EFFECTS OF VARIOUS TYPES OF MULCHES ON COFFEE

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

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To my parents.

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SUMMARY

The main objectives of the work reported here were to study the effect of various types of mulches on soil temperature, moisture, chemical properties, weed growth, vegetative growth and coffee yields.

The experiment was carried out at the University of Nairobi Field Station Kabete. It was laid out in a randomised block design with four replicates and five treatments which included; bare soil, grass mulch, transparent polyethylene mulch, white and black polyethylene mulches.

Soil temperatures were measured twice a day at 7 cm, 15 cm, 1m and 2m depths. At 7 cm depth mercury thermometers were used while at the other depths glass bead thermistors of the type (151-114) were used. Soil moisture was determined gravimetrically at three depths 0-15 cm, 60 cm and 120 cm at the interval of 10 days. Soil chemical properties at 0-15 cm depth was analysed six months after application of mulches, while samples taken one year after application of mulches were analysed for chemical properties for both top-soil (0-15 cm) and sub-soil (15-45 cm). Coffee growth was measured in terms of lateral branch extension and number of nodes grown after every two weeks. Weed growth assessment was done at the time when weeding was being done on the coffee estate.

The studies conducted during a one year period with various types of mulches on coffee showed that soil temperatures at 7 cm and 15 cm depth were highest under transparent polyethylene mulch, followed by black polyethylene mulch and then white polyethylene mulch.

These mulches had higher soil temperatures than bare soil, while the grass mulch gave lower soil temperatures than bare soil. Soil temperatures decreased with increasing depth up to 2 metres and with increasing depth

the differences between the treatments tended to be narrowed. At 7 cm and 15 cm depth the soil temperatures seemed to rise and fall approximately in phase with the air temperatures, while at two metres depth soil temperatures under the various types of mulches and bare soil seemed to be almost equal and at equilibrium.

Grass mulch was shown to be superior to artificial polyethylene mulches with respect to soil moisture conservation. In general mulching increased the soil moisture content and since moisture is often a limiting factor in plant growth it is suggested that the practice of grass mulching on coffee should be continued. Regulation of soil moisture is considered desirable not only for the attainment of high yields but also for the conservation of organic matter.

In areas with wet and dry seasons, mulches might help in evenning the release of mineral soil nitrogen consequently minimising the "nitrogen flush". In addition to higher soil moisture content the grass mulch increased soil organic matter, cation exchange capacity, magnesium and potassium.

Mulches were shown to be effective as weed control measure, this being particularly so with the artificial polyethylene mulches. No significant differences were obtained between the treatments in terms of coffee growth, root distribution and yields. The artificial polyethylene mulches were found to deteriorate very fast, the transparent polyethylene mulch was estimated not to last more than six months.

The grass mulch was established to be superior to the polyethylene mulches in the conservation of soil moisture in addition to adding organic matter and nutrients to the soil. It is suggested that grass mulching on coffee should be continued.

CHAPTER ONE

1. INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

1.1.1. Coffee Mulching in Kenya

Mulching is an important cultural practice in coffee culture, this has been established through many field experiments. In Kenya the most commonly cultivated mulch crop is napier grass (Pennisetum Purpureum), which is planted in many coffee estates especially for the purpose. Other materials used are sisal waste, coffee pulp, saw dust, wood shavings, banana trash, maize stover, rushes and papyrus cut from wet valleys (Gilbert, 1945; Robinson and Wallis, 1960; Blore, 1964; Mehlich, 1966; Wapakala, 1966).

On chosing a suitable grass material for mulching coffee a number of factors have to be taken into consideration. The persistence of the mulch material in the field, which is the length of time during which an effective cover of the ground is obtained is of great importance. A material such as sisal waste is much better in terms of persistence than the widely used napier grass (Robinson and Wallis, 1960). Wapakala, (1966) evaluated several grasses which included Hyperrhenis sp. such as Hyperrhenia Cymbaria, Hyperrhenia rufa, Hyperrhenia ruprechtii, together with Panicum maximum, Panicum coloratum, Cymbopogon validus and Cymbopogon afronardus for their persistence as mulches in the field. Hyperrhenia cymbaria was found to be a good mulch, which could be recommended as a replacement for napier grass which has several disadvantages. Saccharum spontaneum is good in persistence but due to its high carbon: nitrogen ratio there is a danger of nitrogen fixation by soil micro-organisms.

The mineral content of mulching material is another factor to be considered. When one or several nutrients are considerably out of balance the excessive and continuous use of such material may lead to reduced quality of coffee (Blore, 1964; Northmore, 1963). It has been noted that mulching with materials high in potassium content causes a strong tendency of inducing magnesium deficiency (Robinson and Chenery, 1958). Mulching materials of high carbon: nitrogen ratio may lead to fixation of nitrogen by soil micro-organisms (Wapakala, 1966). The mineral content of different mulching materials may vary greatly but most of the available materials supply nitrogen, phosphorus and sulphur in norminal and unharmful quantities. They generally supply low quantities of magnesium, calcium and potassium, except sisal waste and elephant grass which supply excessive quantities of calcium and potassium respectively (Mehlich, 1966).

Yield in terms of dry matter production, percentage seed germination and the ease of mechanical handling are other factors to be considered for a good grass mulching material (Wallis, 1960; Wapakala, 1966; Mehlich, 1966).

1.1.1.1. Application of grass mulches in young coffee

It is strongly recommended that new coffee plantings should be mulched immediately the seedlings are transplanted in the field. If mulching material is limited a circular application around each tree to a distance 45cm to 60cm from the stem is suitable. Alternatively and particularly if the land is steep and soil erosion is a danger a line of mulch 90cm to 120cm wide may be applied in the line of the seedlings along the contour (Jones, 1954; Robinson and Wallis, 1960).

1.1.1.2. Application of grass mulches in mature coffee

Assuming sufficient mulch material is available, mature coffee planted on the flat or only gently undulating soil of high fertility should be mulched in the alternate inter-rows and there after this mulch should be rotated from one side of the tree row to the other annually. Alternate row mulching is recommended in that it is as effective as complete mulch in addition to that it saves the mulching material and it reduces the danger of damaging feeder roots when the mulch disintegrates and there is no replacement (Mcmaster, and Solly, 1952; Robinson and Wallis, 1960). Mature coffee planted on steep slopes, particularly where the average rainfall is 900-1025 mm or less per year, should be mulched in every inter-row space annually (Robinson and Wallis, 1960).

Mitchell (1976b) recommends that with close-spaced coffee grass mulch should be applied in strips along the tree rows when coffee is planted and the mulch cover should be maintained for two years. After two years the soil in the tree rows is covered by the coffee canopy and there is no need to apply mulch in high density coffee.

1.1.1.3. Time of application

The time of application in mature coffee is dependent upon rainfall distribution and its quantity. In coffee districts East of the Rift Valley, where there is a distinct bimodal rainfall distribution, mulch should be applied before either of the rains preferably before the long rains each year, to make best use of the rain water.

Coffee districts West of the Rift Valley where there is a single-peak rainfall distribution and the average total rainfall is 1000mm or less the application should be made before the rains. If the average total rainfall is much in excess of 1000 mm to 1100 mm the mulch application should not be made until the end of the rainy season and should only be sufficient to provide a good soil cover from the end of one rains to the expected beginning of the following wet season. There is experimental evidence to suggest that a heavy mulch cover present throughout the year will depress the yields of coffee obtained if the annual rainfall is 1100 mm or more. This is presumed to be a result of temporary soil waterlogging over prolonged periods with consequent inadequate aeration of the soil (Pereira and Jones, 1954; Robinson and Wallis, 1960).

1.1.1.4. Mulching problems in coffee

One of the major difficulties in mulching of coffee is the supply of mulching material which is required in very large quantities. It has been estimated that one acre of land is required to supply two acres of planted coffee with enough napier grass for mulching (Gillet, 1944). Sanders, (1953) estimated that the use of stem and leaf of banana, enough mulch is obtained from one acre of banana plantation to mulch one acre of coffee.

The control of weeds among partially decomposed mulch residues is also a field problem associated with mulching (Pereira and Jones, 1954), but the use of herbicides almost eliminates this problem, herbicides have been reported by Mitchell (1967) to increase the persistence of grass mulch.

Labour for the hand application of grass mulches could be expensive and time consuming. The time period in which grass mulches offer protection is short and this adds to the expenses due to the need for frequent additions of new mulch material. In the dry season grass mulches stand the risk of fire if care is not taken. Grass materials for mulches are becoming limited as land is becoming scarce. Napier grass which is the most common mulch grass in Kenya, inspite of its many advantages, is unsatisfactory in certain respects such as:-

(i) It has a tendency to root in the field.

(ii) It is difficult to harvest mechanically.

(iii) Due to its high potassium content it has been shown to adversely affect the uptake of magnesium (Wallis, 1960; Blore, 1965; Wapakala, 1966).

1.1.2. Objectives of the experiment

Artificial mulches have not been tried on coffee in Kenya and this experiment was aimed at investigating the effects of these mulches and to compare them with grass mulches. Polyethylene mulches were tried and the effects that were investigated were:

(a) Effect of mulches on soil temperature.

(b) Effect of mulches on soil moisture.

(c) Influence of the mulches on soil chemical properties.

(d) Mulch effects on vegetative growth and yield of coffee.

(e) Mulch effect on weed control.

(f) The persistence of the mulches.

1.2. LITERATURE REVIEW

1.2.1. Defination of mulching

Mulching can be defined as "the application of a covering layer of material to the soil surface" (Rowe-Dutton, 1957). Unger, (1975) defines a mulch as "any material at the soil surface that is grown and maintained in place, any material grown but modified before placement, and any material processed or manufactured and transported before placement". Some examples of materials used for mulching are crop residues, leaves, clippings, bark, paper, plastic films, petroleum products, polyethylene sheets and gravel.

Rosenberg, (1974) defines mulching as the application or creation of any soil cover that consitutes a barrier to the transfer of heat or vapour. Examples of mulches that have been used in agriculture are:-

(a) The dust mulch, created by finely pulverising the upper layer of soil.

(b) Plant residues, created by allowing plant materials to stay in a layer over the soil surface.

(c) Stubble mulch, created by permitting residues of small grain crops to remain standing in the field.

(d) Straw mulch, created by combines blowing out small grain-straw over fields at harvest time (Rosenberg, 1974).

1.2.2. Soil temperatures

The soil derives its heat almost entirely directly from the sun and loses much of it by radiation into the sky. The temperature of the surface layer of a bare soil is controlled by the rate it is absorbing solar energy. The surface soil temperature is seen to vary in phase with the incoming radiation during the day, but during the night it continues to fall, though much more slowly than it rises during the day (Russell, 1973).

The thermal diffusivity of soil is less than that of air at rest, soil temperature changes will be observed as waves during the course of a day. The amplitude of the temperature wave at the ground surface will be great, but will diminish with depth (Rosenberg, 1974). This is illustrated on figure 1 where the damping of the daily temperature wave with depth in a bare Rothamstead soil is shown.

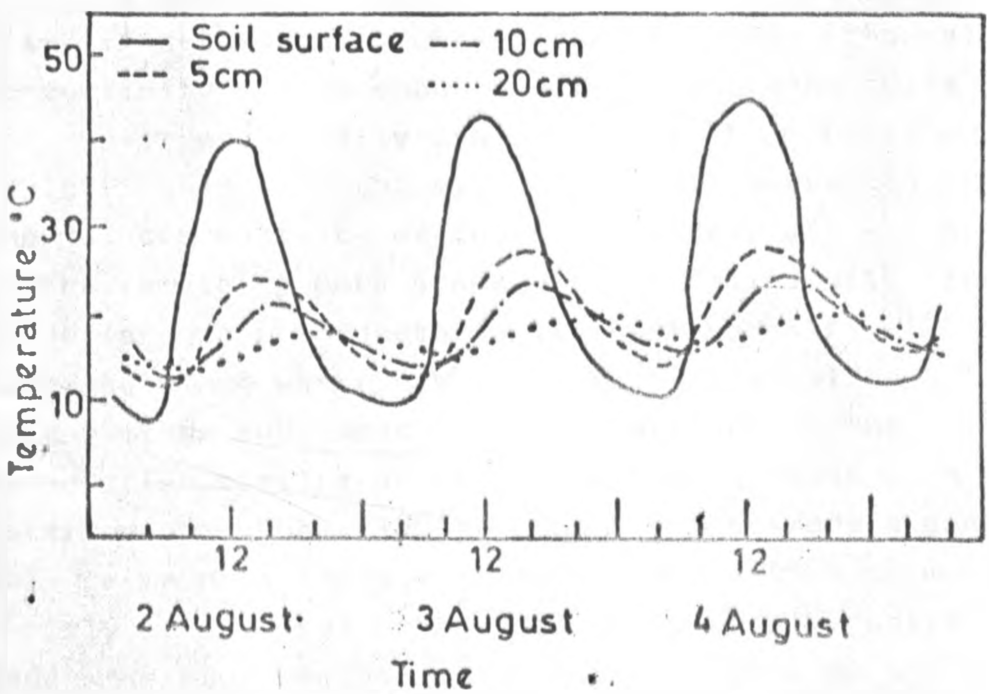
1.2.2.1. <u>Daily and seasonal patterns of soil temperature</u>

The pattern of decreasing amplitude of soil temperature wave has been shown by Baker (1965). The amplitude of soil temperature in summer and winter decreases with increasing depth in both bare and sod-covered soil at St. Paul Minnesota. At 40cm, depth the wave is virtually damped out, especially in winter, and at 81 cm depth no diurnal wave occurs. In summer soil temperatures decrease with depth during the day time, temperature gradients direct heat into the soil. At night however, the temperature is highest between 20 and 40 cm at this level heat is directed both upwards and downward (Rosenberg, 1974).

In winter at St. Paul Minnesota, the 81 cm depth was shown to be warmest and the diurnal wave was still only barely evident at 40 cm. This is shown on figure 2. The soil temperature below the soil surface follows the changes in surface temperature though it lags behind the surface and the diurnal variation is reduced (Russell, 1973).

Figure 1.

The damping of the daily temperature wave with depth in a bare Rothamstead soil.



Near the surface of the soil the daily temperatures fluctuations can be very great. In England daily temperature fluctuations occur down to approximately 60 cm, between 60 cm and 14 metres there are only seasonal fluctuations and below 14 metres there are no fluctuations (Cooper, 1973). Rosenberg (1974), gives as a "rule of thumb" that it may be assumed that the annual wave is extinguished at a depth that is approximately 19 times the depth of the diurnal wave.

1.2.2.2. Texture of the soil and its influence on soil temperature.

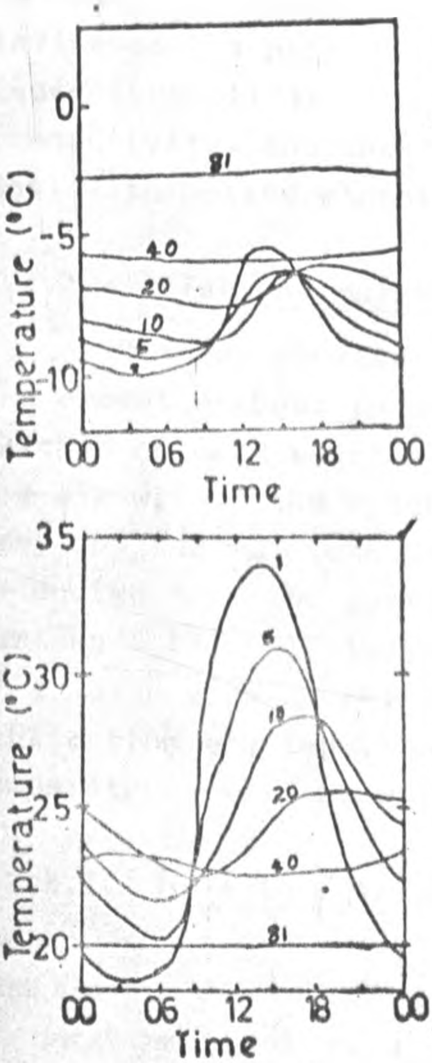
A coarse-textured soil such as sand and silt loam (fine-textured), when saturated their thermal conductivity may be about equal. Since sand holds less water and usually drains better it will dry more rapidly than will the silt, this will cause the thermal conductivity of the sand to decrease sharply as the remaining pore space will be filled with air which is a poor conductor. Its heat capacity will decrease since water has the highest thermal capacity of any other substance in soil, furthermore the evaporative cooling of the surface will cease when the water becomes unavailable. For these reasons a sandy soil warms more rapidly in spring and will cool more rapidly after a rain than will silty or clay soils under the same weather conditions, because of the lower moisture content and thermal capacity (Rosenberg, 1974)

1.2.2.3. Temperature and water relations in soils

Moist soil is usually cooler than dry soil, one reason for this is the high specific heat of water. Dry soil has a specific heat that is approximately one fifth that of water, hence a given amount of heat will

Figure 2.

Average hourly soil temperature under bare soil at St. Paul, Minnesota soil depth is shown in (cm)



January 1961

July 1961

(After Baker 1965)
(In Rosenberg,(1974).

raise the temperature of moist soil less than that of a dry soil. Evaporation of moisture from the surface of the soil also cools the soil (Cooper, 1973). When the soil surface is moist, most of the net radiation absorbed is used to evaporate water, but as the soil becomes drier an increasing quantity is dissipated either as sensible heat to the air or as heat flux into the soil (Russel, 1973). The moisture in soil moves in response to water potential gradients and also as a result of temperature gradients in the soil, therefore the temperature profile may influence the patterns of moisture distribution in soil (Rosenberg, 1974). The variation of thermal conductivity, and thermal diffusivity of a sandy loam soil with moisture content is given on figure 3.

1.2.3. Effect of mulches on soil temperature

Mulches applied to the surface of a soil affects the amount of heat received and the way it is dissipated. Mulches of dead vegetation, to some extent immobilise the air within the mulch and because still air has a very low thermal conductivity, heat is only slowly conducted from the surface of the mulch to the soil surface (Russel, 1973). The physical characteristics of a mulch such as colour, roughness and manner of application are important in determining the way soil temperatures will be affected (Quashu and Evans, 1967).

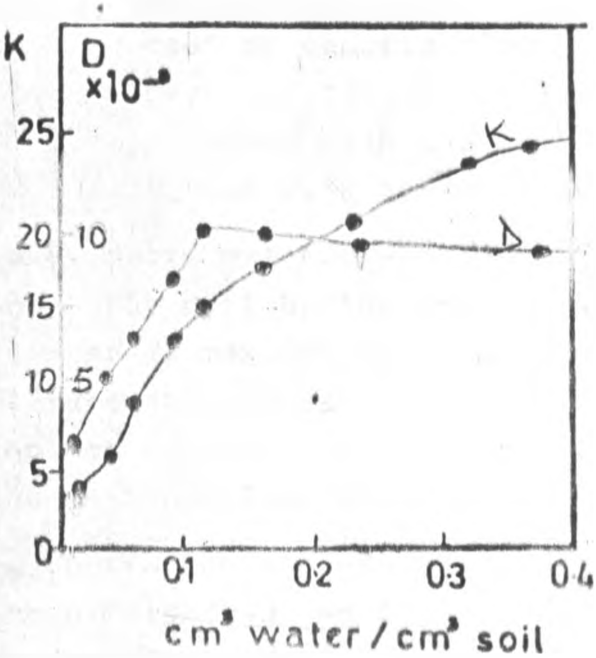
1.2.3.1. Organic mulches

The general effect of organic mulches is to increase soil temperatures in cold seasons and to decrease it in hot seasons (Gilbert, 1945; Jacks et-al, 1955; Van wijk et-al, 1959; cooper, 1973; Russel, 1973; Rosenberg, 1974).

Mulches have been reported to influence soil temperatures in the following ways:-

Figure 3.

Variation of thermal conductivity, and thermal diffusivity of a sandy loam soil with moisture content.



K - Therm conductivity in J / °C / cm / sec
D - Diffusivity cm²/sec.

The saturated soil held 0·38 cm³ water/cm³ soil

(After Moench and Evans, 1970 (In Russell 1973).

(a) The mulch acts as an insulating layer on the soil surface, reducing the amount of heat that enters the soil.

(b) A lesser fraction of incident radiant energy is converted into heat at the surface if the reflection coefficient, of the mulch exceeds that of the unmulched soil.

(c) Evaporation is reduced, which means a smaller fraction of the total heat generated at the surface is used as latent heat of vaporization, such that sensible heat constitute the larger fraction as compared with the unmulched soil (van Wijk et-al, 1959).

In U.S.A. maize mulched with oat straw, showed that for the early part of the season mulch decreased the weekly average maximum soil temperature at 10cm depth. The differences between mulched and unmulched treatments were not as marked in the minimum soil temperatures as for the maximum (van Wijk, et-al, 1959).

Barrentine and Waddle (1972) showed that cotton pods as a mulch reduced the mean soil temperature at 7.5 cm depth by 1 to 2^{o}C below that of other mulches such as black asphalt mulch. In a coffee nursery trial in Kenya grass mulch restricted the rise of soil temperature during the day by 5^{o}C, but the soil temperature under petroleum mulch was comparable to that under bare soil (Blore, 1964). Lower soil temperatures under straw mulch was shown to be a major factor in reducing maize growth in United States of America (Burrows and Larson, 1962). In a straw mulch trial on the growth of Alfalfa the maximum soil temperatures at 2.5 cm depth were shown to be 9.0^{o}C below the maximum for bare soil treatment (Evenson and Rumbangh, 1972). The usual effect of a straw mulch is to lower soil temperatures, during the summer and increase it during the winter. The thermal conductivity of a mulch is usually much lower than that of the soil, the heat gain or loss is therefore less under mulch (Hanks et-al, 1971).

The annual mean range between maximum and minimum soil temperature was reported to be reduced by one half under sugar cane trash mulch as compared to paper mulch, the bare soil temperature range being lower than that under paper mulch (Magistud et-al, 1935).

Straw mulch at the rate of eight tons per acre reduced soil temperatures at 2.5 cm depth by as much as 17.7°C during the day (McCalla and Duley, 1946). Parker and Larson (1962) reported 1° to 2°C lower soil temperatures under straw mulch than under bare soil. Differences between straw mulched soil and bare soil minimum soil temperatures were reported to be small, the mulched soil was slightly warmer while the soil was cooling and slightly cooler than bare soil when the soil was warming (Moody et-al, 1963).

1.2.3.2, Artificial mulches

The colour of plastic mulches greatly affect soil temperatures. White or reflective plastics decrease or have no effect on soil temperature, clear plastics have been shown to consistently result in higher soil temperatures than bare soil. Results with black plastics are variable some reports indicate higher and others lower soil temperatures, while others report little effect (Unger, 1975).

Law and Cooper (1974) working on maize in Kenya showed that clear polyethylene mulch was effective in creating higher soil temperatures than bare soil. Hopen (1965) recorded higher soil temperatures under clear polyethylene mulch while the black mulch was intermediate and bare soil had the lowest soil temperatures. Clear plastic was shown to increase soil temperature as compared to bare soil at 2.5 cm depth (Greb , 1966). In an experiment carried out to determine the influence of gravel, straw, black painted gravel, aluminium painted gravel and plastic mulches on soil temperatures, soil temperatures were highest under clear plastic, followed by bare soil, black painted gravel, aluminium painted gravel and straw covered treatments respectively (Hanks et-al, 1961).

Petroleum sprays and resin mulches consistently resulted in higher soil temperatures (Unger, 1975). Blore (1964) in a petroleum mulch trial on young Kenya coffee, showed that during the day soil temperatures under petroleum mulch were comparable to those under bare soil, while soil temperatures under grass mulch were 5^{o}C lower. Soil temperatures at 1 cm depth were reported to be 5^{o}C higher under petroleum mulch than under bare soil (Kowsar et-al, 1969).

Higher soil temperatures under asphalt mulch was reported to be due to decreased evaporation and increased absorption of radiant energy (Myhr, 1966). Black granular mulch (Coke) showed higher soil temperatures at 15 cm depth than bare soil during the day. The pre-sunrise readings did not show detectable temperature differences between mulch and bare soil (Qashu and Evans, 1967), Higher soil temperatures under black granular mulch (Coke) than under bare soil was also reported by Hasan et-al (1967).
Black asphalt mulch was reported not to affect soil temperatures (Barrentine and Waddle, 1972).

Polyethylene coated paper mulchees have been reported to increase soil temperatures (Liptay and Ticssen, 1970). Paper mulch was shown to increase soil temperatures (Magistad et-al, 1935). A stone mulch increased soil temperatures compared to bare soil, which was suggested to be a factor in production of high quality grapes on stony slopes (Lamb and Chapman, 1943).

1.2.4. Effects of mulches on soil moisture

Mulches affect soil moisture through increased infiltration, run-off control, reduced evaporation and weed control (Unger, 1975). Mulches have been reported to conserve soil moisture and thus resulting in improved water-plant relations (Jacks et-al, 1955; moody et-al 1963; Northmore, 1963; Greb et-al, 1967; Kowsar et-al 1969; Liptay and Tiessen, 1970; Reynolds, 1970; Koshi and Fryrear, 1973).

1.2.4.1. Infiltration rate

Vegetable mulches have been shown to improve the infiltration of rain water into the soil, which is a major factor in the conservation of soil moisture by these mulches (Beutner and Aderson, 1943; Pereira and Jones, 1954; Mehlich, 1966; Evanson and Rumbaugh, 1972; Eavis, 1976). Mannering and Meyer (1963) showed that the application of wheat straw mulch at the rate 1, 2 and 4 ton/acre maintained very high infiltration rates resulting in essentially no erosion, The ¼ and ½ ton/acre of mulch lost 3 tons and 1 ton of soil per acre respectively, where there was no mulch 12 tons of soil per acre was lost. Clean weeding caused on average 15 percent reduction in infiltration rate during very heavy rain storms compared with minimum weeding or when a grass mulch was incorporated into the soil during cultivation (Pereira, 1964). High infiltration rates can be maintained by keeping a continuous stubble cover on the ground, mulches not only increase infiltration rates of rain water and minimise its direct impact on the soil but also decrease the run-off velocity (Rattan, Lal ,1972).

1.2.4.2. Run-off

Mulches are generally accepted as erosion control measure, this is mainly due to their effect on run-off control. When run-off is checked the rain-water is accepted into the soil and therefore higher soil moisture contents will result (Gilbert, 1945, Duley, 1953, Ekern, 1967, Sogo and ozaki, 1967). John Adams (1966) reported that surface covers of straw and gravel mulch increased water intake by reduced run-off. The protective action of a surface cover is the interception and absorption of rain drop impact which prevents surface sealing and preserves the structure of the immediate soil surface, run-off is thus reduced by mulching and this aids to conserve soil moisture (Beale et-al, 1955; Mannering and meyer, 1963; Evenson and Rumbaugh; 1972). Water loss by run-off was shown to be reduced greatly by straw mulch at the rate of 8 tons per hectare (Lattanzi et-al, 1974).

The effect on run-off losses of mulching maize grown on various slopes, as investigated in Nigeria showed that mulching was as good as forest fallow in controlling soil erosion and run-off as shown on table 1.

Table 1. Effect of mulching on run-off losses under maize as compared with forest fallow (Total rainfall 295 mm)

Run-off losses (mm)

Slope	unmulched maize	mulched maize	Forest fallow
1	19	6	5
5	119	23	4
10	125	17	5
15	52	5	6

(After Rattan Lal, 1973).

