects. The sole plot could result in lowered yields in the long run as benefits of hedgerows have shown to be long term (Nelson et al. 1997).

Table 46a. On-farm maize yield (t ha^{-1}), 94/95.

Control structure	Grain yield	Std (±)	Biomass yield	Std (±)
Sole maize/ control	1.15	0.1	2.2	>0.05
Senna/maize	1.05	<0.05	2.5	<0.05
Leucaena/maize	1.1	0.05	2.5	0.10
Gliricidia/maize	1.15	<0.05	2.3	0.15
"Fanya juu"/maize	1.35	<0.05	2.55	>0.05
Stone terrace	1.3	0.2	2.15	>0.05
Grass strip/maize	1.1	0.1	2.15	0.2

Trashline/maize	1.2	<0.05	2.45	0.1

N.B. 5 plots were used to determine the yields.

Table 46b. On-farm cowpea yield (t ha^{-1}), 94/95

	Grain	Std	Biomass	Std
Sole cowpea/ control	0.45	0.1	2.1	0.1
Senna/cowpea	0.35	0.05	2.0	0.2
Leucaena/cowpea	0.3	<0.05	1.75	0.2
GLiricidia/cowpea	0.3	0.1	1.65	0.1
Fanya juu"/cowpea	0.55	<0.05	2.35	0.1
S.terrace/cowpea	0.5	<0.05	1.95	0.3
Grass strip/cowpea	0.3	0.05	2.0	0.1
Trashline/cowpea	0.45	<0.05	1.85	0.2

N.B. 5 plots were used to determine the yields

Tables 46a and 46b show the maize and cowpea yields for the short rains of 94/95. The results show that maize grain yield was higher in "Fanya juu" terraces and stone terraces than in AF and grass strip plots. This was possibly due to more moisture being conserved by the Fanya juu terrace plot and possibly the stone terraces as well as having no competition for water and other resources such as in the AF plots. With the exception of trashline with respect to Senna and possibly Leucaena and of Senna with respect to Gliricidia these are small differences for grain yields and this makes the picture rather complex. Also for biomass the picture appears complicated as improvement only applied for "Fanya juu" with respect to control, Gliricidia, stone terraces and grass strips, but also for Senna and Leucaena with respect to control, stone terraces and grass strips and for trashlines with respect to control and stone terraces.

The yield results for the cowpea in Table 46b show that the AF and grassed plot grain yields were depressed, as observed near the rows close to the hedgerows and grass strips, compared to the Fanya juu terraces, stone terraces, trashline and control plots. The reasons for these differences have already been earlier discussed. For grain yields, the "Fanya juu" terrace appears to be more effective in moisture conservation than the trashlines and the control, but only very marginally so with respect to the stone terraces. This may be because the terrace has one of its ends closed and hence trapped more water and runoff nutrients, especially from harvested water, which may have benefitted the cowpea. As to cowpea biomass, the depression of yield with respect to "Fanya juu" was larger in Gliricidia and Leucaena and the grass strips, that came close to the control and were better than the stone terraces and the trashlines. This is again complicated picture.

In the AF plots, the additional biomass harvested at the end of the season from the trees could be (i) fed to the animals, when used as animal feed during the dry season, (ii) used as protection against erosion, when placed at the soil surface, or (iii) used as manure for soil fertility improvement, when incorporated into the soil. It should be noted that the biomass yield from hedgerows changed from season to season but on average was over 2 t ha^{1} per season.

Table 47a. On-farm maize yield (t ha^{1}), 1995.

Conservation structure	Grain yield	Std (±)	Biomass yield	Std (±)
Sole maize/ control	0.75	0.2	2.3	0.1
Senna/maize	0.6	0.05	2.2	>0.05
Leucaena/maize	0.45	0.1	2.2	0.1
Gliricidia/maize	0.5	>0.05	2.6	0.1
Fanya juu/maize	1.05	0.1	2.1	0.1
S.terrace/maize	0.85	0.05	2.1	0.1
Grass strip/maize	0.45	<0.05	2.0	0.2
Trashline/maize	0.8	<0.05	1.65	0.3

N.B 4 plots were used to determine yields.

Table 47b On-farm sorghum yield (t ha^{1}), 1995

	Grain	Std	biomass	Std
Sole sorghum/ control	0.45	0.1	1.9	<0.05
"Fanyajuu"/sorghum	0.75	0.15	2.0	0.1
S.terrace/sorghum	0.6	0.17	1.95	0.2
Grass strip/sorghum	0.5	0.1	1.85	0.3
Trashline/sorghum	0.55	0.18	2.10	0.15

N.B 4 plots were used to determine yields

Table 47c. On-farm bulrush millet yield (t ha^{-1}), 1995

	Grain	Std	Biomass	Std
B.rush millet				
Control	0.5	0.05	1.3	0.05
F.juu/millet	0.85	0.18	1.8	0.3
S.terrace/millet	0.65	0.12	1.65	<0.05
Grass strip/millet	0.55	0.2	1.4	0.1
Trashline/millet	0.6	0.15	1.55	0.2

N.B 4 plots were used to determine yields.

The results in Table 47a show that the "Fanya juu" had the highest maize grain yields followed by stone terraces, trashlines and the controls had appreciably higher maize grain yields compared to the AF/grass plots and control, as earlier explained. As for the biomass yields, the picture is very different with only trashlines falling below and Gliricidia falling above a 2.15 ±0.15 t ha^{-1} yield.

As for the sorghum yields in Table 47b where no AF plots are involved, the results for the grain show that the "Fanya juu" terraces had appreciably more yield than the others. Stone terrace >trashline >grass strip >control was the sequence that followed but only the edges of this distribution were clearly different. As well as getting runoff water from the roads, the "Fanya juu" terrace appear to be more effective in water retention for crop use, as said earlier, possibly because it was closed at one end while the other structures were not and therefore retained less water. For the biomass yields the differences were small and 2.00±0.15 t ha^{-1} covered it all.

The grain yields for the bulrush millet in Table 47c showed exactly the same picture as the sorghum grain yields, with the biomass, used as fodder, in this case following the grain pattern.

It is to be noted here that the drought tolerant crops, such as the sorghums and millets and to a lesser extent Katumani maize, seem to be grown during the long rains. The farmers argue that they expect low or very insufficient rains in the majority of cases of the long rains and their strategy to at least secure some harvest is using the millets and sorghums, which require less rainfall, mature quickly, in less than 100 days, and can be stored for long periods of time without suffering pest damage.

4.11.6. Discussion.

Although maize yields of well over one t ha^{-1} can be achieved by the farmer on the well terraced and conserved areas during years of average rainfall, the maize yields in the AF plots are lower because of moisture competition between the crop and the tree/grass. These yields can further be improved as "Fanya juu" terraces have been shown to be profitable in the long run (Tjernstrom, 1986), as well confirmed by our results. They are nevertheless still far below the yields obtained under optimal experimental conditions involving fertilizers, of >3 t ha^{-1} (Nadar and Faught, 1984a; 1984b). The yields of other drought tolerant crops are also high in well conserved soils, with again "Fanya juu" as clear winner, with even lower amounts of rainfall, and again less AF/grass grown soils, due to the same competition effects as mentioned in maize, as shown by the cowpea and partly by the sorghum/millet results.

Data under optimal experimental conditions, which include fertilizers, show that yields for cowpea can be as high as 2.5 t ha^{-1} (Ikombo, 1989), while that for sorghums and millets can be as high as 4.5 t ha^{-1} and 1.7 t ha^{-1} (Acland, 1971). There is, therefore, a lot of room to exploit this yield potential for the benefit of the farmers, but the inputs remain the main problem. Although there are reduced yields in the AF plot, it should be borne in mind that there are large quantities, of over 2 t ha^{-1}, drymatter produced by the hedgerows for fodder and/or mulch, which go to the improvement of soil fertility and/or feeding of the animals during the dry season. In the long run the AF plots may be more sustainable. It was indeed observed during the surveys that the mulch from AF was used either by incorporating it into the soil for soil fertility improvement, or by placement on the soil surface for moisture conservation or by even directly cutting the hedgerows and taking away the cuttings as fodder for the animals.

The AF plots have been operational for about seven years or so and the yields obtained from the alleys depend on the nutrients released by the mulches over the years into the soil as well as the build up of natural terraces as observed over the years for soil erosion control. The general feeling of the farmers is they have controlled erosion but also created competition for light, nutrients and moisture with the associated crop.

Efforts to fight hunger in this food deficit area were initiated about three decades ago When the Katumani Research Centre started work particularly to deal with the production of drought tolerant crop varieties, which would give the farmer some stable yields with low rainfall amounts. The first approach to deal with food shortages was through breeding programmes. This programme led to the development of early maturing, drought escaping, stably yielding crop varieties such as Katumani maize composite, Katumani bean 1 and bean 2, cowpea varieties M66 and K80, early and medium maturing pigeon peas, improved varieties of sorghums, bulrush and finger millets, improved sweet potatoes as well as improved cassava varieties. The farmer, on the other hand, has also his own seed varieties, which he has developed through many years of experience and trial and error, and he has continued to use them along with the improved varieties for the security of his food needs. Early maturing crops like sorghums and millets and beans, when mixed with long maturing maize, give the farmer the hope of getting some food even when the season is poor and keeps the chances to get overall harvests in case the season is good. This appears to be one of the main reasons behind mixed cropping found in this area.

The second approach to fight hunger in this area was through soil and water management strategies. These aimed at minimising soil degradation through erosion by water, loss of soil nutrients, loss farming land through gulley erosion and land degradation of loss vegetation and soil through overgrazing. Among the techniques of water conservation was the use of tillage operations which would make the soil cloddy and allow for more infiltration and reduce surface runoff, the use of farm yard manure to increase the soil organic matter and so enhance water holding capacity of the soil and its nutrients status.

Agroforestry was introduced here also in the late 1980s, with a view to assisting the farmers in erosion control via contour hedgerows which help build up of terraces in a cheap way, soil fertility improvement through mulch and the provision of livestock fodder to alleviate feed shortages during the dry periods.

However, while they appreciated the provision of fodder for their animals from the hedgerows and/or fertility improvement through mulching and/or the build up of level bench terraces with time at minimal costs, there were nevertheless disadvantages as concerns the early width, which was fixed at 4 m and which constrained the use of oxen for weeding and ploughing. Although it is not clear why the 4 m width was chosen, it is suspected that this width was copied from the humid tropics. The farmers, as observed, would have preferred a bigger alley width, which would enable them to weed and plough easily and conveniently using oxen at periods of labour shortages when most children that supply labour are in school. However, Coulson, Mungai and Stigter (private communication) have argued that benefit will appreciably reduce at larger spacings, as the amount of biomass in dryland areas is already smaller than in the more humid regions. The width of spacing would anyway have to depend on slope steepness similar to the way terraces are constructed and laid out.

Farmers further argued that hedgerows were competing with their crops for light, water and soil nutrients hence limiting crop yields. They react by preferring to weed other parts of the farm, with other crops, first and later come to weed the alley cropped plots, allowing weeds to grow and mask parts of the benefits of expected yields. This as earlier mentioned confirms the fact that they treat the alley cropping as not theirs but "belonging to the researcher". Infact, when the incentives used to attract farmers to this alley cropping, such as improved seed varieties, are delayed in their delivery, the farmer will leave the AF plots unplanted and keep on waiting for the seeds, while the rest of the farm is planted with other crops. Since it is the farmer who decides on what is to be grown at his/her farm, it is very important to create a suitable interactive environment in on-farm research so that he is convinced of the usefulness of a new technology including its disadvantages so that he can judge it against the traditional technologies which he deems vital in solving farming problems.

As earlier noted, the working draught animals are normally weak during the dry season, when ploughing operations should be done, due to lack of sufficient feeds, while the ground is also hard to break. So the farmer waits to plough till the onset of the rains, when the soil had become wet and soft. The use of fodder, from for example Leucaena in the alley cropped plots, can to some extent reduce the fodder shortages and enhance the use of draught animals for effective early and dry ploughing, particularly when soil fertility can be kept up otherwise.

4.12. Connecting on-station and on-farm research.

The on-station grain yields for cowpea for the short rains 92/93, 93/94 and 94/95 (in review tables 48 and 49) showed that the obtained yields were still low and particularly depressed in the AF and grass plots. From the review table 49 it is shown for the 94/95 season that on-station grass strip grain and biomass yields are slightly higher but representative for on-farm conditions (for the cowpea), while the Senna grain yields do not differ on-farm/on-station. Only the control grain and biomass yields are really higher on-station than in the on-farm situation (Table 49). For grain yields, mulch on-station and Fanya juu on-farm are similar, the latter having highest on-farm grain yields. Although this also applies to biomass yields these, remain much smaller than the sole cowpea and the mulch/cowpea biomass yields. This must partly have been as a result of differences in the management aspects such as weeding time, manuring and even plant densities as well as partly due to possible soil variations and a complete difference in the history of the plots.

Table 48. On-station cowpea grain and biomass yield (t ha^{-1})

	92/93 season		93/94 season	
	Grain	biomass	Grain	biomass
Sole cowpea	0.32	3.9	0.56	2.9
Senna/cowpea	0.39	2.2	0.36	1.1
Grass/cowpea	0.30	2.05	0.30	1.3
Mulch/cowpea	0.43	2.3	0.65	3.4

Table 49. On-station and on-farm 94/95 cowpea yield (t ha^{-1})

	on-station		on-farm	
	Grain	biomass	Grain	biomass
Sole cowpea	0.7	4.8	0.45	2.1
Senna/cowpea	0.35	2.6	0.35	2.0
Grass/cowpea	0.40	2.1	0.3	2.0
mulch/cowpea	0.60	3.8		
F/juu/cowpea			0.55	2.35

The fact that the Senna and grass plots differ appreciably less or not at all shows (review in Tables 48 & 49) the overwhelming effect of the competition phenomena. The farmer is indeed convinced that the tree is competing with the crop for nutrients, water and light, which he attributes to the overlapping of roots and shade of the tree. This is confirmed by Ong's (1994) and Mungai et al. (1996b) doubts from on-station work on whether alley cropping can work in the semi-arid areas in infertile (acid) soils with moisture deficits.

For the maize yield pattern, the only season for which comparisons in yield patterns between on-station and on-farm experiments could be made were the long rains 1995, which was still a bad year for the farmers. In 1994 long rains, there were yields on-station but a total crop failure in the on-farm. Yield trends were monitored on-farm in 94/95, when no maize crop was grown in the on-station experiments, which had cowpea. These maize yields would therefore be included in the discussion.

Table 50. On-farm 94/95 maize yields (t ha^{-1})

	Grain	biomass
Sole maize	1.15	2.2
Senna/maize	1.05	2.5
Grass/maize	1.1	2.15

The on-farm maize yields for the 94/95 season of just over 1 t ha^{-1} (review in Table 50), were below the yields of over 3 t ha^{-1}, using fertilizer, which have been achieved in the Katumani dryland research centre, on slightly sloping land and from slightly sloping control plots at ICRAF Machakos field station (e.g. Howard et al. 1995; Ong et al. 1992). There was actually no real difference in the maize yields between the control, Senna/maize and grass/maize (Table 50). This is possibly because the hedges and grass strips had been heavily browsed by the animals during the dry period of 1994 long rains, when there was very little feed for the animals. This meant that the hedges and grasses posed little competition to the maize crop, as they took time to recover and establish growth, during which time the maize had fully grown, for this was an above average rainfall season.

For the 1995 long rains, there was yield depression in both the AF and grass strip plots on the on-station (Table. 42) and on-farm (Table. 47) alike (see review table 51).

Table 51. Grain and biomass maize yields (t ha^{-1}), long rains 1994 and long rains 1995.

	On-station (1995)		On-farm (1995)		On-station (1994)	
	grain	biomass	grain	biomass	grain	biomass
sole maize	2.7	5.3	0.75	2.3	1.8	4.0
Senna/maize	1.5	3.4	0.6	2.2	0.6	1.4
Grass/maize	1.0	1.9	0.45	2.0	0.8	1.6
mulch/maize	2.5	5.3			1.8	3.8
F/juu/maize			1.05	2.1		

The yields were, however, except for the grass stripped plot biomass yields higher on-station than on-farm. The grass strip plot on-station had in 1995 maize biomass yields that were similar to the on-farm yield conditions and those of the Fanya juu systems (Table 51). The on-station mulched plots did appreciably better. These differences were for the control and +M as a result of differences mentioned for the cowpea above. All situations were on steep slopes, of over 10 %. There is still a gap between the on-station research results and the farmers' results, which needs to be made narrower to boost the farmers' yields.

The differences are, however, obviously less for competitive situation in AF and they were least for the case of extreme competition of grasses. The clear yield advantages of earthen and stone terraces over hedgerow cropping calls for integrated soil and water management strategies where the farmer will compromise yield losses due to the hedgerow in order to gain some fodder and mulching for soil fertility improvement as well as the build up of natural terraces with time. Because of the unwanted 4 m width brought along with the alley cropping technology, even at very gentle land slopes of less than 5 % slope, some fine tuning of the alley width is crucial so that more room is created for the use of oxen in ploughing, planting and even weeding, which eases labour constraints at critical periods of the rainy season. The alley width, as earlier discussed in section 4.11, should be laid out as is done with terraces, for hedgerows will eventually build up into bench terraces for erosion control *inter alia*. Certainly, there is still the additional labour for lopping the hedgerows to keep them low, especially for short crops like cowpeas and beans, to reduce shading. Although the farmer will need some trees which will keep moisture competition with the crops to a minimum, it remains doubtful whether *Senna siamea, Leucaena leucocephala* and *Gliricidia sepium* can be accepted as alley crop trees on the basis of crop yield alone, given the observed yield depressions over the years on the farms and on-station. The farmer has still kept the grass strip as soil erosion control structure although it presents severe competition for the farmers associated crop. The reason for this could be that, the grass strip offers the farmers other services as well as providing to the farmer grass for thatching and is a good and durable stabiliser for the erosion control embankment, which saves on money spent on repairing unstabilised weak embankments.

CHAPTER FIVE.