In an experiment done at Kericho (Kenya) on land with 10% slope mulching was shown to be effective in controlling run-off as shown on table 2.

Table 2. Rainfall and Run-off

Rainfall	Manual tillage	Herbicide non-tillage	Oats	Mulch
1st year 2082.6	180.9	159.5	65.1	53.7
2nd year 2045.2	126.7	162.3	79.8	26.7
3rd year 1985.4	32.4	90.2	38.9	21.5

(After Othieno, 1975)

1.2.4.3. Evaporation

Mulches could theoretically reduce soil water losses by reducing soil temperature, impeding vapour diffusion, acting as periodic focal points for temporary vapour condensation and absorption into the mulch material, and by reducing wind velocity at the soil interface; The reduction of soil temperatures by mulches of plant materials has been shown to be the major factor involved in the evaporation reduction process (Greb, 1966).

Reduced evaporation due to mulches has been reported to be one of the factors that enable mulches to conserve soil moisture (Foster, 1962; earl and Carter, 1963; mehlich, 1966; Evenson and Rumbaugh, 1972; Papendick et-al, 1973).

The low soil temperatures under cotton pod mulch can explain the reduced evaporation under this mulch (Barrentine and Waddle, 1972). A stone-mulch was shown to reduce evaporation from the soil surface (Lamb and Chapman, 1943). Straw and gravel mulches were shown to reduce evaporation thus allowing the storage of more soil moisture (John Adams, 1966). Pereira and Jones (1954) reported that although evaporation reduction is a factor in improved soil moisture conditions under grass mulches, the increased infiltration rates secured by the mulch is quantitively greater than the subsequent reduction of evaporation. Quashu and Evans (1967) reported that a mulch acts as a barrier to evaporative losses of water to the atmosphere. A laboratory study investigating the comparative effectiveness of a dust, ground maize cob and gravel mulch in inhibiting evaporation of soil water indicated that gravel mulch was more effective than either dust or ground maize cob mulch, the dust mulch proving to be the least effective (Bendit and Kirkham, 1963). Laboratory and field experiment with granular mulch (Coke) showed that under this mulch evaporation suppression from wet sand was proportional to the relative area covered by the mulch (Hasan et-al, 1967).

1.2.4.4. Weed control

It is generally accepted that mulches control weeds. When weeds are controlled the water that could be lost through transpiration by the weeds is conserved in the soil for crop use (Gilbert, 1945, Rowe-dutton, 1957; Northmore, 1963; Ekern, 1967; Reynolds, 1970).

1.2.5. Soil nutrients and fertility

Mulches of plant materials have the effect of adding organic matter together with other plant nutrients to the soil (Gilbert, 1945; Jacks et-al, 1955; Northmore, 1963; Pereira, 1963). The amount of nutrient element added to the soil will depend on the type of mulching material, this is because different materials may vary greatly in their mineral contents (Mehlich, 1966).

Robinson and HoseGood (1965) working with grass mulch on coffee in Kenya reported increased organic carbon, kjeldahl nitrogen and reduced acidity due to mulching. The levels of exchangeable potassium and phosphorus were greatly increased. Despite the reduced acidity the exchangeable calcium and manganese were reduced. The exchangeable magnesium level was increased in the top soil but due to leaching in the greater sampling depth the magnesium levels was lowered.

Sanders (1953) showed that banana trash mulch increased the organic matter of the soil considerably and increased coffee yields in Tanzania. On tea soils in Kenya, mulching with grass resulted in increased percentage carbon and nitrogen in the soil. Soil phosphorus was also increased mainly in the first 2 cm of soil, so were calcium and potassium levels (Kizza, 1969).

In Kenya grass mulches have been shown to have a strong tendency to induce magnesium deficiency by supplying an excess of antagonizing potassium. Iron chlorosis in coffee is frequently associated with magnesium deficiency for the same reason. In coffee magnesium deficiency occurs chiefly on the older leaves in those axils where flowers or cherries are developing.

The critical level of magnesium in the leaves of Arabica and Robusta coffee below which the magnesium-deficiency sydrome is likely to occur is 0.2%, while the critical ratio of potassium to magnesium in the leaves is about 10:1 (Robinson and Chenery, 1958).

Coconut husks have been shown to supply plenty of potassium in the soil due to their high nutrient content of 20-25% K_2O in the ash (Brunim, 1966).

Polyethylene - coated paper mulch was shown to result in higher nitrate nitrogen levels in the soil than bare soil. The higher soil temperatures and moisture levels together with better aeration contributed to nitrogen-mineralization. In addition to increased mineralization the higher nitrogen levels were also due in part to reduction in leaching of soluble nitrogen (Liptay and Ticssen, 1970). In an experiment done on pineapples using straw and paper mulches, it was shown that because straw had a high carbon: nitrogen ratio the material caused a reduction in available nitrogen in the soil; nitrates do not accumulate in the soil until the carbon: nitrogen ratio has been lowered (Magistad et-al, 1935). 1935). Sawdust either used as a mulch or mixed with soil was shown to decrease the nitrate content of the soil (White et-al, 1959).

Mulches conserve the humus already in the soil by preventing overheating of the top layer and hence preventing oxidation (McMaster and Solly, 1957).

1.2.5.1. Relationships between applications of cattle manure, mulch and nitrogen fertilizer on coffee in Kenya.

In a trial carried out on an eroded slope, substantial yield responses were obtained over a 8 year period to either cattle manure or mulch applied to coffee. Where both were applied together the yields obtained were no greater than when mulch was applied alone, this is shown on table 3 below.

Table 3. Coffee yields: interaction of cattle manure and all rows mulching

cwt clean coffee per acre

Rainfall (inches)		Control	Manure	All row mulching	Mulch + manure
1950	24	0.61	0.91	1.49	1.54
1951	54	6,67	6.95	12.30	11.86

(After Pereira and Jones, 1954)

A negative interaction of sulphate of ammonia with grass mulch was first detected in Kenya in 1951 (Anon, 1955). The application of mulch and/or cattle manure modifies in a differential manner both the type of nitrogen fertilizer and quantities of nitrogen applied. Modifications may be summarized in the following manner:-

(a) If neither cattle manure nor mulch is applied, sodium nitrate fertilizer should be used.

(b) When cattle manure or mulch is applied any nitrate form of fertilizer should not be used, an ammonium form should be selected.

(c) Where cattle manure is used the rate of fertilizer application should be half the application that would have been, if no manure was applied.

(d) If only grass mulch is applied ammonium form of fertilizer should be applied at the normal rate.

(e) Experimental evidence has shown that when an application of grass mulch and a dressing of cattle manure are made together in the same season, the mulch eliminates or at least substantially reduces the response to cattle manure (Pereira and Jones, 1954).

It would therefore be more economical to apply one or the other as alternatives in any one season. The exceptions to this are those areas where the average rainfall total is low with an uncertain distribution, also on slopes mulch should be used rather than cattle manure in order to prevent soil erosion. In the case of new plantings the simultaneious use of cattle manure and mulch can be advised. (Robinson, 1959; Robinson and Wallis, 1959).

1.2.6. Soil structure

Mulches in general improve or maintain soil structure, this is brought about by the effect of mulches on breaking the force of rain droplets so preventing soil compation, protection against explosure to alternate rain and sun also checks crusting of the soil. Organic mulches add organic matter to the soil which brings about aggregation of the soil particles (Beutner et-al, 1943; Beale et-al, 1955; Rowe-Dutton, 1957; mannering and meyer, 1963; pereira, 1964; Lattanzi et-al, 1974; Unger, 1975). Total pore space, free draining pore space and rainfall acceptance were reported to be increased on a latosolic coffee soil in Kenya due to mulching. This is shown on table 4 below.

Table 4. Physical analysis of a Kikuyu red loam soil

Analysis	No mulch	With mulch	% increase over no mulch
Total pore space	63.5	69.3	+ 8
Free-draining pore space	14.0	26.7	+ 91
Rainfall acceptance	0.50	0.78	+ 53

(After Robinson and Hosegood, 1965)

Stauffer (1946) showed that wheat straw mulch favoured the formation of larger soil aggregates than soya bean straw or maize stalks.

Incorporation of mulch into the soil during tillage improved soil structure as indicated by the higher infiltration rates on table 5 below.

Table 5.. Effects on soil structure of tillage implements when incorporating mulch grass

Rainfall acceptance in/hr after a storm 6in/hr

Implement	Mulch	No mulch	Mean
Forked hand hoe	5.0	5.3	5.1
Modified rotavator	5.6	4.3	5.1
mean	5,3	4.8	

(After pereira et-al, 1964).

Koshi and Fryrear (1973) reported that straw mulch at the rate of 11.2 tons/ha reduced the bulk density, increased the hydraulic conductivity, air porosity, total porosity and organic matter content of the soil.

1.2.7. Soil biological regime

Mulches modify the composition of the soil fauna and micro-organisms. Grass mulch was reported to modify the species composition of small arthropods in the soil, by increasing the participation of plant decomposing collembola and oribaticles at the expense of other species, (Holler-land, 1958). Covering the soil with polyethylene mulches hindered aeration of the profile and activity of aerobic micro-organism. The populations of anaerobes increased especially in the lower layers (Hrbacek et-al, 1966).

Plant residues used as a mulch increased the total number of micro-organisms, the number of azotobacter and the intensity of nitrification in a clay soil. Peat, saw dust and tar-paper had a negative effect which may have been due to the presence of toxic substances (Kuzniar, 1957). In another experiment saw-dust mulch was shown to increase earthworm and nematode populations in the soil more than wood chips or peat mulches (Vannierop and White, 1958).

1.2.8. Erosion control

Erosion control is one of the important beneficial effects of mulches . Barnett, et-al, (1967) showed that two tons of grain straw per acre provided addquate protection to newly prepared and seeded 2.1 backslopes, when subjected to one-year frequency storms 1.3 inches of rain in 30 minutes. In another experiment mulches reduced erosion by 11.7 ton/acre on 10-12 per cent slopes (Borst and Medirski, 1957). Reduction of 40 per cent erosion has been achieved by protecting the soil with mulches (Lattanzi, et-al, 1974).

The amount of surface run-off and soil erosion on a field of young tea with a ten percent slope were measured under four soil management treatments (manual weeding, herbicide weeding, oats planted between rows of tea and grass mulch), for a period of three years. The study was made in Kenya on a typical tea soil derived from a massive sheet flow of phonolite lava. The run-off and soil erosion were greatest in the absence of erosion control measures (manual weeding and herbicide weeding). Mulching gave the lowest run-off and least erosion. In general, the amounts of run-off and soil erosion were both greatest in the first year when the ground cover provided by the tea canopy was between 1 and 30 percent, but they were reduced to very small amounts in the third year when the ground cover was more than 60 percent. This is shown on table 6 below.

Table 6. Rainfall and soil erosion

	Eroded soil •/ha			
Rainfall	manual tillage	Herbicide non-tillage	Oats	Mulch
1st year 2082.6	161.28	168.08	34.90	0.46
2nd year 2045.2	48.28	80.71	4.31	0.14
3rd year 1985.4	1.23	6.09	0.42	0.08

(After Othieno, 1975)

The effect on run-off losses of mulching maize grown on various slopes as investigated in Nigeria, showed that mulching was as good as a forest fallow in controlling soil erosion (Rattan Lal, 1973) Surface covers of Straw and gravel mulch increased water intake and essentially eliminated erosion (John Adams, 1966). A stone mulch was shown to greatly decrease soil erosion (Lamb and Chapman, 1943). Gravel was shown to adequately control wind erosion on smooth, bare sandy loam soil. Resin emulsion and asphalt emulsion controlled wind erosion on a level sandy loam soil in Kansas U.S.A. (Chepil, et-al, 1963). Mulch tillage considerably controlled erosion (Beale, et-al, 1955).

1.2.9. Crop response to mulches

1.2.9.1. Plant growth

Crop responses to mulches come as a result of the effects of mulches on soil water, temperature, erosion and weed control together with soil nutrients, soil structure and other effects of mulches that affect the plant growing environment.

Mulches can aid germination, emergence and seedling growth which is one of the most critical periods in the life cycle of a plant. This is achieved by moderating or improving the soil and aerial environment to which the seeds and seedlings are subjected (Unger, 1975).

Higher soil water contents coupled with improved temperature conditions seem to be the factors involved in the beneficial effects of mulches on germination and seedling growth. Mulches generally increase soil moisture content in the zone where seedlings are normally placed (Kowsar et-al, 1969).

In field and greenhouse experiments involving the application of straw or polyethylene materials as mulch showed that the rate of emergence, growth and earliness of maturity of maize was increased (Wallis, 1957). In Washington U.S.A. a region where inadequate water in the seedbed at planting time is a limiting factor to.early establishment of winter wheat mulch conserved enough moisture to allow early establishment (Papendick et-al, 1973).

Under conditions where crusting was a factor, stabilized vermiculite and coke placed over the seeds resulted in better emergence of sugarbeet than occured with seeds placed under bare soil (Ririe and Hills 1970).

Cotton pod mulch was shown to slow cotton seedling growth (Barrentine and waddle, 1972). Low soil temperatures have been reported to be a primary causative factor in the reduced growth of maize in some parts of United States (Van Wijk et-al, 1959; Burrows and Larson, 1962; Moody et-al, 1963).

Germination and growth rate of maize has been increased due to clear polyethylene mulch in Kenya (Law and Cooper, 1974). Clear polyethylene mulch induced earlier start of vegetative cycle and reduced the total growth cycle of maize by about one month (Ballif and Dutil, 1971).

Root development and response of sugar cane to fertilizers has been improved by mulching on saline - Akali subsoils in Barbados (Eavis, 1976). Straw mulch was shown to increase alfalfa growth by as much as 13 cm the greatest growth difference appearing late in the season (Evenson and Rumbaugh, 1972). In an experiment on establishment of perennial grasses and legumes both straw mulch and wood bark mulch improved the establishment (Powell, 1976).

In a shaded coffee nursery bed in Kenya neither grass nor petroleum mulch affected seedling growth, although small differences in soil temperatures were noted (Blore, 1964). In Tanzania mulching was shown to increase stem weight, yields and top/root ratio of coffee seedlings (Bull, 1962). Mulching improved the growth of coffee trees in a year of seasonal drought (Robinson and Hosegood, 1965). Mulching coffee with grass, there is a tendency for the feeder roots to grow into the top layers of the soil (McMaster, 1952). Grass mulches affect the mineral distribution of certain elements in the coffee plant (Robinson and Hosegood, 1965).

Table 7. Comparative chemical analysis of first fully open coffee leaf on bearing primaries

Results expressed as percentage of element in leaf dry matter

Analysis	no mulch	mulch
Nitrogen	1.97	2.01
Phosphorus	0.109	0.157
Potassium	2.56	2.72
Calcium	1.29	1.09
Magnesium	0.44	0.38
Sodium	0.044	0.032

(After Robinson and Hosegood, 1965).

1.2.9.2. Crop yields

Many reports have indicated higher crop yields when mulches are applied than when they are not. Higher maize yields have been reported due to mulching (White et-al, 1959; Jones et-al, 1960; Moody et-al, 1963; macmillan and millette, 1971). Cotton yields have been increased by mulching not only due to increase in soil moisture but also the effect of depressing toxic concentrations of aluminium and manganese in the soil (Mills, 1954; Landelout and Boig, 1955).

Peach and apple trees grew better and carried heavier fruit crops when straw mulch was used as compared to bare soil (Baxter 1970). Yield increases of up to 64% in melons have been reported due to mulching with bituminous emulsion combined with a weed killer (Sasso and Bianco, 1967). Blundell, (1954) reported yield increases of sugar cane ratoons after mulching with sugar cane trash. Yield increases on red currants, strawberry, eggplant, cabbage, apricott, grain sorghum and potatoes have been reported due to mulching (Bajwa and chadner, 1968; gerakis, 1969; Thorsrud, 1969a 1969b; John Adams, 1970; Reynolds, 1970). Mulching on pasture crops during establishment has been shown to increase the pasture production (Beutner and Aderson, 1943; Evenson and Rumbaugh, 1972; Powell, 1976). Saw-dust mulch increased yields of maize, tomatoes and lina beans (White, et-al, 1959). Sugar cane trash mulch was shown to increase the yield of pineapples (magistad et-al, 1935).

In Ghana cocoa was shown to give higher yields when the ground was covered with grass mulch during establishment, than when the soil was left bare, or the weeds allowed to regenerate and cutlassed at regular intervals. Mulch was superior to the other treatments and the superiority persisted for three years after the application of mulch ceased (Acquaye and Smith, 1965).

In Malawi coffee yields have been shown to respond favourably to napier grass mulch in the absence of shade (Foster, 1964). Sanders (1953) working in Tanzania reported yield increases of up to 50% in unshaded single-stem coffee on mulching with banana trash.

The Kenya coffee yields have been shown to respond favourably to grass mulches (Anon, 1945; pereira and Jones, 1954; Anon, 1957; Anon, 1958; Anon, 1959). Robinson and mitchell (1964) reported coffee yield increases of 33% over unmulched treatment. Considering the various recommended cultural practices, mulching with grass has been shown to give the greatest response in Kenya. Mulching increases the overall yield and also the proportion of gade "A" sized beans. Between 1959 - 74 mulching increased yields by 24% and the proportion of grade "A" beans by 4%

(Anon, 1964; Wapakala, 1965,1966; Mitchell, 1968, 1969, 1976a; Chawdhry, 1973).

1.2.10. Crop growth and its influence on mulch effects .

Law and Cooper (1974) working on maize in Kenya showed that a clear polyethylene mulch was effective in creating higher soil temperatures than under bare soil, but as the season progressed there was little difference between mulch and bare soil. This was closely correlated to increased leaf area index and therefore shading of the soil. Similar results have been reported by McCalla and Duley (1946)where by due to shading, a growing crop decreased the temperature difference between mulched and unmulched soil. Othieno (1975) showed that in establishing tea in Kenya run-off and soil erosion were greatest in the first year when the ground cover provided by the tea canopy was between 1-30%. Run-off and erosion were reduced to very small amounts in the third year when the ground cover provided by the tea canopy was more than 60%.

1.2.11. Other effects of mulches

Other effects of mulches include, weed control, winter protection, soil salinity control and reduction of pest and disease incidences.

Weed control by mulches is evident due to shading and mechanical suppression of the weeds. However some materials such as fresh manure, cereal straw or hay cut when seeding may even increase the weed problem by introducing weed seeds. Couch grass(*Digitaria scalarum*) tends to be shallow rooted under mulches and can be relatively easily pulled. Napier grass. (*Pennisetum purpureum*) due to its tendency to root in the field could increase weed problem when applied as a mulch before it is properly dry

(Gilbert, 1945; peroeira and Jones, 1954; Rowe-Dutton, 1957; Northmore, 1963; Mehlich, 1966; Ekern, 1967).

Winter protection is an important role played by mulches in temperate regions. Over a five year period, the regular use of mulches for winter protection of strawberries was shown to increase yields substantially (Collins, 1966).

Damage due to salts in the soil is most severe at germination and plant seedling stages, mulches maintain a high water content and reduce evaporation from the seed zone, this reduces the salinity hazard and aid plant establishment (Unger, 1975, Eavis, 1976).

Conservation of moisture by mulches could aid in reducing the incidence of certain physiological dis-orders such as blosson end rot in tomatoes (Rowe-Dutton, 1957) Black and white polyethylene mulches kept lettuce heads out of contact with the soil this reduced slime rot from 52.7% to 16.3% with white mulch and 18.2% with black (Wilborn, et-al, 1957). Mulching with wood shavings or coconut fronds was shown to reduce the incidence of Southern blight in dwarf beans and resulted in considerable increase in yields (Reynolds, 1970).

CHAPTER TWO

MATERIALS AND METHODS

2.1. Location of experiment site

The experiment was carried out at Kabete Field Station of the Faculty of Agriculture, University of Nairobi. The Field Station is situated in the Upper Kabete at an altitude of 1800 metres. It lies about 8.5 kilometres North West of the University Main Campus and 2 kilometres North of Nairobi-Nakuru road on Loresho Ridge. The station lies within latitudes 1^{0} 14' 20" S to 1^{0} 15' 15" S and longitudes 36^{0} 44'E to 36^{0} 45' 20"E (Wamburi, 1973).

The rainfall is 925mm per year spread over the long rains from late March to end of June and short rains from October to December. The soil is a deep red, latosal containing more than 60% clay after complete dispersion, but because of its stable micro-structure it has many of the properties of a loam (Browning and Fisher 1975). The rocks from which the soil has been derived is the Kabete trachyte which resulted from volcanic lava flow. The soils of this area are commonly known as the Kikuyu red loams.

The Field Station is part of the former Kirima Kimwe coffee Estate, the plantation dating back to the 1930's (Wamburi, 1973). It was on this coffee plantation where the experiment was done. In general the coffee plantation is managed on a capped multiple stem system, but the experiment was carried out on bushes that were not capped, since these bushes had been stumped in 1974 during the normal change of cycle prunning. The coffee bushes were spaced at 2.75m x 2.75m., which is the conventional spacing of coffee in Kenya.

2.2. Experimental design and layout

The experiment was laid out in a randomised block design comprising of four replicates and five treatments. The treatments included:-

(i) Bare soil (no mulch)

(ii) Grass mulch

(iii) Transparent polyethylene mulch

(iv) Black polyethylene mulch

(v) White polyethylene mulch

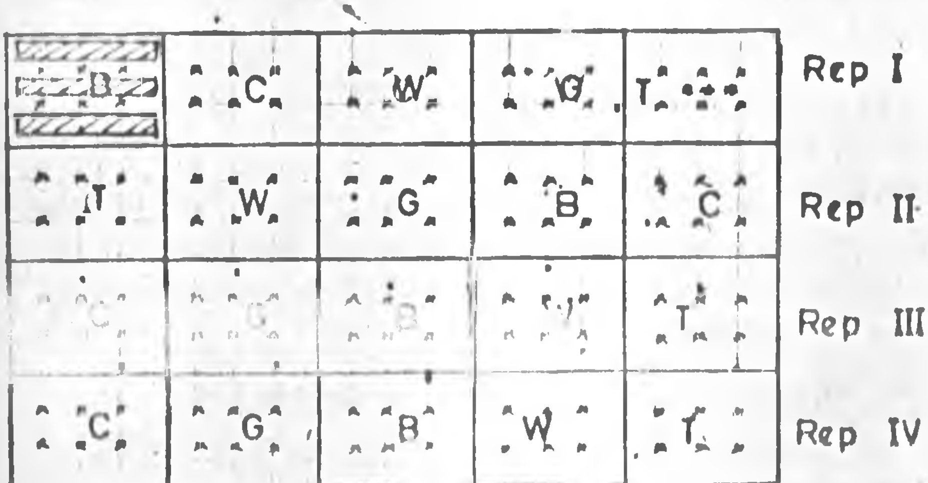
Each treatment comprised of six coffee bushes separated from the next plot by a guard row of coffee bushes. The stem bases of the guard row bushes were white-washed to mark the plots clearly. In every plot there were three inter-rows and this is where the mulches were laid down as a complete mulch. The width of the mulches was 2.4 metres, this left about 20 cm on either side of the base of the coffee bushes unmulched.

Figure (4) illustrates the layout of the experiment in the field.

The artificial mulches used were polyethylene sheetings of the gange 1000 x 240 cm. Black and transparent polyethylene sheets were available in the market but the white type was not. To get the white polyethylene material a transparent sheet was painted white by applying as uniform cover as possible of white plastic paint.

When the polyethylene mulches were laid down in the field, soil was placed at the edges to prevent the wind blowing underneath and displacing them. On these mulches small holes were made where the ground seemed hollow to prevent any accumulation of rain water at the surface. These holes were made at random at

Figure 4. Layout of the experiment in the field.



Mulched (shown on one plot)
Gard row coffee bushes
Experimental coffee bushes
Thermistors — shown on one plot
C — Bare soil
G — Grass mulch
T — Transparent polythene mulch
B — Black polythene mulch
W — White polythene mulch

the sites where it seemed possible for rain water to accumulate. During the cause of the experiment whenever puddles formed during the rains holes were made on the polyethylene mulches to allow water to soak into the ground.

Napier grass (pennisetum purpureum) was used for the grass treatment, enough grass was applied such that when it settled after about two weeks gave a thickness of about 15 cm. The bare soil treatment was kept clear of any vegetable materials on the soil surface or any other type of material.

The black and transparent polyethylene mulches together with the grass mulch were laid down on 9th April 1976, but the white polyethylene mulch was not laid down until 20th April 1976 due to the need for painting.

2.3. Soil moisture content determination

Soil moisture determination was made for each plot, by oven-drying samples taken from three depths, 0-15 cm, 50-60cm and 110-120cm. One of the six coffee bushes which were the experimental bushes in a plot was picked at random and the samples were then taken on any of the three inter-rows also picked at random at about 90 cm from the base of the coffee bush. This has been shown to be the best location to take moisture samples in coffee (Wallis, 1963).

The depths at which the soil moisture samples were taken are in relation to the root distribution in coffee. It has been found that coffee roots explore extensively the first three metres of the soil, but the bulk of the roots are found within 120 cm of the surface, with most of the feeder roots being found within the first 60 cm of the soil surface (Wallis, 1963).

A soil auger was used for taking the soil samples which were collected in aluminium cups with fitting lids. In the field each sample was placed in a cup and the cup number noted, care was taken to close the cups tightly to avoid any loss of moisture before the weights of the wet samples was taken.

The moisture content of the soil samples was obtained by taking weights of the wet samples and the dry weights after oven drying the samples at 105°C for 24 hours. The weight of each particular cup and lid was also taken.

Samples for moisture determination were taken at the interval of 10 days. In 1976 this was done between 13/5/76 and 12/10/76, while in 1977 the samples were taken between 12/1/77 and 5/5/77. After taking the soil samples, the mulches were carefully placed back in position, leaving the holes that have been made not filled with soil to avoid sampling from the same place another time.

2.4. Soil temperature measurement

Mercury thermometers that could take soil temperatures at 7 cm depth were used between 17/5/76 and 13/8/76. Only ten thermometers were available and these were used on two of the replicates. Temperature readings were taken twice a day at 8.30 a.m. and at 2.30 p.m.

Glass bead thermistors of the type 151-114 obtained from Radio spares, were used for measuring soil temperatures between 6/12/76 and 29/4/77. Figure(5) gives a diagram of the thermistor used.

The thermistors were first soldered into electrical wires. This was done by joining the two thermistor terminals to the wires by the use of solder. To make sure that the two terminals do not touch one another when installed in the soil, a piece of rubber tube was inserted at the soldered joint of one of the terminals and an adhensive material (Araldit) was used to hold the two terminals together as shown on figure 5.

The thermistors were calibrated by taking six thermistors at a time and placing them close together with a mercury thermometer and placing them in a pot containing wet sand. The pot was cooled overnight in a refrigerator and the next day on placing it at room temperature, as the temperature rose, for every (°C) rise a meter reading was taken for each of the thermistors. The calibration for temperatures above room temperature was done by pouring hot water into the pot containing the thermistors and a thermometer. On pouring hot water the temperature of the sand rose, and as it started to fall for every (°C) drop a meter reading was taken for each of the thermistors. The temperature range for which the thermistors were calibrated was 13°C to 32°C.

The meter readings and the temperatures were drawn on a table, from which a meter reading could be interpreted as a temperature reading in (°C). Table 8 gives the calibration table for ten of the thermistors.