5. Conclusions and recommendations/weather advisories.

5.1 Explaining grain yields from other parameters.

5.1.1 Rainfall.

Referring to the review Tables 5.1 (adding here that rainfall in 1993 was only 108.5mm) and 44 (in section 4.10.7 (b)), there was a clear cut increase in maize grain and in biomass yields with increase in rainfall amount over the seasons for all the treatments for the maize crop. The in grain and biomass yields in H+M, H-M and G-M treatments were, however, depressed as compared to those in C and +M treatments, because of competition in senna/maize and grass/maize systems for moisture, light and nutrients (Table 44). Maize, which is normally grown during the short rainy seasons, which have more, and more reliable precipitation than the long rains, was not grown during the short rains in our experiments, as this was an on-going long term experiment. It is therefore likely that any further increase in rainfall towards and over 300 mm, would also have resulted in further increase in grain and biomass yields, with also the depressions remaining in intercropping, as shown by Mungai et al. (1996b) for flat soil, since for all the rainfall seasons for maize, rainfall was below 300 mm per season. However, at too high rainfall treatments may interfere with this picture for sloping land, as we will see for the cowpea.

The cowpea review Table 43, in section 4.10.7 (a), shows that except for the +M treatments 93/94 and 94/95, which were close to similar, there was also a general trend of cowpea grain yield increase in C and +M treatments with advancing seasons. However, 92/93 was the wettest season, with 662 mm, against the 288.5 mm and 549 mm in 93/94 and 94/95, as indicated in Table 5.1. There was highest grain yield in the 94/95 season in the G-M treatment while drier and wetter conditions gave equally less grain yield there. G-M biomass yield, however, clearly lower in the driest year. At the same time, there was a small decrease in cowpea grain yields in H+M and H-M treatments with advancing seasons (review Table 43), with the differences between wettest and driest year indeed being not the largest. For biomass yields the lowest yields were again in the driest year, while the wet years had similar biomass yields. The cowpea grain and biomass yield reductions in H+M, H-M and G-M treatments for 93/94 and 94/95 compared to the C and +M treatments were as a result of competition in cowpea/senna systems for the available growth resources: water, light and nutrients. However, in the wettest year, 92/93, there were no cowpea grain yield decreases compared to the C plot (even an increase for H+M and H-M, and only a considerable decrease between +M and G-M. Given the already high differences in soil loss and runoff observed at wetter years documented in Table 5.1, it is likely that 92/93 problems in C and +M (also biomass) cowpea plots will at least be partly due to serious soil losses, while indeed H+M and to lesser extent H-M suffer less from such losses because of hedge and mulch. In the G-M plots, these effects are counteracted by prolific grass growth. It looks likely that other parameters, such as light use efficiency and water use efficiency, were equally affected by such factors as discussed above. They will be used below to assist in further understanding of yield results.

Table 5.1. Review on soil loss/runoff

Year	Treatment	Soil loss ($t\ ha^{-1}$)	Runoff (mm)	Mulch rate ($t\ ha^{-1}$)	Rainfall (mm)
93/94	C	2.55	10.0	2.4	288.5
	+M	0.45	1.0		
	H+M	0.5	0.5		
	H-M	0.7	4.7		
	G-M	0.15	1.8		
1994	C	9.7	8.4	1.9	242.4
	+M	0.8	5.6		
	H+M	0.06	1.8		
	H-M	1.5	5.8		
	G-M	0.2	4.8		
94/95	C	60.7	59.5	1.3	549.0
	+M	40.0	19.5		
	H+M	1.4	16.5		
	H-M	18.0	47.3		
	G-M	12.9	30.0		
1995	C	32.9	20.5	2.0	285.0
	+M	2.0	9.6		
	H+M	0.1	1.3		
	H-M	13.3	18.2		
	G-M	2.0	9.3		

5.1.2. Mulch and crop cover.

As seen from Table 2 in section 4.4.7 and review Table 44, mulch cover improved maize grain and biomass yield performance in the H+M compared to the more depressed yields in the H-M and G-M, treatments with the exception of the 1993 season when rainfall was quite low and G-M was bad but H+M and H-M worse in yields. The presence of mulch as an additional protective cover on steep slopes in the H+M treatment improved the maize grain yields by 0.5 t ha^{-1} and its biomass by 1.2 t ha^{-1} in 1994 and by 0.6 t ha^{-1} and 0.9 t ha^{-1} respectively in 1995 compared to the H-M treatment. The yield increases for maize grain in the H+M plot over the G-M treatment were 0.3 t ha^{-1} and 1.1 t ha^{-1} for 1994 and 1995 long rains respectively, while for biomass it was 1.0 t ha^{-1} and 2.4 t ha^{-1} respectively (Table 44). During these two maize seasons, there was more % mulch cover in 1995 than in 1994 (Table 2), while the % crop cover was till day 58 inclusive but no longer at 78 days relatively higher in 1994 than in 1995. A combination of crop cover and mulch cover for the three seasons shows that (i) for 93 this sum was lower than 50% for the whole season for C, H-M and G-M, while for H+M and +M this was only the case from 67 DAS and 86 DAS onwards, when it was no longer so important; (ii) for 1994 it was also below 50% for the whole season for C, H-M and G-M plots, but for the H+M plot only from day 58 onwards, although it was often close; (iii) for 1995 this sum was less than 50% for the C plot till day 58, for the H-M and G-M plot till day 78 and for H+M only from day 148 till the end, when it was no longer important. (Also compare Table 2). It can therefore be concluded that mulch cover was responsible for additional soil erosion reduction and for yield increase in the H+M treatment compared to H-M and G-M treatments in 1994 and 1995 maize seasons (review Table 5.1). The mulch had no influence on maize grain and biomass yields compared to the control plot in 1994 and 1995 and a negative influence in the driest year, 1993, for several reasons. The most likely reasons are interception of light rains early in the season, confirmed by the soil moisture data and sub-optimal temperatures near the soil surface, caused by the presence of the mulch. However, the last effect must be small, as temperatures in 1994 and 1995 give only maximum differences of 2°C between the (lower) temperature in the mulched plots and those in the control, for weekly average temperatures.

The C and +M treatments showed an increase in cowpea grain yield except for 94/95 in +M treatment when there was a decrease in yields (Table 43), which was attributed to a negative mulch effect, confirmed by the soil moisture data. Recalled from the cowpea yield review table 43 for the cowpea seasons, there was a decrease in grain yields in H+M and H-M treatments over the seasons except for the G-M treatment which in 94/95 season showed higher grain yields. The review of crop and mulch cover in Table 2 shows that mulch cover alone was nowhere sufficient to effectively protect the soil against erosion in 93/94 nor in 94/95. Crop cover alone only reached 50% in mulched plots in 94/95 season at 76 DAS in H+M, although it was close at 56 DAS, while it was also sufficient for erosion control, alone, at 76 DAS and 56 DAS in the +M plot in that same season (Table 2). It was moreover sufficient in unmulched plots on 75 DAS in C and H-M (93/94) and on the C plot on 56 DAS and 76 DAS. Combining mulch and crop cover this sum was lower than 50%, so insufficient for control of soil erosion: (i) for 92/93 (not having G-M) from the start to 36 DAS for C and H-M plots, which is somewhat more dangerous than the period from the start to 22 DAS that holds for +M and H+M plots; (ii) for 93/94 for the whole season in H-M and G-M plots, for the period from the start till below 65 DAS for the C plot and, better than the others, from 25 DAS till the end but always above 30% for H+M and only from above 35 DAS, but higher than 40% while often close to 50%, for +M; and (iii) for 94/95 for the whole season for the H-M and G-M plots, from the start to 48 DAS for C and from the start to only 26 DAS for +M and H+M, which therefore were better protected.

A combination of mulch and crop cover can therefore be concluded to have reduced soil erosion in mulched treatments a lot better than in the other plots, except that diseased cowpea may have contributed to more soil erosion (Table 5.1) through poor crop cover development in 94/95 season. Except for this 94/95 season, when grain yield and not the equally important biomass was similar in H+M and in H-M but higher in G-M treatments, there was a grain and biomass yield advantage over the seasons of the H+M treatment over the H-M (although similar for grain in 93/94) and G-M treatments (although similar for biomass in 93/94) which can be attributed to the presence of mulch and the hedgerow barrier (Table 43) and their influence on runoff and soil loss. It can therefore be concluded that the combination of mulch and hedgerow barrier had biomass and under very wet conditions also grain yield advantages over hedgerow barrier or (with grain advantage replacing biomass advantages in the driest season) grass strip alone, which were sufficiently high to justify the use of mulches in the H+M treatment. In the wettest season the mulched plots yielded most grain and the H+M plot high biomass.

Mulch gave cowpea grain yield advantages in the +M plot of about 0.1 t ha $^{-1}$ when compared with the C treatment (35% in 92/93 and 15% in 93/94) save for 94/95 (Table 43) when mulch rate was very low (1.3 t ha^{-1}), but a comparable biomass yield advantage there was only in 93/94. The positive role of mulch cover is clearly demonstrated in Table 1 in section 4.3 where most of the most erosive rainstorms of high intensities appear to occur within the first 36 days of crop development, resulting in high soil loss and runoff when soil cover is low (Table 2). It can therefore be concluded that soil erosion control by mulches from the hedgerows is necessary as long as crop cover alone is low and insufficient to provide enough protective soil cover during the initial stages of crop development. In the long run this will also show to result in getting sustainable yields.

5.1.3 PAR (%) interception.

As can be seen from tables 21 and 23 in section 4.7 as well as from the review table 5.2, alley cropping resulted in higher PAR interception at the crop/tree interface than in the middle rows of maize in the alley in the senna/maize systems (H+M; H-M). For the maize/grass systems the row of maize next to the grass intercepted also more PAR than the middle rows (Tables 21, 23 and 5.2). Table 5.2 shows also that PAR interception was on a representative day 54 ± 5% for C, +M, H3+M H1-M and full G-M treatments, but was higher in H1+M and H2+M as well as lower in H2-M and H3-M treatments for maize in 1994. In the 1995 maize season the situation was that C, +M, H2+M, H3+M, H2-M, H3-M, G2-M, G3-M treatments had PAR interception of 59 ±4% while in all interfaces (H1+M, H1-M and G1-M) intercepted PAR was about 15 to 20% (absolute values) higher. The difference between G-M results of these years was due to the grass cutting at 48 DAS of '94. The year 1995 was wetter compared to 1994 (Table 5.2) and this resulted overall in more crop growth and more PAR interception and therefore more grain yield in 1995 than in 1994 (Table 44).

Table 5.2. Representative date (half way the season) for the review of PAR(%) interception

Season	DAs	C	+M	H1+M	H2+M	H3+M	H1-M	H2-M	H3-M	G1-M	G2-M	G3-M	Rainfall
92/93	60	80	74	91	76	90	80	71	79	74	61	66	663
93/94	58	44	46	67	48	61	60	46	49	60	40	60	300.5
1994	65	54	57	70	64	53	59	42	37	57	49	53	342.4
94/95	73	91	92	91	58	69	87	60	66	80	52	59	540
1995	73	61	60	80	62	60	81	65	57	74	50	55	285

N.B. In 94/95 only interface measurements and their separation were made as well as measurements at 2 m away from the trees but measurements at 1 m from the hedges were only used for analysis purposes.

Tables 24 and 26 show that light use efficiencies were not very different between these two seasons, with a slight tendency for 1994, in which less total PAR was received, to be higher, but everywhere within the measuring accuracies. Differences in LUE between treatments were due to competition differences as discussed in section 4.7.6.(d).

Because the PAR interception was similar in H+M and H-M in 1995, there must be differences in maize yield which cannot be explained on the basis of PAR interception alone. It can hence be concluded that the presence of mulch in the H+M treatment accounted for the that the presence of mulch in the H+M treatment accounted for the difference in yields, most likely particularly by runoff suppression under the higher rainfall conditions (table 5.1), as already mentioned earlier in this chapter. The sole maize in C and +M treatments had higher grain and biomass yields than the AF and G-M treatments, although they had intercepted less PAR than the interfaces of the latter plots. This can partly be explained on the basis of the sole maize (C4 plant) being better than the maize/senna (C4+C3 plants) or maize /grass interfaces in the use of intercepted PAR as shown in table 24 and 26 in sections 4.7.6 (a) and 4.7.6 (c) respectively. Competition for growth resources however also lowers LUE.

As shown in table 5.2, PAR % interception was very similar in C and +M treatments also in 92/93, 93/94 and 94/95 cowpea seasons, with clearly more PAR interception in wetter seasons. In 92/93, for the representative dates selected, PAR interception was 75 ± 5% in C, +M, H2+M, full H-M and G1-M, while higher in H1+M and H3+M and lower in G2-M and G3-M. This is rather well in line with the grain yield picture of this wettest season. There was more grain yield in the H+M than in other treatments and lower grain yield in G-M (Table 43). Contrary to the other years it was the H+M plot that was closer to the C plot than the +M plot in biomass yields, because of earlier mentioned negative mulch factors that also made them similar to H-M and G-M. In 93/94 PAR interception on the representative day was 48 ± 4% for all treatments, apart from the interfaces in H+M, H-M and G-M. It can be seen from table 43 that therefore competition for light, water and nutrients was the grain and biomass yield determinig factor, with an additional positive soil moisture related effect in mulched plots. For 94/95 season, there was no difference in PAR interception among C and +M treatments and H+M and H-M interfaces (90 ± 3%), with the G-M interface lagging behind by 10% (absolute) PAR interception (Table 5.2), because of stronger competition by the grass. The C and +M treatments had higher grain and biomass yields having intercepted equally high or higher PAR compared to H+M, H-M and G-M interfaces. Competition for water and nutrients therefore determined relative grain and biomass yields but with relatively high PAR and high PAR interception and less negative rain and soil moisture effects that must have spoiled the wettest season for C (grain mostly) and +M plots (Tables 5.2 and 43). The high soil loss figures for all but H+M and the differences in runoff show that the higher yields in 94/95 for C and +M plots must be considered unsustainale in the long run.

Table 25 on light use efficiency (LUE) shows that there were no substantial differences in LUE among the five cowpea treatments. The LUE for cowpea, as a C3 plant, was appreciably smaller than for the C4 maize. The grain and biomass yield differences between the treatments are therefore not due to any light limitations in the 94/95 season but due to competition for other resources, in this season particularly nutrients.

5.1.4 Soil moisture.

Referring to Table 3 in section 4.5.5 on 1994 long rains weekly and seasonal soil moisture storage, for a season of below average rainfall but not an extremely dry one, it was found that the C and +M treatments had relatively higher moisture storage levels when compared to AF and G-M treatments. The low moisture reserves in the AF and G-M plots must have been due to a combined soil moisture extraction by both the maize/*Senna* and grass/maize systems compared to the sole maize moisture extraction in the C and +M treatments respectively. The high weekly moisture storages in the C and +M treatments (Table 3) correspond to relatively high grain yields in C and +M treatments compared to relatively lower weekly soil moisture storages in H+M, H-M and G-M and correspondingly low grain and biomass yields in these plots (Table 44 in section 4.10.7 (b)). In these cases total biomass pictures (including hedges and grass) and WUE have also to be considered (Table 27). The maize grain and maize biomass yield as well as total biomass yield in the H+M treatment were relatively higher than in H-M and G-M, although it had relatively lower total moisture storage, because of the water being differently used, that led after all to a higher total water use efficiency of the H+M plot (Table 27). This cannot be due to mulch alone, as the +M plot had a lower water use efficiency than the C plot for the same yields. Without knowing differences in the rooting pattern produced by differences in soil moisture we can give no answer to this question. However, it is clear that the H+M rooting system for maize has been formed in much drier conditions than any of the other crops. A negative effect of mulching, on water use efficiency but not on yields must have been more than compensated by a positive one causing or caused by lower moisture contents throughout but particularly in weeks 1-7.

With the above anomalies in +M and H+M treatments admitted, sole maize (C4 plant) in the C treatment was more efficient in the use of water (WUE) than maize/senna (C4+C3 plants) or maize/grass (C4+C4 plants) systems. The maize/grass system had lower WUE although both grass and maize are C4 plants, because of the severity of competition for water, light and nutrients.

In the 94/95 cowpea season, which was wet, as shown in Table 4 in section 4.7.6 (b), the C plot had relatively higher weekly soil moisture than the other treatments almost throughout, to which match a highest water use efficiency (Table 28) and high total biomass (Table 28) as well as highest grain and biomass yields (Table 43). The H+M and H-M treatments had fluctuating but rather similar moisture storage levels, with the +M and G-M treatments having also similar moisture storage levels. In the case H+M/H-M they were rather fluctuating over the season, while G-M was lower than +M early in the season and later in the season but +M inbetween. A further check on the WUE in Table 28, section 4.7.7.(b), shows that the H+M and H-M treatments took rather similarly more water for their transpiration needs (Tr) compared to the C and +M treatments, with G-M more than C and rather similar to

+M. This resulted in lower WUE in these treatments than in the C treatment with the exception of +M, treatment which was not any better than the AF treatments and only slightly better than the G-M treatment.

When the data of Table 4 are compared with the grain yield values in Table 43 and the WUE and total biomass yield figures in Table 28 for H+M, H-M and G-M treatments, the correspondingly lower grain yield values, because of competition for growth resources, showed little differences between H+M and H-M, that also had similar total biomass yields. For G-M, with lowest WUE that only differed 10-15% from the others, lower cowpea and total biomass yield but somewhat higher grain yield than H+M and H-M, only comparison with +M is interesting. The +M treatment had higher cowpea grain and biomass yields but rather similar total biomass yields than the G-M treatment although they had similarly lower soil water storage values in the early weeks and generally somewhat lower than the C plot. This was of course because of competition for nutrients and light between cowpea and grass, while the two systems had not very different (15%) WUE. This similarity will not necessarily have applied to all parts of the season. Reasons for the lower WUE compared to C may again have been root systems.

For the 1995 maize season, the picture drawn from Table 5 in section 4.6.7 shows that the C and (to a somewhat lesser extent) +M treatments had relatively higher seasonal soil water storage than the H+M, H-M and G-M treatments, with the G-M in the middle between H+M and +M. The AF and G-M' treatments transpired water less efficiently from the soil profile compared to the C treatment (Table 29) because of the presence of hedges and grass. Total biomass is however highest in H+M, almost identically lower in C, +M and H-M and lowest in G-M, while maize grain and biomass yields are higher in C and +M and decreases in the sequence H+M, H-M, G-M. The picture is therefore almost identical to that of the 1994 long rains maize season, particularly in the explanation of the H+M high yields (root system formation in earlier weeks) and WUE and the low WUE of the +M plot, be it that the soil moisture conditions were even better in 1995. This made, WUE's higher, except for the G-M, making the effect in H+M smaller, falling well below WUE of the C plot in 1995, but producing the highest biomass.