Thermistors were installed at three depths 15 cm, 1m and at 2 m, a soil auger was used for digging holes of the required depth. After placing the thermistors, the holes were filled up with soil, leaving only the wires attached to the thermistor at the surface of the mulches. Temperature readings were taken twice a day at 9.00 a.m. and at 3.00 p.m.

Figure 5.

Diagram of bead thermistor type 151-114

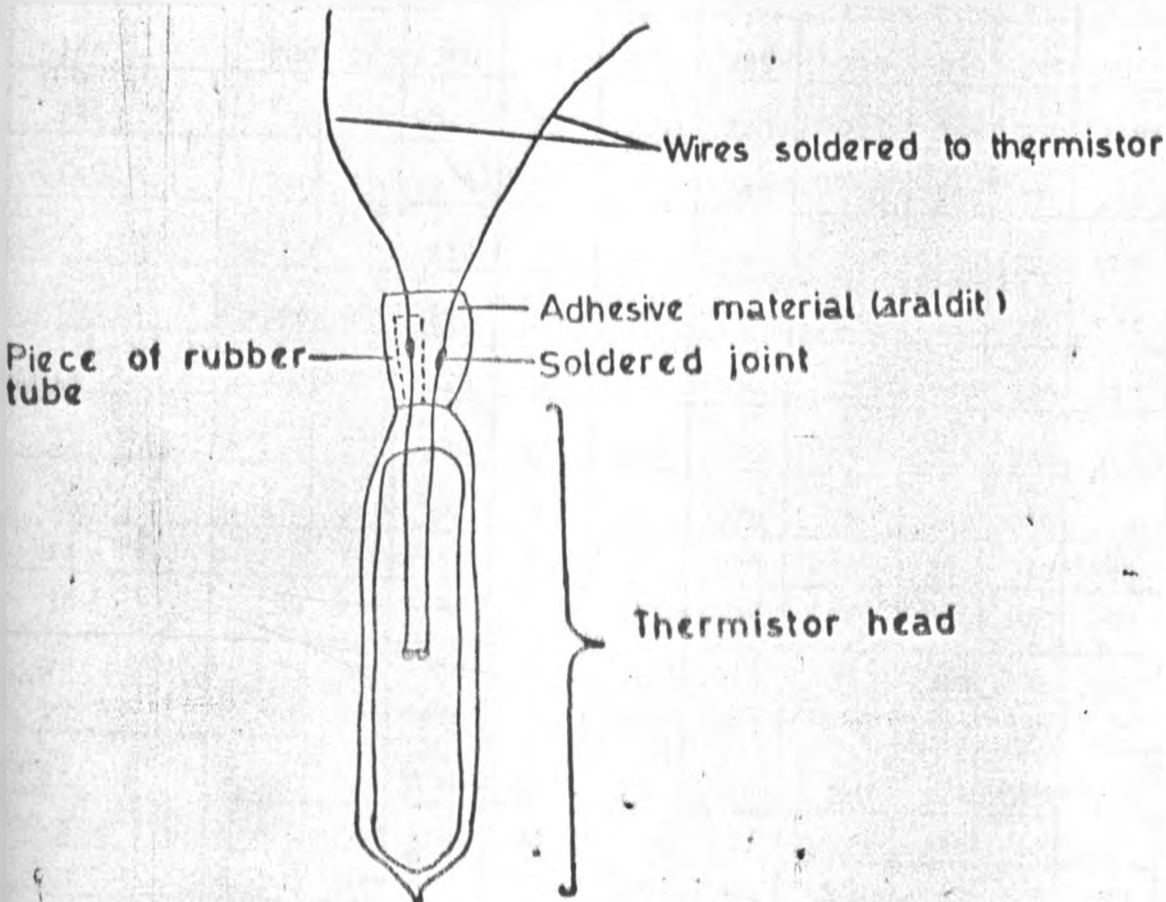
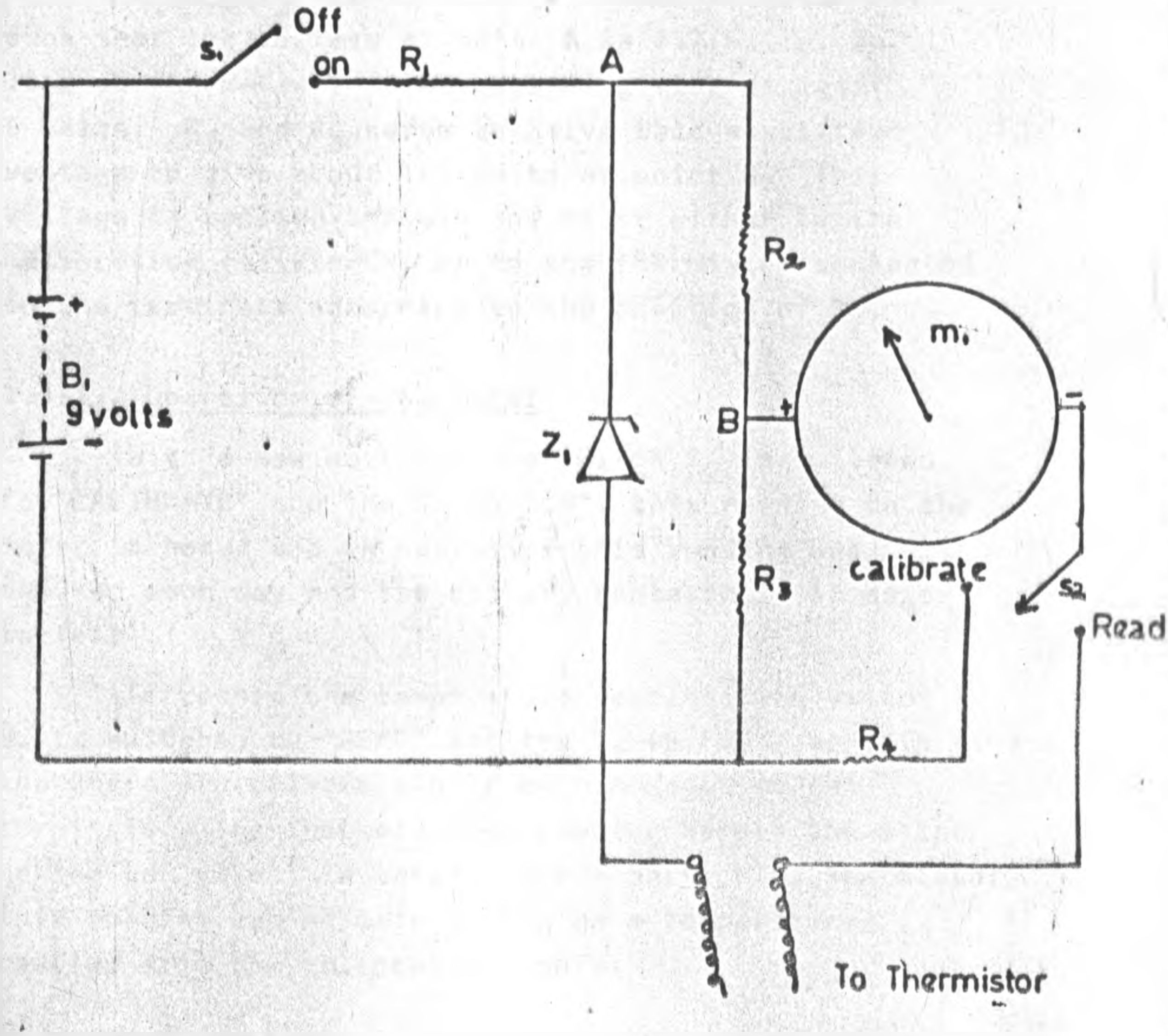


Table 8. Calibration table for the soil thermistors

Temperature	Thermistor number and meter reading									
°C	1	2	3	4	5	6	7	8	9	10
13	205	175	175	210	220	200	185	210	230	210
14	210	180	185	215	225	205	190	220	235	215
15	220	190	190	220	235	215	200	230	245	225
16	230	200	200	230	245	225	210	240	255	235
17	235	205	205	235	250	230	215	245	260	240
18	240	210	210	245	255	240	220	250	270	245
19	250	215	215	250	260	245	225	225	275	250
20	255	220	220	255	265	250	230	260	280	255
21	260	225	225	260	270	255	235	270	285	260
22	265	230	230	270	280	260	240	275	290	270
23	270	240	240	280	290	270	250	280	300	280
24	280	250	250	290	300	280	255	290	310	285
25	290	260	260	300	310	285	265	300	320	290
26	295	265	265	305	315	295	275	310	325	300
27	300	270	270	310	320	300	280	320	330	310
28	310	280	280	320	335	310	290	325	345	320
29	320	290	290	335	345	320	300	335	355	330
30	340	300	300	350	360	330	310	350	370	340
31	350	310	310	360	370	340	320	360	380	350
32	360	320	320	370	380	360	330	370	395	360

Figure 6 Circuit of meter for thermistor type 151-114



B1 - 9 volts battery type 216

S1 - On-Off switch

S2 - Calibrate - read switch

Z1 - Zener diode (voltage stabilizer)

m1 - 500 micro amp meter full scale deflection

R1 - Dropper resistor 1000 ohms

R2, R3 - Form a potential divider to further reduce the voltage applied to applied to the resistor R1 R2 = R3 = 1000

R4 - is the calibration resistor 3300 ohms.

R_1 and Z_1 form a voltage stabilising circuit such that the voltage at point A is 2.7 volts, so long as the battery is capable of giving at least 5 volts. R_2 and R_3 serve to halve this stabilised voltage to give about 1.3 volts at point B. This voltage is applied through the meter either to the calibration resistor R_4 or to the thermistor connected to the terminals according to the position of S_2.

2.4.1. Operation of the meter

With a new battery, the switch S_2 is switched to "CALIBRATE" and the S_1 to "ON", this reading on the meter is noted and in operation this reading was checked each day and the battery replaced if it began to fall.

To record the temperature readings the switch S_2 is switched to "READ" and the S_1 to "ON", at this time the thermistors leads should be connected to the terminals. The instantaneous reading before the meter begins to "climb" is taken. For a particular thermistor this reading can be interpreted as a temperature reading from the calibration table.

2.5. Flush growth measurement

Flush growth of the coffee bushes was determined both in terms of lateral branch extension and number of nodes grown. This was done on two coffee bushes per treatment, in which four lateral branches per bush were tagged three nodes from the tip on 10/9/76. After every two weeks the length in (mm) of each branch from the tag to the tip was measured by the use of a tape measure. The nodes infront of the tag were also counted after every two weeks. Growth was determined by taking the difference between the two weeks interval measurements. Growth measurements were done between 10/9/76 and 1/3/77.

2.6. Assessment of weed growth

Before the mulches were laid down all the plots were clean weeded. Assessment of weed growth was made once per season at a time when the general weeding of the coffee estate was about to be carried out. A 10 x 10cm quandrat was used for taking the weed samples. In every plot four quandrat samples were taken and the harvest bulked together to give a single sample for that plot. Only the top parts of the weeds were taken, the roots were not included. The fresh weight of the weeds were taken and this was used to determine how much weed can be expected in a hectare of a particular treatment. Indentification of the common weeds in the experiment was also done.

The most common type of weeds in the experimental area were Oxalis latifolia, cyperus rotundus and Digitaria scalarum. Other kinds of weeds included:-

Bidens pilosa

Tagetes minuta

Dactyloctenium aegyptium

Setaria verticillata

Oxygonum sinnatum

Commelina benghalensis

Conyza stricta

Erucastrum arabicum

Asystasia schimperi

Lipidium banariense

Amaranthus hybridus

2.7. Soil chemical properties

Soil samples taken six months after the application of the mulches at a depth (0-15 cm) were analysed for organic carbon, total nitrogen, cation exchange capacity (CEC), potassium, sodium, magnesium and calcium.

2.7.1. Determination of organic carbon

The walkley-Black method was used for the determination of organic carbon in the soil. In the walkley-black method, the carbon is oxidised with potassium dichromate ($K2C_0207$) in the presence of concentrated (36N) sulphuric acid. Potassium dichromate is added to a carefully weighed sample of soil ground to pass a 0.5mm sieve and then the concentrated sulphuric acid is rapidly added. The heat of dilution obtained by diluting 20ml of acid with 10ml of dichromate is a convenient way of supplying a standard amount of heat to assist the oxidation. (Ahn, 1973a).

2.7.2. Determination of total nitrogen in the soil

The kjeldahl method was used for the determination of total nitrogen in the soil. This method essentially involves two steps. First the digestion of the sample to convert the nitrogen to the ammonium form and the second step involves the determination of the ammonium in the digest. (Ahn, 1973b)

2.7.3 Determination of cation exchange capacity

The cation exchange capacity was determined by the following method:

(a) Saturation of the soil sample with ammonium.

(b) Removal of ammonium acetate from the soil sample.

(c) Distillation of the NH_4 held by the soil colloids.
(Ahn, 1973a)

2.7.4. Determination of exchangeable calcium and magnesium by versenate titration

A titration for calcium is performed alone and then a second titration is done for calcium and magnesium together, the exchangeable magnesium being obtained by the difference between the two titrations. The calcium and magnesium is extracted from the soil sample by shaking with neutral normal ammonium acetate (Ahn, 1973a).

2.7.5. Determination of exchangeable potassium and sodium in the soil

The exchangeable potassium and sodium extracted from the soil sample by shaking with neutral normal ammonium acetate was determined by flame photometer method. Standard solutions with known concentrations of sodium and potassium were used to obtain standard curves of concentrations either of Na^+ or K^+ against galvanometer deflections. From the standard curves the concentration of either potassium or sodium was obtained after getting a galvanometer deflection of the solution from the soil sample (Ahn, 1973a).

2.7.6. Soil analysis done at Ruiru Coffee Research Foundation

Soil samples taken one year after the application of the mulches were analysed at Ruiru Coffee Research Foundation Kenya. Four auger samples were made per plot, of which 0 - 15 cm represented the top-soil and 15 - 60cm represented the sub-soil. Samples from plots of the same treatment were bulked to give single samples per treatment for top-soil and sub-soil. The mass analysis method for soil fertility evaluation of National Agricultural Laboratories (Kenya) was used.

2.8. Root distribution

Root distribution was determined up to 60 cm by digging trenches about one metre from a coffee bush. Roots at the depths 0-20 cm, 20-40 cm and 40-60 cm were collected by carefully taking soil slices of the width 5 cm and 3 cm depth on the side of the trench. All the roots in a slice of soil were collected, washed and the dry weight taken.

2.9. Coffee yields

Coffee harvesting was done on six coffee bushes which comprised each experimental plot and the weight of cherry taken. Harvesting was done as the coffee berries became ready for picking. The 1976/77 crop was picked seven times starting on 30/11/76 and ending on 15/3/77. The 1977 crop was picked six times starting on 15/3/77 and ending on 15/7/77.

2.10 Assessment of deterioration of mulches

Six months after the application of the mulches, a visual scoring assessment of the mulches was done. It was difficult to assess the grass mulch together with the polyethylene mulches, but the cover provided by the grass was also noted by estimating the thickness of the grass mulch.

Artificial mulches were assessed by randomly taking three areas per plot and estimating the percentage cover provided by the polyethylene. The area taken was that between four coffee bushes within the experimental plots.

2.11 Analysis of leaves

Leaf samples taken one year after application of mulches were analysed for various nutrients at Ruiru Coffee Research Foundation, Kenya. Leaves were sampled from the six experimental coffee bushes per plot, and these were bulked to give a single sample per treatment. The fourth leaf pair, counting from the first fully-open leaf at the tip of a primary branch was taken for the leaf samples. The primary branches from which the leaves were taken were those from the mid-canopy of the cropping region of the tree.

Statistical Analysis

The experiment was set up as a randomised block design comprising of four replicates and five treatments. The analysis of variance for soil moisture per depth, soil chemical properties, flush growth of coffee, root distribution, coffee yields and assessment of weed growth, was done as a randomised block with the number of degrees of freedom shown on the table 9.

Table 9.

Source	degrees of freedom
Blocks	3
Treatment	4
Error	12
Total	19

The analysis of variance for soil temperatures was done as a split plot design, considering the treatment effects, time of day and the interaction between time of day and treatment. The degrees of freedom were variable because the number of thermistors were not the same in all the periods due to losses in the field. Table 10 gives the degrees of freedom available for soil temperatures at 7 cm depth.

Table 10. Analysis of Variance soil temperature at 7 cm depth

Source	degrees of freedom
Treatment	4
Main error	5
Main total	9
Time of day	1
Time x treatment	4
Sub error	5
Total	19

The analysis of variance for the variation of soil moisture with depth was also done as a split plot design, the main interest being, the depth effects and the interaction between depth and treatment. To test these effects a pooled error mean square (EMS) obtained from the analysis of variance for soil moisture per depth was used. The analysis of variance for the variation of soil temperature with depth was not done because the pooled (EMS) could not be used to test the effects, because the (EMS) for the various depths were not comparable.

Table 11. Analysis of variance variation of soil moisture With depth

Source	degrees of freedom
Block	3
Mulches (M)	4
Total	19
Depth (D)	2
M x D	8
Pooled (EMS)	12

The treatment means were compared using orthogonal comparisons, the planned comparisons were:-

Table 12.

C	G	T	B	W	
+4	-1	-1	-1	-1	Z1
	+3	-1	-1	-1	Z2
		+2	-1	-1	Z3
			+1	-1	Z4

C - bare soil (no mulch)

G - Grass mulch

T - Transparent polyethylene mulch

B - Black polyethylene mulch

W - White polyethylene mulch

Z1- bare soil compared to mulched soil

Z2- grass mulch compared to polyethylene mulches

Z3 - Transparent compared to black and white polyethylene mulches.

Z4- Black compared to white polyethylene mulch

CHAPTER THREE

RESULTS

3.1. SOIL TEMPERATURES

3.1.1. Soil temperatures at 7cm depth taken by the use of Thermometers

Soil temperatures under different types of mulches between 17/5/76 and 13/8/76 gave highly significant differences and during the 1st, 2nd, 6th and 10th weeks showed significant differences. In the 11th week there were no statistical differences between the treatments. The analysis of variance is given in the appendix I.

The average weekly soil temperatures and weekly average air temperatures are presdnted in figure (7). Transparent and black polyethylene mulches showed higher soil tempeatures than bare soil during the thirteen weeks. The white polyethylene mulch showed higher soil temperatures than bare soil most of the times but in a few cases had lower soil temperatures. The grass mulch gave lower soil temperatures than bare soil. The air temperature was lower than bare soil temperature and also lower than the soil temperature under the grass mulch.

The general pattern of temperature changes during the thirteen weeks shows that from the first week soil temperatures were rising reaching a peak in the fourth week. During the sixth week the lowest soil temperatures were recorded in all the treatment. In the eighth week another peak was reached but it was not as high as that of the fourth week. There was a small drop in the twelfth week and by the thirteenth week the soil temperatures were rising again. A similar pattern is indicated by the weekly average air temperatures except that the fluctuations of the temperatures with time are not as pronounced as that of the soil temperatures particularly under the transparent and black polyethylene mulches. The soil temperatures under the grass mulch do not fluctuate much with time.

The weekly average morning soil temperatures at 7cm depth and the weekly minimum air temperatures for the period 17/5/76 to 13/8/76 are presented in figure (8). In the morning the mulches gave higher soil temperatures than bare soil. The transparent polyethylene mulch gave the highest soil temperatures among the polyethylene mulches. The black and white polyethylene mulches gave almost similar soil temperatures. The grass mulch gave lower soil temperatures than the polyethylene mulches, but in a few cases it showed higher soil temperatures than either the black or white polyethylene mulches.

The minimum air temperatures were lower than the morning soil temperatures in all the treatments. The difference being very large as compared to that indicated in figure (7). As shown on figure (7), the soil temperatures follow closely the pattern of air temperature changes, the same pattern is indicated in figure (8).

Considering the morning soil temperatures the different treatment seem to give more uniform temperatures than the average of morning and afternoon soil temperatures in the same treatment.

Figure (9), gives the afternoon weekly average soil temperatures under different types of mulches and the maximum air temperatures for the same period as that of figures (7) and (8). Figure (9) shows a similar pattern to that of figures (7) and (8) considering the general pattern of temperature changes within a particular treatment. The different treatments indicate that the transparent and black polyethylene mulches had the highest soil temperature with the former showing higher soil temperatures than the latter. The white polyethylene mulch gave higher soil temperatures than

Figure 7.

Average soil temperatures under different types of mulches at 7cm depth.

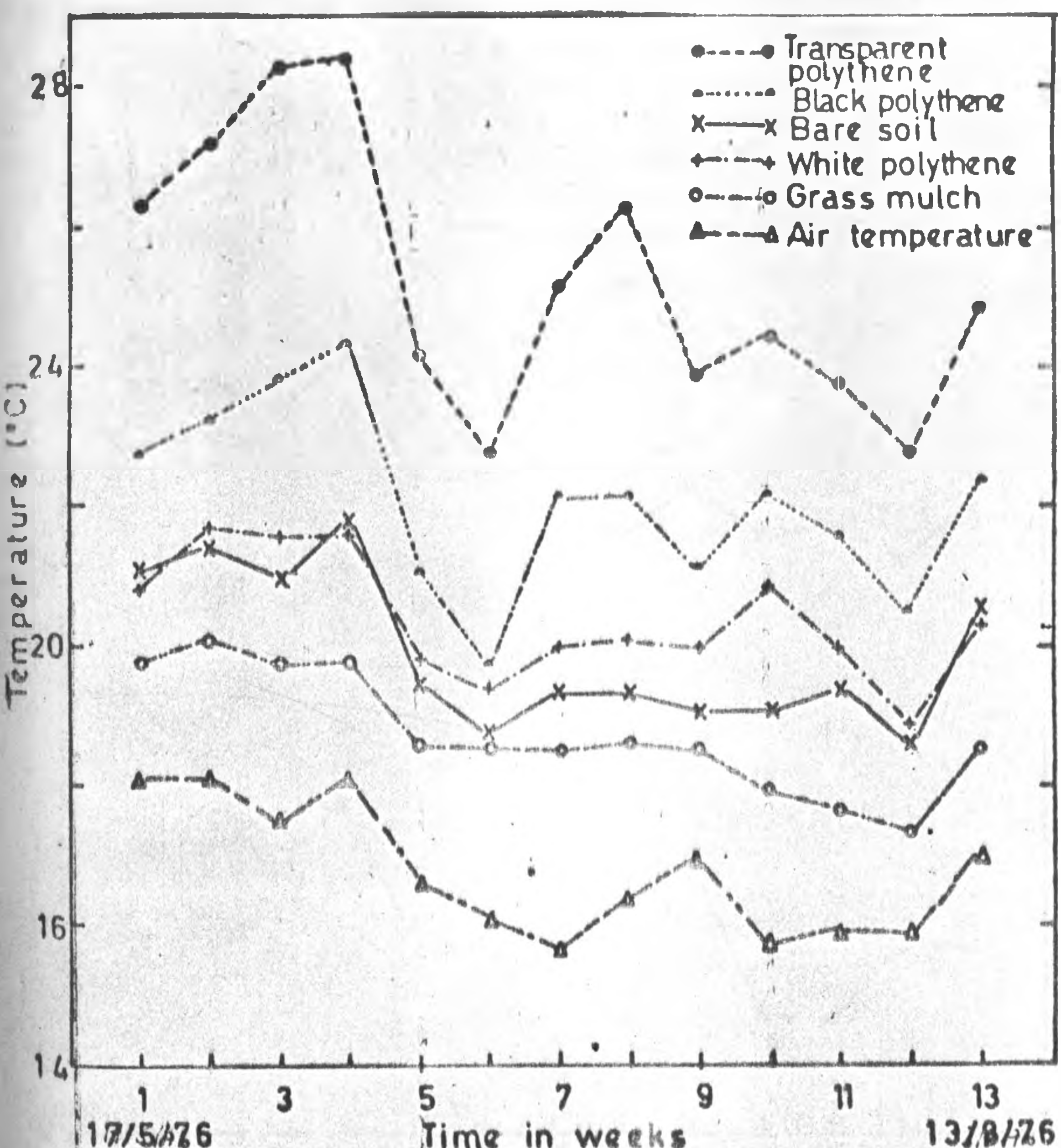


Figure 8.

Morning soil temperature under different types of mulches at 7cm depth.

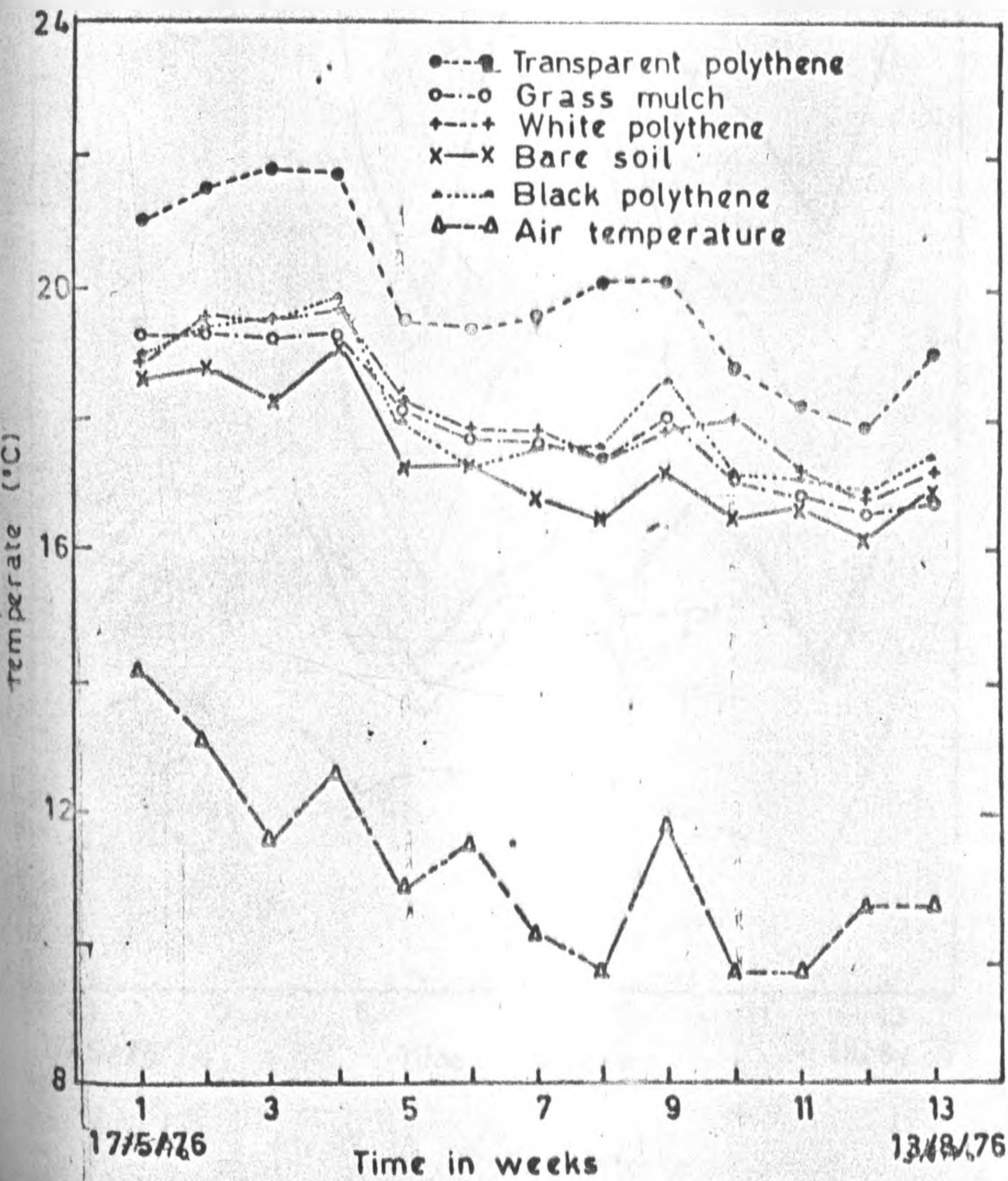
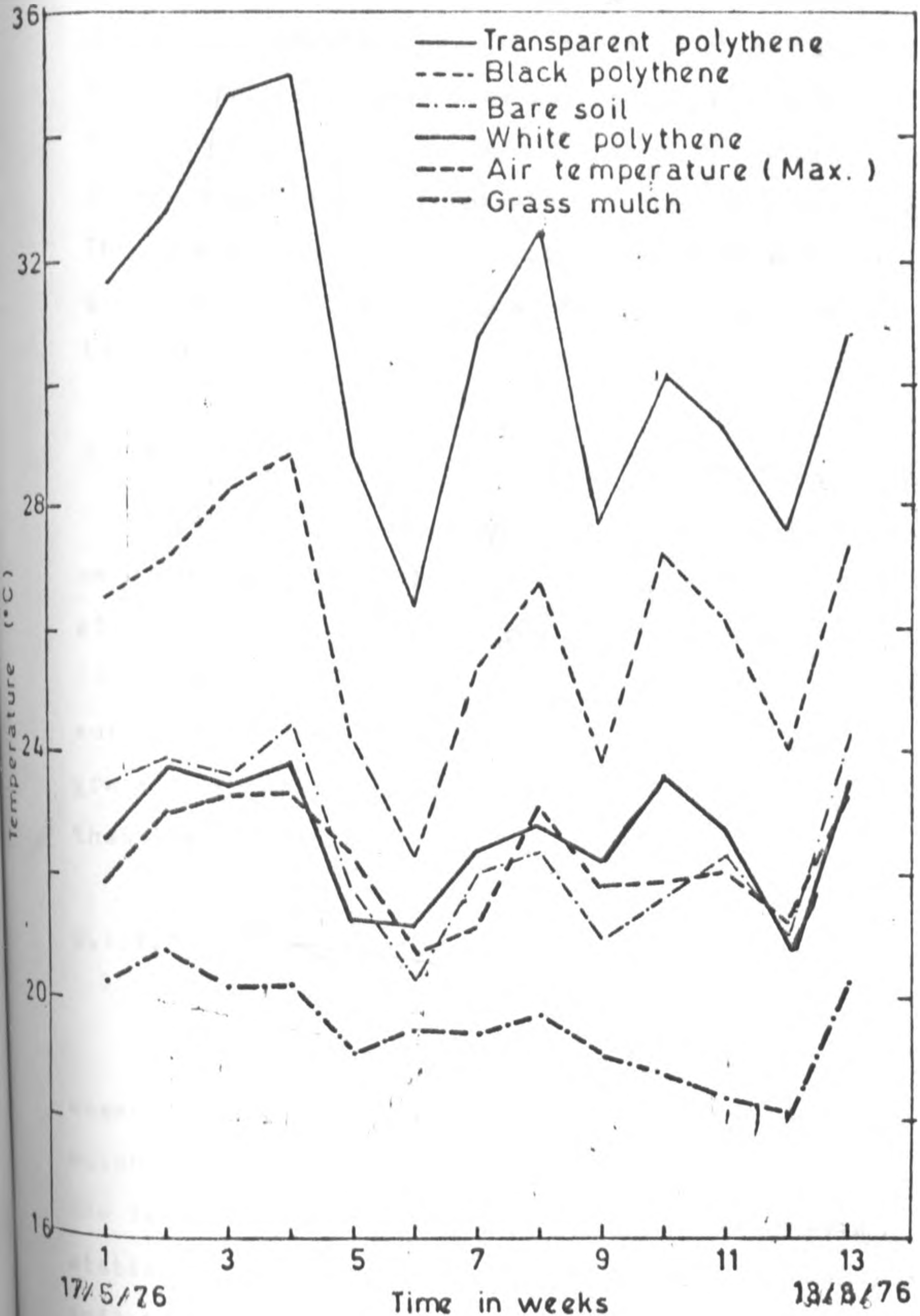


Figure 9.

Afternoon soil temperatures under different types mulches at 7cm depth.



bare soil in some cases while in others it showed lower soil temperatures. The grass mulch had lower soil temperatures than bare soil throughout the thirteen weeks. The maximum air temperature was higher than the soil temperature under the grass mulch. The bare soil and white polyethylene mulch seemed to give soil temperatures almost similar to the maximum air temperatures.

3.1.1.1. Comparison between bare soil and mulched soil

As shown on table (13) the bare soil temperatures as compared to the mulched soil temperatures showed significant differences in the 3rd, 7th, 8th, 9th and 12th weeks. During these weeks the bare soil had lower soil temperatures than the polyethylene mulches. The grass mulch was shown to have lower soil temperatures than the bare soil.

3.1.1.2. Comparison between grass and polyethylene mulches

As shown on table (13), during the thirteen weeks the grass mulch as compared to the plyethylene mulches gave highly significant differences and in the 1st 2nd 6th and 11th weeks the differences were statistically significant. The grass mulch showed lower soil temperatures than the polyethylene mulches during the thirteen weeks.

Table 13.

Comparison of five day week average soil temperatures uder different types of mulches at 7 cm depth

Temperature (°C)

Time five day weeks		Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
17/5/76	1	21.1	19.8	26.3	22.8	20.8	1.91	NS	*	**	NS
	2	21.4	20.1	27.2	23.3	21.7	2.80	NS	*	*	NS
	3	21.0	19.8	28.2	23.9	21.5	1.49	*	**	**	NS
	4	21.8	19.8	28.4	24.4	21.7	1.88	NS	**	**	NS
	5	19.5	18.6	24.2	21.1	19.8	0.90	NS	**	**	NS
	6	18.8	18.6	22.9	19.8	19.4	1.06	NS	*	**	NS
	7	19.4	18.5	25.2	22.2	20.0	-	**	**	**	NS
	8	19.4	18.6	26.3	22.2	20.1	-	*	**	**	*
	9	19.1	18.5	23.9	21.2	20.0	-	*	**	**	NS
	10	19.1	17.9	24.5	22.2	20.8	-	NS	**	*	NS
	11	19.4	17.6	23.8	21.6	20.0	-	NS	*	NS	NS
	12	18.6	17.3	22.8	20.5	18.8	-	*	**	**	*
13/8/76	13	20.6	18.5	24.9	22.4	20.4	-	NS	**	**	*

Z1 Bare soil VS mulched soil
Z2 Grass mulch VS polyethylene mulches
Z3 Transparent polyethylene mulch VS non transparent
Z4 Black VS white polyethylene mulches

NS not significant
* significant at 5%
** significant at 1%

3.1.1.3. Comparison between transparent polyethylene mulch and black and white polyethylene mulches

Transparent polyethylene mulch gave higher soil temperatures than either the black or white polyethylenes except in the 9th week when it showed higher soil temperatures but statistically insignificant. The comparison is shown on table (13).

3.1.1.4. Comparison between black and white polyethylene mulches

As shown on table (13) there were no significant differences between the black and white polyethylene mulches except in the 8th, 12th and 13th weeks when the black polyethylene mulch gave higher soil temperatures than the white polyethylene mulch.

3.1.1.5. Time of day

The time of day morning or afternoon during which the temperature readings were taken gave highly significant differences between the treatments. The analysis of this data is given in appendix I. In all the treatments lower soil temperatures were recorded in the morning than in the afternoon.

Grass mulch gave higher soil temperatures than bare soil in the morning while in the afternoon it gave lower soil temperatures. The polyethylene mulches gave higher soil temperatures than bare soil in the morning. The transparent and black polyethylene mulches gave higher soil temperatures than bare soil also in the afternoon. In the afternoon the white polyethylene mulch showed lower soil temperature than bare soil between the first and fifth weeks and again in the twelfth and thirteenth weeks, in the other weeks it gave higher soil temperatures than bare soil.

3.1.1.6. Fluctuation in daily soil temperature

As shown on table (14) the difference between morning and afternoon soil temperatures showed that the grass mulch gave a more uniform soil temperature as compared with bare soil. The grass mulch had the effect of increasing soil temperature in the morning and decreased it in the afternoon and thus reduced the daily fluctuation in soil temperature.

The daily soil temperature fluctuation was high under the transparent and black polyethylene mulches as compared to bare soil. The transparent polyethylene mulch gave a higher fluctuation than the black polyethylene mulch.

Soil temperatures seemed to fluctuate less under the white polyethylene mulch than under bare soil. As shown on table (14) the daily soil temperature fluctuation was lower under white polyethylene mulch than under bare soil for most of the thirteen weeks except in the 6th, 9th and 10th weeks when the temperature fluctuation was a little higher under white polyethylene than under bare soil.

Table 14. Daily soil temperature fluctuation at 7cm depth

These are the differences between afternoon and morning soil temperatures

(°C)

Time in weeks	Air temperature difference max. and Min.	Bare soil	Grass mulch	Polyethylene mulches		
				Transparent	Black	White
17/5/76 1	7.7	4.9	1.0	10.6	7.5	3.7
2	9.9	5.1	1.5	11.3	7.7	4.3
3	11.8	5.3	0.9	12.9	8.6	4.0
4	10.7	5.3	0.9	13.3	8.9	4.0
5	11.4	4.4	1.0	9.3	6.2	3.1
6	9.2	3.0	1.8	7.0	5.0	3.4
7	10.9	5.2	1.8	11.2	7.8	4.6
8	13.3	5.8	2.3	12.3	9.1	5.4
9	10.0	3.7	1.0	7.6	5.2	4.3
10	12.2	5.1	1.7	11.4	10.0	5.6
11	12.5	5.6	1.5	11.1	9.0	5.5
12	10.6	4.8	1.6	9.7	7.1	4.0
13/8/76 13	12.7	7.3	3.4	11.8	9.9	6.3

3.1.1.7. Interaction between treatment and time of day

The analysis of this data is given in Appendix I. Statistically significant differences were obtained except in the 9th week when the differences were not statistically significant.

It was shown that grass mulch gave high soil temperatures in the morning as compared to bare soil while in the afternoon it gave lower soil temperatures.

The polyethylene mulches gave higher soil temperatures than bare soil in the morning. In the afternoon the transparent and black polyethylene mulches also showed higher soil temperatures than bare soil, but the differences were greater in the afternoon than in the morning. The white polyethylene mulch gave lower soil temperatures than bare soil during some of the weeks while in others it showed higher soil temperatures than bare soil in the afternoon.

3.1.2. Soil temperatures at 15 cm depth taken by the use of thermistors

Soil temperatures at 15cm depth taken between 6/12/76 and 29/4/76 and analysed as five day week averages showed significant differences between treatments in all the weeks for which the analysis of variance was done. Soil temperatures at this depth were taken for twenty one weeks but due to losses of thermistors in the field the analysis of variance could only be done for sixteen weeks, this is given in the Appendix II.

Figure (10) illustrates the differences between the various treatments. The polyethylene mulches gave higher soil temperatures than bare soil except in the 1st and 2nd weeks when the white polyethylene mulch recorded lower soil temperatures than bare soil. The transparent polyethylene mulch gave the highest soil temperatures among the polyethylene mulches. During the first eleven weeks the black polyethylene mulch gave higher soil temperatures than the white polyethylene, after the eleventh week the black and white polyethylene mulches gave almost similar soil temperatures.

The grass mulch gave lower soil temperatures than bare soil during the whole period. The average air temperatures are shown on figure (10) to be lower than the soil temperatures under the polyethylene mulches and bare soil, but seemed to have no difference with the soil temperature under the grass mulch. The soil temperatures under the polyethylene mulches and under bare soil follows the pattern of the air temperatures, thus as air temperature rises, the soil temperatures also increased.

3.1.2.1. Comparison between bare soil and mulched soil

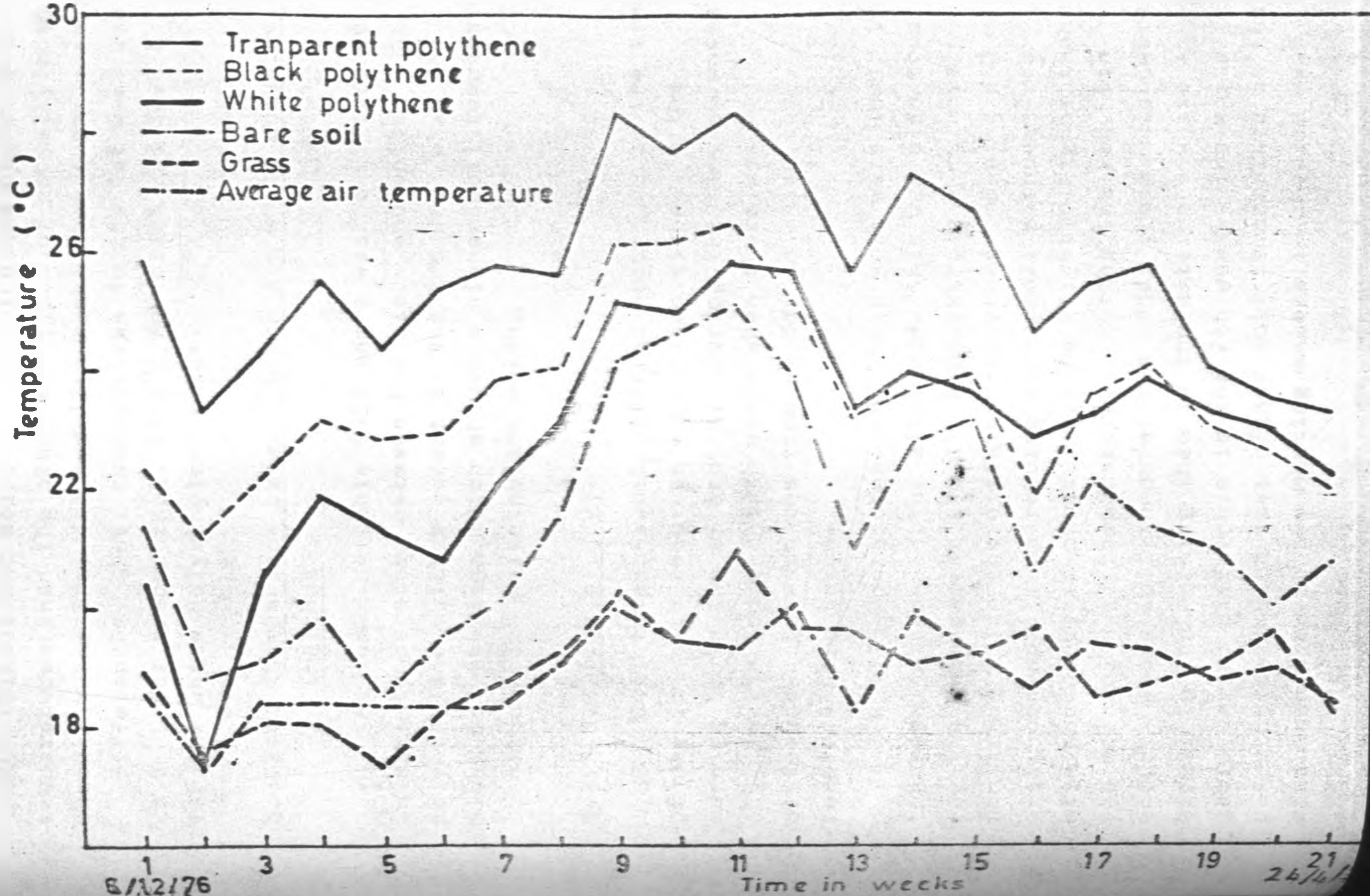
As shown on table(15) bare soil compared to mulches indicated significant differences in the 5th, 6th, 7th and 13th weeks. During these periods bare soil gave lower soil temperatures than the polyethylene mulches but higher than the grass mulch. The weekly average soil temperatures in the 5th week was 18.5, 17.3, 24.4, 22.9 and 20.8 °C respectively for bare soil, grass mulch, transparent, black and white polyethylene mulches.

3.1.2.2. Comparison between grass and polyethylene mulches

The grass mulch compared to the polyethylene mulches gave lower soil temperatures under grass than under the polyethylenes. Soil temperatures in the 4th week were 18.0, 25.5, 22.8 and 21.3°C respectively for grass mulch, transparent, black and white polyethylene mulches. A similar trend was shown during the whole of the sixteen weeks.

Figure 10.

Average soil temperatures under different types of mulches at 15 cm depth



3.1.2.3. Comparison between transparent polyethylene mulch and black and white polyethylene mulches

Transparent polyethylene mulch had higher soil temperatures than the other two types of polyethylenes except in the 3rd, 4th and 12th weeks when there were no differences. Soil temperatures in the 1st week was 25.8 °C for transparent, 22.3°C for black and 20.3°C for the white polyethylene mulch.

3.1.2.4. Comparison between black and white polyethylene mulches

As shown on table (15), there was no difference in soil temperature between the black and white polyethylene mulches except in the 2nd week when the black polyethylene mulch showed a higher soil temperature than the white polyethylene mulch.

3.1.2.5. Time of day

Soil temperatures differed according to the time of day in which readings were taken either in the morning or in the afternoon. During the sixteen weeks only in the 2nd and 13th weeks when there was no difference between the time of day in which the readings were taken.

Soil temperatures under bare soil were lower in the morning than in the afternoon, this was also true for the transparent and black polyethylene mulches. Under the grass mulch the differences between morning and afternoon soil temperatures were small although the afternoon soil temperatures were slightly higher than the morning soil temperatures. During the 2nd, 5th and 8th weeks soil temperatures under grass mulch were higher in the morning than in the afternoon while there was no difference in the 7th week. The white polyethylene mulch gave higher soil temperature in the afternoon than in the morning except in the 2nd week

Table 15. Comparison of five-day-week average soil temperature under different types of mulches at 15 cm depth

Temperature (°C)

Time five day weeks		Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
6/12/76	1	21.4	18.9	25.8	22.3	20.3	-	NS	*	**	NS
	2	18.8	17.6	23.3	21.2	17.5	-	NS	*	**	*
	3	19.1	18.1	24.3	22.2	20.6	2.46	NS	*	NS	NS
	4	19.8	18.0	25.5	23.1	21.9	2.86	NS	**	NS	NS
	5	18.5	17.3	24.4	22.8	21.3	2.06	*	**	*	NS
	6	19.5	18.3	25.4	22.9	20.8	2.04	*	**	**	NS
	7	20.1	18.7	25.8	23.9	22.1	17.6	*	**	*	NS
	8	21.5	19.2	25.6	24.0	23.1	1.16	NS	**	*	NS
	9	24.2	20.2	28.3	26.1	25.1	1.32	NS	**	**	NS
	10	24.6	19.5	27.7	26.1	25.0	0.26	NS	**	**	NS
	11	25.1	20.9	28.3	26.4	25.8	1.12	NS	**	*	NS
	12	23.9	19.6	27.5	25.0	25.6	1.72	NS	**	NS	NS
	13	21.0	19.6	25.6	23.2	23.2	0.65	*	**	**	NS
	14	22.9	19.0	27.2	23.7	23.9	1.22	NS	**	**	NS
	15	23.1	19.2	26.6	23.9	23.6	0.92	NS	**	**	NS
25/3/77	16	20.6	19.6	24.6	21.8	22.6	1.18	NS	**	*	NS

Z1 Bare soil VS mulched soil

NS not significant

when there was no difference.

3.1.3. Soil temperatures at one metre depth taken by the use of thermistors

Soil temperatures taken between 6/12/76 and 29/4/76 and analysed as five day week averages showed significant differences among the treatments during some of the weeks and in other weeks no significant differences were obtained. Significant differences between the treatments were obtained in the 7th, 8th, 9th, 12th, 13th, 14th and 15th weeks and in the rest of the weeks no significant differences occured between the treatments. The analysis of variance is given in appendix III.

Figure (11) illustrates the pattern of soil temperatures at one metre depth. During the 7th and 8th weeks the transparent and black polyethylene mulches gave higher soil temperatures than bare soil. The white polyethylene mulch and grass mulch gave lower soil temperatures than bare soil. In the 12th, 13th and 14th weeks the polyethylene mulches had higher soil temperatures than bare soil with the transparent polyethylene giving higher soil temperatures than the other two types of polyethylene mulches. The average soil temperature in the 12th week was 21.4, 19.8, 25.6, 23.7 and 22.1°C respectively for bare soil, grass mulch, transparent, black and white polyethylene mulches. In the 15th week only the transparent and white polyethylene mulches showed higher soil temperatures than bare soil.

Table (16) give the comparison between the various treatments. Bare soil showed no significant differences as compared to mulched soil. This was also true when black and white polyethylene mulches were compared, except in the 1st week when the black polyethylene mulch gave higher soil temperature than the white polyethylene.

Figure 11.

Average soil soil temperatures under different types of mulches at 100cm depth.

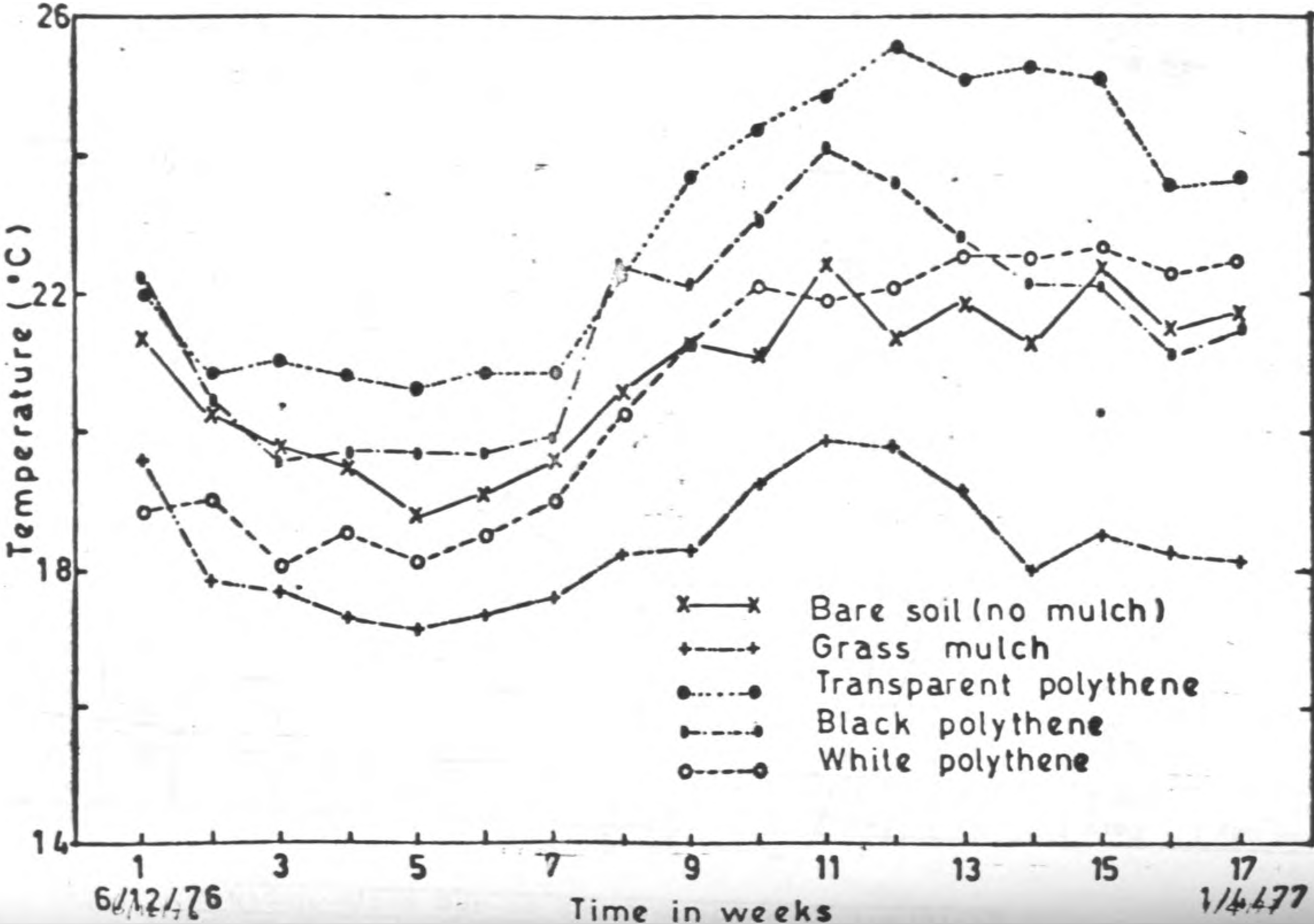


Table 16. Comparison of five day week average soil temperatures under different types of mulches at one metre depth

Temperature (°C)

Time five day week		Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
6/12/76	1	24.1	19.6	22.0	22.2	18.8	2.01	NS	NS	NS	*
	2	20.3	17.8	20.4	19.0	19.0	1.79	NS	NS	NS	NS
	3	19.8	17.7	21.0	19.6	18.0	1.06	NS	*	*	NS
	4	19.5	17.3	20.8	19.7	18.5	1.50	NS	*	NS	NS
	5	18.8	17.1	20.6	19.7	18.1	1.14	NS	*	NS	NS
	6	19.1	17.3	20.9	19.7	18.5	1.44	NS	*	NS	NS
	7	19.6	17.6	20.9	19.9	19.0	0.77	NS	*	NS	NS
	8	20.6	18.2	22.3	22.4	20.3	1.01	NS	*	NS	NS
	9	21.3	18.3	23.7	22.2	21.3	1.52	NS	**	NS	NS
	10	21.1	19.3	24.4	23.1	22.1	-	NS	*	NS	NS
	11	22.5	19.9	24.9	24.1	21.9	-	NS	NS	NS	NS
	12	21.4	19.8	25.6	23.7	22.1	-	NS	*	*	NS
	13	21.9	19.2	25.1	22.9	22.6	--	NS	**	**	NS
	14	21.3	18.0	25.3	22.2	22.5	-	NS	**	*	NS
8/3/77	15	22.4	18.5	25.1	22.2	22.7	-	NS	**	*	NS

Z1 Bare soil vs mulched soil
Z2 Grass mulch vs polyethylene mulches
Z3 Transparent polyethylene mulch vs non transparent
Z4 Black vs white polyethylene mulches

NS not significant
* significant at 5%
** significant at 1%

The grass mulch when compared to the polyethylene mulches showed that lower soil temperatures occured under grass than under the polyethylenes except during the 1st and 2nd weeks when there were no statistically significant differences.

The transparent polyethylene mulch gave higher soil temperatures than the other two types of polyethylene mulches in the 3rd, 12th, 13th, 14th and 15th weeks, but during the other weeks there was no difference.

3.1.3.1. Time of day

Differences occured during the time of day in which the temperature readings were taken either in the morning or in the afternoon. In the 1st week higher soil temperatures were recorded in the afternoon than in the morning in all the treatments. During the 6th week lower soil temperatures were recorded in the afternoon than in the morning except under grass mulch where there was no difference.