So sole maize (C4 plant) in the C plot was better in the use of water for biomass production than H+M (C4+C3 plants), H-M (C4+C3 plants) and G-M (C4+C4 plants). The low values of Tr (but the C plot apart, the 1994 values were even lower) for the five treatments in Table 29 also show that except for the +M treatment which had the highest Tr value, the C plot transpired the lowest amount of water (among the relatively low values in comparison with the cowpea season) compared to rather similar H+M, H-M and G-M treatments. With the above +M exception, therefore, it can be again concluded that the sole maize (C4 plant) in the C treatment was relatively more efficient than the maize/senna (C4+C3 plants) or maize/grass (C4+C4 plants) systems in the use of water.

5.1.5 Near soil surface temperatures.

As concluded in 4.8.8, on the whole weekly average soil temperatures at 7.5 cm depth remained below 28°C and above 18°C. For germination the lowest temperatures may therefore have been suboptimal, at least for maize (Van Wijk and Derksen, 1966), somewhat negatively influencing germination under mulch as well as in places heavily shaded by the grass strips and under combination of hedgerow shade and mulch. For mulch this effect may only have been serious for maize in 1993, that however mostly suffered from drought. For shade the effect is additional to PAR interception by hedges and grass and competition for water and nutrients so difficult to assess percentually. There is no negative temperature effect for cowpea grain, as concerns mulch, for it is only in the 94/95 season out of the three cowpea seasons when grain yield was somewhat (15%) lower in +M treatment than in C treatment (Table 43). Apart from earlier mentioned early soil moisture low levels, the high wetness may also have been involved here more more in decreasing biomass yields, through effects on rooting systems or other factors we have not been able to quantify. It is in the two wet years that cowpea biomass is lower in +M and the same applies to total biomass in the year WUE was determined. This must be for the largely ununderstood reasons, where temperatures may not be expected to be very much involved in such differences, but lower temperatures may be an additional factor in growth suppression.

5.1.6 Soil erosion and runoff losses.

As can be seen from review table 5.1, all the treatments including the C treatment, in the 93/94 cowpea season had soil erosion rates below the stipulated T value of 5 t ha^{1} for the region. Runoff from the C treatment was only 3.4% of the total seasonal rainfall and therefore of minor importance for crop production. The grain yields from the AF and G-M treatments were depressed compared to those in C and +M treatments (Table 43), but soil erosion/runoff losses were not involved.

In 94/95 cowpea season, except for the H+M treatment, soil erosion rates were above the T value in all treatments. Although the C treatment without any erosion control structure had the highest soil erosion rate of 60 t ha^{1}, it showed higher cowpea grain and biomass yields compared to the other treatments (Table 43) but total biomass was rather similar to H+M and H-M plot results (Table 28). In section 5.1.4 we have suggested a low WUE, next to early low soil moisture values due to inefficient evapooration of intercepted light rains most likely caused by wetness, possibly through root growth, to be involved. The most effective structure in both the control of soil erosion and runoff was the combination of hedge and mulch (H+M) in the H+M treatment (Table 5.1). This did not result in higher grain yields compared to the C and +M treatment (Table 43) because of competition between cowpea and senna for growth resources. It can therefore be concluded that the benefits of soil erosion control are for the time being masked by the competition effects of the hedgerows (and grass strips) with the cowpea crop, if the biomass of the hedges is not taken into consideration. However, the results of this season point to a future in which sustainable (low) yields are obtained in H+M while the other plots degrade further. The very high erosion rates beyond the stipulated T value for this region in this season can lead to loss of soil depth and constrain crop production in the long run.

Soil erosion rates and runoff were quite high for this season because most of the high intensity erosive rainstorms occurred within the first 30 days of the season (Table 1), when crop cover was still poorly established (Table 2), and because of the damage of the crop cover development by the cowpea disease in this season. The proportion of rainfall lost as runoff this season was just above 10% . This must have had little effect, since this was an above average rainfall season, but must nevertheless be considered high compared to other water losses.

As can be seen from Table 5.1, soil erosion rates for the 1994 maize season were below the T value in all treatments except for the C plot. This was an indication that mulch in the +M, hedge and mulch in the H+M, hedge alone in the H-M and grass alone in the G-M treatments were effective in erosion control. Despite this erosion control effectiveness in these treatments, the accompanying grain yields were lower than in the C and +M treatments (Table 44), but for the H+M treatment total biomass yield was similar to that of C and +M (Table 27). Again the advantages of H+M soil conservation are shared by hedge and crop (here maize) and maize grain and biomass yields are lower than in C and +M but higher than in H-M and G-M. The C plot must loose over time.

In 1995, except for the C and H-M treatments, which had erosion rates in excess of the T values for the region, the +M, H+M and G-M treatments effectively controlled erosion to below tolerable rates (Table 5.1). The H+M was notably again the most effective in erosion control of all the treatments. Table 44 shows that the AF and G-M treatments had depressed maize grain and maize biomass yields when compared to the C and +M treatments. However, total biomass yields in H+M was largest of all and those in C, +M and even H-M 10-15% lower (Table 29). The reasoning applied above holds again. If total biomass is valued, the H+M soil conservation is already showing its importance, that can only grow over time. Any possibility to diminish competition of the hedges will increase the conservation benefits.

From table 5.1 it can also be concluded that except for the 94/95 cowpea season, when rainfall was well above average (549 mm), and mulch rate certainly below optimal (1.3 t ha^{-1}), mulch rates of about 2 t ha^{-1} in the +M treatment, in other seasons, were very effective in the control of soil erosion. It can therefore be recommended that farmers use this mulch rate, which is obtained from the existing senna hedgerows, for the control of soil erosion.

In Table 1 on the analysis of rainstorms it is shown that most of the erosive rain storms occurred in the first 36 days in the four rainy seasons. This was when the crop cover had not reached the optimal 50% required for effective erosion control (Table 2). Hence the use of the recommended mulches for the interception of erosive raindrop impacts and reduction of soil erosion. In a very dry year mulching had a negative effect on maize grain and biomass yields, while negative effects were also recorded in wet years of cowpea, for biomass in both cases and for grain only in one. We have forwarded the possibility of soil moisture influencing root development for the wetter years and interception of scarce early rainfall for the driest year.

5.2. Contour hedgerows as soil and water conservation method.

5.2.1 General

We want to group some of the above once more under the direct treatments. As shown in Table 5.1, contour hedgerow barriers with additional mulch cover (in H+M treatment) on steep slopes were the most effective biological structure in the control of soil erosion. This was clearly depicted in all four seasons in Table 5.1, when soil erosion rate remained below the T value of 5 t ha^{-1} for the region. The H+M treatment was also the most effective in the control of runoff in all the seasons shown in Table 5.1. This effectiveness in erosion and runoff control was only partly reflected in total biomass yields in the years in which WUE was determined (Tables 27-29). In the long run and when soil fertility can be kept up, sustainable (but low) yields may be expected with the exception of very dry years such as 1993, when disadvantages of mulch strengthen the competitiveness of the hedges.

When contour hedgerows alone are considered, they reduced soil erosion to below the T value in two seasons out of four (of which two there was one of near average rainfall and of below that value). They were the least compared to +M, H+M and G-M treatments in terms of runoff control effectiveness (Table 5.1), also in drier years among the four measured. When compared to H+M treatment, the H-M treatment had lower to similar cowpea grain and biomass yields and the one year we measured WUE it points into the same direction for total biomass (Table 43; Table 28). The same is also true for maize grain, maize biomass and total biomass yields as shown in Tables 27, 29 and 44, where only the driest maize year, 1993, gave similarity in maize yields (total biomass data not available for 1993).

As for the G-M treatment, the grass strip barrier was quite effective in the control of soil erosion, being second to the H+M barrier, for it was only in one season out of the four seasons when the T value was beyond the tolerable rate (Table 5.1). In terms of runoff control effectiveness, only in two seasons out of the four seasons was G-M second to H+M treatment, be it that in the three drier years of Table 5.1 it was close to +M. In the wetter year it was better in soil loss prevention than in runoff reduction compared to +M, although better in both compared to H-M (Table 5.1). This effectiveness in erosion control was not reflected in cowpea grain yields, which were even lower in G-M treatment than in H-M treatment, except in the 94/95 season when the yields were relatively higher. For cowpea biomass yields G-M was lower than or similar to H-M. In total biomass it was always lowest, for cowpea as well as for maize crop conditions. The situation for maize yield was that G-M treatment had similar grain and biomass yield as the H-M treatment in 1994 but in the 1995 season H-M values were higher. In the driest maize year, the very low yields were higher in G-M and the biomass yields also, but close to similar. So roughly H-M and G-M had more or less similar yields with the exception of 1995 and biomass as well as the total biomass in all years covered.

Except for the 94/95 season, when the mulch rate was below optimal (1.3 t ha^{-1}) and when there was soil loss of 40 t ha^{-1}, mulch rate at optimal quantities of 2 t ha^{-1} effectively kept soil loss below the T levels (Table 5.1). Mulch was ranked second or third after H+M and/or G-M in erosion control (soil loss and runoff) effectiveness, except this 1994/95 when it was among the worst in soil loss. When this is compared to cowpea grain and biomass yield advantages in Table 43, grain yield was higher in +M than in C treatment in the wettest and driest year but not in 94/95 when C had somewhat higher grain yields than +M. For cowpea biomass yields +M was highest in the driest average rainfall year but in the two wet years it was lower than C, in the wettest year 92/93 even lower than H+M and similar to H-M and G-M. In 94/95 (Table 28) it was among the two lowest in total biomass yield because it had no additional hedges.

The maize grain and biomass yields in Table 44 and of course the total biomass yields of Tables 27 and 29, which are similar to those in Table 44 for C and +M) show that the +M treatment did not have any yield advantage over C treatment and was worse in the driest year (1993).

The conclusion reached here is that the effectiveness of mulch in soil erosion control and runoff control are with the exception of 94/95 soil loss rather good for the former and rather average for the latter. The yield benefits of mulch over control are irregular, which is thought to be due to differences in water relations, directly or indirectly. It is therefore H+M treatment that appears most recommendable, apart from the driest years, with an important economic use of other products preferably compensating for the lower but sustainable yields in the long run.

5.2.2 Hedgerows with crops but without mulches.

From fig. 4.101 in section 4.5.10, it is most clearly shown that more runoff water is concentrated at the hedgerows than at 1 or 2 m away into the alley. The yields per row for maize are also higher closer to the hedgerow than 1 or 2 m from the hedgerow as shown in figs. (4.146, 4.152 and 4.158) in section 4.10. This concentration of runoff water, soil particles and related nutrients at the contour hedgerow barrier must have helped in the better development of the maize crop and resulted in higher yields near the hedgerow, be it that in the driest year and the driest of the near average years of rainfall, yields of the H-M plots were still appreciably lower and also still lower in the wettest year than C and +M yields. It can therefore be concluded from this point of view that contour hedgerows without mulches led to some soil and water conservation and enhanced maize grain yields at the rows next to the hedgerows with respect to what they would have been with only competition and no additional inputs. On the whole, the soil and water conservation benefits are even more masked because of the yield depressions in the middle rows due to higher competition between maize and senna and less additions due to the hedges, if any, as shown in figures (4.146, 4.152 and 4.158) and finally in total yields in Table 44. As we have stated earlier, the total biomass picture is very different. In 1995 it was among the highest and only clearly lost out to H+M in total biomass, while in 1994 was 25% lower than C, +M and H+M but 25% higher than G-M.

Higher yield depressions for cowpea were found in the rows next to the hedgerow, as shown among others in figs. (4.149) and (4.155), and as to their contribution to biomass yields finally in table 43. It can therefore be concluded for cowpea that the soil and water conservation benefits of the hedgerows are counteracted by the yield depressions from cowpea/senna competition. However, in 94/95, the drier of the wettest years, for cowpea, the total biomass picture was very different (Table 28), the H-M treatment scoring as the C plot and better than the +M plot.

5.2.3 Contour hedgerows with crops and mulches.

As can be seen in fig. 4.100 in section 4.5.10 for the maize crop, the mulch and contour hedgerow barrier concentrated runoff water, soil particles and related nutrients at the barrier more than at 1 or 2 m from the barrier into the alley. This contributed to yield increases at the rows of maize near the hedgerow compared to those in the middle of the alley (figs. 4.145, 4.151 and 4.157 in section 4.10). Overall yield reductions in H+M treatment compared to C treatment nevertheless remained, as shown in Table 44. Fig. (4.145) shows in fine structure that for the driest year maize yield totals remained far below sole crop plots. It came above half in the driest of the wetter years (fig. 4.151) and the yield totals for maize grain and biomass came rather close to those of the sole crop plots in 1995 (fig. 4.157). For the total biomass yields H+M was the highest in 1995 while it was among the highest in 1994 (Tables 27 and 29).

As shown in figs. (4.148 and 4.154), cowpea yields were again generally depressed at the rows near the hedgerows, with exceptions occurring in the biomass for some rows in the drier of the wettest years, although moisture and perhaps nutrients were concentrated at these points. For 94/95 we concluded at the end of section 5.1.3

that in this year competition for nutrients caused the (relatively smaller) differences, while for 93/94 this was competition for light, water and nutrients.

Table 5.3. **Review on soil evaporation expressed as a percent of total rainfall**

	Treatment				
Season	C	**+M**	**H+M**	**H-M**	**G-M**
1994	66.3	57.5	56.5	62.6	64.3
1994/95	50.0	46.0	45.5	48.5	49.5
1995	49.0	43.0	42.5	46.0	46.5

When a comparison was made between the water loss via runoff in review Table 5.1 and water loss via soil evaporation in review Table 5.3, it became evident that soil evaporation for the maize as well as the cowpea crop, although somewhat variable, was comparatively larger. Runoff was a relatively small factor (just more than 10% for the worst case in the wettest year) when compared to soil evaporation, which is taking between more than 40% and up to 65% of the total rainfall (Table 5.3). Even when our microlysimeter has overestimated soil evaporation somewhat, this statement remains true.

5.2.4 Grass strips with crops and without mulches.

As shown in fig. 4.102 in section 4.5.10, runoff water, soil particles and related nutrients were very much concentrated at the grass strip and this decreased towards the centre of the grass alley. At the same time, figs. (4.147, 4.153 and 4.159) for the maize crop showed that grain yields were far more depressed near the grass strip than at 1 and particularly than at 2 m from the grass strip. The concentration of inputs by the grass strip barrier at the grass strip does not or hardly benefit the crop near it because of severe competition for water, nutrients and light between crops and grass. Only the middle rows come closer and closer to higher and higher yields with increasing rainfall. In the driest year overall yield comes not further than less than half the low mulched plot yield. In the wetter 1994 it is just under half the much higher yields in the +M plot, and more or less the same is true in the wettest year, with the highest yields and a bit lesser percentage of them. In the total biomass picture G-M is the overall looser.

This yield depression is also witnessed in cowpea in figs. (4.150 and 4.156) in section 4.10 and finally in the total cowpea yields in Table 43. The pictures look a bit like the normal distribution in statistics, with averages for the G-M plots for cowpea grain being just over half that for C plots (with the exception of the driest year, when they are similar) and for cowpea biomass on average just below that. In the total biomass picture it loses heavily, with the exception of the +M plot, from which it loses narrowly. The conclusion drawn from this picture is that whereas grass strips conserve both soil and water through their barrier effects, these benefits are masked by the resulting yield depressions because of the competition for water, nutrients and light between the crop and the grass strip. A recommendation on the use of grass strips would be to leave out the first crop row next to the grass strip, for our results show that very little yield is obtained by keeping this row, particularly in the wetter years. The difference of that row with the highest row yields is no much higher than that of the next outer row and as both grass and cowpea, and of the latter both grain and other biomass, are used, it may not be worth the trouble.

5.3 Mulch and evaporation from the soil

Mulch benefits of soil evaporation are shown in review Table 5.3. The review table shows that mulch somewhat reduced soil evaporation in the mulched plots (+M and H+M) treatments compared to non mulched plots (C, H-M and G-M) respectively. If these soil moisture conservation advantages of mulches would have been higher, they could have partly been responsible for the general yield advantages of H+M and +M treatments over the H-M and G-M treatments (Tables 43 and 44). However, the differences are too small (<10%) to have any but small effects. The largest difference is smaller than 4% of the 1994 rainfall (<10mm), a bit more than 3% of the 1995 rainfall (<10mm) and a bit more than 2% of the 1994/95 rainfall (about 12mm), the last one in a wet year.

5.4 Consequences of on-farm results and their connection with on-station results for farming/cropping systems in Eastern Kenya.

A dilemma faces the farmers in semi-arid Kenya who farm under limiting water availability for crop and pasture production. The semi-arid areas were initially meant for ranching and not for rainfed agriculture. The migrating farmers who have occupied the steeply sloping lands prone to land degradation had no alternative for high quality productive land but to settle in these fragile environments. The existing traditional soil and water management practices have been employed over the past by the farmers to improve on water conservation and soil conservation for increased crop and pasture yields on sloping land. These conservation techniques include structural methods of soil and water conservation, e.g. "Fanya juu" terraces, which though effective in erosion control as shown through higher maize, sorghum and millet yields compared to AF, control, grass strips, trashlines and stone terraces in Table 47, have been put up at high costs. The farmer would therefore be ready to use any conservation technology as successful as "Fanya juu" as long as it is less costly than the existing ones.

Alley cropping, despite its advantages of development of natural terraces over time with minimal costs, provision of mulches for erosion control and/or the provision of fodder for animals during the dry season, has the main disadvantage of competition of the hedgerows for growth resources with the associated crop. This results in reduced grain and biomass yields (but often not in reduced overall total biomass yields) in the already low crop yields in the semi-arid areas. As can be seen from review Table 49, there were cowpea grain yields in senna/cowpea system of the same magnitude on-farm and on-station, while the cowpea biomass yield of the system was higher by 0.6t ha^{-1} on-station than on-farm. The same table shows that cowpea/grass systems resulted in reduced grain yields both on-station and on-farm, with more yield on-station. The F/juu terrace cowpea system on-farm had more grain and biomass yield than the sole cowpea, senna/cowpea and grass/cowpea systems on-farm. There were even grain and biomass yield differences between the on-station and on-farm controls, with the former showing more grain and biomass yield than the latter.