During the 8th week higher soil temperatures were recorded in the afternoon than in the morning under bare soil, black and white polyethylene mulches while under the transparent polyethylene mulch the reverse was true, no difference occured under grass mulch. In the 15th week lower soil temperatures were obtained in the morning than in the afternoon in all the treatments.

The inter-action between time of day and treatment gave no significant differences at one metre depth.

3.1.4. Soil temperatures at two metres depth taken by use of thermistors

Soil temperature reading at two metres depth was taken for twenty one weeks between 6/12/76 and 29/4/77. For the first ten weeks a statistical analysis was done but for the rest of the period this was not possible due to losses of thermistors in the field. The analysis of variance is given in the appendix IV.

Differences occured among the treatments only in four of the ten weeks, this was during the 3rd, 7th, 9th and 10th weeks. During the 3rd week the grass mulch and the black polyethylene mulches showed lower soil temperatures than bare soil while the transparent and white polyethylene mulches gave higher soil temperatures. During the 7th week the polyethylene mulches and the bare soil gave slight differences, with the grass mulch showing lower soil temperatures than the rest of the treatments. The same trend was shown in the 9th and 10th weeks. Table (17) gives the average soil temperatures under the different treatments at two metres and the average air temperatures. The mean temperatures for the twenty one weeks shows that the soil temperatures under the various treatments were approximately equal to the mean air temperature for the twenty one weeks.

As shown on table (18), when the bare soil is compared to the mulched soil no differences were obtained at this depth. Grass mulch when compared to the polyethylene mulches showed lower soil temperatures under grass except in the first two weeks when there was no difference. Among the polyethylene mulches there was no difference, when the transparent polyethylene was compared to the black and white polyethylenes or when the black was compared to the white polyethylene mulch. However in the 9th week the black polyethylene mulch gave higher soil temperature than the white polyethylene mulch.

Table 17. Average soil temperature under different types of mulches at 2 metres depth

(^{o}C)

Time in weeks	Bare soil	Grass mulch	Polyethylene mulches			Average air temperature
			Transparent	Black	White	
6/12/77 1	21.4	21.2	21.0	21.9	21.6	21.5
2	20.1	19.5	20.3	20.2	20.1	18.8
3	19.9	18.7	20.5	19.6	20.3	19.1
4	19.7	18.9	19.7	20.1	20.0	19.9
5	19.7	18.4	19.6	19.5	19.8	18.5
6	19.4	18.8	19.8	19.6	19.5	19.5
7	20.0	19.0	20.1	20.1	20.1	20.1
8	20.9	19.6	20.9	20.6	20.7	21.6
9	21.0	19.5	20.9	21.8	20.3	24.2
10	22.2	20.2	22.0	22.2	22.3	24.7
11	22.5	21.2	22.8	23.0	21.9	25.1
12	21.2	20.2	21.0	22.2	21.5	24.0
13	21.4	20.4	22.1	22.4	20.8	21.1
14	21.1	19.5	21.2	21.5	21.1	23.0
15	21.5	19.7	21.8	21.5	20.9	23.1
16	21.3	20.4	21.7	21.9	21.4	20.6
17	21.2	19.7	20.9	22.2	21.0	22.2
18	21.3	19.2	21.0	21.8	20.8	21.3
19	22.9	21.0	22.8	22.6	21.0	21.0
20	21.6	20.9	21.8	22.4	20.7	20.0
29/4/77 21	22.2	20.3	21.7	21.0	20.8	20.7
MEAN	21.1	19.8	21.1	21.3	20.8	21.4

Table 18.

Comparison of five day week average of soil temperatures under different types of mulches at two metres depth.

Temperature (°C)

Time five day weeks		Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
6/12/76	1	21.4	21.2	21.0	21.9	21.6	2.07	NS	NS	NS	NS
	2	20.1	19.5	20.3	20.2	20.1	0.21	NS	NS	NS	NS
	3	19.9	18.7	20.5	19.6	20.3	0.24	NS	**	NS	NS
	4	19.7	18.9	19.7	20.1	20.0	0.21	NS	*	NS	NS
	5	19.7	18.4	19.6	19.5	19.8	0.36	NS	*	NS	NS
	6	19.4	18.8	19.8	19.6	19.5	0.10	NS	*	NS	NS
	7	20.0	19.0	20.1	20.1	20.1	0.09	NS	**	NS	NS
	8	20.9	19.6	20.4	20.6	20.7	0.36	NS	*	NS	NS
	9	21.0	19.5	20.9	21.8	20.3	0.09	NS	**	NS	**
11/2/77	10	22.2	20.2	22.0	22.2	22.3	0.26	NS	**	NS	NS

Z1 Bare soil VS mulched soil

Z2 Grass mulch VS polyethylene mulches

Z3 Transparent polyethylene mulch VS non transparent

Z4 Black VS white polyethylene mulches

NS not significant

* significant at 5%

** significant at 1%

3.1.4.1. Time of day

During the 4th week bare soil showed higher soil temperatures in the afternoon than in the morning while the grass and white polyethylene mulches showed lower soil temperatures in the afternoon. The transparent polyethylene mulch gave no difference.

During the 7th week lower soil temperatures were recorded in the afternoon under bare soil, transparent, black and white polyethylene mulches, no difference occured under the grass mulch. In the 10th week higher soil temperatures occured in the afternoon than in the morning except under the white polyethylene mulch where the reverse was true.

3.1.5. Variation of soil temperature with depth

The soil temperatures under different treatments starting on 6/12/76 to 1/4/77 is presented on figure (12). The soil temperatures at each particular depth has been presented in the previous sections. Within the treatments soil temperatures vary most at 15cm depth, while at one metre and two metres depth there was little variation in soil temperatures between the treatments.

In general the soil temperatures tend to decrease with depth from 15cm such that at two metres depth they tend to stabilize at one level for all the treatments. The transparent, black and white polyethylene mulches as shown on figure (12), except in the second week gave high soil temperatures at 15cm depth which decreased with depth and at two metres depth they had almost similar soil temperatures. During the second week the white polyethylene mulch gave low soil temperatures at 15cm depth, this kept on increasing with depth and at two metres depth the soil temperature was similar to that of the other polyethylene mulches.

Bare soil temperatures seemed to be stable with little variation with increasing depth in the 1st, 3rd, 4th and 6th weeks, bare soil showed high soil temperatures at 15 cm depth which decreased with increasing depth such that at two metres the soil temperature was similar to that under the polyethlene mulches.

In the 13th and 16th weeks as shown on figure (12) bare soil showed low soil temperatures at 15cm depth which increased with depth and at two metres the soil temperature was the same as that of the polyethylene mulches.

Grass mulch during the 1st to 5th weeks and again in the 12th, 13th, 15th and 17th weeks showed low soil temperatures at 15cm depth, the soil temperature increased with depth and at two metres tended to equal that under bare soil and polyethylene mulches though slightly lower. In the 6th to 11th weeks grass mulch showed high soil temperatures at 15 cm depth and this decreased with depth until at two metres depth the soil temperatures were similar to that under the other treatments.

3.2. SOIL MOISTURE

3.2.1. Soil moisture content at 0-15cm depth

Soil moisture samples taken between 13/5/76 and 12/10/76 showed significant differences between the treatments at 0-15cm depth in all the sampling dates except on 13/7/76. The analysis of variance is given in appendix V Figure (13) shows the soil moisture pattern under the various treatments at 0-15cm depth for the period between 3/6/76 and 12/8/76. The grass mulch is shown to conserve more soil moisture than any of the other treatments. The black and white polyethylene mulches gave higher soil moisture contents than bare soil most of the times. The transparent polyethylene mulch gave lower soil moisture content than bare soil most of the times.

Figure 12.

Variation soil temperature with depth.

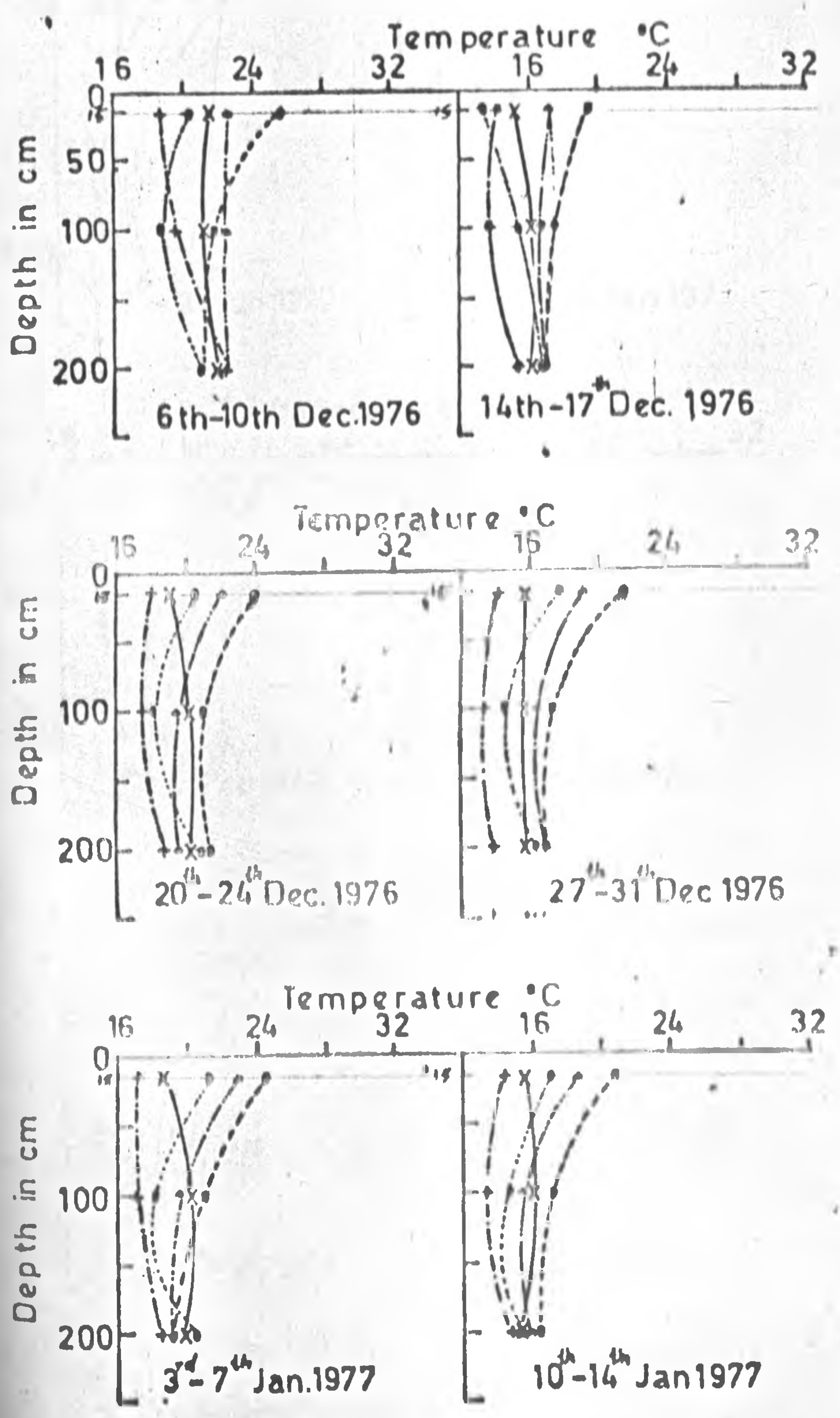


Figure 12 (contd...)

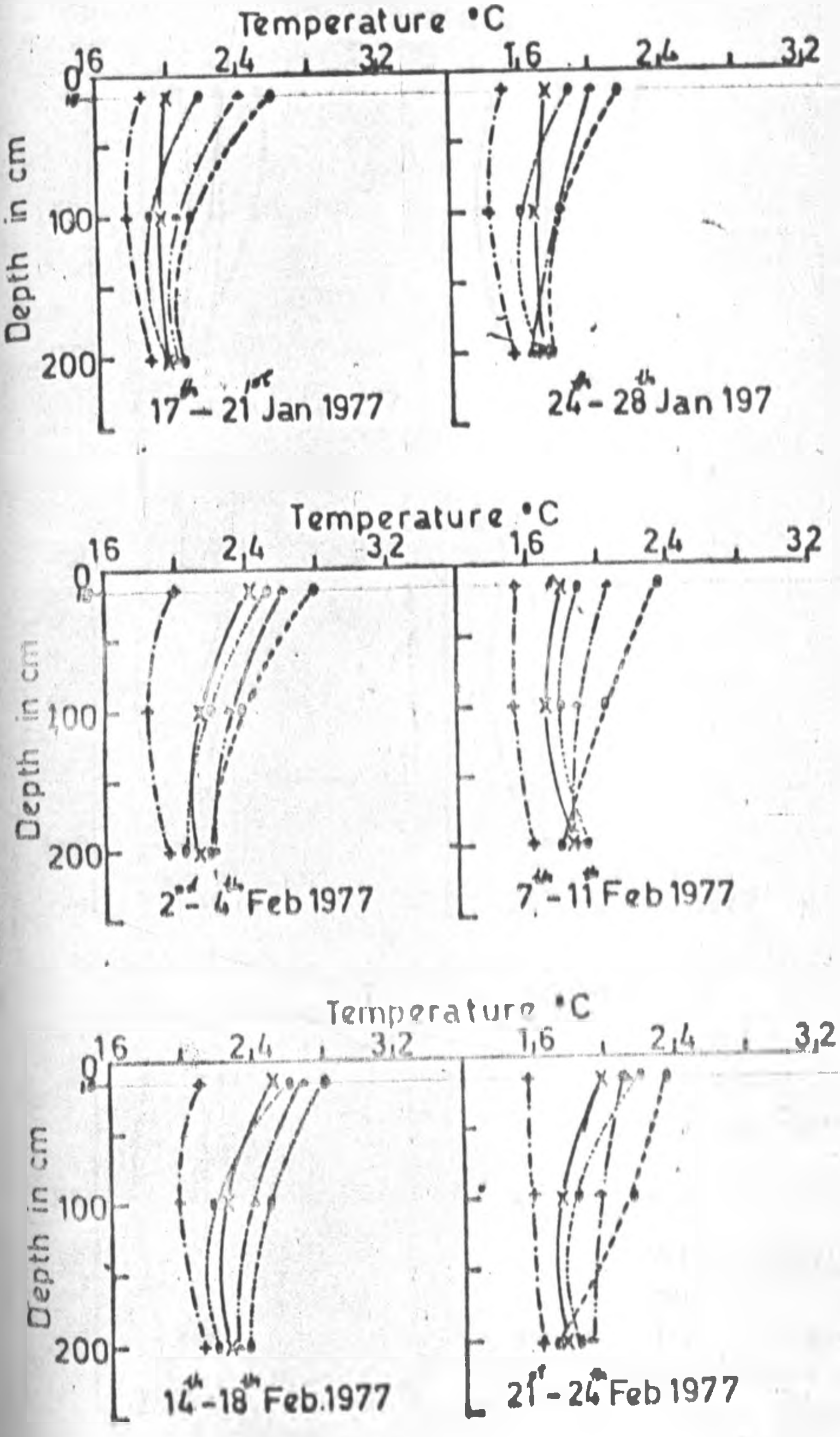
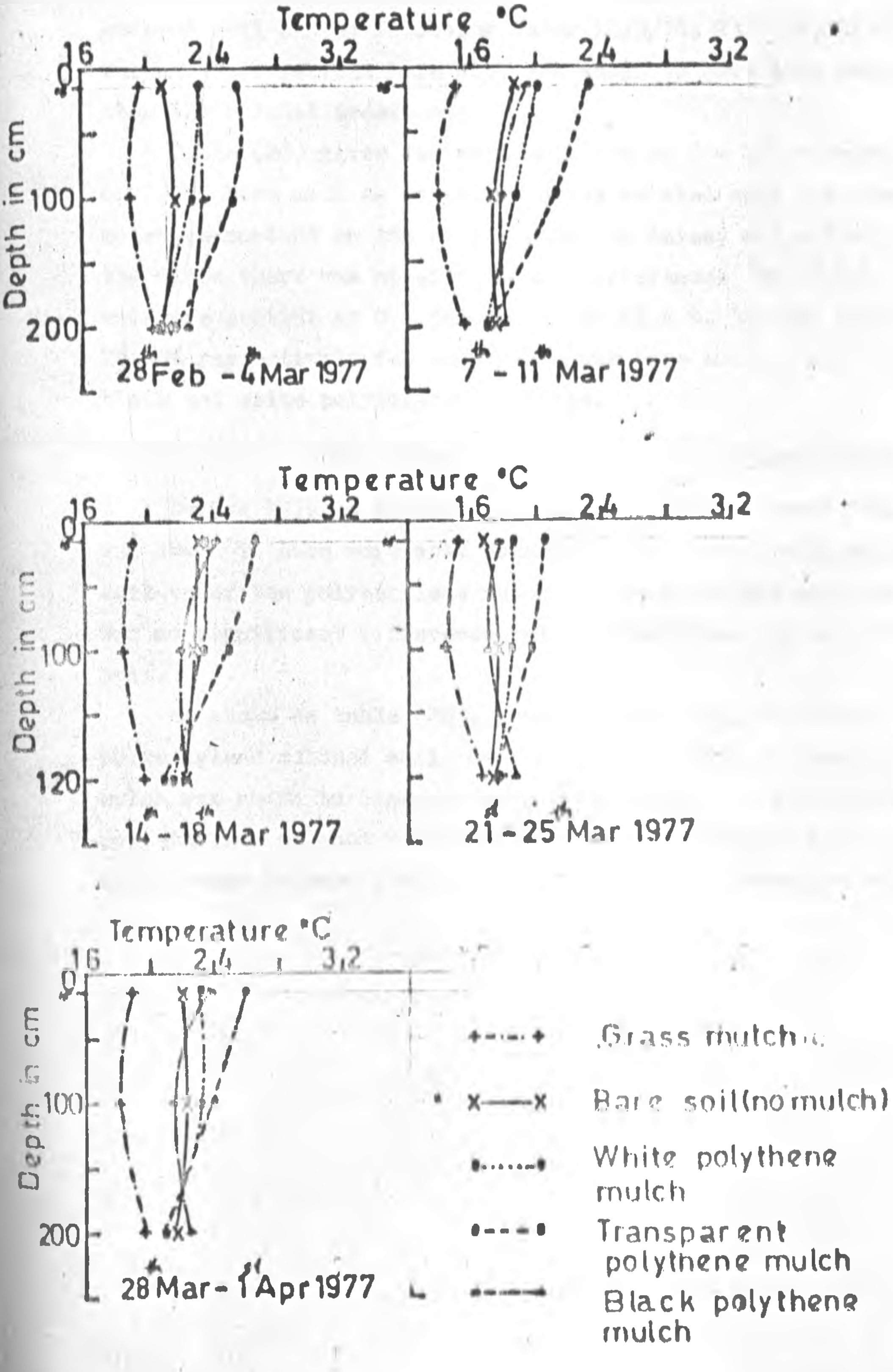


Figure 12 (Contd...)



3. 2. 1. 1. Comparison between bare and mulched soil

As shown on table (19) bare soil was shown to differ from the mulched soil on the following dates 13/5/76, 23/7/76, 12/8/76 and 12/10/76. During these periods bare soil was shown to have less moisture content than the mulched treatments.

Table (20) gives the soil moisture at 0 - 15 cm depth during part of 1977, Bare soil as compared to the mulched soil was shown to have less moisture content on two of the sampling dates, while during the rest of the dates there was no significant difference. On 11/2/77 the soil moisture content at 0 - 5cm depth was 25.4 %, 32.90%, 25.90%, 27.90% and 26.60% respectively for the treatments bare soil, grass mulch, transparent, black and white polyethylene mulches.

3. 2. 1. 2. Comparison between grass and polyethylene mulches

During 1976 as shown on table (19) the soil under the grass mulch was shown to have more soil moisture content at 0 - 15cm depth than the soil under the polyethylene mulches, except on one occasion when there was no significant difference between the grass and polyethylene mulched soil.

As shown on table (20), grass mulched soil as compared to the polyethylene mulched soil during part of 1977, the soil under grass mulch was shown to conserve more moisture at 0 - 15cm depth than the polyethylene mulched soil. On 5/4/77 and 5/5/77 there were no significant differences between grass mulched soil and polyethylene mulched soil.

Figure 13.

Average moisture content in oven dried soil under different types of mulches at 0 – 15 cm depth. (1976)

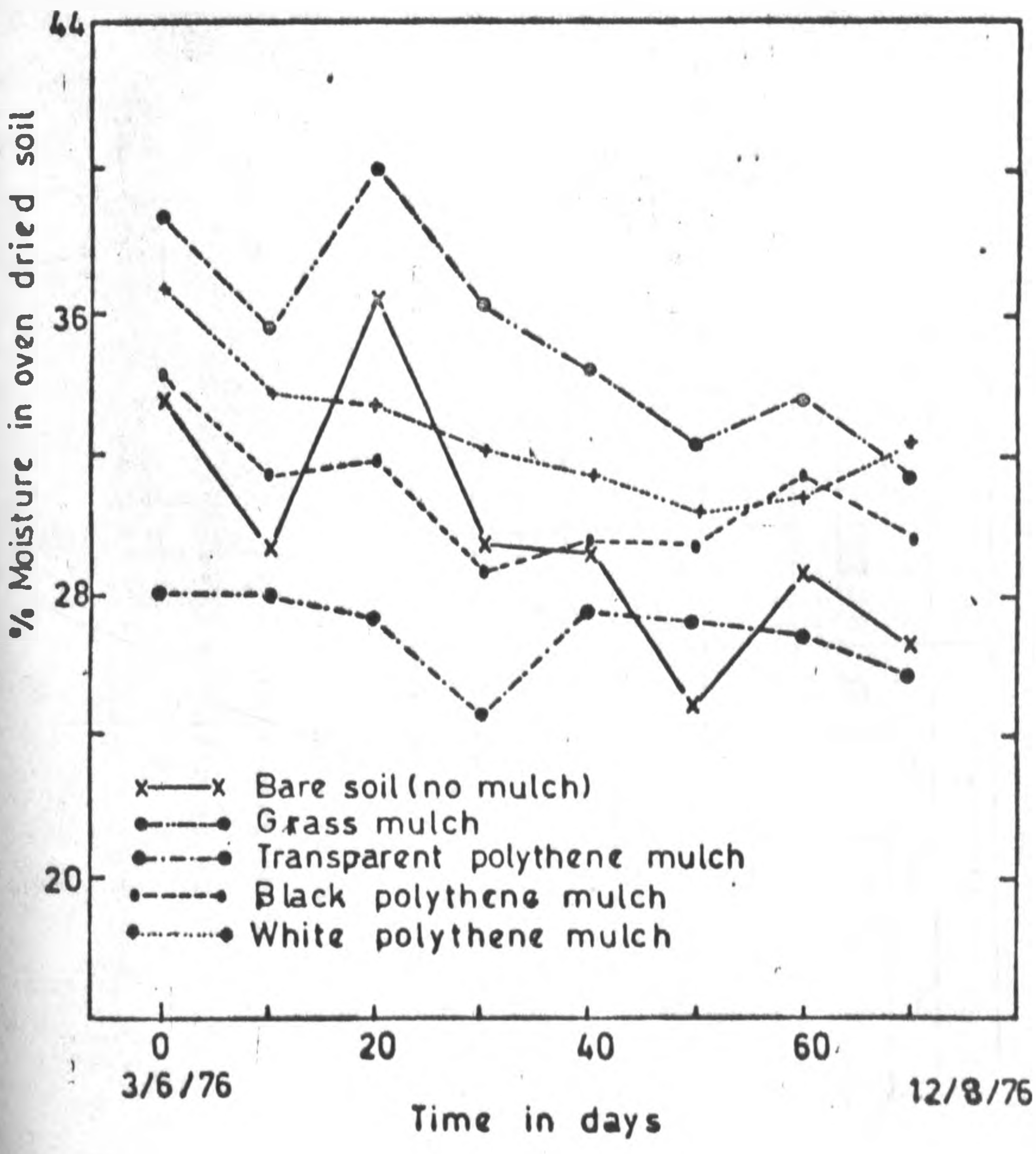


Table 19. Percentage moisture in oven-dried soil at 0-15cm depth (1976)

Date	Bare soil	Grass mulch	Transparent Polyethylene	Black Polyethylene	White Polyethylene	SE	Z1	Z2	Z3	Z4
13/5/76	27.85	37.28	25.33	29.56	32.21	1.82	*	**	**	NS
3/6/76	33.61	38.71	27.98	34.07	36.67	2.23	NS	**	**	NS
14/6/76	29.19	35.69	27.96	31.26	33.79	2.60	NS	**	**	NS
24/6/76	36.52	40.02	27.26	31.80	33.44	4.00	NS	**	*	NS
2/7/76	29.51	36.20	24.50	28.56	31.96	3.26	NS	**	*	NS
13/7/76	29.22	34.34	27.52	29.23	31.32	5.71	NS	*	NS	NS
23/7/76	24.94	32.24	27.05	29.33	30.26	3.33	*	*	NS	NS
2/8/76	28.67	33.55	26.78	31.37	30.94	2.01	NS	**	**	NS
12/8/76	26.58	31.26	25.90	23.62	32.37	1.37	**	NS	**	**
21/9/76	26.51	33.43	24.94	28.37	27.50	1.77	NS	**	*	NS
1/10/76	24.40	30.54	23.98	26.87	25.87	3.24	NS	**	NS	NS
12/10/76	20.60	34.03	24.56	24.30	25.24	3.51	**	**	NS	NS

Z1 - Bare soil VS mulched soil

Z2 - Grass mulch VS polyethylene mulches

Z3 - Transparent polyethylene mulch vs non-transparent

Z4 - Black VS white polyethylene mulches.

NS - Not significant

* - Significant at 5%

** - Significant at 1%

Table 20.

Percentage moisture in over-dried soil at 0-15 cm depth (1977)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
12/1/77	31.79	37.45	32.21	28.60	30.17	3.33	NS	**	NS	NS
2/2/77	28.77	33.72	27.42	32.14	29.43	7.70	NS	*	NS	NS
11/2/77	25.44	32.92	25.94	27.94	26.57	2.39	*	**	NS	NS
22/2/77	28.58	31.23	25.76	30.22	27.70	1.68	*	*	*	NS
4/3/77	33.57	38.27	29.06	34.30	32.85	7.70	NS	*	*	NS
14/3/77	29.90	36.43	28.36	31.48	27.48	4.61	NS	**	NS	NS
24/3/77	36.23	39.22	30.51	30.98	36.71	4.21	NS	**	NS	*
5/4/77	34.81	39.04	35.01	33.60	36.05	5.25	NS	NS	NS	NS
15/4/77	42.96	44.98	38.89	40.65	40.62	3.46	NS	**	NS	NS
5/5/77	40.30	41.94	39.60	35.90	40.12	4.44	NS	NS	NS	NS

Z1 Bare soil VS mulched soil

Z2 Grass mulch VS polyethylene mulches

Z3 Transparent polyethylene mulch VS non transparent ?

Z4 Black VS white polyethylene mulches

NS not sifnificant

* significant at 5%

** Significant at 1%

In 1977 as shown on table (20) no significant differences occured on comparing transparent to black and white polyethylene mulched soils except on two occasions when the soil under transparent mulch gave lower soil moisture than the soil under the other two types of polyethylene mulches.

3. 2. 1. 4. Comparison between black and white Polyethylene mulches.