Table 50 for on-farm maize yield shows that the maize grain yields were similar in AF treatment, grass strip and control. This lack of difference in grain yields may be due to the fact that the grass strip and the hedgerows had been heavily browsed by livestock in the previous dry season. This table also shows that there was somewhat more maize biomass yield in the senna/maize system than in sole maize or maize/grass systems. When these yields of about 1 t ha^{-1} were compared with maize yields from Katumani research centre (e.g. Nadar and Faught, 1984b) and ICRAF research station (e.g Howard et al. 1995), grown on slightly sloping land and using fertilizers, of over 3 t ha^{-1} they were found to be appreciably lower. Furthermore, comparison of maize grain yields on-station and on-farm, in review Table 51, clearly shows that whereas 1995 maize grain yields were all over higher on-station than on-farm, maize biomass was higher on-station than on-farm in sole maize and senna/maize systems but similar in the grass/ maize systems. There were grain and biomass yield reductions resulting from the use of *Senna*/maize and grass/maize systems in both years on-station while percentually and absolutely these differences were smaller on-farm for grain and very much smaller for biomass.

From the on-farm yield data on both cowpea and maize as shown in Tables 45, 46 and 47, the F/Juu terraces sometimes to a somewhat less extent stone terraces and occasionally partially the trash lines show a clear cut advantage on yields when compared to the *Senna*, *Gliricidia*, *Leucaena* or even the *Panicum maximum* grass strip, basically because of lack of competition for water, nutrients and light in the "Fanya juu", stone and trashline terraces, the latter building up to a lesser extent. These data show that the soil conservation techniques used by the farmer, with the exception of the grass strip, conserve soil and moisture and enhance crop yields. The agroforestry techniques of soil erosion control and moisture conservation using tree shrubs are quite effective in erosion control, especially when combined with mulch (Table 5.1). The on-farm results also confirm that the major drawback with the use of agroforestry as erosion control and water conservation structures is yield depressions resulting from trees that form relatively low amounts of biomass but are still competing with the associated crops in semi-arid areas of limiting rainfall, with already low crop yields. Because of the yield depressions, our hypothesis "that alley cropping with on-surface mulching sufficiently conserved soil, soil water and soil fertility to obtain yields that will not decline over time under equal soil water conditions" will only apply in the long run to H+M plots like ours. A comparable statement for mulch or barrier alone appears to have limited application in the cases of +M, H-M and G-M treatments in our system under our conditions. The soil loss and runoff are substantially controlled for soil and water conservation and the microclimate improved, via the use of hedgerows and mulches in H+M, and crop yields, though perhaps at a lower level, can be sustained in the long run. If an H+M system would be used in Machakos for twenty years, soil loss would be negligible or extremely low (Table 5.1). The water + inputs from the water (soil particles and nutrients) + inputs from the decomposing mulch would guarantee a minimum fertility, somewhat fluctuating but not deteriorating, against the competition that, averaged over severall years, would guarantee total biomass yields of certain level, including grain yields.

A compromise may therefore be necessary, in order to accommodate the issue of reduced crop yields with the use of alley cropping, between the advantages of erosion control from hedgerow barriers and mulch obtained from the hedgerows and the provision of for example fodder for the animals or other ecnomic use of course. When the hedgerows are partly pruned pruned for fodder, the hedgerows do contribute less to soil fertility and erosion protection through mulch, but the hedgerows help build up natural contour barriers for erosion control without extra cost and water particles and nutrients are redistributed. However, always, so much mulch should remain to keep T below the acceptable level. For our slopes and soils this level appeared to be about 2 t ha^{-1}. The most suitable hedgerow trees will therefore be those with highest output, for which water and nutrients are obtained from layers with least roots from the associated crop(s), and of which the prunings are showing highest protection against soil erosion, highest contribution to soil fertility and highest nutrinational values for those amounts that may be used for fodder or highest other values (or other economic purposes) without jeopardising soil protection so much that values of soil loss and runoff become higher than tolerated.

5.5 Weather advisories

From the total figures on rainfall and their distribution (figs. 4.1-4.6) on-station, two of the rainy seasons had rainfall below average. Out of these two seasons, 1993 was a real crop failure with very (low yields) while 1994 resulted in just rather low grain and biomass yields as shown in Table 44. From the six seasons of on-station study, the short rains were wetter and more reliable than the long rains. Since Katumani maize would do better with more rain (Table 44) than cowpea (Table 43), which is prone to disease attack under very wet conditions, it is advisable that maize is grown during the short wetter and more reliable seasons and cowpea is grown in long rains with less rainfall.

The rainfall data from on-farm research are rather poorly kept because of the lack of a systematic way of rainfall data collection. It was difficult to get rainfall data for the short rains of 93/94 and the long rains of 1994, although yield data showed 93/94 was a good season, while crop failure was recorded in 1994. From the four years of yield data patterns and from the available rainfall data for the short rains of 94/95 and long rains of 1995 on Kakuyuni catchment, it appears (from this "time limited" on-farm study) that rainfall fails on average something as one out of every two seasons. This confirms why government famine reliefs are a common feature in this area. Our observations show that 1994 was an outright crop failure while data on rainfall in fig. 4.146 and yield data in Table 47 show that 1995 long rains were a near crop failure if the poorly distributed rainfall was not supplemented (water harvesting) with rain water from roads and use if no drought tolerant crops had been used.

It is therefore advisable to the farmers to plough early and plant early, following scientific methods developed to determine appropriate planting times or being "in time" advised on such dates by an agrometeorological service or advisory team operating regionally (Onyewotu, 1996). This is in order to take advantage of the early showers of rainfall and reduce the chances of a crop failure when the rainfall is after all below average and poorly distributed over the seasons. Farmers are further advised to make use of drought tolerant plant cultivars that have been specifically bred and tailored to give reasonable yields under limiting rainfall conditions. Because the aim is to minimise soil and water losses and maximise use of the limited rainfall, farmers on sloping land are advised to continue to (i) make use of appropriate tillage techniques which enhance water infiltration, (ii) use water harvesting techniques from external catchments such as roads, which increase water available to the plant, (iii) use soil and water conservation structures, including AF with promising trees, which control and reduce soil loss and water runoff and retain soil as well as water for use by the crop. This may make the on-farm productivity sustainable. In this thesis it was shown on-station for maize yields (table 44) that the H+M treatment can be sustained in the long run. This has been shown elsewhere as the case (Nelson et. al. 1997). The effective reduction of soil loss by the H+M to below T value over the seasons and the water conserved resulted in accompanying sustainable maize grain yields of upto 2 t ha^{-1} (table 44). For example compromising between the use of sufficient mulch from the hedgerow for soil and water loss control and loss of some yields through AF cometition may in the long run be accetable to the farmer.

The estimates on soil evaporation show that it is a major factor in the water balance equation, for it takes a high percentage of the limited rainfall in the semi-arid areas (Table 5.3). The study also shows that mulching with senna biomass affordable/available is most of the time effective in reducing soil erosion and runoff (Table 5.1), but not evaporation. Farmers are advised to make use of any technique, such as the use of biomass mulch, windbreaks, "artificial" mulches, zero tillage and self mulching etc. to minimise soil evaporation without negatively affecting crop yields. Positive influences on soil fertility from decomposing mulches or other organic material may be an advantage.

Finally, proper making and keeping of rainfall records is advisable in the semi-arid areas of Kenya. This would enable enable farmers to get better sowing dates, to get an idea on the character of the ongoing seasons and to plan and make use of creating (strategic) food reserves during years of bumper harvests for use in years of crop failures. This would reduce dependence on government famine reliefs. Also the economic use of yields would improve this way. Our approach could be part of what Stewart (1991) called response farming.

5.2.6 Further research

The following is proposed for further research particularly on sloping lands, on-station as well as on-farm:

i) root studies to (a) clearly separate below ground from above ground competition, which was shown to be crucial in this study for example for the hedges and for the grass strip, where competition between the hedge/grass and the crop was very severe; (b) determine differences between crop rooting patterns as a function of soil water. This may help in explaining the yield differences in systems from differences in competition potential, as well as shed more light on factors determining root distributions.

ii) identify more drought tolerant, less competitive and higher yielding treess/shrubs, preferably with an economic potential, for use in the semi-arid areas, together with crop varieties suited to the semi-arid areas as Senna competed rather heavily with the associated crops for growth resources when grown as a hedgerow, reducing the crops yields.

(iii) quantify (a) nutrient losses through runoff and soil losses since erosion removes the top soil which contains plant nutrients and can lead to lower crop yields; (b) nutrient distributions in the field related to the water and soil conserving properties of hedgerows; (c) nutrient contributions from decomposing mulches on the surface.

(iv) carefully monitor in addition to the root studies, the yield depressions on a per row basis for different trees/crop combinations at the on-farm level on sloping lands with a view to understanding better rooting and light competitions.

(v) study the "fixed" alley width of 4 m that has contributed to the low rate of alley cropping technology adoption and transfer. However, the conserving properties may be expected to considerably reduce at larger width also because even less mulch will become available. Hence a need arises for research on appropriate width and ploughing methods which will be compatible with the farmers requirements of using oxen for ploughing and weeding to save on labour but not necessarily with large spacing of alleys.

(vi) examine critically the method used to determine soil evaporation losses, particularly during rainy and dry days when the microlysimeters no longer represent the surrounding conditions, because of the large portion of soil water used up in inefficient soil evaporation

(vii) examine critically the sampling with ceptometers, at a higher frequency and with more replicates in order to what is needed to get a representative daily measure of PAR interception during a plant's growth period, also improving light use efficiency computations.

(viii) critically examine the way TDR soil moisture measurements can properly replace neutron probe soil moisture measurements in the top soil and determine the most suitable access tube density for an appropriate averaging of soil moisture content by neutron probe in an inhomogeneous environment as sloping alley.

CHAPTER 6.

REFERENCES

Acland, J.D. (1971). East african crops. An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda. FAO, Rome, Italy. 252pp.

Acheampong, E., Duguna, B., Heineman, A.M., Kamara, C.S., Kiepe, P. Kwesiga, F., Ong, C.K, Otieno, H.J. and Rao, M.R. (1992). A synthesis of ICRAF'S research on alley cropping. Paper presented at an alley farming conference. IITA. Ibadan. Nigeria.

Adams, J.E. (1966). Influence of mulches on runoff, erosion and moisture depletion. Soil Sci. Soc. Americ. Proc. 30: 110-114.

Agassi, M., and Levy, G.J.(1991). Stone cover and rainfall intensity effects on infiltration, erosion and water splash. Aust. J. Soil Res. 29: 565-575.

Ahn, P.M. (1975). Erosion hazards and farming systems in East Africa. In: Soil conservation and management in the humid Tropics. D.J. Greenland and R, Lal. (eds). 165-176pp

Allan, L. (1988). Farm household economics and the design and impact of biological research in Southern Africa. Agric. Admin. Ext. 29: 23-34.

Allen, S.J. (1990). Measurement and estimation of evaporation from soil under sparse barley crops in Northern Syria. Agric. For. Meteorol. 49: 291-309.

Andrews, R.E. and Newman, E.I. (1970). Root density and competition for nutrients. Oecol. Plant. 5: 319-334.

Andriesse, J.P.(1987). Monitoring project of nutrient cycling soils used for shifting cultivation under various climatic conditions in Asia. Final report. Joint KIT/EEC projects TSD-A-116-NL. Royal Tropical Institute Amsterdam. The Netherlands, 141pp.

Angus, J.S., Hasegawa, S., Hsiao, T.C., Liboon, S.P, and Zandstra. (1983). The water balance of post monsoonal dryland crops. J. Agric. Sci.(Cambridge) 101: 699-710.

Ball, B. (1985). Root distribution and nutrient cycling of some tree-shrubs suitable for alley cropping in the humid tropics. MSc.thesis, Faculty of Graduate studies. Universityof Guelph, Canada. 268pp.

Bandy, C.K. and Stigter, C.J. (1997). Agronomy of multiple cropping in warm climates. In press.

Barber, R.G. and Thomas, D.B. (1979). Measurement of soil loss and runoff from simulated rain storm at Kabete, Katumani and Iiuni. Paper presented to the third annual general meeting of the soil science society of East Africa, Nairobi.

Barber, R.G., Thomas, D.B. and Moore, T.R. (1979). The erodibility of two soils from Kenya. J. Soil Sci. 30: 579-591.

Barnett, A.P., Disker, E.B. and Richardson, E.C.(1967). Evaluation of mulching methods for erosion control on nearly prepared and seeded highway backslope. Agron. J. 59: 83-85.

Bashir, N. (1988). A study of alley cropping maize and green grams with Leucaena leucocephala at Mtwapa Coast Province, Kenya. MSc. Thesis Department of Crop Science, University of Nairobi, Kenya. 113pp.

Bashir, N., Getahun, A. and Ngugi, D.N. (1991). Shading effects of alley cropped Leucaena leucocephala on weed biomass and maize yield at Mtwapa, Coast Province, Kenya. Agrof. Syst.13: 1-11.

Beadle, C.L. and Lag, S.P.(1985). Photosynthesis. Is it limited in biomass production. Biomass 8: 119-168.

Bley, J., Van der Ploeg, R.R., Sivakumar, M.V.K. and Allison, B.E. (1991). A risk-propability map for millet production in south west Niger. In: Soil water balance in the Sudano-Sahelian zone. Proc. Niamey Workshop, February 1991. M.V.K Sivakumar, J.S. Wallace, C, Renard and C, Giroux.(eds). IAHS publ. No.199. 571-581pp

Blomley, T. (1994). Indigenous agroforestry *Melia volkensii* in Kenya. In: Agroforestry Today 6: (4) 10-11.

Bohringer, A. (1991). The potential of alley cropping as a labour efficient management option to control weeds. A hypothetical case. Paper presented at the Department of Agronomy and Soil Science, University of Hawawii, Honolulu, USA.

Bohringer, A. and Cadwell, R. (1989). *Cajanus Cajan* (L) as a potential agroforestry component in Eastern Province of Zambia. Agrofor. Syst. 9: 127-140.

Bowen, G.D. (1985). Attributes of trees as crop plants. In: M.G.R. Cannel and J.E Jackson (Eds.). Institute of Terrestrial Ecology, Natural environmental Research Council, 592pp.

Bowen, G.D. (1964). Root distribution of *Pinus radiata*. CSIRO. Aust. Div. Soils Tech. Rep. No 1/64 Adelaide, 14pp.

Bradford, J.M. and Huang, C. (1995). Splash and detachment by water drops. In: M. Agassi (ed). Soil erosion, conservation and rehabilitation. Marcel Dekker, Inc. New York U.S.A.

Braun, H.M.H. (1977). The reliability of the rain seasons in Machakos and Kitui Districts. Misc. Paper M12, Kenya Soil Survey, National Agricultural Laboratories, Nairobi, Kenya.

Bryan, W.B. and Pera, S.A. (1988). Effects of planting sequence and time, and nitrogen on maize legume intercrop yield. J. Agron. and Crop. Sci. 161: 17-22.

Budelman, A. (1989). The performance of selected leaf mulches in temperature reduction and moisture conservation in the upper soil stratum. Agrofor. Syt 8: 53-66.

Bussiere, F. and Cellier, P. (1994). Modification of soil temperature and water content regimes by a crop residue mulch: Experiment and modelling. Agric. For. Meteorol. 68: 1-28.

Cannel, M.G.R., Milne, R., Sheppard, L.R. and Unsworth, M.H. (1987). Radiation interception and productivity of willow. J. Appl. Ecol. 24: 261-278.

Carl, F.J. (1985). Nutrient cycling in tropical forest ecosystems. John Wiley and Sons, Chichester, U.K. 190pp

Carter, J. (1995). Alley farming: Have resource poor farmers benefitted. Natural resource perspectives. No 3. Overseas Development Institute (ODI). U.K.

Central Bureau of Statistics. National Development plans 1978-83, 1984-1988, 1989-1993, Nairobi, Kenya.

Chambers, R. (1983). Rural development: putting the last first. Harlow, Longman, U.K. 246pp

Chase, R.G. and Boudouresque, E. (1987). A study of the methods for the revegetation of barren crusted Sahelian forest soils. Proc. Intern. Workshop 7-11 Jan., ICRISAT Sahelian Centre, Niamey, Niger.

Coe, R. (1994). Through the looking glass: 10 common problems

in alley cropping. In: Agroforestry Today. 6: (1) 9-11.

Cooper, P.J., Keatinge, J.D.H., and Hughes, G., (1983). Crop evapotranspiration - a technique for calculating its omponents by field measurements. Field Crops Res. 7: 299-312.

Corlett, J.E., Black, C.R., Ong, C.K. and Monteith, J.L. (1992). Above and below ground interactions in a Leucaena/millet alley cropping system. Light interception and dry matter production. Agric. For. Meteorol. 60: 73-91.

Coulson, C.L. (1985). Radiant energy conversion in three cultivars of *Phasiolus vulgaris*. Agric. For. Meteorol. 35: 21-29.

Critchely, W.R.S., Reij, C. and Willocks T.J. (1994). Indigenous soil and water conservation: A review of the state of knowledge and prospects for building on traditions. Land degrad. and rehab. 5: 293-314.

Daamen, C.C., Simmons, L.P., Wallace, J.S., Laryea, K.B. and Sivakumar, M.V.K. (1993). Use of microlysimeters to measure evaporation from sandy soils. Agric. For. Meteorol. J. 65: 159-173.

Davies, J.W.(1975). Mulching effects on plant climate and yield. WMO-No. 388, Technical note NO.136, WMO, Geneva.

Dent, D. and Young, A. (1981). Soil survey and land evaluation. Allen and Unwin, London, U.K. 278pp

Dowkers, D.M. (1971). A note on the reduction in the yield of Taboran maize by late planting. E. Afr. Agr. For. J. 1: 33-34.

Duley, F.L. and Hayes, O.E. (1932). The effects of the degrees in slope on runoff and soil erosion: J. Agric. Res. 45: 349-360.

Dunne, T., Dietrich, W.E. and Brunengo, M. J. (1978). Recent and past rates of erosion in semi-arid Kenya. Geomorphol. suppl. 29: 99-100.

Ekwue, E.I. (1990). Effect of organic matter on splash detachment and the process involved. Earth Surf. Process. Land Forms 15: 175-181.

Elwell, H.A. (1980). Design of safe rotational systems. Department of conservation and extension, Harare, Zimbabwe, 50pp.

Elwell, H.A. and Stocking, M. (1974). Rainfall parameters and a cover model to predict runoff and soil loss from grazing trials in the Rhodesian sandveld. Proc. Grassl. Soc. South Africa 9: 157-164.

Elwell, H.A., and Stocking, M.A. (1976). Vegetation cover to estimate soil erosion hazard in Rhodesia. Geoderma 15: 61-70.

Elwell, H.A., and Stocking, M.A. (1982). Developing a simple yet practical method of soil loss estimation. Trop. Agric. (Trinidad) 59: 43-48.

Fajemisin, J.M. and Olaniyan, G.O. (1976). Exploiting weather variability for the improvement in the level and efficiency of maize production in Nigeria. WMO-No.481. Secretariat of the World Meteorological Organisation (ed.). Proceedings of the Symposium on the agrometeorology of the maize (corn) Iowa State University U.S.A. 5-9 July 1976.

FAO (1993). Agroecological assessment for national planning the example of Kenya. Soils Bulletin No. 67. Rome,Italy.

FAO/UNESCO, (1988). Soil map of the world 1:5.000.000. Revised legend. FAO. Rome.

FAO. (1984). Irrigation and water drainage Paper No. 24. Crop and water requirements. Rome, Italy.

Fetcher, J., Allison, B.E., Sivakumar, M.V.K. Van der Ploeg, R.R. and Bley, J. (1991). An evaluation of the SWARTER and CERES with millet models for south west Niger. In: Soil water balace in the Sudano-Sahelian zone. (Proc. Niamey Workshop, February, 1991). M.V.K. Sivakumar, J.S wallace, C. Renard and C. Gioux.(eds). pp 505-513.

Fissiha, T.W. (1983). The effects of narrow grass strips in ontrolling soil erosion and runoff on sloping lands. MSc. Thesis. Department of Agricultural Engineering, University of Nairobi, Kenya. 140pp.

Foster, G.R., Young, R.A., Romkens, M.J.M. and Onstad, C.A. (1985). Processes of soil erosion by water. In: R.F Follet and B.A Stewart (eds). Soil erosion and crop productivity. American Society of Agronomy, Inc., Crop Science Society of America, Inc. Soil Science Society of America, Inc., Madison, Winconsin, U.S.A. 533pp

Foster, G.R. and Lane, L.J.(1987). User requirements, U.S.D.A- Water erosion Prediction Project (WEPP). NSRL report No.1. National Soil Erosion Research Laboratory, West Lafayette, I.N., U.S.A.

Fujisaka, S. (1993). A case of farmer adaptation and adoption of contour hedgerows for soil conservation. Expl. Agric. 29: 97.-105.

Gabreels, B and Vogtlander, A. (1993). Soil moisture measuremnt with Time Domain Reflectometry. Test of Polish Easy Test TDR system for Tropical soil conditions in Kenya. Report to the TTMI-Project. Department of Geography University of Gronigen and Department of Meteorology, Wageningen Agricultural University, The Netherlands.

Gachene, C.K.K. (1986). Nutrient losses in eroded soil materials from some Kenyan soils. In: D.B Thomas, E.K Biamah, A.M. Kilewe, L. Lundgren and B.O Mochoge (eds.), Soil and water conservation in Kenya. Proceedings of the third national soil and water conservation workshop. Kabete, Kenya.

Gachene, C.K.K. (1995). Effect of soil erosion on soil properties and crop response in Central, Kenya. Ph.D. Thesis. Department of Soil Science, University of Uppsala, Sweden. 198pp.

Gardner, C.M.K., Bell, J.P., Cooper, J.D., Dean, T.J., Gardner, N., and Hodnett, M.G. (1991). Soil water content. K.A. Smith, and C.E. Mullins (eds.). In: Soil analysis physical methods. Marcel Dekker, New York, U.S.A, 1-73.

Gichuki, F.N. (1991). Conservation profile. In: M. Mortimore (ed.). Environmental change and dryland management in Machakos District, Kenya (1930-1990). ODI working paper 56. U.K.

Gifford, R.M. (1974). A comparison of potential photosynthesis, productivity and yield of plant species with differing photosynthetic metabolism. Aust. J. Plant Physio. 1: 107-117.

Gollany, H.T., Schumacher, T.E., Evenson, P.D., Linstrom, M.J. and Lemmen, G.D. (1991). Aggragate stability of eroded and desurfaced typic Argiustall. Soil Sci. Soc Am. 55: 811-816.

Gomez, K.A. and Gomez, A.A. (1984). Statistical procedures for Agricultural Research. 2nd Edition. International Institute for Rice Research. John Wiley ans Sons, Singapore. 680pp.

Gosse, G., Varlet-Grancher, C., Bonhomme, R., Chartier, M., Allirand, J.M and Lemaire, G.(1986). Production maximale de matière sèche et rayonnement solaire intercepté par un couvert végétal. Agronomie, 6: 47-56

Government of Kenya, (1986b). Sessional paper No.1. On economic management for renewed growth. Nairobi, Kenya.

Government of Kenya, (1994). Sessional paper No.2. On National food policy. Kenya Government printers. Nairobi, Kenya. 56pp

Government of Kenya, (1981). On National Food Policy. Government Printers. Nairobi, Kenya.

Government of Kenya 1983. National development plan 1978-1983. Government printers, Nairobi, Kenya.

Government of Kenya (1986a). The Agriculture Act revised edition Chapter. 318 of the laws of Kenya. Government printer, Nairobi, Kenya.

Greacen, E.L. (1981). Soil water assessment by the neutron probe. Division of soils, CSIRO Aldelaide, Australia.140pp.

Greb, B.W., Smika, D.E. and Black, A.L. (1967). Effect of straw mulch rates on soil water storage during summer fallow in the great plains. Soil Sci. Soc. Americ. Proc. 31: 556-559.

Gregory, P.J. (1989). Relation between growth and water use. Water use efficiency. In: Soil, crop and water management systems for rain fed agriculture in the Sudano-Sahelian Zone: Proc. of an International workshop. 7-11 Jan 1987. ICRISAT, Niamey, Niger.

Gregory, P.J.(1987). Root growth of legume crops (*Cicer arietinum, Lens culinars, Pisum sativam and Vicia faba*) and effects of water and salt stress. In: World crops: Cool season food legumes R.J. Summerfield (ed.). Dortrecht, Netherlands. Martinus Nijhoff.

Gregory, P.J. and Squire, G.R.(1979). Irrigation effects on roots and shoots of pearl millet (Pennisetum typhoides). Xpl. Agric. 15: 161-168.

Hall, D.O. (1979). Solar energy use through biology-Past, present and future. Solar energy 22: 307-328.

Harcombe, P. (1977). Soil nutrient loss as factor in early tropical secondary succession. Biotr. Suppl. 12: 8-15.

Hoekstra, D.A., Torres, F., Raintree, J.B., Danhofer, T., and Kariuki, E. (1984). Agroforestry systems for the semi-arid areas of Machakos District, Kenya.

Hogberg, P. and Kvarnstorm, M. (1982). Nitrogen fixation by the woody legume *Leucaena leucocephala* in Tanzania. Plant & Soil 66: 21-28.

Howard, S.B., Ong, C.K., Rao, M.R., Mathuva, M. and Black, C.R.(1995). The partitioning of light and water in Leucaena-maize agroforestry systems. In: Ecophysiology of tropical intercropping. (Eds) HerveSinoquet and Pablo Cruz. INRA, Paris, France. 123-135pp

Huang, C., Bradford, J.M., and Cushman, J.H. (1983). A numerical study of the raindrop impact phenomenon: The elastic deformation case. Soil Sci. Soc. Am. 47: 855-861.

Huang, C., Bradford, J.M. and Cushman, J.H (1982). A numerical study of raindrop impact phenomenon: The Rigid case. Soil Sci. Soc. Am. J. 46: 14-19.

Hudson, N. (1971). Soil conservation. Batsford, London, U.K. 320pp.

Hughes, G., Keating, J.D.H. and Scott, S.P.(1981).Pigeon peas as a dry season crop in Trinidad, West Indies. Interception and utilisation of solar radiation. Tropical Agriculture. 58: 191-199.

Hughes, G., Keatinge, J.D.H., Cooper, P.J.M. and Dee, N.F. (1987). Solar radiation interception and utilisation by (*Cicer arietinum L.*) chickpea. Crops in northern Syria. J. Agri. Sc. (Cambridge). 108: 419-424.

Ibrahim, A.I. (1992). Water use efficiency of dura and groundnut under traditional and non-traditional irrigation practices in the Gezira scheme, Sudan. PhD Thesis, Department of Environmental Sciences and Natural esources, University of Gezira, Wad medani, Sudan. 360pp.

Ikeorgu, J.E.G, Ezumah, H.C. and Wahua, T.A.T. (1989). Productivity of species in cassava/maize, okra/egusi melon complex mixtures in Nigeria. Field Crops Res. 21: 1-7.

Ikombo, B.M. (1984). Effects of farmyard manure and fertilizers in semi-arid areas of Eastern Kenya. E. Afr. ric. For. J. 44: 266-274.

Ikombo, B.M. (1989). Phosphorus nutrition of tropical crop legumes. PhD. Thesis, University of Queensland. Australia. 268pp

Itabari, J.K., Gregory, P.J. and Jones, R.R. (1993). Effects of temperature, soil and water status and depth of planting on germination and emergence of maize (*Zea mays*) adapted to semi-arid Eastern Kenya. Expl. Agric.29: 351-364.

Jaetzzold, R. and Schmidt, H. (1983). Farm management Hand book of Kenya. Vol. 2: Natural conditions and Farm management information. East Kenya (Eastern and Coast Provinces). Ministry of Agriculture, Nairobi, Kenya.

Jain, H.K. (1975). Development of high yielding varieties of pulses: Perspective, possibilities and experimental approaches. In: International Workshop on grain legumes, ICRISAT, Hyderabad, India. 177-185pp.

Jenik, J. (1978). Roots and root systems in tropical trees: morphologic and ecological aspects. In: P. Tomlison and M. Zimmerman (Eds), Tropical trees and living systems. Camb. Univ. Press, Cambridge. 323-349pp.

Jennings, G.D. and Jarret, A.R. (1985). Laboratory Evaluation of mulches in reducing erosion. Amer. Soc. Agr. Eng. 28 (5): 1466-1470.

Johnsson, K. L., Fidjeland, L., Maghembe, J.A. and Hogberg, P. (1988). The vertical distribution of fine roots of five tree species and maize in Morogoro Tanzania. Agrofor. Syst. 6: 63-69.

Julie, I. (1990). The role of trees in maintaining and improving soil productivity: A review of literature. In: R.T. Prinsley (ed.). Agroforestry for sustainable production. Economic implications. Commonwealth Secretariat publications, Marlborough House, London. U.K.

Kang, B.T., Wilson, G.F. and Sipkons, L. (1981). Alley cropping maize (Zea mays) and leucaena in southern Nigeria. Plant & Soil. 63: 165-197.

Keulen, H. Van., Goudriaan, J. and Seligman, N.G.(1990.). Modelling the effects of nitrogen on canopy development and crop growth. In: G. Russel, B. Marshall and P.G. Jarvis (eds). Plant canopies: their growth, form and function. Cambridge University press, Cambridge, U.K. pp83-99.

Khatibu, A.I., Lal, R. and Jana, R.R. (1984). Effects of tillage and mulching on erosion and physical properties of a sandy clay loam in an equatorial humid region. Field Crops Res. 8: 239-254.

Kibe, J.M., Ochung, H. and Macharia, P.N. (1981). Soils and vegetation of the ICRAF experimental Farm (Machakos District). Ministry of Agriculture. National Agricultural Laboratories. Kenya Soil Survey. Detailed Soil Survey Report No. D 23.

Kiepe, P. (1995). No Runoff, no soil loss: Soil and water conservation in hedgerow barrier systems. Ph.D thesis. Wageningen Agricultural University, The Netherlands. 114pp

Kilewe, A.M. and Ulsaker, L.G. (1984). Soil physical characteristics and their application to agriculture. E. Afr. Agric. For. J. 44: 247-255.

Kilewe, A.M. (1985). Measurement and prediction of soil erosion in Kiambu and Muranga Districts of Kenya National Environmental Secretariat. Ministry of Environment and Natural Resources, Nairobi, Kenya. 18pp

Kilewe, A.M. (1989). Soil and water management. National research priorities. Proc. of the Third National Workshop, Kabete, Nairobi, 16-19 September, 1986. D.B. Thomas, E.K. Biamah, A.M. Kilewe, L. Lundgren and B.O. Mochoge (eds). 539-551pp.

Kilewe, A.M. (1987). Prediction of erosion rates and the effects of topsoil thickness on soil productivity. Ph.D. Thesis, Department of Soil Science, University of Nairobi, Nairobi, Kenya. 294pp.

Kinama, J.M. (1990). Land degradation in the semi-arid areas of Kenya. The case of Katumani/Kimutwa area near Machakos Town, Kenya. MSc. dissertation, University of East Anglia, U.K. 48pp.

Kinama, J.M. (1992). The develoment of animal drawn implements in the semi-arid areas of Eastern Kenya. A review paper presented at the First Animal Traction for Eastern and Southern Africa Workshop (ATNESA) held from 11th - 23rd January, 1992. LUSAKA, ZAMBIA. pp 12.

Kinama, J.M., Ng'ang'a, J.K, Stigter, C.J., Torquebiau, E. and Gichuki, F.N. (1995). The effects of microclimate, soil and water conservation and competition of contour hedgerows (alley cropping) on sloping lands for sustainable land use in Machakos district, Kenya. In: C.J Stigter, F.N. Wangati, J.K. Ng'ang'a, and D.N. Mungai (eds.) The TTMI - Project and the Picnic model. An internal evaluation of approaches and results and prospects for TTMI- units. Proc. of TTMI workshop, April, 1994, Nairobi, Kenya.

Kramer, P.J. and Boyer, J.S. (1995). Water relations of plants and soils . Academic press, San Diego, U.S.A. 495pp.

Kristensen, K.J. (1973). Depth interval and top moisture measurement with the neutron probe. Nordic Hydrol. 4: 77-83.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S.,Kohl, K.D.(1991). WEPP soil erodibility experiments for rangeland and cropland soils. J. Soil Conservation 46: 39-44.

Lal, R. (1989). Agroforestry systems in soil surface management of a Tropical soil. Agrofor. Syst. 8: 7-29.

Lal, R. (1988). Minitoring soil erosion impact on crop productivity (187-200pp). In: R. Lal (ed). Soil erosion research methods. 244pp.

Lal, R. (1990). Soil erosion in the Tropics. Principles and Management. McGraw-Hill, Inc. New York, U.S.A. 580pp.

Lal, R. (1991). Myths and scientific realities of agroforestry as a strategy for sustainable management for soils in the Tropics. In: Stewart, J.I. (Ed.), Advances in soil science Vol. 15: 91-137.

Lal, R. (1987). Managing the soils of sub-saharan Africa. Science, 236: 1072.

Lal, R. (1976b). Soil erosion on alfisols in Western Nigeria. II. Effects of mulch rates Geoderma 16: 377-387.

Lal, R. (1976a). Soil erosion on Alfisols in Western Nigeria. Effects of slope, crop rotation and residue management. Geoderma 16: 363-375.

Lal, R. (1981). Soil erosion problems on alfisols in western Nigeria. Effects of erosion on experimental plots. Geoderma, 25: 215-230.

Lang, R.D. (1979). The effect of ground cover on surface runoff from experimental plots. Journal of the soil conservation service of New south Wales, 35:100-114.

Le Bissonais, Y. (1995). Soil characteristics and aggragate stability. In: M. Agassi (Ed). Soil erosion, conservation and rehabilitation. Marcel Dekker, Inc. New york, U.S.A.

Legg, B.J., Day, W., Lawlor, D.W. and Parkinson, K.J. (1979). The effects of drought on barley growth: models and measurements showing the relative importance of leaf aea and photosynthetic rate. J. Agric. Sc. 92: 702-716.

Ling, A.H. and Robertson, G.W. (1982). Reflection coefficient of some tropical vegetation covers. Agric. Met. 27: 141-144.

Pleuning, R., Condon, A.G., Dunin, F.X., Zegelin, S. and Denmead, O.T. (1994). Rainfall interception and evaporation from soil below a wheat canopy. Agric. For. Meteorol. 67: 221-238.

Mannering, J.V. and Meyer, L.D. (1963). The effects of various rates of surface mulch on infiltration and erosion. Soil. Sci. Soc. Americ. Proc. 27: 84-86.

Marimi, P.M. (1979). The effects of some tillage methods and cropping systems in conserving rainfall in a semi-arid area of Eastern Kenya. Proc. of Soil and Water Conservation Workshop, Kabete, University of Nairobi, Nairobi, Kenya.

Marshall, B. and Willey, R.W.(1983). Radiation interception and growth in an intercrop of pearl millet-groundnut. Field Crops Res. 7: 141-160.

Mbithi, P.M. and Barnes, C. (1973). The squatter problem in the context of rural development in Kenya. Institute for development studies, University of Nairobi, Kenya.

Mbuvi P.J. and Van de Weg, R.F. (1975). Some preliminary notes on the soils of Katumani, Kampi-ya-mawe, Embu and Murinduko Agricultural Research Stations. Report No. P25, Kenya Soil Survey, Nairobi.

McCormak, D.E., Young, K.k, and Kimberlin, L.W.(1982). Current criteria for determining soil loss tolerance. In: B. L. Schmidt, R.R. Allmaras, J.V. Mannering and R.I. Papendick (Eds). Determinants of soil tolerance. Spec. Pub. 45. American society of agronomy and Soil Science Society of America. Madison. U.S.A., pp95-111.