At 0 - 15cm depth in 1976 as shown on table (19), soil under black polyethylene mulch was shown not to differ significantly from the white polyethylene mulched soil in terms of soil moisture content. However on 12/8/76 the soil under black polyethylene mulch showed a higher soil moisture content than the soil under the white polyethylene mulch. On this date the soil moisture content was 29.62% for soil under black polyethylene and 32.37% for soil under white polyethylene mulch.

In 1977 as shown on table (20) no significant differences occured between black and white polyethylene mulched soils, except on 24/3/77 when soil under the black polyethylene mulch showed a lower soil moisture content than the soil under the white polyethylene mulch.

3. 2. 2. Soil moisture content at 60cm depth.

Soil moisture content samples taken at 60cm depth during part of 1976 from 13/5/76 and 12/10/76 showed significant differences between the treatments in some of the times but in others there were no significant differences between the treatments. The analysis of variance is given in appendix V.

3. 2. 2. 1. Bare soil compared to mulched soil

As shown on table (21) during 1976 there were no significant differences between bare soil and mulched soil, except on 12/8/76 when bare soil was shown to have less moisture content than the mulched soil. On this date the moisture content at 60cm depth was 31.65%, 35.81%, 32.95%, and 32.95% respectively for bare, grass, transparent polyethylene, black polyethylene and white polyethylene mulched soils.

In 1977 as shown on table (22) no significant differences occured between bare soil and mulched soil except on 24/3/77 when bare soil was shown to have less soil moisture. During this period bare soil gave 30.40%; grass mulched soil 31.71%, while the polyethylene mulched soil gave 30.00%, 31.31% and 37.14% respectively for transparent, black and white polyethylenes.

3. 2. 2. 2. Grass mulch compared to polyethylene mulches

As shown on table (21) in 1976 the grass mulch concerved more soil moisture than the polyethylene mulches. Out of the twelve sampling dates in eight of them the grass mulched soil gave higher soil moisture than the polyethylene mulched soil, while in the other four there was no significant difference.

In 1977 as shown on table (22), out of ten sampling dates the grass mulch conserved more soil moisture at 60cm depth than the polyethylene mulches, except on three of the sampling dates. Moisture content on 12/1/77 at 60cm depth was 38.29% for grass mulched soil and 30.80%, 30.30% and 31.17% respectively for transparent, black and white polyethylene mulched soil.

3. 2. 2. 3. Comparison between transparent polyethylene mulch and black and white polyethylene mulches.

As shown on table (21) during 1976 the transparent polyethylene mulched soil showed lower soil moisture content than soil mulched with the other two types of polyethylenes at 60cm depth on four of the twelve sampling dates, while during the other dates there was no significant difference.

In 1977 as shown on table (22) the transparent polyethylene mulched soil was shown not to differ significantly from the soil mulched with white or black polyethylene, except on 24/3/77 when it gave a lower soil moisture content.

Table 21.

Percentage moisture in oven-dried soil at 60 cm depth (1976)

Date	Bare soil	Grass mulch	Transparent polythylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
13/5/76	35.38	37.46	31.13	31.51	36.12	1.25	NS	••	•	••
3/6/76	38.17	39.24	34.75	35.91	37.90	1.86	NS	•	NS	NS
14/6/76	35.17	37.16	33.97	34.33	35.71	1.74	NS	•	NS	NS
24/6/76	34.70	37.28	32.71	35.02	36.66	2.66	NS	NS	•	NS
2/7/76	33.94	36.52	31.39	33.33	34.14	2.85	NS	•	NS	NS
13/7/76	32.78	36.25	32.62	33.63	35.01	2.77	NS	NS	NS	NS
23/7/76	31.98	34.62	31.66	31.82	32.14	0.73	NS	••	NS	NS
2/8/76	32.31	35.40	31.07	31.80	33.85	1.17	NS	•	NS	NS
12/8/76	31.65	35.26	30.81	32.95	32.95	0.53	•	••	•	NS
21/9/76	29.66	32.85	29.35	31.29	30.73	0.70	NS	••	•	NS
1/10/76	30.22	32.16	30.10	31.79	31.50	0.80	NS	NS	NS	NS
12/10/76	29.02	30.29	29.13	29.58	30.18	0.23	NS	NS	NS	NS

Z1 Bare soil VS mulched soil

Z2 Grass mulch VS polyethylene mulches

Z3 Transparent polyethylene mulch VS (non transparent)

Z4 Black VS white polyethylene mulches

NS not significant

• significant at 5%

•• significant at 1%

Table 22.

Percentage moisture in oven-dried soil at 60 cm depth (1977)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
12/1/77	34.28	38.29	30.86	30.70	31.17	1.73	NS	••	NS	NS
2/2/77	31.90	35.22	31.48	30.15	31.10	1.55	NS	••	NS	NS
11/2/77	30.97	33.20	29.17	30.79	29.41	1.16	NS	••	NS	NS
22/2/77	29.32	32.05	29.50	30.98	29.60	0.72	NS	•	NS	NS
4/3/77	33.69	37.04	31.32	30.30	35.65	6.14	NS	•	NS	•
14/3/77	32.26	35.97	30.08	33.91	30.05	1.22	NS	••	NS	••
24/3/77	30.40	31.71	30.00	31.31	37.14	2.61	•	NS	••	••
5/4/77	31.66	38.07	34.54	37.98	36.23	8.49	NS	NS	NS	NS
15/4/77	42.45	43.06	41.38	41.91	41.37	0.50	NS	•	NS	NS
5/5/77	41.24	41.49	40.07	38.84	41.41	0.61	NS	NS	NS	•

Z1 Bare soil VS mulched soil
Z2 Grass mulch VS polyethylene mulches
Z3 Transparent polyethylene mulch VS (non transparent)
Z4 Black VS white polyethelene mulches

NS not significant
• significant at 5%
•• significant at 1%

3. 2. 2. 4. Comparison between black and white polyethylene mulches

In 1976, the black polyethylene mulched soil gave lower soil moisture content than the white polyethylene mulched soil at 60cm depth on 13/5/76 as shown on table (21). On the other dates there was no significant difference between the two.

As shown on table (22), on 14/3/77 the black polyethylene mulched soil gave a higher soil moisture content at 60cm depth than the white polyethylene mulched soil. On 4/3/77, 24/3/77 and on 5/5/77 the black polyethylene mulched soil gave a lower soil moisture than the white polyethylene mulched soil. On the other sampling dates there was no significant difference between the black and white polyethylene mulched soil.

3. 2. 3. Soil moisture content at 120 cm depth.

Soil moisture samples at 120cm depth taken between 13/5/76 and 12/10/76 showed significant differences between the treatments on four out of the twelve sampling dates. The analysis of variance is given in appendix V. In 1977 samples taken between 12/1/77 and 5/5/77 showed significant differences between the treatments in seven out of ten sampling dates.

3. 2. 3. 1. Bare soil compared to mulched soil

As shown on table (23), no significant differences occurred between the treatments at 120cm depth except on 23/7/76 when less soil moisture was recorded under bare soil.

In 1977 as shown on table (24), on three dates bare soil was shown to record lower soil moisture content than the mulched treatments.

Table 23.

Percentage Moisture in Oven-dried Soil at 120 cm depth (1976)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polythylene	White polyethylene	SE	Z1	Z2	Z3	Z4
13/5/76	35.56	37.29	34.51	32.86	34.31	1.53	NS	**	NS	NS
3/6/76	38.96	41.55	39.57	39.21	39.83	2.40	NS	NS	NS	NS
14/6/76	37.20	39.41	37.94	37.20	38.23	1.34	NS	NS	NS	NS
24/6/76	37.34	38.60	35.68	37.18	38.60	1.05	NS	NS	*	NS
2/7/76	36.24	37.96	35.48	36.37	36.62	2.00	NS	NS	NS	NS
13/17/76	36.20	38.31	36.22	37.05	36.65	0.97	NS	NS	NS	NS
23/7/76	33.94	35.93	35.98	35.40	34.98	0.83	**	NS	NS	NS
2/8/76	36.26	38.55	35.80	36.14	36.26	1.27	NS	*	NS	NS
12/8/76	36.12	37.63	34.37	36.05	35.38	0.71	NS	NS	*	NS
21/9/76	32.64	35.73	31.95	34.45	34.27	0.95	NS	*	*	NS
1/10/76	33.18	34.92	34.00	35.35	35.36	0.94	NS	NS	NS	NS
12/10/76	32.49	33.24	33.20	32.28	34.29	0.97	NS	NS	NS	NS

Z1 Bare soil vs mulched soil

Z2 Grass mulch VS polythene mulches

Z3 Transparent polythene mulch VS nontransparent

Z4 Black VS white polythene mulches

NS not significant

* significant at 5%

** significant at 1%

Table 24.

Percentage moisture in over-dried soil at 120 cm depth (1977)

Date	Bare Soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SD	Z1	Z2	Z3	Z4
12/1/77	31.87	40.26	31.42	33.52	32.02	1.84	•	••	NS	NS
2/2/77	31.30	38.55	32.11	34.34	32.23	1.24	•	•	NS	NS
11/2/77	31.18	34.23	31.75	31.89	30.87	0.83	NS	••	NS	NS
22/2/77	29.90	34.80	31.10	31.97	29.95	0.60	•	••	NS	•
4/3/77	33.86	36.63	30.82	32.53	34.34	2.53	NS	••	•	NS
14/3/77	33.37	36.82	31.33	36.04	31.84	0.87	NS	••	••	••
24/3/77	30.83	35.37	30.72	33.13	33.00	1.71	NS	••	NS	NS
5/4/77	31.91	36.70	33.30	34.05	36.23	4.97	NS	NS	NS	NS
15/4/77	43.73	44.69	42.18	43.00	42.65	0.18	NS	••	NS	NS
5/5/77	41.86	42.57	42.79	42.53	44.54	1.87	NS	NS	NS	NS

Z1 Bare soil VS mulched soil

Z2 Grass mulch VS polythylene mulches

Z3 Transparent polyethylene mulch VS (non transparent)

Z4 Black VS white polyethylene mulches

NS not significant

• Significant at 5%

•• Significant at 1%

3. 2. 3. 2. Grass mulch compared to the polyethylene mulches.

As shown on table (23), on three sampling dates during 1976 the soil under grass mulch gave higher soil moisture content than the polyethylene mulched soil. On the other dates there was no significant difference between grass mulched soil and polyethylene mulched soil.

Grass mulched soil constantly gave higher soil moisture than the polyethylene mulched soil during 1977 as shown on table (24), except on 5/4/77 and 5/5/77 when there was no significant difference between the grass mulched soil and the polyethylene mulched soil.

3. 2. 3. 3. Comparison between transparent polyethylene mulch and black and white polyethylene mulches

As shown on table (23), the transparent polyethylene mulched soil indicated lower soil moisture content at 120cm depth than either the black or white polyethylene mulched soil on 24/6/76, 12/8/76 and 21/9/76, while during the other sampling dates there was no significant difference.

In 1977 as shown on table (24), the transparent polyethylene mulched soil gave lower moisture content than either black or white polyethylene mulched soil on two out of the ten sampling dates. During the other dates there was no significant difference.

3. 2. 3. 4. Comparison between black and white polyethylene mulches

In 1976 as shown on table (23), no significant differences occured in soil moisture content at 120cm depth between black and white polyethylene mulched soil. Table (24) shows that during 1977 on two occasions the black polyethylene mulched soil gave a higher soil moisture content than the white polyethylene mulched soil.

During most of the sampling dates there was no significant difference between the two treatments.

3. 2. 4. Soil moisture at 0 - 120cm depth

Figure (14), gives the average soil mositre for the whole profile considered o - 120cm depth for part of 1976 between 3/6/76 and 12/8/76. While figure (15) gives the pattern for the period between 2/2/77 and 15/4/77.

Figure (14) shows the grass mulched and white polyethylene mulched soil to have recorded more soil moisture than bare soil most of the time. The black polyethylene mulched soil gave lower moisture contents or same as bare soil in the first half of the period considered, while during the other half it gave higher soil moisture content than bare soil. The transparent polyethylene mulched soil gave lower soil moisture content than bare soil at 0 - 120cm depth except on one of the sampling dates.

Figure (15) shows the grass mulched soil to have recorded higher soil moisture content than the other treatments most of the times. The black and white polyethylene mulched soil gave higher soil moisture contents than bare soil most of the times, while in a few cases showed lower soil moisture contents. The transparent polyethylene mulched soil showed lower soil moisture content than bare soil in most of the occassions.

Figure (16) gives the average monthly rainfall for the year 1976 and the monthly average air temperatures for that year. Figure (17) gives the monthly average rainfall and monthly average air temperatures for part of 1977.

Figure 14.

Average moisture content in oven-dried soil under different types of mulches at 0-120 cm depth in 1976

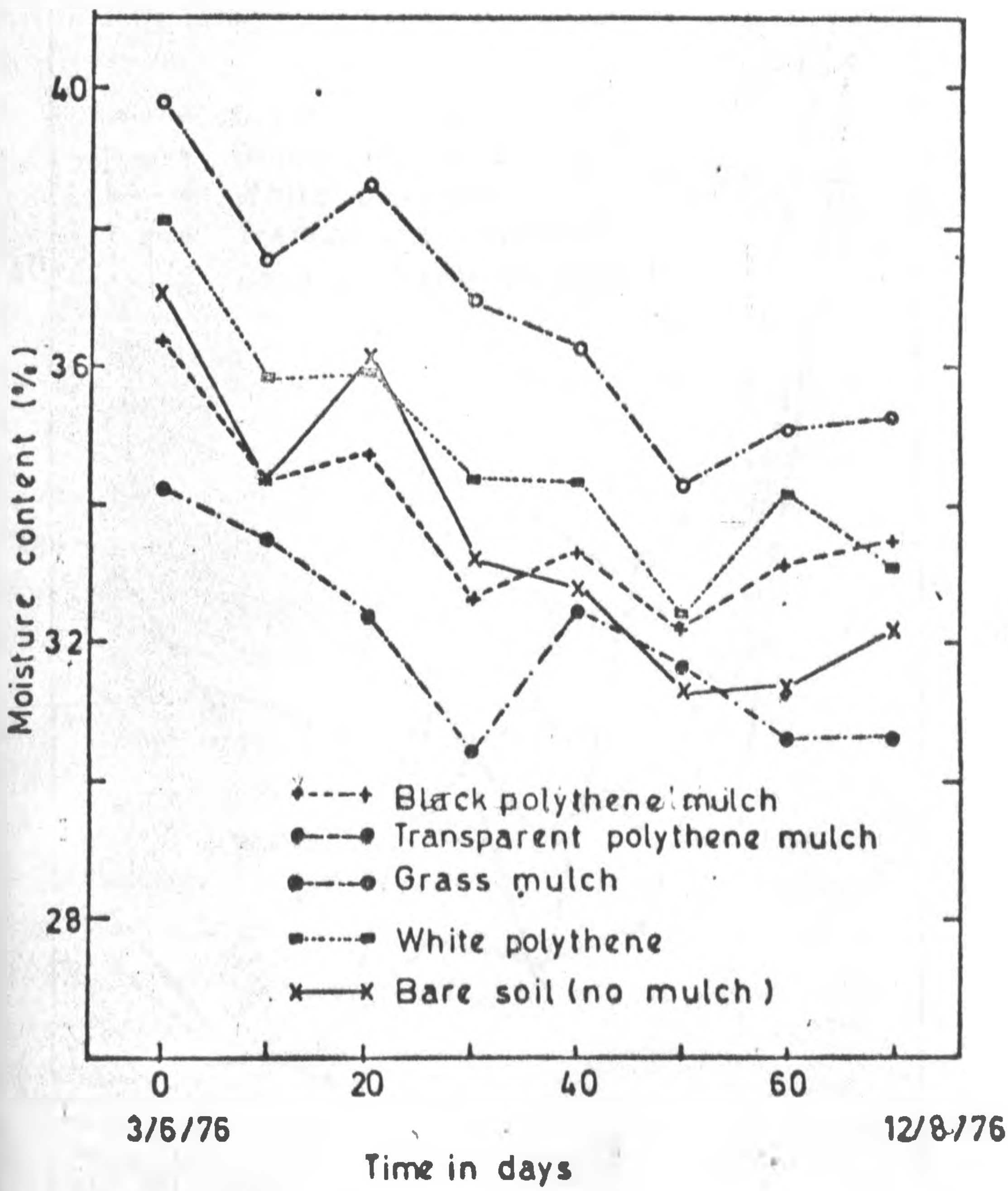
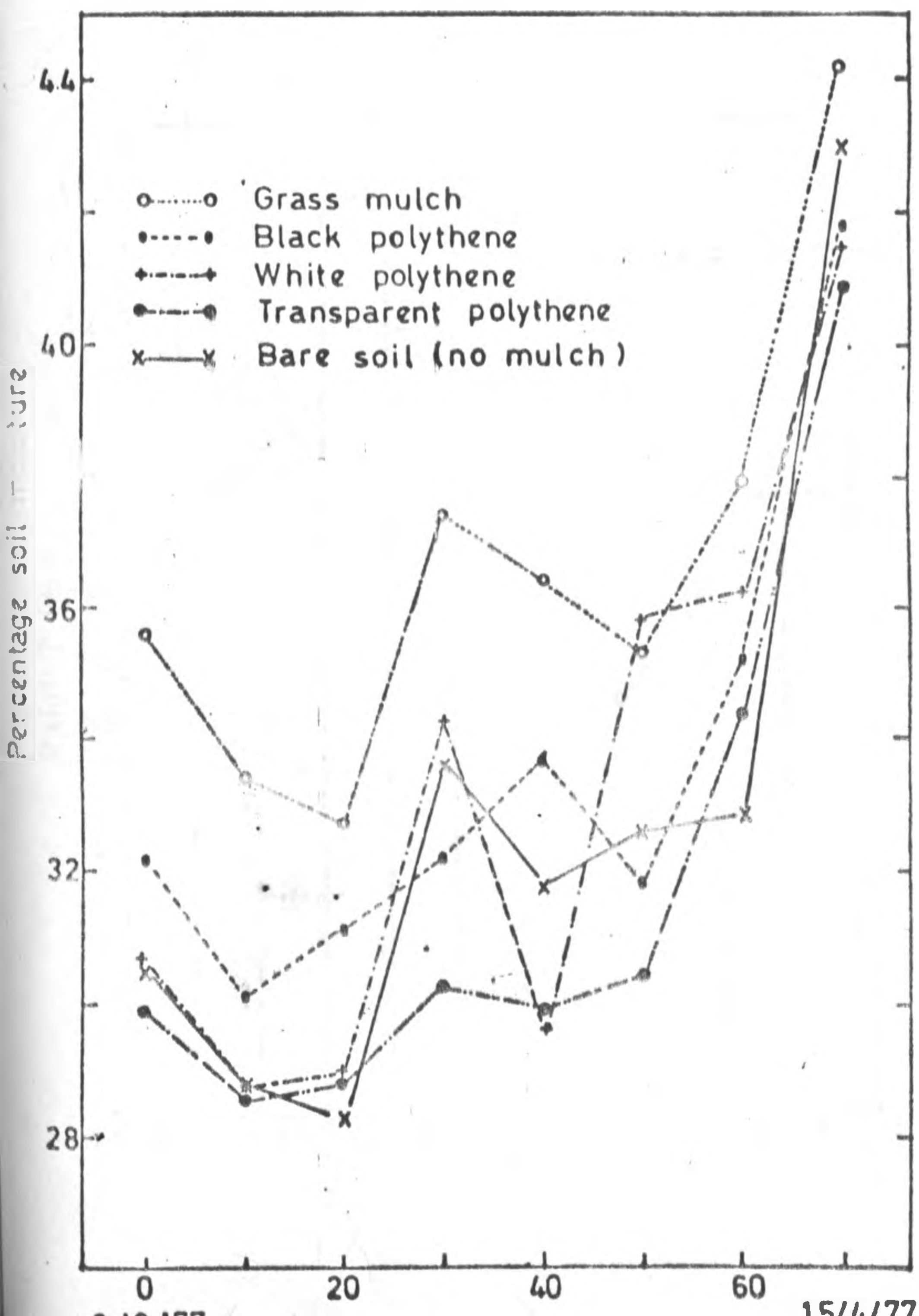
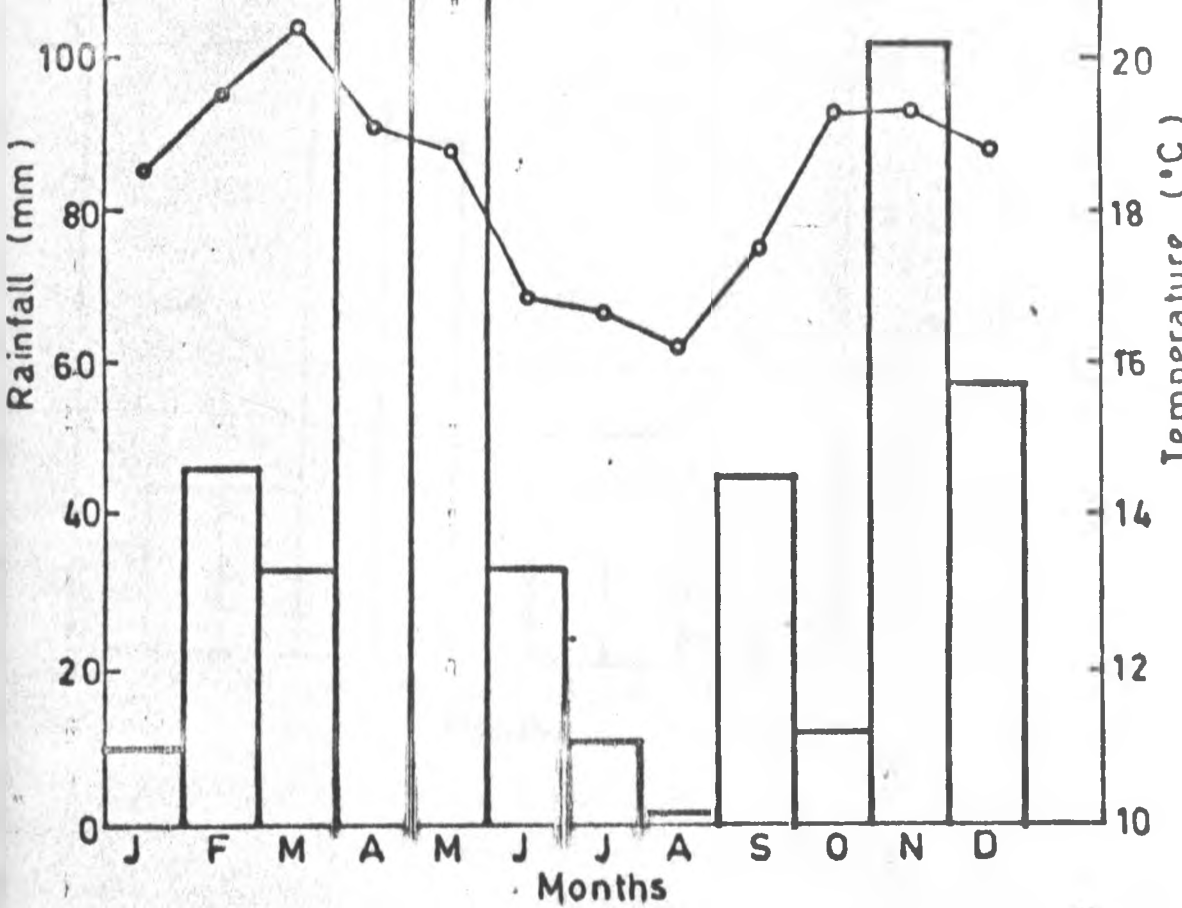


Figure 15

Average moisture content in oven-dried soil under different types of mulches at 0 - 120cm depth in 1977.





Rainfall (mm)
100
80
60
40
20
0
J F M A M J J A S O N D
Months
Temperature (°C)
20
18
16
14
12
10

Figure 16.

Rainfall and ambient temperatures at Kabete during the year 1976.

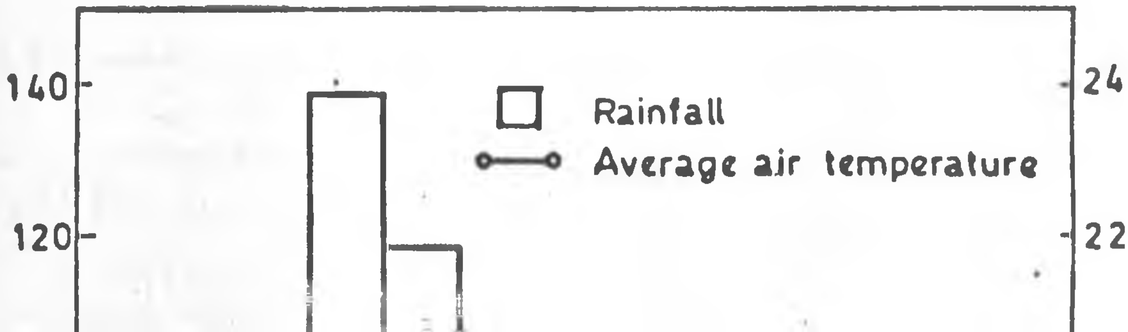
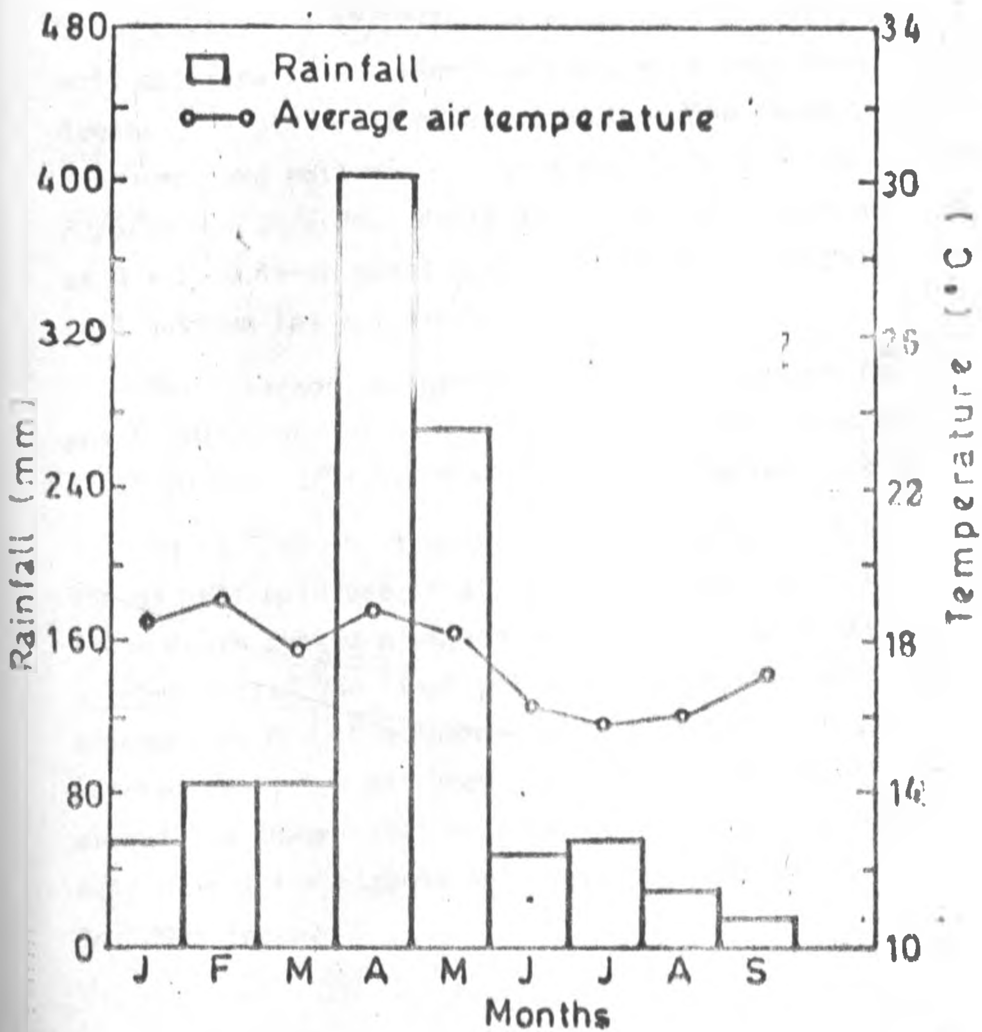


Figure 17.