Mclntyre, B.D., Riha, S.J. and Ong, C.K. (1996). Light interception and evapotranspiration in hedgerow agroforestry systems. Agric. and For. meteorol. 81:31-40.

Meyer, L.D., Johnson, C.B. and Foster, G.R. (1972). Stone and woodchip mulches for erosion control on construction sites. J. Soil Water Conserv. 27(6): 264-272.

Meyer, L.D., Wischmeir, W.H. and Foster, G.R. (1970). Mulch rates required for erosion control on steep slopes. Soil. Sci. Soc. Americ. Proc. 34: 928-931.

Monteith, J. L. (1977). Climate and efficiency of crop production in Britain. Phil. Trans. Royal Soc. London. Ser. B. 281: 277-94.

Monteith, J.L., Ong, C.K. and Corlett, J.E. (1991). Microclimatic interactions in agroforestry systems. Forest Ecol. and Managem. 45: 31-44.

Moore, T.R. (1978). An initial assessment of rainfall erosivity in East Africa. University of Nairobi, Faculty of Agriculture, Department of Soil Science, Technical Communication No. 11, Nairobi, Kenya.

Morris, R.A., Villegas, A.N., Polthanee, A., and Centeno, H.S. (1990). Water use by monocropped and intercropped cowpea and sorghum grown after rice. Agron. J. 82: 664-668.

Mortimore, M., Tiffen, M., and Gichuki, F. (1993). Sustainable growth in Machakos. ILELA Newsletter 9:(4) 6-10.

Moss, J.R. (1992). Measuring light interception and the efficiency of light utilisation by the coconut palm (Cocos nucifera). Expl. Agric. 28: 273-285.

Moss, A.J. and Green, T.W. (1987). Erosive effects of the large water drops that fall from plants. Austr. J. Soil Res. 25: 9-20.

Mstat-C version 1. (1990). Mstat Development team, Michigan State University (MSU). Michigan, U.S.A.

Muchena, F.N. (1986). Soil fertility constraints in improving cereal yields in soils of the arid and semi-arid areas of Kenya. Paper presented at Organisation of African Unity (OAU) Drought Symposium held at Kenyatta International Conference Centre May, 1986, Nairobi, Kenya.

Mugendi, D.N., Mochoge, B.O., Coulson, C.L., Stigter, C.J. and arap Sang, F.K. (1994). Decomposition of Cassia siamea loppings in semi-arid Machakos, Kenya. Arid Soil Res. Rehabil. 8: 363-372.

Mugendi, D. N. (1990). Plant nutrient aspects of mulch incorporation in alley cropping trials on semi-arid Machakos, Kenya. MSc thesis. Department of crop Science. University of Nairobi. 85pp.

ule, H.M. (1984). Keynote speech. E. Afr. Agric. For. J.4: 5-8.

Mungai, D.N., Stigter, C.J., Ng'ang'a, J.K. and Coulson, C.L. (1996a). New approach in research education to solve problems of dryland farming in Africa. Arid Soil Res. Rehab. 10: 169-177.

Mungai, D.N., Stigter, C.J., Coulson, C.L., Ng'ang'a, J.K. and Umaya, G.O. (1996b). Alley cropping maize (*Zea mays L.*) and *Cassia siamea lam.* under semi-arid conditions in Machakos, Eastern Kenya. Unpublished paper.

Mungai, D.N. (1991). A micrometeorological investigation of yield differences in alley cropping trials in the semi-arid areas of Machakos District, Kenya. Ph.D. Thesis, Department of Geography, University of Nairobi, Kenya. 362pp.

Muniafu, M.M., (1991). Photosynthetic efficiency of *Phaseolus vulgaris L.* under two moisture levels. MSc. thesis. Department of Botany, University of Nairobi, Kenya. 87pp.

Musyoka, J., Charles, R. and Kaluli, J. (1991). Inter-agency collaboration in the development of agricultural technologies at national and district level in Kenya. Agricultural Administration (Research and Extension net work). Network paper 23. Overseas Development Institute, U.K.

Mutiso, S.K. (1991). Rainfall in environmental profile In: M. Mortimore (Ed). Environmental change and dryland management in Machakos District, Kenya (1930-1990). ODI working paper 53, U.K.

Mwangi, G. (1989). Effect of *Leucaena leucocephala*, *Casia siamea* and *Terminalia browni* leaf mulch on maize performance and nutrients under semi-arid conditions in Machakos, Kenya. MSc. thesis, Department of Crop Science, University of Nairobi, Kenya. 115pp.

Nadar, H.M., and Faught, W.A.(1984b). Maize yield response to different levels of Nitrogen and Phosphorus fertilizer application. A seven season study. E. Afir. Agric.For. J. 44: 147-156.

Nadar, H.M. and Faught, W.A. (1984a). Effects of legumes on the yield of associated and subsequent maize intercropping nd rotation systems without nitrogen fertilizer. E. Afr. Agric. For. J. 44: 127-136.

Nadar, H.M. (1984). Maize yield response to row spacing and population densities under different environmental conditions. E. Afr. Agric. For. J. 44: 157-165.

Nair, P.K. (1984). Soil productivity aspects of Agroforestry. International Council of Research in Agroforestry (ICRAF), Science and Practice of Agroforestry 1, 85pp.

Nambiar, E.K.S. (1984). Significance of first order lateral roots on the growth of young *radiata pine* under environmental stress. Aust. Res. 14: 187-199.

Nambiar, E.K.S. (1983). Root development and configuration in intensively managed *radiata pine* plantations. Plant & soil. 71: 37-47.

Nelson, R.A., Grist, P.G., Menz, K.M. Cramb, R.A, Paningbatan, E.P and Mamicpic, M.A. (1997). A cost-benefit analysis of hedgerow intercropping in the Philippine uplands using the SCUAF model. Agr. For. syst. 35:203-220.

Newman, S.M. (1989). Inexpensive instrumentation for monitoring PAR in agroforestry. In: W.S. Reifsnyder and T.O. Darnhofer (Eds). Meteorology and Agroforestry. ICRAF, Nairobi, Kenya. pp297-304

Ngatunga, E.L.N., Lal, R. and Uriyo, A.P. (1984). Effects of surface management on runoff and soil erosion from some plots at Mlingano, Tanzania. *Geoderma 33:* 1-12.

Njoroge, K. (1984). Maize breeding at Katumani: The first 25 years. *E. Afr. For. agric J. 44:* 287

Norman, Moo.J.T., Pearson, C.J. and Searle, P.G.E. (1984). *The ecology of Tropical food crops.* Cambridge University Press, London, 369pp.

Norman, M.J.T., Pearson, C.J. and Searle, P.G.E. (1995). The Ecology of tropical food crops. 2nd Ed. Cambridge university press, Cambridge, U.K. 430pp.

Nurzefa, S.B. (1990). The effects of surface stone cover and soil loss and runoff. MSc. thesis, Department of Agricultural Engineering, University of Nairobi, Kenya.

Nyamai, D.O. (1987). Crop production in an intercropping system with tropical leguminous trees. Ph.D. thesis, Oxford University, Oxford, U.K. 268pp.

Nyamai, D.O., Kanja, F.M., Pegorie, J. (1990). *Report on the development phase of the on-farm Dryland Agroforestry Research Project (DARP)* located in Kakuyuni. DARP, Machakos Kenya.

Nyamai, D.D. (1995). On-station versus on-farm agroforestry research. Which dilemmas?. In: C.J. Stigter, F.J. Wangati, J.K. Ng'ang'a and D.N. Mungai (Eds). The TTMI Project and The Picnic model. An internal evaluation of approaches and results and prospects for TTMI-Units. *Proc. of the T.T.M.I workshop.* April, 1994, Nairobi, Kenya.

Nye, P.H. and Tinker, P.B. (1977). *Solute movement in the soil root system.* University of California Press, Berkeley, U.S.A, 342pp.

Oduol, P.A.(1994). Genetic assessment of perenial *Sesbania species* in agroforestry systems. Ph.D. thesis. University of Edinburgh. U.K. 293pp.

Okali, C. and Sumberg, J.E. (1986a). Examining divergent strategies in farming systems in research. *Agric. admin 22:* 233-253.

Okigbo, B.N. and Lal, R. (1978). Residue mulches and agri-silviculture in tropical African agriculture. *Paper presented at the International Conference on basic techniques in ecological agriculture Montreal, Canada.*

Okting'ati, A. and Mongi, H.O. (1986). Agroforestry and the small farmer: A case study of Kilema and Kirua Vunjo in kilimanjaro. International Tree Crops J. 1: 257-265.

Ong, C.K. (1995). The 'dark side' of intercropping: Manipulation of soil resources. In: H. Sinoquet and P. Cruz (Eds). Ecophysiology of tropical intercropping. INRA, Paris, France. 45-65pp.

Ong, C.K. (1994). Alley cropping - a research review. In: Ecology and farming. Department of Agronomy, Wageningen Agricultural University, The Netherlands pp28-29.

Ong, C.K., Rao, M.R. and Muthuva, M. (1992). Trees and crops. Competition for resources above and below the ground. Agroforestry Today, 4 (2) :4-5.

Ong, C.K. and Black, C.R. (1992). Complementarity in resource use in intercropping and agroforestry systems. Paper presented at the 52nd International Easter school on "Resource capture by crops" 30th March-2nd April 1992. School of Agriculture, Sutton, Bonington, England.

Onyango, A.A. (1995). Experience in using scientific results in Government of Kenya extension work. In: C.J. Stigter, F.J. Wangati, J.K. Ng'ang'a and D.N. Mungai (Eds). The TTMI Project and the Picnic model. An internal evaluation of approaches and results and of prospects for T.T.M.I - Units. Proc. of the TTMI workshop, April 1994, Nairobi, Kenya.

Onyewotu, L.O.Z, Ogigirigi, M.A. and Stigter, C.J. (1994). A study of competitive effects between a Eucalyptus camaldulensis shelter belt and an adjacent millet (Pennisetum typhoides) crop. Agric. Ecosystems and Environment 51: 281-286.

Otengi, S.B.B. (1996). An investigation of the influence of mulching and agroforestry systems on the microclimatic conditions affecting soil moisture and a maize/bean intercrop in semi-arid areas of Laikipia district. PhD. Thesis, Department of Meteorology, University of Nairobi, Kenya. 635pp.

Otengi, S.B.B., Ng'ang'a, J.K., Mungai, D.N., Stigter, C.J. and Liniger, H.P. (1994). An investigation of the influence of mulching and agroforestry systems on microclimatic conditions affecting soil moisture and yields of a maize/bean intercrop. In: C.J. Stigter, F.J. Wangati, J.K. Ng'ang'a and D.N. Mungai (Eds). The TTMI Project and the Picnic model. An internal evaluation of approaches and results and of prospects for TTMI-Units. Proc. of the TTMI workshop, April 1994, Nairobi, Kenya.

Othieno, C.O., Stigter, C.J. and Mwampaja, A.R. (1985). On the use of Stigter's Ratio in expressing the thermal efficiency of grass mulches. Expl. Agric. 21: 169-174.

Othieno, C.O. (1982). Diurnal variations in soil under tea plants. Expl. Agric. 18: 195-202.

Othieno, C.O. and Ahn, P.M. (1980). Effects of mulches on soil temperatur e and growth of tea plants in Kenya. Exp. Agric. 16: 295-302.

Othieno, C.O. and Laycock, D.H. (1977). Factors affecting soil erosion within tea fields. Trop. Agric. (Trinindad) 54: 323-329.

Othieno, C.O. (1975). Surface runoff and soil erosion on fields of young tea. Trop. Agric. (Trinindad) 52: 299-308.

Palaniappan, S.P. (1988). Cropping systems in the Tropics. Principles and management. Wiley Eastern limited, New Delhi, India. 215pp.

Pearcey, R.W., and Ehleringer, J. (1984). Comparative ecophysiology of C3 and C4 plants. Plant Cell Environ. 7: 1-13.

Pellek, R. (1992). Contour hedgerows and other soil conservation interventions for hilly terrain. Agrofor. Syst. 17: 135-152.

Pluaborg, P. (1995). Evaporation from bare soil in a temperate humid climate. Measurement using microlysimeters and time domain reflectometry. Agric. For. Meteorol. J. 76: 1-17.

Poesen, J., Ingelmo-Sanchez, F., and Mucher, H. (1990). The hydrological response of soil surface to rainfall as affected by cover and position of rock fragments in the top layer. Earth Surf. Proc. Land Forms 15: 653-671.

Raad. G, de. (1994). Testing a capacitative soil moisture probe for tropical conditions at Machakos, Kenya. Report to the TTMI- Project. Department of Geography. University of Groningen and Department of Meteorology. Wageningen Agricultural University. The Netherlands. 65pp

Raintree, J.B. (1983). Preliminary diagnosis of land use problems and agroforestry potentials in Northern Mbere Division, Embu, District, Kenya. ICRAF working paper No.1., ICRAF, Nairobi, Kenya.

Rao, M.R. and Wesley, S.B. (1989). Agroforestry for african semi-arid zone. In: Agroforestry Today. 1.(1) : 5-11.

Rao, M.R. and Coe, R.D. (1991). Measuring crop yields in on farm agroforestry studies. Agrofor. Syst. 15: 275- 289.

Rawlins, S.L. (1976). Measurement of water content and state of water in soils. In: T.L. Kozlovski (Ed). Water deficit and plant growth , vol. IV: Soil water management, plant response and breeding for drought resistance. Academic press, New York. pp1-55.

Redhead, J. (1979). Soil mycorrhiza in relation to soil fertility and productivity. In: H.O. Mongi and P. Huxley (Eds). Soil research in agroforestry. Proc. of an expert consultation, ICRAF, Nairobi, Kenya.

Richards, P. (1985). Indigenous agricultural revolution. Ecology and food production in West Africa. Hutchnson, London, U.K, 192pp.

Rocheleau, D. (1991). Participatory research in agroforestry: Learning from experience and expanding our repertoire. Agrofor. Syst. 15: 111-137.

Rocheleau, D., Weber,F. and Field-Juma A. (1988). Agroforestry in dryland Africa. Science and practice of agroforestry. ICRAF, Nairobi, Kenya, 311pp.

Ruhigwa, B.A., Gichuru, M.P. and Tariah, N.M. (1992). Root distribution of *Acioa barteri*, *Alchornea Cordifolia*, *Cassia siamea* and *Gmelina arborea* in acid Ultisol. Agrofor.Syst. 19: 67-78.

Rukandema, M. (1984). Farming systems of semi-arid Eastern Kenya. A comparision. E. Afr. Agric. For. J. 44: 422-435.

Russel, G., Marshall, B. and Jarvis, P.G. (1989). Plant canopies: their growth form and function. Cambridge University press, Cambridge, U.K. 178pp.

Russel, C.E. (1983). Nutrient cycling and productivity in native and plantation forests in Jari Florestal, Para Brazil. Ph.D. thesis. Institute of Ecology, University of Georgia, Athens, U.S.A. 133pp.

Sanchez, P.A., Palm, C.A., Davey, C.B., Szolt, L.T. and Russel, C.E., (1985). Trees as soil improvers in the humid tropics. In: Cannel, M.G.R. and Jackson, J.E.(Eds), Attributes of trees as crop plants. Institute of terestrial ecology, Huntingdom, U.K. pp327-385.

Sanchez, P.A. (1979). Soil fertility and conservation considerations for agroforestry systems in the humid tropics of Latin America. In: H.O. Mongi and P. A. Huxley (Eds). Soil research in agroforestry proceedings of an expert consultation. March 26-30 ICRAF, Nairobi, Kenya.

Shakoor, A., Ngugi, E.C, Muthoka, M.S. and Kamau, J.W. (1984). Improvement of cowpea varieties for dryland areas in Kenya. E. Afr. Agric. and For. J. 44: 306-311.

Singh, R.P., Ong, C.K. and Saharan, N. (1989). Above and below ground interactions in alley-cropping in semi-Arid India. Agrofor. Syst. 9: 259-274.

Soil survey staff.(1990). Keys to soil taxonomy, S.M.S.S. Technical monograph 19, fourth edition. Virginia polytechnic and state university, Blacksburg, Virginia, 422pp.

Squire, G.R. (1993). The physiology of tropical crop production C.A.B. International, Wallingford, U.K. 236pp

Sreenivas, L., Johnston, J.R. and Hill, O. (1947). Some relationships of vegetation and soil detachment in the erosion process. Proc. Soil Sci. Soc. Amer. 12: 471-474.

Stewart, J.I., and Kashasha, D.A.R.(1984). Rainfall criteria to enable response farming through crop-based climate analysis. E. Afr. Agric. For. J. 44: 58-79.

Stewart, .J.I. (1991). Principles and performances of response farming. In: R.C. Munchow and J.A Bellany (Eds.), climatic risk in crop production: Models and management for the semi-arid tropics and subtropics. CBA International, Walling ford, 361-382.

Stigter, C.J. (1985b). Wind protection in traditional microclimate management - Examples from east Africa. In: J.Grace (Ed.). Effects of shelter on the physiology of plants and animals. Progress in Biometeorology. Vol.2. Swets and Zeitlinger, B.V., Lisse, The Netherlands.

Stigter, C.J., and Musabilha, V.M. (1992). The conservative ratio of PAR to total radiation in the tropics. J. appl. Ecol. 19: 853-858.

Stigter, C.J. (1986). Microclimate management and manipulation in traditional farming. W.M.O.(CAgM) report 25, WMO, Geneva.

Stigter, C.J. (1984a). Examples of mulch use iicroclimatic management by traditional farmers in Tanzania. Agriculture, Ecosystems and Environment 11: 175-176.

Stigter, (1984b). Mulching as a traditional method of microclimatic management. Arch. meteorol. Geoph. Biocl. B35: 147-154.

Stigter, C.J. (1985a). Physics of mulching with particular emphasis on grass mulches. Paper presented at the international colloquium on Energy flux at the soil/atmosphereinterface. International Centre for Theoretical physics. Trieste, Italy.

Stocking, M.A. (1984). Erosion and soil productivity. A review - FAO, Rome, Italy. 103pp.

Stocking, M.A. (1988). Assessing vegetative cover and management effects pp (163-185). In: R. Lal (Ed). Soil erosion research methods. 244pp..