Rainfall and ambient temperatures

at Kabete part of 1977.



3. 2. 5. Variation of soil moisture with depth

There were signigicant differences in soil moisture effects between depths in samples taken between 13/5/76 and 12/10/76, the analysis of variance is given in appendix VI.

In all the treatments as shown on figure (18), soil moisture increased with depth lower soil moisture being obtained at 0 - 15cm depth the highest soil moisture content being obtained at 120cm depth. However on 24/6/76 the grass mulched and bare soil showed high soil moisture content at 0 - 15cm depth which decreased with depth up to 120cm depth. On 12/10/76 the grass mulched soil again showed a high soil moisture at 0 - 15cm/decreased with increasing depth up to 60cm /which depth. The high soil moisture at 0 - 15cm depth under bare soil and grass mulched soil was due to a rainfall of about 22mm that fell between 20/6/76 and 22/6/76. While on 12/10/76 the high soil moisture content at 0 - 15cm depth might have been due to a rainfall of about 10mm that fell between 1st and 4th October.

The interaction between depth and treatment for the period 13/5/77 and 12/10/76 showed no significant differences except on 14/6/76, 24/7/76, 12/10/76 and 13/5/76. The analysis of variance is given in appendix VI.

On 13/5/76 the transparent polyethylene mulched soil showed the lowest soil moisture of all the treatments up to 60cm depth, but at 120cm depth showed a higher soil moisture than the black polyethylene mulched soil. The black polyethylene mulched soil had a higher soil moisture at 0 - 15cm than either bare soil or transparent polyethylene mulched soil, but at 120cm depth the black polyethylene mulched soil showed the lowest soil moisture of all the treatments. The grass mulched soil showed the highest soil moisture content of all the treatments up to 120cm depth.

On 14/6/76 the grass mulched soil gave the highest soil moisture than the other treatments from 0 - 15cm to 120cm depth. The white polyethylene mulched soil showed the second highest soil moisture down to 120cm depth. The black polyethylene mulched soil showed a high soil moisture than bare soil at 0 - 15cm depth while the transparent polyethylene mulched soil had a lower soil moisture than bare soil at this depth. At 60cm depth bare soil showed a high soil moisture than either black or transparent polyethylene mulched soil. At 120cm depth bare soil and black polyethylene mulched soil had similar soil moisture contents, while the moisture content under the transparent polyethylene mulched soil was slightly higher than that under either bare soil or black polyethylene mulched soil.

On 24/6/76 bare soil and grass mulched soil showed high soil moisture at 0 - 15cm depth which decreased with depth to 120cm depth while the polyethylene mulched soil had low soil moiture contents at 0 - 15cm depth which increased with depth, though little differences occured after 60cm depth between the treatments on 12/10/76. On this date the grass mulched soil had a high soil moisture content at 0 - 15cm depth which decreased with depth up to 60cm and started increasing again up to 120cm depth.

Soil moisture samples taken between 12/1/77 and 5/5/77 gave highly significant difference in the variation of soil moisture with depth, on 24/3/77 and 15/4/77 the differences were statistically significant, while on 12/1/77 and 4/3/77 no statistically significant differences were obtained. The analysis of variance is given in appendix V11.

As shown on figure (18), low soil moisture contents was obtained at 0-15cm depth in most of the cases. On 2/2/77 the black polyethlene mulch was shown to have a high soil moisture content at 0-15cm depth which increased with depth up to 60cm and then started increasing towards 120 cm depth.

Bare soil had a high soil moisture content at 0-15cm depth which decreased with depth up to 120cm depth on 24/3/77. On the same date the white polyethylene mulch showed low soil moisture content at 0-15cm depth which increased with depth up to 60cm depth and started decreasing towards 120cm depth. This was also noticed with the black polyethlene mulch on 5/4/77.

3.3. SOIL CHEMICAL PROPERTIES

3.3.1. Soil chemical properties six months after application of mulches

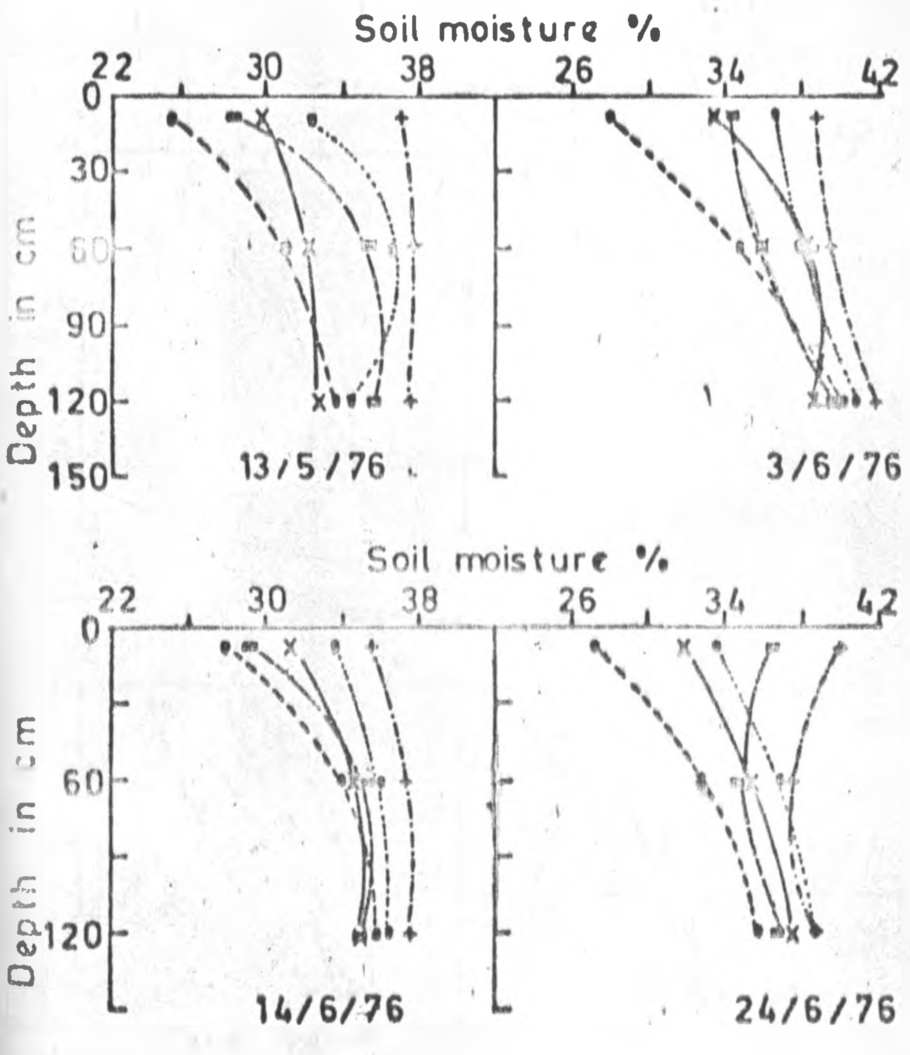
The analysis of soil chemical properties at 0-15cm depth six months after application of mulches is given on table (25). Differencesoccured between the treatments as regards per cent carbon, cation exchange capacity and potassium in the soil, while no differences were obtained on total nitrogen, calcium, magnesium and sodium in the soil.

3.3.1.1. Carbon

Bare soil compared to mulched soil gave no statistically significant differences, this was also true when soil under polyethlene mulches was compared. Soil under grass mulch showed a high percentage carbon as compared to soil under the polyethylene mulches.

Figure 18.

Variation, soil moisture with depth.



(a)

(b)

Figure 18 (Contd.....)

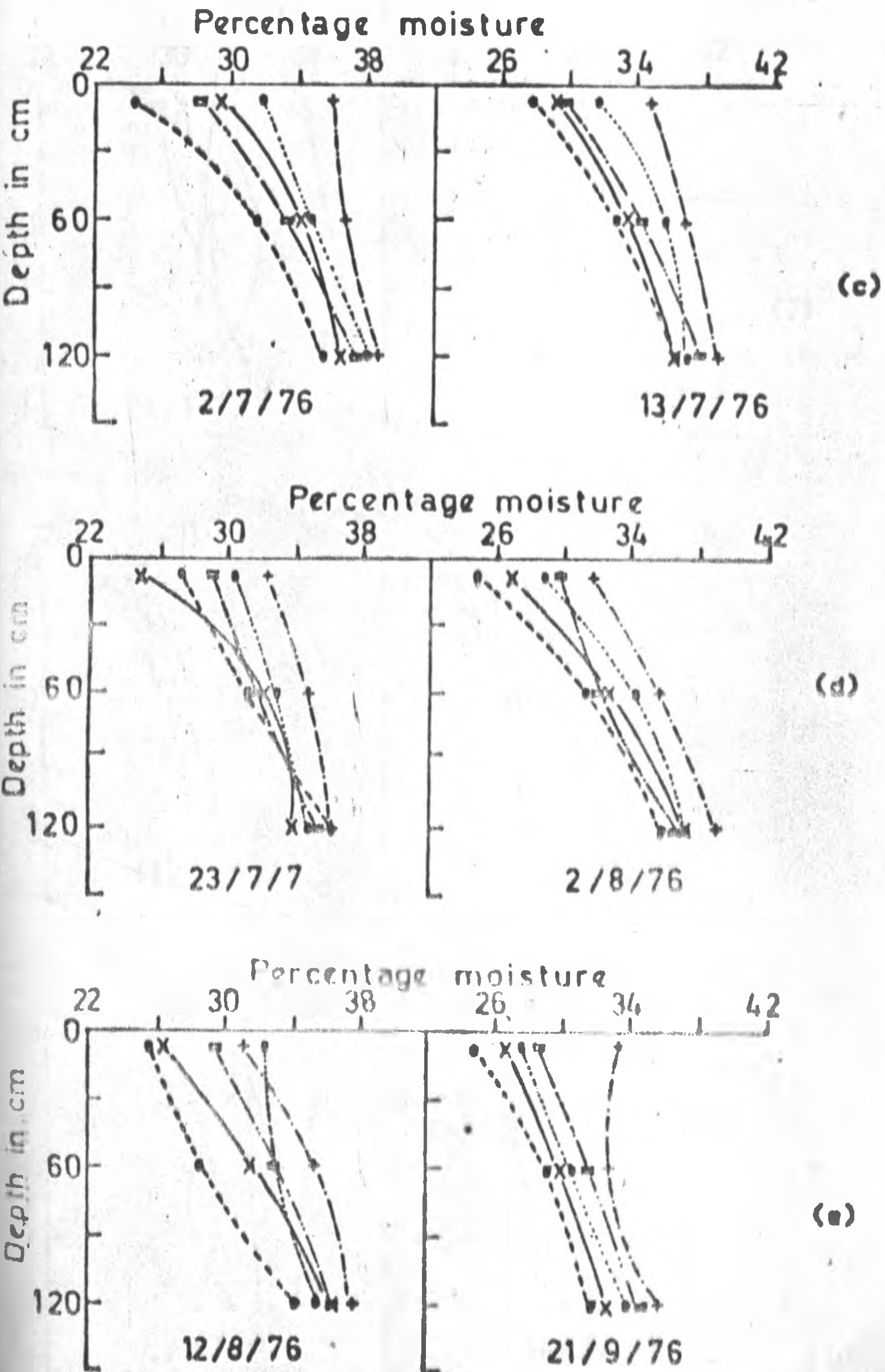


Figure 18 (Contd...)

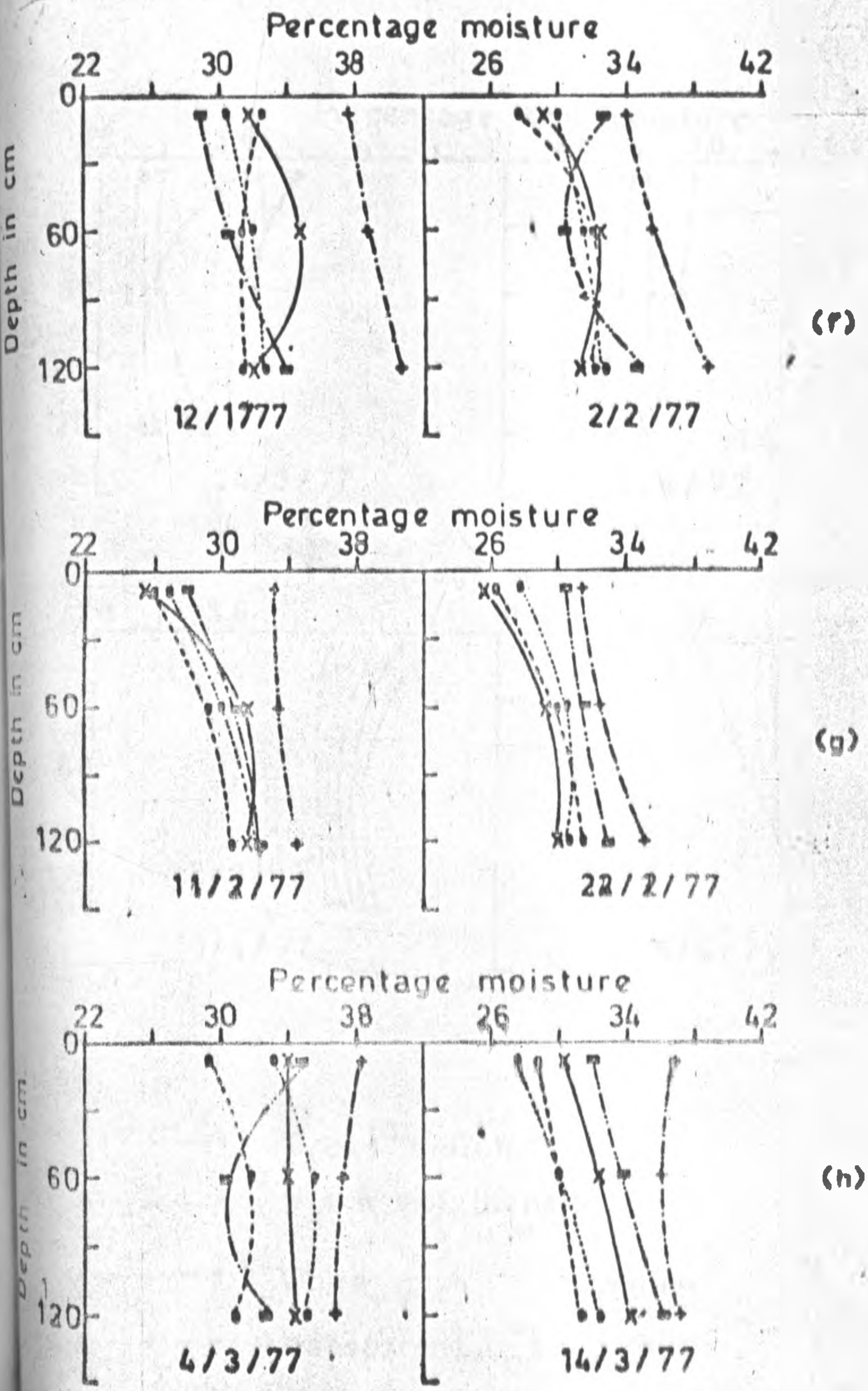


Figure 18 contd.....

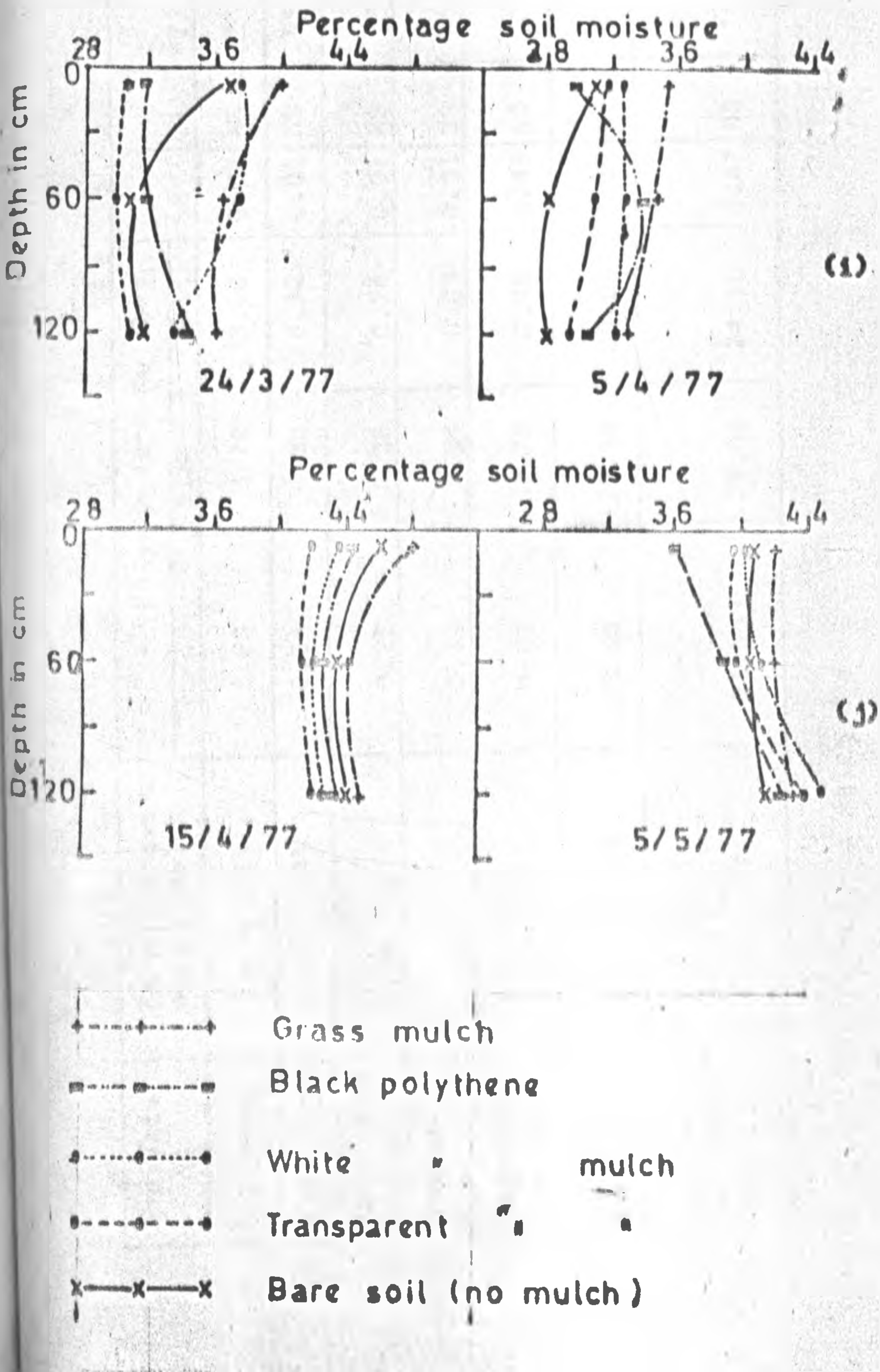


Table 25. Soil chemical properties six months after application of mulches at 0-15cm depth

Analysis	Bare soil	Grass mulch	Polyethylene mulches			SE	Z1	Z2	Z3	Z4
			Transparent	Black	White					
% Carbon	3.30	4.40	3.60	3.70	3.60	0.07	NS	**	NS	NS
% Nitrogen	0.45	0.41	0.34	0.38	0.32	0.01	NS	NS	NS	NS
Potassium m.e.%	0.24	0.36	0.26	0.28	0.28	0.01	NS	**	NS	NS
Sodium m.e. %	0.09	0.09	0.11	0.09	0.09	0.01	NS	NS	NS	NS
Magnesium m.e. %	3.88	4.79	3.62	3.75	2.96	0.43	NS	*	NS	NS
Calcium M.E. %	22.25	20.75	23.09	20.69	20.04	2.19	NS	NS	NS	NS
cation exchange capacity (C.E.C.)	24.40	25.70	24.30	25.00	24.10	0.47	NS	**	NS	NS

Z1 - Bare soil vs mulched soil

Z2 - Grass mulch vs polyethylene mulches

Z3 - Transparant vs non transparent polyethylene mulches

Z4 - Black vs white polyethylene mulches

NS - not significant

* - significant at 5%

** - significant at 1%

3. 3. 1. 2. Total nitrogen

As shown on table (25) no statistically significant differences occured between the treatments as regard the total nitrogen in the soil.

3. 3. 1. 3. Cation Exchange Capacity (C. E. C.)

Bare soil as compared to mulched soil and the comparison between the polyethylene mulched soils gave no statistically significant differences. However the soil under grass mulch indicated a higher cation exchange capacity than the soil under polyethylene mulches.

3. 3. 1. 4 Potassium

As shown on table (25), comparisons between bare soil and mulched soils showed no statistically significant differences. Soils under polyethylene mulches also showed no statistically significant differences. Higher potassium levels were obtained in the soil under the grass mulch then in the soils under the polyethylene mulches.

3. 3. 1. 5 Sodium

Sodium level in the soils was not affected by the treatments and no statistically significant differences were obtained.

3. 3. 1. 6 Magnesium

Comparison of soil under grass mulch and soil under polyethylene mulches indicated a higher magnesium level in the soil under the grass mulch. There were no statistically significant differences when the other treatments were compared.

3. 3. 1. 7. Calcium

No statistically significant differences were obtained between the treatments on the calcium levels in the soil.

3. 3. 2. Soil chemical properties one year after application of mulches

Soil chemical properties one year after application of mulches for top and sub-soil is given on tables (26) and(27). Statistical analysis could not be done on this data since the soil samples from one particular treatment were bulked and analysed for chemical properties as a single sample.

3. 3. 2. 1 Carbon

As shown on table (26) the percentage carbon in the soil did not vary much between the treatments, although soil under grass mulch indicated a higher carbon level than soil under the other treatments. The sub-soil percentage carbon levels as shown on table (27) were lower than the top-soil carbon levels shown on figure (26). Soil under grass, white and transparent mulches seemed to give slightly higher carbon levels in the sub-soil than the bare soil and soil under black polyethylene mulch.

3. 3. 2. 2. Potassium

In the top soil as shown on table (26), soil under grass mulch gave higher potassium levels than soil under the other treatments. While in the sub-soil the bare soil and soil under grass mulch showed higher levels than soil under polyethylene mulches. Higher potassium levels were obtained in the top soil than in the sub-soil except under the black polyethylene mulch and in the bare soil.

3. 3. 2. 3. Phosphorus

In the top-soil as shown on table (26), bare soil and soil under black polyethylene mulch gave higher phosphorous levels than the other treatments, this was also true in the sub-soil as indicated in table (27).

3. 3. 2. 4 Sodium

Bare soil seemed to indicate lower sodium levels in both the top soil and sub-soil than the soil under the mulches as shown on tables (26) and(27).

3. 3. 2. 5 Calcium

In the top soil as shown on table (26), bare soil and the soil under polyethylene mulches seem to show higher calcium levels in the soil than the soil under grass mulch. In the sub-soil as shown on table (27), the soil under polyethylene mulches gave higher calcium levels than either bare soil or soil under grass mulch.

3. 3. 2. 6. Magnesium

As shown on table (26), the Magnesium levels in the top soil seemed to be lowest under grass mulch, the other treatments giving almost similar levels of magnesium in the soil. In the sub-soil as shown on table (27) the bare soil magnesium levels were lowest followed by soil under grass mulch.

3. 3. 2. 7. PH of the soil

The PH of the soil did not seem to vary with the treatments, but the sub-soil had a slightly higher PH than the top soil as shown on tables (26 and (27).

Table 26. Soil chemical properties one year after application of mulches at 0-15cm depth

Analysis	Bare soil	Grass mulch	Polyethlene mulches		
			Transparent	Black	White
% carbon	2.85	3.00	2.78	2.78	2.78
Potassium m.e. %	1.20	2.44	1.52	0.94	1.24
Phosphorus ppm	21	17	16	24	18
Sodium m.e. %	0.24	0.34	0.37	0.29	0.34
Calcium m.e.%	6.60	5.10	5.50	7.00	5.90
Magnesium m.e. %	2.55	2.25	2.55	2.75	2.45
pH	4.80	4.90	4.80	4.80	4.90
$\frac{Ca + Mg}{K}$	7.6	3.0	5.3	6.7	6.7

Table 27. Soil chemical properties on year after application of mulches at 15-45 cm depth

Analysis	Bare soil	Grass mulch	Polyethylene mulches		
			Transparent	Black	White
% carbon	1.56	1.80	1.80	1.65	1.78
Potassium m.e. %	1.46	1.39	0.99	0.94	0.92
Phosphorus ppm.	22	18	17	24	17
Sodium m.e. %	0.23	0.31	0.42	0.29	0.46
Calcium m.e. %	4.90	4.30	6.60	6.40	5.70
Magnesium m.e. %	2.25	2.45	3.20	2.65	2.90
pH	5.40	5.20	5.20	5.20	5.30
$\frac{Ca + Mg}{K}$	7.40	4.90	9.90	9.60	9.30

3.4. FLUSH GROWTH OF COFFEE

3.4.1. Lateral branch extension

Flush growth of coffee was shown to be affected by the treatments during some of the periods while in others no differences occured. Coffee growth in terms of lateral branch extension is shown on table (28).

Between 8/10/76 and 22/10/76 bare soil was shown to allow less growth of the lateral branches than the mulched treatments. During the same period grass mulch encouraged more growth than the polyethylene mulches. Similar effects were shown in the period between 5/11/76 and 26/11/76. Bare soil encouraged more lateral branch growth than the mulched treatments in the period between 26/11/76 and 10/12/76, this was also observed in the period 8/1/77 to 9/1/77.

Between 9/1/77 and 2/2/77 bare soil allowed less growth than the mulches, while more growth was allowed by the polyethylene mulches as compared to the grass mulch. During this period the transparent polyethylene mulch allowed more growth than either black or white polyethylene mulches, while more growth occured in the black than white polyethylene mulch treatments.

In the period 22/10/76 to 5/11/76 grass mulch allowed more growth than the polyethylene mulches. In the periods 2/2/77 to 19/2/77 and 19/2/77 to 1/3/77, bare soil allowed less growth of the lateral branches than the mulch treatments. Grass mulch was better than the polyethylene mulches. The transparent polyethylene mulch was better than the other two polyethylenes and the black polyethylene mulch allowed more growth than the white polyethylene mulch.