Summerg, J. and Okal, C. (1988). Farmers, on farm research and the development of new technology. Expl. Agric. 24: 333-342.

Sunfleck Ceptometer user manual.(1989). Delta-T Devices Agrisearch Equipment. The Netherlands.

Sunfleck Ceptometer user's manual.(1988). Decagon Devices Inc. Delta-T Devices, Cambridge, U.K.

Swanson, N.P., Dedrick, A.R., Weekly, H.E. and Haise, H.R. (1965). Comparing mulches-Scientists check effects of four mulching materials on 6% slope. Agric. Res: 13 (8): 15.

Tessema, S. (1983). Animal feeding in small farm systems. CIMMYT technical networkshop, Ezulwin, Swaziland.

Thomas, D.B. (1991). Soil erosion in environmental profile In: M. Mortimore (Ed), Environmental change and dryland management in Machakos District, Kenya (1930-1990). ODI working paper 53. U.K.

Tian, G., Brussaard and Kary, B.T. (1993). Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions. Effects of soil fauna. Soil Biol. Biochem. 25: 731-739.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994). More people less erosion. Environmental recovery in Kenya. John Wiley and Sons, New York, U.S.A. 311pp.

Tjernstrom, R, (1989). Report on technical and socio economic evaluation of soil conservation by the ministry of agriculture and livestock development: In: D.B Thomas, E.K Biamah, A.M Kilewe, L. Lundgren and B.O. Mochoge (Eds). Proc. Soil and water conservation in Kenya. Department of Agricultural Engineering. University of Nairobi. Nairobi, Kenya.

Toky, O.P. and Bisht, R.P. (1992). Observations of the rooting patterns of some agroforestry trees in an arid region of North Western India. Agrofor. Syst. 18: 245-263.

U.S. Department of Agriculture (1951). Soil survey manual. US Govt. printing office. Washngton, D.C.

Ulsaker, L.G. and Kilewe, A.M. (1984). Runoff and soil erosion for an alfisol in Kenya. E. Afr. Agric. and For. J.44: 210-239.

Umaya, G.O. (1991). The spatial and temporal distribution of the active roots of *Cassia siamea* and *Zea mays* (Katumani composite B), in alley cropping under semi-arid conditions in Machakos District, Kenya. MSc. thesis, Department of Botany, University of Nairobi, Kenya. 98pp.

Van Bavel, C.H.M., Nixon, P.R. and Hauser, V.L. (1963). Soil moisture measurements with the neutron probe method. Agrc. Res. Serv., U.S.A. Dept. Agric: 1-38.

Van NoorDwijk, M., Kurniatun, H., Syekhfani, M.S. and Flach, E.V. (1991). *Peltophorum pterocarpa* (DC) Back (Caesalpiaceae), a tree with a root distribution suitable for alley cropping on acid soils in the humid tropics. In: B.L McMichael and H. Persson (eds), plant roots and their environment. Elsevier, Amsterdam, 526-532.

Van Wijk, W.R. and Dohsen, W.J. (1966). Sinusoidal temperature variation in a layered soil. In: W.R. Wijk (Ed.). Physics of plant environment. North Holland Publ. Comp., Amsterdam, 382.pp.

Visvalingam, M. and Tandy, J.D. (1972). The neutron method for measuring soil moisture content - a review. J. Agric Sci., 23(4): 499-511.

Wallace, J.S., Gash, J.H.C., McNeil, D.D. and Sivakumar, M.V.K. (1988). Evaporation from sparse dryland millet crop in Niger, West Africa. Proceedings of International Conference on dryland farming. P.W. Unger, T.V. Sneed, W.R. Jordan and R. Jensen (Eds.). Texas agricultural Experiment Station, Armavillo, Bushland Texas. pp325-327.

Wallace, J.S. (1991). The measurement and modelling of evaporation from semi-arid land. Soil water balance in the Sudano-Sahelian zone. Proceedings of the Niamey Workshop February, 1991. IAHS Publ. No.199, 1991. pp131-145.

Wang, S.T. (1984). Management of problem soils in Taiwan, ROC. In: Ecology and management of problem soils in Asia. F.F.T.C Book series No. 27, Taipei, Taiwan pp 74-78

Wangia, C. and Tory, P. (1994). A review of the socio-economic and policy aspects of soil conservation in Africa In: T.L. Napier, S.M. Camboni, and S.A. El-swaify. adopting conservation on the farm. An international perspective on the socio-economics of soil and water conservation Soil and water conservation society, Iowa, U.S.A. pp119-132

Wanjura, D.F. and Hatified, J.L. (1986). PAR and IR reflectance, transmittance and absorptance of four crop caopies. Soil and Water Division of ASAE, USDA presented as SAE paper No. 85-3023.

Weischmeier, W.H. and Smith, D.D.(1978). Predicting rainfall-erosion losses from cropland East of The Rocky mountains. U.S. Dept. Agri. Handbook 282, U.S. Gov. Print. office, Washington, D.C, U.S.A.

Weischmeier, W.H. and Mannering, J.V. (1969). Relation of soil properties to its erodibility. Soil Sc. Soc. Am. Proc. 33: 131-137.

Whiteman, P. (1981). An agronomist's testimony - changing outlook towards experimental work. Paper for presentation at a workshop organised by CIMMYT East African Economics programme on the planning and management of adaptive experiments, the interpretation of observed responses and field testing the resulting technologies-UNDP/FAO/GOK. Sorghum and millet programme, Machakos, Kenya

Wiersum, K.F. (1984). Surface erosion under various Tropical agroforestry systems in C.L. O'Loughlin and AJ Pearce, eds. symposium on effects of forest land use on erosion and slope stability, Honolulu, Hawaii U.S.A. East-west centre, pp231-39.

Wiersum, K.F. (1988). Viewpoints on agroforestry. Department of forestry. Wageningen Agricultural University, The Netherlands. 256pp.

Wiersum, K.F. (1985). Effects of various vegetation layers in an *acacia auriculiforms* forest plantation on surface erosion in Java, Indonesia. In: S.A. El-Swaify, W.C. Moldenhauer and A.Lo, (Eds). Soil erosion and conservation. Ankey, Iowa, U.S.A. Soil conservation society of North America, pp79-89.

Wilson, J.W. (1981). Analysis of light interception by single plants. Ann. Bot. 48: 501-505.

Wilson, G.F. and Kang, B.T. (1980). Developing stable and productive biological cropping systems for the humid tropics In: B. Stonehouse (Ed), Biological husbandry. A scientific approach to organic farming. B. Stone house (ed.). Bulten worth. London.

Young, A. (1987). The potential of agroforestry for soil conservation part II. Maintanance of soil fertility. ICRAF working paper No.43., ICRAF, Nairobi, Kenya.

Young, A. (1991). Soil fertility. In: M. Avery, M.G.R Cannel, and C.K Ong (Eds). Biophysical research in Asian Agroforestry. Win Rock International, U.S.A. pp187-207.

Young, A. (1989). Agroforestry for soil conservation. C.A.B. International. 276pp

CHAPTER 7

APPENDICES

Appendix (3.1)

DIAGNOSTIC FARM SURVEY ON TRADITIONAL SOIL AND WATER CONSERVATION TECHNIQUES AND ON GENERAL FARMING ACTIVITIES AT KAKUYUNI CATCHMENT, MACHAKOS.

Farmers name..................

District.....................

Location.....................

Village.......................

(1) Size of the farm..........(ha)

(a) When did you get this farm?.............

(b) Was the farm inherited from your parents?.........

(c) Did you migrate to this place? if so when did you migrate and where were you from?..................

(d) Do you have another farm somewhere else?

(e) Who manages the other farm if the answer to (d) is yes?

(f) State whether you possess a title deed to your farm .....

(g) if not why?.........

(h) Do you own the farm with other people?

(2) What proportion of your farm is under crop production?....(ha)

(a) Which crops do you grow on your farm?

Appendix (3.2)

(b) List the cash crops on your farm....

(c) List the food crops on your farm..

(d) Do you grow the crops in pure stands or mixtures, rotations?. State any other method of growing crops.

(e) State whether you grow enough food for your family with surplus for sale..........

(f) what crops do you plant during the short and long rains? what reasons do you have for planting them like this?

(g) Estimate the yield for maize, sorghums, millets, beans, cowpeas, pigeon peas from your farm.

(3) What proportion of your farm is under livestock production?.........(ha)

(a) which animals do you keep on your farm?........

(b) Do you sell some of your livestock at certain times of the year?............

(c) When do you do this and why?....................

(d) How do you keep livestock on your farm?..... state whether you tether your animals or they graze and browse all over the farm......................

(4) What do you prefer having on your farm?.....Livestock or crops or both?

what are the reasons for your choice?

Appendix (3.3)

(5) State the main farming problems encountered in this area?

(a) is rainfall amount adequate for both livestock and crop production?

(b) do you have sufficient farm inputs such as fertilizers, manures, dipping facilities, labour and capital for most of the seasons.

(c) state the marketing facilities for both crops and livestock. Do you get good financial returns from your farm produce?

(d) What food storage problems do you face on your farm? What methods have you used to reduce the above problems?

(e) Do you have enough feeds for your livestock?

(f) what parts of the year do you face feeds shortage for your livestock?

(g) What solutions do you have the feed shortages?

(6) Soil and water management techniques

(a) is soil erosion a problem on your farm?

(b) what are the main forms of soil erosion?

(c) since you settled here how has the vegetation cover changed over the years?....................

(d) Has it worsened or improved?........Give reasons for the answer you give.....

Appendix (3.4)

(e) In order to tackle the problem of soil erosion, mentioned in (6a) what methods of soil and water conservation have you been using?........

(i) cutoff drains...... (ii) gabions.......

(iii)check dams.........(iv) fanya juu terraces....

(v)stone terraces...... (vi) trash lines.......

(vii) mulching ....(viii) crop rotations..

(ix) intercropping......(x) early planting.....

(xi) ploughing and planting along the contour...

(xii) shifting cultivation............

(xiii) water harvesting...................

(xiv) grass strips and hedgerows....

(xv) any other specify........

(f) where is soil erosion more serious?......

(i) grazing land...... or (ii) cropping land

what do you think is the reason for this?......

(g) which conservation measures do you have (i) on gazing land and (ii) on cropping land..............

(h) where did you acquire the skills to use the conservation measures mentioned above?..........

(i) from the chiefs baraza......

(ii)from agricultural/livestock extension staff...

(iii) from neighbours ....

(iv) any other specify

Appendix (3.5)

(I) what benefits do you get from these conservation measures?

(i) improved yields from both grazing and cropping lands

(ii) cash benefits......

(iii) poles for construction purposes and fuel wood

(iv) shades/live fencing and as ornamental plants

(v) any other specify

(j) can you estimate the cost of some of these conservation measures?

(i) estimate the cost of fanya juu terrace construction/m^3

(ii) cost of making trash lines......

(iii) ploughing and planting along the contour....

(iv) constructing check dams.......

(v) water harvesting..........

(v) grass strips..............

(k) Do you have trees/shrubs on your farm?.....

(i) Name the indigenous trees........

(ii) Name the exotic trees..........

(l) what benefits do you get from these trees?..

(i) shade (ii) cash returns (iii) mulches (iv) fire wood

(v) fruits (vi) any other specify....

Which government ministries/ organisations brought some of the tree species on your farm?..........

Appendix (3.5)

(I) what benefits do you get from these conservation measures?

- (i) improved yields from both grazing and cropping lands
- (ii) cash benefits......
- (iii) poles for construction purposes and fuel wood
- (iv) shades/live fencing and as ornamental plants
- (v) any other specify

(j) can you estimate the cost of some of these conservation measures?

- (i) estimate the cost of fanya juu terrace construction/m^2
- (ii) cost of making trash lines......
- (iii) ploughing and planting along the contour....
- (iv) constructing check dams.......
- (v) water harvesting..........
- (v) grass strips..............

(k) Do you have trees/shrubs on your farm?.....

- (i) Name the indigenous trees........
- (ii) Name the exotic trees..........

(l) what benefits do you get from these trees?..

(i) shade (ii) cash returns (iii) mulches (iv) fire wood

(v) fruits (vi) any other specify....

Which government ministries/ organisations brought some of the tree species on your farm?..........

Appendix 4.1

Table (i) Average seasonal soil moisture (cm^{3}cm^{-3}) ranking for the 92/93 rainy season

Treatment	Ranking	Measurement point
C	0.26 A	1
	0.23 CDE	2
	0.23 CDE	3
+M	0.20 BCD	1
	0.25 BC	2
	0.25 BC	3
H+M	0.25 BC	H+M1
	0.22 DEF	H+M2
	0.21 EF	H+M3
H-M	0.21 EF	H-M1
	0.22 DEF	H-M2
	0.20 FG	H-M3
G-M	0.28 A	G-M1
	0.18 G	G-M2
	0.18 G	G-M3

The figures followed by different letters are statistically different while figures followed by similar letters are not.

Table (ii) Average seasonal soil moisture levels(cm^{3}cm^{-3}) and ranking among depths for the short rains 92/93.

Treatment	Ranking	Depth	Treatment	Ranking	depth
C	0.32 A	6	+M	0.27 BCD	6
	0.25 CDEF	5		0.23 DEFGH	3
	0.24 CDEFG	4		0.23 DEFGH	4
	0.24 CDEFG	2		0.21 FGHIJ	2
	0.24 CDEFG	3		0.21 FGHIJ	5
	0.20 GHIJ	7		0.20 GHIJ	7
	0.19 HIJK	1		0.17 JK	1
H+M	0.31 AB	6	H-M	0.24 CDEFG	6
	0.26 CDE	5		0.22 EFGHI	4
	0.26 CDE	4		0.22 EFGHI	2
	0.24 CDEFG	3		0.22 EFGHI	3
	0.21 FGHJ	2		0.21 FGHIJ	5
	0.19 HIJK	7		0.18 IJK	1
	0.19 HIJK	1		0.17 JK	7
G-M	0.28 ABC	6			
	0.22 EFGHI	4			
	0.22 EFGHI	3			
	0.21 FGHIJ	5			
	0.20 GHIJ	2			
	0.20 GHIJ	7			
	0.15 K	1			

1=0-30cm 2=30-45cm 3=45-60cm 4=60-75cm 5=75-90cm 6=90-105cm 7=105-120cm.

Appendix 4.2

Table (iii) Average seasonal soil moisture(cm^{3}cm^{-3}) ranking by points of measurement for the long rains of 1993.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.21 A	1	+M	0.09 D	1
	0.17 B	2		0.11 C	2
	0.17 B	3		0.12 C	3
H+M	0.07 EF	H+M1	H-M	0.06 F	H-M1
	0.06 F	H+M2		0.08 E	H-M2
	0.06 F	H+M3		0.08 E	H-M3
G-M	0.06 F	G-M1			
	0.07 EF	G-M2			
	0.12 C	G-M3			

Table (iv) Average seasona soil moisture(cm^{3}cm^3) ranking among depth/treatment for thelong rains of 1993.

Treatment	Ranking	Depth	Treatment	Ranking	Depth
C	0.30 A	6	+M	0.17 D	6
	0.22 B	5		0.13 E	4
	0.21 BC	7		0.13 E	7
	0.20 C	4		0.12 EF	5
	0.18 D	3		0.11 FG	3
	0.13 E	2		0.06 J	2
	0.05 JK	1		0.03 LM	1
H+M	0.09 HI	5	H-M	0.09 HI	4
	0.09 HI	3		0.09 HI	3
	0.09 HI	4		0.09 HI	6
	0.08 I	6		0.08 I	5
	0.06 J	7		0.08 I	7
	0.04 KL	2		0.05 JK	2
	0.02 M	1		0.02 M	1
G-M	0.11 FG	4			
	0.10 GH	7			
	0.10 GH	5			
	0.10 GH	3			
	0.09 HI	6			
	0.06 J	2			
	0.03 LM	1			

Table (v) Average seasonal soil moisture (cm^{3}cm^3) ranking by points of measurement for the short rains 93/94

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.22 A	1	+M	0.15 C	1
	0.19 B	2		0.15 C	2
	0.13 D	3		0.11 E	3
H+M	0.11 E	H+M1	H-M	0.11 E	H-M1
	0.11 E	H+M2		0.11 E	H-M2
	0.11 E	H+M3		0.08 G	H-M3
G-M	0.09 F	G-M1			
	0.14 CD	G-M2			
	0.14 CD	G-M3			

Appendix 4.3

Table (vi) Average seasonal soil moisture ranking (cm'cm') by depth for the short rains of 93/94.

Treatment	Ranking	Depth	Treatment	Ranking	Depth
C	0.20 CD	6	+M	0.14 FG	3
	0.16 E	4		0.13 GH	4
	0.15 EF	7		0.12 HI	5
	0.15 EF	3		0.12 HI	6
	0.15 EF	5		0.09 KL	2
	0.11 IJ	2		0.08 LM	7
	0.09 KL	1		0.08 LM	1
H+M	0.13 GH	3	H-M	0.13 GH	4
	0.12 HI	4		0.12 HI	3
	0.12 HI	6		0.11 IJ	6
	0.11 IJ	5		0.11 IJ	5
	0.10 JK	2		0.10 JK	7
	0.09 KL	7		0.09 KL	2
	0.07 MN	1		0.07 MN	1
G-M	0.30 A	5			
	0.22 B	4			
	0.21 BC	6			
	0.20 CD	3			
	0.19 D	2			
	0.10 JK	7			
	0.06 N	1			

Table (viii). Soil and water storage changes over the rain season and calculation example of ET (mm) for mulch plot long rains of 1994.

Week	rain	soil water	change in soil water after one week	ET
			163.5	
1	35.8	163.5	172.5	26.8
2		172.5	166.5	6.0
3	7.4	166.5	151.5	22.4
4	44.4	151.5	177.0	18.9
5		177.0	159.0	18.0
6	9.0	159.0	163.5	4.5
7	28.8	163.5	163.5	28.8
8	62.6	163.5	221.0	5.1
9	3.0	221.0	207.0	17.0
10	6.6	207.0	186.0	27.6
11	6.2	186.0	165.0	27.2
12	15.8	165.0	153.0	27.8
13	2.0	153.0	138.0	17.0
14		138.0	115.0	22.5
15		115.5	105.0	10.5
16	2.0	105.0	99.0	8.0
17	3.0	99.0	88.5	13.5
18		88.5	79.5	9.0
19		79.5	70.5	9.0
20		70.5	76.5	-6.0 *
21		76.5	76.5	0.0
22		67.0		
Total				313.6.

N.B ET has not been adjusted for runoff and this is done in Table (xviii).
* The negative value is unusual and was brought about by the error which may have resulted in wrong moisture values by the neutron probe in table 3.

Appendix 4.4. Table (vii). Calculation example of soil water storage (mm) from weekly measurements per season for the +M plot in the long rains of 1994.

week	Soil layer (cm) for different depths (in cm)							Soil water storage (mm) in 300 and 150mm of soil for different layers (cm)							
	0-30	30-45	45-60	60-75	75-90	90-105	105-120	300 0-30	150 30-45	150 45-60	150 60-75	150 75-90	150 90-105	150 105-120	Total
1	0.05	0.13	0.17	0.18	0.16	0.2	0.15	15	19.5	25.5	27	24	30	22.5	163.5
2	0.06	0.16	0.18	0.17	0.15	0.19	0.18	18	24	27	25.5	22.5	28.5	27	172.5
3	0.07	0.14	0.17	0.17	0.15	0.19	0.15	21	21	25.5	25.5	22.5	28.5	22.5	166.5
4	0.05	0.14	0.16	0.12	0.15	0.18	0.16	15	21	24	18	22.5	27	24	151.5
5	0.1	0.16	0.17	0.16	0.15	0.2	0.14	30	24	25.5	24	22.5	30	21	177
6	0.06	0.14	0.17	0.17	0.15	0.17	0.14	18	21	25.5	25.5	22.5	25.5	21	159
7	0.07	0.14	0.19	0.15	0.15	0.18	0.14	21	21	28.5	22.5	22.5	27	21	163.5
8	0.08	0.1	0.16	0.17	0.15	0.21	0.14	24	15	24	25.5	22.5	31.5	21	163.5
9	0.14	0.21	0.24	0.26	0.22	0.19	0.18	42	31.5	36	39	33	28.5	27	237
10	0.07	0.16	0.18	0.21	0.23	0.27	0.19	21	24	27	31.5	34.5	40.5	28.5	207
11	0.06	0.12	0.17	0.2	0.2	0.26	0.17	18	18	25.5	30	30	39	25.5	186
12	0.06	0.11	0.16	0.16	0.16	0.23	0.16	18	16.5	24	24	24	34.5	24	165
13	0.06	0.12	0.15	0.14	0.15	0.2	0.14	18	18	22.5	21	22.5	30	21	153
14	0.05	0.1	0.12	0.13	0.13	0.2	0.14	15	15	18	19.5	19.5	30	21	138
15	0.03	0.07	0.11	0.11	0.12	0.18	0.12	9	10.5	16.5	16.5	18	27	18	115.5
16	0.02	0.08	0.1	0.1	0.11	0.16	0.11	6	12	15	15	16.5	24	16.5	105
17	0.03	0.05	0.09	0.1	0.1	0.16	0.1	9	7.5	13.5	15	15	24	15	99
18	0.03	0.08	0.07	0.08	0.1	0.12	0.08	9	12	10.5	12	15	18	12	88.5
19	0.04	0.04	0.07	0.07	0.08	0.12	0.07	12	6	10.5	10.5	12	18	10.5	79.5
20	0.03	0.04	0.06	0.06	0.08	0.1	0.07	9	6	9	9	12	15	10.5	70.5
21	0.03	0.04	0.07	0.07	0.08	0.1	0.09	9	6	10.5	10.5	12	15	13.5	76.5
22	0.02	0.03	0.07	0.07	0.08	0.09	0.07	6	4.5	10.5	10.5	12	13.5	10.5	67.5

Appendix 4.5

Table (ix) Average seasonal soil moisture (cm^3cm^{-3}) ranking by point of measurement for the long rains 1994.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.17 A	1	+M	0.11 F	1
	0.13 D	2		0.14 C	2
	0.15 B	3		0.13 D	3
H+M	0.08 G	H+M1	H-M	0.08 G	H-M1
	0.06 1	H+M2		0.07 H	H-M2
	0.06 I	H+M3		0.07 H	H-M3
G-M	0.08 G	G-M1			
	0.07 H	G-M2			
	0.12 E	G-M3			

Table (x) Average seasonal soil moisture (cm^3cm^{-3}) ranking by depth for the long rains of 1994.

Treatment	Ranking	Depth	Treatment	Ranking	Depth
C	0.20 A	6	+M	0.17 B	6
	0.16 BC	3		0.14 DE	5
	0.16 BC	5		0.14 DE	4
	0.16 BC	4		0.14 DE	3
	0.15 CD	7		0.13 EF	7
	0.14 DE	2		0.11 GH	2
	0.08 JK	1		0.05 MN	1
H+M	0.10 HI	3	H-M	0.10 HI	3
	0.08 JK	4		0.09 IJ	4
	0.07 KL	5		0.08 JK	2
	0.06 LM	6		0.07 KL	5
	0.06 LM	2		0.07 KL	6
	0.05 MN	1		0.05 MN	7
	0.04 N	7		0.05 MN	1
G-M	0.12 FG	4			
	0.11 GH	3			
	0.10 HI	5			
	0.09 IJ	6			
	0.08 JK	2			
	0.08 JK	7			
	0.04 N	1			

Table (xi). Soil moisture (cm^3cm^3) ranking by point of measurement for the long rains of 94/95.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.22 A	1	+M	0.15 EF	1
	0.18 BC	2		0.17 CD	2
	0.19 B	3		0.17 CD	3
H+M	0.16 DE	H+M1	H-M	0.14 F	H-M1
	0.15 EF	H+M2		0.14 F	H-M2
	0.14 F	H+M3		0.14 F	H-M3
G-M	0.17 CD	G-M1			
	0.15 EF	G-M2			
	0.17 CD	G-M3			

Appendix 4.6

Table (xii) Average seasonal soil moisture(cm^3cm^{-3}) ranking by depth for the short rains of 94/95.

Treatment	Ranking	Depth	Treatment	Ranking	Depth
C	0.27 A	2	+M	0.20 CD	3
	0.18 EF	7		0.19 DE	2
	0.17 FG	4		0.18 EF	1
	0.17 FG	3		0.18 EF	7
	0.14 HI	6		0.17 FG	4
	0.14 HI	1		0.16 FG	6
	0.10 L	5		0.10 L	5
H+M	0.19 DE	1	H-M	0.22 B	7
	0.17 FG	4		0.20 CD	1
	0.17 FG	7		0.17 FG	4
	0.16 FG	3		0.16 FG	5
	0.16 FG	5		0.15 GH	2
	0.13 IJ	2		0.11 KL	3
	0.12 JK	6		0.08 M	6
G-M	0.21 B	1			
	0.17 FG	2			
	0.17 FG	7			
	0.15 GH	5			
	0.14 HI	3			
	0.13 IJ	4			
	0.12 JK	6			

Table (xiii) Average seasonal soil moisture(cm^3cm^{-3}) ranking by point of measurement for the long rains of 1995.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.20 A	1	+M	0.14 CD	1
	0.16 B	2		0.15 BC	2
	0.15 BC	3		0.16 B	3
H+M	0.13 DE	H+M1	H-M	0.12 E	H-M1
	0.12 E	H+M2		0.12 E	H-M2
	0.10 F	H+M3		0.10 F	H-M3
G-M	0.13 DE	G-M1			
	0.13 DE	G-M2			
	0.15 BC	G-M3			

Table (xiv) Average seasonal soil moisture(cm^3cm^{-3}) ranking by depth for the long rains of 1995.

Treatment	Ranking	Depth	Treatment	Ranking	Depth
C	0.22 A	6	+M	0.20 B	6
	0.18 C	5		0.16 CDE	4
	0.18 C	4		0.16 CDE	3
	0.17 CD	3		0.16 CDE	5
	0.16 CDE	7		0.15 DEF	7
	0.15 DEF	2		0.13 FGH	2
	0.11 HI	1		0.10 IJ	1
H+M	0.15 DEF	3	H-M	0.14 EFG	3
	0.14EFG	5		0.13 FGH	4
	0.14 EFG	4		0.13 FGH	2
	0.12 GHI	2		0.12 GH1	6
	0.12 GHI	6		0.12 GHI	5
	0.08 KL	1		0.09 JK	7
	0.08 KL	7		0.07 KL	1
G-M	0.17 CD	6			
	0.16 CDE	3			
	0.16 CDE	4			
	0.15 DEF	7			
	0.15 DEF	5			
	0.12 GHI	2			
	0.06 L	1			

Appendix 4.7

Table (xv) Average seasonal TDR moisture(cm^{3}cm^3) ranking at points of measurement for the 94/95 season.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.11 CDE	1	H-M	0.14 AB	H-M1
	0.12 CD	2		0.11 DE	H-M2
	0.12 CD	3		0.09 G	H-M3
+M	0.11 DE	1	G-M	0.15 A	G-M1
	0.10 EF	2		0.11 CDE	G-M2
	0.10 EF	3		0.09 G	G-M3
H+M	0.13 B	H+M1			
	0.10 EF	H+M2			
	0.09 G	H+M3			

Table (xvi). Average seasonal TDR moisture(cm^{3}cm^3) ranking at points of measurement for the 1995 season

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	0.09 C	1	H-M	0.12 B	H-M1
	0.09 C	2		0.09 C	H-M2
	0.09 C	3		0.07 F	H-M3
+M	0.09 C	1	G-M	0.13 A	G-M1
	0.08 E	2		0.09 C	G-M2
	0.09 C	3		0.08 E	G-M3
H+M	0.12 B	H+M1			
	0.09 C	H+M2			
	0.07 F	H+M3			

Table (xvii). Calculation of transpiration (Tr) from the equation in the C plot for the short rains of 94/95.

Tr = P - ΔS - Rn - Es - L - Eplant: Eplant assumed = 0 mm Rn = 60 mm (figure 4.9), Es = 275 mm (table 14)

Tr = 521 - 60 - 275 - 30 = 156 mm   L = 30 mm (table xviii)

where P - ΔS = 521 mm, 521 mm was calculated using 1994/95 short rains data and neutron probe values in table 4. The procedure followed is as shown in table (viii) for the +M plot for the 1994 long rains season.

Table (xviii) Calculation of percolation losses C plot for 94/95 short rains.

Week	Depth (cm)	Vol. water content (cm3cm^{-3})	FC (cm3cm^{-3})	Percolation losses (mm)
7	90-105	0.37	0.34	0.03*150 = 4.5
8	90-105	0.35	0.34	0.01*150 = 1.5
9	90-105	0.37	0.34	0.03*150 = 4.5
10	90-105	0.38	0.34	0.04*150 = 6.0
11	90-105	0.38	0.34	0.04*150 = 6.0
12	90-105	0.36	0.34	0.02*150 = 3.0
13	90-105	0.37	0.34	0.03*150 = 4.5
Total				= 30.0

N.B. No percolation occurred in soil layers (depths) 0-90cm.

Appendix 4.8

Table (xix). Volumetric water content ($cm3cm^{-1}$) in control plot, 1994/95 season

			depth				
week	0-30cm	30-45cm	45-60cm	60-75cm	75-90cm	90-105cm	105-120cm
1	0.04	0.06	0.08	0.1	0.11	0.14	0.12
2	0.04	0.06	0.07	0.1	0.11	0.14	0.14
3	0.12	0.17	0.12	0.1	0.11	0.14	0.12
4	0.12	0.16	0.13	0.1	0.11	0.14	0.12
5	0.1	0.14	0.13	0.11	0.11	0.14	0.12
6	0.21	0.23	0.23	0.2	0.16	0.13	0.1
7	0.24	0.26	0.28	0.3	0.32	0.37	0.24
8	0.14	0.21	0.25	0.27	0.28	0.35	0.23
9	0.15	0.22	0.25	0.28	0.29	0.37	0.24
10	0.26	0.3	0.3	0.29	0.29	0.38	0.27
11	0.2	0.25	0.28	0.27	0.31	0.38	0.31
12	0.12	0.2	0.24	0.25	0.28	0.36	0.25
13	0.19	0.23	0.24	0.25	0.27	0.37	0.24
14	0.23	0.23	0.25	0.25	0.24	0.32	0.23
15	0.11	0.18	0.21	0.21	0.23	0.32	0.22
16	0.1	0.14	0.17	0.17	0.2	0.24	0.19
17	0.1	0.14	0.14	0.15	0.17	0.21	0.14
18	0.06	0.1	0.13	0.14	0.15	0.17	0.15

Table (xx). Calculation of soil evaporation losses from the C plot in the long rains of 1994.

Difference in microlysimeter reading (g)	Conversion factor equivalent water depth (mm)	Water loss (mm)
48.3	0.12	5.8
32.5	0.12	3.9
35.0	0.12	4.2
33.3	0.12	4.0
32.5	0.12	3.9
25.0	0.12	3.0

Table (xxi). Example of ranking general overall PAR means among treatments at the points of measurement short rains of 92/93.

Original order	Ranked order alphabetically
mean 1 = 51.1 A	mean 1 = 51.1 A
mean 2 = 30.6 B	mean 3 = 30.6 B
mean 3 = 30.6 B	mean 2 = 30.6 B

where 1, 2 and 3 are the measuring points

All numbers sharing same letter are in one rank.

Table (xxii). Ranking of PAR means among treatments for cowpea for the short rains of 92/93.

Original order	Ranked order alphabetically.
mean 1 = 30 B	mean 3 = 43.5 A
mean 2 = 29.2 B	mean 4 = 43.2 A
mean 3 = 43.5 A	mean 5 = 41.5 A
mean 4 = 43.2 A	mean 1 = 30 B
mean 5 = 41.5 A	mean 2 = 29.2 B

All numbers sharing same letters are in one rank
where 1 = C, 2 = +M, 3 = H+M, 4 = H-M and 5 = G-M

Appendix 4.9

Table (xxiii). Average seasonal intercepted PAR (in %) ranking at points of measurement within each treatment for the short rains of 92/93.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	30 CD	1	H-M	68 A	H-M1
	34 C	2		30 CD	H-M2
	27 D	3		31 CD	H-M3
+M	30 C	1	G-M	62 B	G-M1
	27 CD	2		30 CD	G-M2
	32 CD	3		32 CD	G-M3
H+M	66 AB	H+M1			
	32 CD	H+M2			
	33 CD	H+M3			

Table (xxiv). Average seasonal intercepted PAR (in %) ranking at points of measurement within each treatment for the short rains of 93/94.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	32 D	1	H-M	81 A	H-M1
	40 D	2		38 D	H-M2
	38 D	3		39 D	H-M3
+M	38 D	1	G-M	51 C	G-M1
	39 D	2		38 D	G-M2
	42 D	3		50 C	G-M3
H+M	71 B	H+M1			
	40 D	H+M2			
	49 C	H+M3			

Table (xxv) Average seasonal intercepted PAR (in %) ranking at points of measurement within treatment for the long rains 1994.

Treatment	Ranking	Measurement point	Treatment	Rranking	Measurement point
C	40 DEF	1	H-M	63 A	H-M1
	39 EF	2		35 EF	H-M2
	39 EF	3		45 BCDE	H-M3
+M	41 CDE	1	G-M	50 BC	G-M1
	37 EF	2		33 F	G-M2
	38 EF	3		49 BCD	G-M3
H+M	70 A	H+M1			
	37 EF	H+M2			
	52 B	H+M3			

Appendix 4.10

Table (xxvi) PAR absorption at points of measurement for five treatments for the short rains of 94/95.

Treatment	Ranking	Measurement point
C	54.2 BC	1
	53.8 BCD	2
	54.6 BC	3
+M	54.4 BC	1
	55.2 BC	2
	55.5 B	3
H+M	77.2 A	1
	54.8 BC	3
	55.8 B	2
H-M	81.4 A	1
	46.6 E	2
	49.6 DE	3
G-M	80.6 A	1
	50.4 CDE	2
	46.4 E	3

Table (xxvii) Average seasonal PAR (in %) ranking at points of measurement within each treatment for the long rains of 1995.

Treatment	Ranking	Measurement point	Treatment	Ranking	Measurement point
C	48 E	1	H-M	92 A	H-M1
	48 E	2		51 CD	H-M2
	48 E	3		46 E	H-M3
+M	49 CDE	1	G-M	89 B	G-M1
	48 DE	2		49 CDE	G-M2
	48 DE	3		43 F	G-M3
H+M	93 A	H+M1			
	51 C	H+M2			
	47 E	H+M3			

Table (xxviii). Calculation of light use efficiency (e) in the control plot for the long rains of 1994.

The total above ground biomass (P) from 1 m^2 was 400± 4gm
Fractional PAR (f) absorbed in the season was (0.37) or 37%
Total global radiation or flux density (S) for the season was
590± 6%

$e = P/(f*S)$, 400 g m^2/(0.37*590) = 1.8 g MJ^{1}
The error arising from this calculation is 6% and 1% which make a cumulative error of about 6.1%.

Appendix 4.11

Table (xxix). Calculation of water use ifficiency (WUE) in the C plot for the long rains of 1994.

The Tr for the C plot 1994 was 150 mm
The total above ground biomass from this plot was 4 kg ha^{-1}
WUE was calculated as total bove ground biomass/Tr = 4000kg ha^{-1} /150 mm = 26.7 kg ha^{-1} mm^{-1}

N.B. Error arising from Es estimation was 10%, Error from neuron probe water changes for determining Et was 5%, error arising from runoff measurements was 5% while error arising from percolation losses estimates was also 5%. Hence total cumulative error for the Tr determination was about 13.2%. Calculated as $\surd(0.05)^2 + \surd(0.05)^2 + \surd(0.05)^2 + \surd(0.1)^2 = \surd 0.0175$

Table (xxx). Calculation of grain yield ha^{-1} from H+M plot in 1993 maize season.

All 4 maize rows were harvested and weighed from 4 sampled alleys.
The mean weight in g of each row was 31.99
There were 10 alleys each with 4 rows of maize in 4 m*10 m plot

So total weight from 10 alleys was 10*4*31.99 = 1279.6g

In I ha total grain yield = 1279.6g*10000m^{2} /400m^{2}(1000g)
= 31.99 kg