Table 28. Coffee Growth in terms of lateral branch extension in (mm)

Date	Bare soil	Grass mulch	Polyethylene mulches			S.E.	Z1	Z2	Z3	Z4
			Transparent	Black	White					
10/9 - 24/9/76	11.18	17.03	11.23	16.43	12.65	5.06	NS	NS	NS	NS
8/10/76	12.90	22.48	11.93	20.88	15.50	17.68	NS	NS	NS	NS
22/10/76	14.03	28.68	15.03	25.40	18.00	18.89	*	*	NS	NS
5/11/76	9.75	23.45	9.70	19.30	14.03	16.50	NS	*	NS	NS
26/11/76	20.15	37.85	20.78	30.70	25.03	17.37	*	*	NS	NS
10/12/76	31.15	24.55	24.45	21.95	25.75	8.74	*	NS	NS	NS
21/12/76	21.50	15.85	19.95	15.85	17.53	8.82	NS	NS	NS	NS
8/1/77	27.48	20.45	24.15	20.65	22.23	14.02	NS	NS	NS	NS
19/1/77	13.58	9.95	10.95	11.38	9.40	2.58	*	NS	NS	NS
2/2/77	9.38	11.35	23.45	11.45	6.98	3.79	*	NS	**	*
19/ 2/77	4.95	11.93	9.88	8.80	4.85	2.07	**	**	*	*
1/3/77	6.35	10.75	8.53	8.88	5.13	1.61	NS	**	NS	*

Z1 - Bare vs mulched soil

Z2 - Grass vs polyethylene mulches

Z3 - Transparent vs non-transparent polyethylene mulches

Z4 - Black vs white polyethylene mulches

NS - No significant

* - Significant at 5%

** - Significant at 1%

3.4.2. Number of nodes grown

Growth of coffee in terms of number of nodes grown is shown on table (29). During some of the periods differences occured between treatments while in others no differences were obtained.

During the period 8/10/76 to 22/10/76 the transparent polyethylene mulch allowed fewer number of nodes to grow as compared to the black and white polyethylene mulches. Bare soil allowed fewer nodes to grow as compared to the mulch treatments in the period between 22/10/76 and 5/11/76. During this period grass mulch allowed the growth of more nodes than the polyethylene mulches, while the transparent polyethylene mulch allowed fewer nodes to grow than either black or white polyethylene mulches.

From 26/11/76 to 10/12/76 bare soil recorded more number of nodes grown than the mulch treatments, while polyethylene mulches showed more nodes grown than the grass mulch. Transparent polyethylene mulch gave more nodes than either black or white polyethylene mulches during this period.

The period between 19/2/77 and 1/3/77 showed fewer nodes grown in the bare soil treatment than in the mulched treatments. Black polyethylene mulch allowed more nodes to grow than the white polyethylene mulch during the period between 2/2/77 to 19/2/77.

Table 29. Growth of coffee in terms of nodes

Date	Bare soil	Grass mulch	Polyethylene mulches			S.E.	Z1	Z2	Z3	Z4
			Transparent	Black	White					
10/9-24/9/76	0.50	0.72	0.47	0.53	0.56	0.03	NS	NS	NS	NS
8/10/76	0.50	0.41	0.41	0.50	0.40	0.02	NS	NS	NS	NS
22/10/76	0.56	0.94	0.38	0.60	0.64	0.04	NS	*	NS	NS
5/11/76	0.01	0.35	0.01	0.22	0.21	0.01	*	*	*	NS
26/11/76	0.97	1.07	0.94	1.00	0.97	0.02	NS	NS	NS	NS
10/12/76	0.79	0.41	0.78	0.47	0.64	0.02	*	*	*	NS
21/12/76	0.38	0.44	0.44	0.51	0.32	0.02	NS	NS	NS	NS
8/1/77	0.59	0.57	0.67	0.56	0.78	0.03	NS	NS	NS	NS
19/1/77	0.38	0.39	0.40	0.25	0.22	0.03	NS	NS	NS	NS
2/2/77	0.45	0.53	0.39	0.60	0.53	0.03	NS	NS	NS	NS
19/2/77	0.35	0.44	0.60	0.47	0.25	0.02	NS	NS	NS	*
1/3/77	0.06	0.29	0.25	0.31	0.24	0.01	*	NS	NS	NS

Z1 - Bare vs mulched soil

Z2 - Grass vs polyethylene mulches

Z3 - Transparent vs non-transparent polyethylene mulches

Z4- Black vs white polyethylene mulches

NS - Not significant

* - Significant at 5%

** - Significant at 1%

3.5. ROOT DISTRIBUTION

Root distribution under the various treatments is given on table (30) no statistically significant differences were obtained between the treatments. However more roots seemed to occur at 20-40cm depth than either at 0-20cm depth or 40-60cm depth in all the treatments except under the transparent polyethylene mulch where slightly more roots occured in the 0-20 cm depth. In the 40-60cm depth fewer roots were found than in the other two upper horizons in all the treatments. The grass mulch gave more total roots than any of the other treatments though the differences were not statistically significant. Bare soil seemed to give slightly more total roots than the polyethylene mulches.

Table 30. Root distribution under different types of mulches

Dry weight (g)

depth (cm).	Bare soil	Grass mulch	Polyethylene mulches			S.E.
			Transparent	Black	White	
0-20	0.18	0.27	0.23	0.17	0.23	0.01
20-40	0.41	0.55	0.21	0.44	0.31	0.02
40-60	0.61	0.09	0.10	0.10	0.13	0.01
TOTAL	0.74	0.91	0.70	0.71	0.66	0.07

3.6. LEAF ANALYSIS

Leaf samples taken one year after application of mulches were analysed for various nutrient elements. The results are given on table (31).

Nitrogen content of the leaves does not seem to vary with the treatments, except the transparent polyethylene mulch which seems to show a lower nitrogen content than the other treatments.

The phosphorus content of the leaves did not seem to vary with the treatments.

Potassium content in the leaves did not vary between the bare soil and grass mulch treatments, while the trees mulched with polythylene allowed lower amounts of potassium in theleaves than the trees on bare soil or those mulched with grass.

Grass mulch and black polyethylene mulch gave higher calcium content in the leaves than the other treatments.

The magnesium content of the leaves did not seem to differ with the treatments, but grass and transparent polyethylene mulches showed slightly lower contents.

Manganese content of the leaves seemed to be low in the grass and transparent polyethylene mulches, While the other treatments gave almost similar levels.

Transparent polyethylene mulch indicated a high zinc content in the leaves. The other treatments did not seem to differ in the zinc content of the leaves.

Bare soil gave high copper content in the leaves while grass mulch gave the lowest copper content in the leaves.

Iron content of the leaves did not seem to differ between bare soil and the polyethylene mulches, while the grass mulch showed lower iron content in the leaves than the other treatments. Boron content in the leaves were higher in the polyethylene mulches as compared with bare and grass mulch.

Table 31. Leaf nutrient content one year after application of mulches

Element	Bare soil	Grass mulch	Polyethylene mulches		
			Transparent	Black	White
% nitrogen	2.76	2.72	2.50	2.88	2.76
% Phosphorus	0.11	0.13	0.11	0.11	0.12
% Potassium	2.04	2.04	1.96	1.68	1.84
% Calcium	1.16	1.56	1.16	1.50	1.24
% Magnesium	0.36	0.33	0.34	0.38	0.37
Manganese ppm	140	108	128	136	140
Zinc ppm	16	16	28	18	16
Copper ppm	30	14	16	20	16
Iron ppm	76	62	76	72	74
Boron ppm	38	46	50	50	46

Coffee Yields

As shown on table (32) lower coffee yields were obtained in 1976 than in 1977 in all the treatments because the coffee bushes had not come into full production after a change of cycle prunning done in 1974. During 1977 the coffee bushes had grown bigger and thus a heavier crop was harvested.

During the two years there were no differences in yields of coffee between the treatments. The average yields for the two seasons indicated higher yields under the polyethylene mulches than the bare and grass mulch.

Table 32. Coffee yields in kg/ha of cherry

	Bare soil	Grass mulch	Polyethylene mulches			S.E.
			Trans-parent	Black	White	
1976	717	639	924	1241	937	70715
1977	7155	7647	8438	7808	8560	2405360
Ave-rage	3936	4018	4681	4525	4749	682999

3.8. ASSESSMENT OF WEED GROWTH

During the months of January and April the bare soil allowed more weeds to grow then the mulched treatments. In March 1976 there was no difference in weed growth between the bare soil and mulched soil. As shown on table (33) the grass mulch gave no differences in weed growth as compared to the polyethylene mulches during January and March 1976, but in April 1977 the grass mulch yielded more weeds than the polyethylene mulched soil

The transparent polyethylene mulch as compared to the black and white polyethylenes, showed more weed growth under the transparent mulch than under the other two during the three months considered.

Black and white polyethylene mulches did not differ in the amount of weed allowed to grow.

When the total harvest for the three months was considered, the bare soil gave more weeds than the mulched soil while the grass mulch yielded more weeds than the

Table 33. Weeds under different types of mulches

(fresh weight ton/ha)

Time	Bare soil	Grass mulch	Polyethylene mulches			S.E.	Z1	Z2	Z3	Z4
			Transparent	Black	White					
Jan. 1976	12.10	2.90	5.70	0.01	1.20	0.65	**	NS	**	NS
March 1976	9.10	8.2	8.3	0.10	3.40	7.46	NS	NS	**	NS
April 1977	25.80	16.80	13.50	0.20	3.60	6.12	**	**	**	NS
Average	15.70	9.30	9.20	0.10	2.80	1.00	**	**	**	*

Z1 - Bare soil vs mulched soil
Z2 - Grass mulch vs polyethylene mulches
Z3 - Transparent vs non transparent polyethylene mulches
Z4 - Black vs white polyethylene mulches

NS - not significant
* - significant at 5%
** - significant at 1%

polyethylene mulches. Among the polyethylene mulches the transparent one allowed more weeds to grow as compared to the black and white polyethylenes. The black polyethylene mulch allowed fewer weeds to grow under it than the white polyethylene mulch.

3.9. Persistence of mulches

A visual assessment of deterioration of the mulches was done six months after the application of the mulches. With the polyethylene mulches it was shown that the black polyethylene mulch could last longer than the other two polyethylenes, followed by the white polyethylene mulch, while the transparent polyethylene mulch deteriorated faster than the other two. In terms of ground cover provided by the mulches assuming the original application to be 100%, six months after the application of the mulches, the black polyethylene mulch provided about 90% cover, while the white polyethylene mulch gave about 80% and the transparent polyethylene mulch gave about 35% ground cover.

The nature of deterioration was such that the transparent polyethylene became brittle on isolated patches and the material broke into pieces leaving big patches of uncovered ground. The paint used to make the white polyethylene mulch was observed to peel off and then the mulch started wearing out in a manner similar to the transparent polyethylene mulch. However the deterioration of this mulch was not as fast as that of the transparent polyethylene mulch. The black polyethylene mulch was shown to last longer and deterioration of this mulch was mainly due to tearing rather than breaking into small pieces like the transparent polyethylene mulch.

CHAPTER FOUR

DISCUSSION AND CONCLUSION

4.1. DISCUSSION

4.1.1. Soil Temperatures

At 7cm and 15cm depth soil temperatures varied greatly among the treatments as shown on tables (7) and (10). Whenever there were significant differences between bare soil and the mulches, temperatures under polyethylene mulches were higher than those under bare soil, while the grass mulch showed lower soil temperatures than bare soil. The usual effect of the grass mulch was to lower soil temperatures in the afternoon and increase it in the morning as compared to bare soil.

Several workers have reported reduction in soil temperatures due to vegetable mulches as compared to bare soil during the day (Gilbert, 1945; Mc calla and Duley, 1946; Jacks et-al, 1955; Burrows and Larson, 1962; Larson, 1962; Moody et-al 1963). Van Wijk et-al (1959) reported straw mulch to decrease weekly average maximum soil temperatures at 10cm depth, the differences between mulched and unmulched treatments were not as marked in the minimum soil temperatures as for the maximum. In a coffee nursery trial grass mulch reduced soil temperatures by 5 °c during the day (Blore, 1964). The general effect of organic mulches is to increase soil temperatures in cold seasons and to decrease it in hot seasons (Jack et-al, 1955; Van Wijk et-al, 1959; Cooper, 1973; Russel, 1973; Rosenberg, 1974). The thermal conductivity of grass mulch is lower than that of bare soil and therefore the heat gain or loss is less under grass mulch (Hanks et-al, 1961).

This might explain the effect of grass mulch on soil temperatures; during the day grass mulch gains less heat and therefore the lower soil temperatures as compared to bare soil; the higher soil temperatures under grass mulch as compared to bare soil in the morning can be explained in terms of the thermal conductivity differences as well. At night grass loses less heat than bare soil and this is reflected in the higher soil temperatures in the morning under the grass mulch. Moist soil is usually cooler than dry soil (Cooper, 1973).

Soil under grass mulch recorded higher moisture than bare soil most of the time. The high soil moisture content under grass mulch may also have contributed to the lower soil temperatures under this mulch as compared to bare soil.

Low soil temperatures due to organic mulches may at times reduce the growth of crops. Cotton pod mulch resulted in low soil temperatures which was shown to slow cotton seedling growth, low soil temperatures due to straw mulches have also been shown to be a primary causative factor in the reduced growth of maize in some parts of the United States of America (Van Wijk et-al, 1959; Burrows and Larson, 1962; Moody et-al, 1963; Barrentine and Waddle, 1972). In a greenhouse experiment root temperatures of about 26°c by day and 20°c by night gave the best results in coffee growth (Coaracy, 1958). Considering the afternoon soil temperature range under grass mulch at 7 cm depth as shown on figure (9), 18.1 $^{\circ}$c to 20.8 $^{\circ}$c this indicates soil temperatures below the optimum of 26 $^{\circ}$c reported by Coaracy (1958). Taking the morning soil temperatures, to approximate the night temperatures, under grass mulch at 7 cm depth as shown on figure (8) the temperature range was 16.5 $^{\circ}$c, this is also shown to be below the night optimum soil temperature of 20 $^{\circ}$c reported by Coaracy (1958).

It can be concluded that soil temperatures at 7 cm depth under grass mulch do not seem to be optimal for coffee growth and therefore coffee growth might be retarded due to these low soil temperatures. However this was not evident in this study as regards the extension of lateral branches or in terms of number of nodes grown. Other effects of grass mulch such as conservation of soil moisture and addition of plant nutrients to the soil might mask the influence of soil temperatures on coffee growth.

The polyethylene mulches showed higher soil temperatures than bare soil whenever significant differences were obtained at 7 cm and 15 cm depths. However the white polyethylene mulch showed lower soil temperatures than bare soil during a few occassions. Among the polyethylene mulches the transparent mulch gave the highest soil temperatures followed by the soil under black and the white polyethylene mulches. Transparent polyethylene mulch has been reported by other workers to increase soil temperatures as compared to bare soil (Hopen, 1965; Greb, 1966; Law and Cooper 1974). Unger (1975) in review reports that the effect of clear plastics on soil temperatures results consistently in higher soil temperatures as compared to bare soil.

The transparent polyethylene mulch allows solar radiation through and thus heats the soil surface. The back radiation is retained due to water droplets that form on its under surface. This results in high soil temperatures under this mulch as compared to bare soil. (Russell, 1973). A given amount of heat will raise the temperature of moist soil less than that of a dry soil. (Cooper, 1973). In this study the soil moisture content under the transparent polyethylene mulch was on many occassions shown to be lower than that under bare soil. Due to the low soil moisture content under transparent polyethylene mulch, a given amount of heat would raise the soil temperature more under this mulch than under bare soil, this might also have contributed to the high soil temperatures recorded under polyethylene mulch.

The high soil temperatures under transparent polyethylene mulch can increase the rate of emergence, growth and earliness of maturity of some crops as has been shown with maize (Wallis, 1957; Ballif and Dutil, 1971; Law and Cooper, 1974). The weekly average afternoon soil temperature range under transparent polyethylene mulch was 26.4°c to 35°c as shown on figure (9) and a range of 17.9°c to 21.8°c for the morning at 7 cm depth. The afternoon soil temperatures at 7 cm depth under the transparent polyethylene mulch seem to be above the optimal during the day of 26°c reported by (Coaracy, 1958). While the morning soil temperatures which are taken to approximate the night soil temperatures are within the optimal soil teperature at night of 20°c reported by Coaracy (1958). Lateral branch extension and number of nodes grown did not indicate any increased growth or retardation, as it is discussed in the later part of this section.

The black polyethylene mulch was shown to have higher soil temperatures than bare soil at 7 cm and 15cm depth. Unger (1975) reports that black plastics increase soil temperatures, while in other reports decreased or no effect on soil temperatures are indicated. Hopen (1965) reported higher soil temperatures under black polyethylene mulch as compared to bare soil. The black polyethylene mulch being a black surface receives most of the solar radiation without reflecting mulch. The mulch being in contact with the soil surface the heat received is used to heat the soil. (Russell, 1973). Like in the case of transparent polyethylene mulch high soil temperatures under black polyethylene mulch might aid in the emergence, growth and earliness of crops. As shown on figure (8) and (9) soil temperatures during the morning which are taken to approximate the night soil temperatures, at 7cm depth they seem to be below the optimum soil temperature 20°C reported by (Coaracy, 1958). However during the day the soil temperatures were within 26°C which Coaracy (1958) reported to give best coffee growth. However in this study no growth differences occurred which could be attributed to this particular mulch.

The white polyethylene mulch showed higher soil temperatures than bare soil during some periods and in others it showed lower soil temperatures than bare soil. Reflective plastics usually decrease or have no effect on soil temperatures. (Unger, 1975). The white polyethylene mulch reflects most of the solar radiation, thus only a little amount gets to heat the soil. In this study the white polyethylene mulch gave higher soil temperatures than bare soil in most occassions. The paint applied to the transparent polyethylene sheet to obtain a white one, might have been not all that reflective in some patches, and also with time the paint kept coming off leaving some patches transparent. This might have caused the white polyethylene mulch to have higher soil temperatures than bare soil during some of the occassions. As with other mulches no growth differences on coffee could be attributed to the temperature effect of the mulches.

As expected the variation of soil temperature with depth indicated that at one and two metres depth there were little differences between treatments. Similar results have been reported by Russell, (1973), Cooper, (1973), and Rosenberg, (1974).

Seasonal changes in soil temperatures would be expected to vary with ambient temperatures (Russell, 1973). At 7cm and 15cm depth seasonal changes in soil temperatures under the various types of mulches and bare soil seemed to rise and fall approximately in phase with the air temperatures. (Fig. (7) and (10)). However at one metre depth changes in soil temperatures under the various types of mulches and bare soil lagged behind changes in air and surface soil temperatures. (Fig. 11) Russell, (1973) reported that soil temperatures at the surface follow the pattern of air temperatures; At greater depths though such changes follow those in air and surface temperatures, there is a time lag. At two metres depth (table 17), the soil temperatures under the various types of mulches and bare soil did not vary much and seemed to be approximately in equilibrium with the air temperature.

4.1.2. Soil moisture

Mulches affect soil moisture through increased infiltration, run-off control, reduced evaporation and weed control. (unger, 1975). In this study whenever significant differences were obtained in the comparison of bare soil and mulched soil, the mulches were shown to conserve more soil moisture than bare soil; Except after a rainfall when the soil moisture content could be higher under bare soil than under the polyethylene mulches; which could be due to the effect of these mulches in impeding the direct penetration of rain water into the soil.

The grass mulch was constantly shown to give higher soil moisture content than bare soil Similar results of organic mulches increasing Soil moisture above bare soil have been reported by other workers who explain it in terms of increased infiltration rates, control of run off, reduced evaporation and control of weeds (Beutner and Darwin, 1943; Gilbert, 1945; Duley, 1953; Pereira and Jones, 1954; Rowe-Dutton, 1957; Sogo and Ozaki, 1967; Reynolds, 1970; Evanson and Rumbaugh, 1972; Papendick et-al, 1973; Rattan Lal, 1973; Othieno, 1975).

As compared to bare soil, higher soil moisture contents were obtained under black and white polyethylene mulches on most occassions. Mulches are generally accepted to increase soil moisture. The polyethylene mulches would increase soil moisture above bare soil through evaporation control, weed control, and to some extent checking the run-off of rain water. The lower soil moisture content recorded during most of the occassions under the transparent polyethylene mulch as compared to bare soil may have been due to the high soil temperatures under this mulch and possibly due to its fast deterioration and more weed growth as compared to the black and white polyethylene mulches. Black and white polyethylene mulches showed no differences in their moisture conservation during most of the occassions.

Grass mulch compared to polyethylene mulches constantly indicated higher soil moisture. Polyethylene mulches could imped the direct penetration of rain water into the soil. It was observed that the polyethylene mulches allowed some of the rain water to collect on their surface. Rowe-Dutton (1957) reports that certain artificial mulches may imped penetration of rain water, these type of mulches may be more effective in increasing soil moisture when used on soils well supplied with ground water rather than on those dependent on rain or irrigation water. The action of polyethylene mulches on impeding the direct penetration of rain water may have caused the lower soil moisture content as compared to the grass mulch.

Conservation of soil moisture results in improved availability of water to plants (Jnoks et-al 1955; Moody et-al, 1963; Oreb et-al 1967; Kowsar et-al, 1969; Liptay and Tiessen, 1970; Reynolds, 1970; Koshi and Fryrear, 1973).

The conservation of soil moisture due to grass mulches has been shown to improve coffee yields in Kenya (Pereira and Jones, 1954). However during this study no yield responses due to mulches was noticed, possibly due to the short period during which the trial was conducted. High soil moisture contents due to mulches are reported to be a factor in the beneficial effects of mulches on germination and seedling growth (Kowsar et-al, 1969).

4.1.3. Soil chemical properties

As shown on table (25) it was only the grass mulch which significantly affected some of the soil chemical properties considered. Grass mulch increased percent carbon, potassium level, magnesium level and cation exchange capacity of the soil as compared to polyethylene mulches, this was also true when grass mulch was compared to bare soil although the comparison between bare and mulched soils indicated no statistically significant differences. Polyethylene - coated paper mulch was shown to result in higher nitrate-nitrogen levels in the soil than bare soil, this was associated with the higher soil temperatures and moisture levels which encouraged nitrogen mineralization. (Liptay, et-al 1970).

Grass mulch being of plant origin adds organic matter to the soil on decomposition (Gilbert, 1945; Sanders, 1951; Jacks et-al 1955; Northmore, 1963; Pereira, 1964; Robinson and Hosegood, 1965; Kizza, 1969). The cation exchange capacity of the soil is associated with the organic colloids (humus) in the soil (Ahn, 1970). since grass mulch increases the carbon level of the soil, this contributes to the increase of the organic colloids in the soil and hence the higher cation exchange capacity of the soil.

Potassium level in the soil has been reported to be increased due to grass mulches (Robinson and Hosegood, 1965; Kizza, 1969). Increase in potasium levels of the soil has a tendency of inducing magnesium deficiency in coffee (Robinson and Chenery, 1958). Magnesium level in the soil has been reported to be increased due to mulching with grass (Robinson and Hosegood, 1965). Mulches of plant materials improve soil fertility by adding organic matter together with other plant nutrients to the soil (Gilbert, 1945; Jacks et-al, 1955; Northmore, 1963; Pereira 1964).

4.1.4. Growth of coffee

As shown on table (28) coffee bushes showed flush growth in the period between 22/10/76 and 10/12/76. The month of October marked the end of the dry season as shown on figure (16) about 10mm of rainfall had fallen during the early part of October. This shows that coffee bushes started flushing at the beginning of the rain. In Kenya new leaves on coffee emerge most rapidly during synchronous growth flushes which occur after rainfall. It has been shown that flushing in coffee might be due to a stimulus associated with rainfall but independent of the soil moisture. (Browning, 1975). Flushing of coffee in terms of number of nodes grown occurred between 22/10/76 and 10/12/76 which were rainy months as shown on table (29). Flush growth differences between treatments were not consistent as during any of the periods one treatment could be shown to be better than the other, while in other periods it could show lower growth. Browning and Fisher (1975) suggests that water stress appears to stimulate coffee trees into compensatory physiological activity when the stress is eventually relieved.

There were no statistically significant differences in coffee yields between the treatments, this was unexpected because in Kenya grass mulches have been reported to increase coffee yields (Anon, 1945; 1957; 1958; 1959; Pereira, and Jones 1954; Mitchell, 1976a). The coffee bushes on which this study was done were stumped in 1974 during the normal change of cycle prunning. During 1976 a small crop was obtained and even in 1977 the bushes had not come into full production. The short period in which the study was carried may mean that the treatment effects might not have affected the coffee bushes long enough for these effects to be reflected in the yields.

Root distribution showed no statistically signifcant differences between the treatments, but the grass mulch seemed to give more roots in the 0 - 40 cm depth and also more roots up to 60 cm depth than the other treatments as shown on table (30). Mcmaster (1952) showed that grass mulch had the effect of inducing feeder roots to grow into the top layers of the soil.

As shown on table (33) all the mulches were effective in controlling weeds. Many reports have indicated the usefulness of mulches in the control of weeds (Gilbert, 1945; Rowe-Dutton, 1957; Northmore, 1963; Ekern, 1967; Reynolds, 1970). The transparent polyethylene mulch allowed more weed growth than black and white polyethylene mulches. This was expected as this polyethylene mulch allows light through which is essential for plant growth. The black and white polyethylene mulches checked weed growth almost completely.

4.2. CONCLUSION

Grass mulch was shown to lower soil temperatures as compared to bare soil, while the polyethylene mulches increased soil temperatures above that of bare soil. Due to the short duration in which this study was carried no conclusive effects of the mulches on coffee growth and yields were established. It would therefore be suggested that further work could be done with these mulches to evaluate more fully their effect on coffee growth and yields. The high soil temperature under polyethylene mulches might lead to a higher nitrogen flush on the onset of the rains, this is also an aspect which is open to further work.

In this study the grass mulch was established to be superior to the polyethylene mulches in terms of moisture conservation it would therefore be recommended that despite the problems associated with the availability of mulching materials due to scarcity of land, the practice of grass mulching in coffee is worthwhile and should be continued. Polyethylene mulches had a lower soil moisture conservation effect than the grass mulch, this was mainly due to their effect on impeding direct penetration of rain water.

However it is felt that polyethylene mulches might be useful in conservation of soil moisture in coffee if tried in connection with trickle irrigation.

Grass mulch was again shown to be superior to the polyethylene mulches in terms of adding organic matter, potassium, magnesium and increasing the cation exchange capacity of the soil. Further work could be done with the polyethylene mulches to evaluate more fully their effect on soil chemical properties particularly the run-down of carbon in the soil and the mineralisation of nitrogen.

With the exception of the black polyethylene mulch the other two polyethylene mulches, transparent and white, were shown to deteriorate very fast such that after six months they were no longer effective as mulches. It is therefore suggested that these mulches do not compare favourably with the grass mulch where the usual practice is to add new material after every year.

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Appendix I: Analysis of variance soil temperatures at 7cm depth

Time in 5 day weeks	df	17/5/76 1	2	3	4	Mean Square 5	6	df	Mean Square 7	8	9	10	13/8/76 11	12	13
Treatment	4	26.3	30.20	45.20	43.88	19.09	11.90	4	27.42	38.03	18.80	27.63	22.17	17.64	23.74
Main error	5	2.69	3.96	2.11	[illegible].66	12.7	1.50	4	0.51	1.02	0.84	2.66	3.69	0.40	1.02
Main total	9	13.18	15.62	21.26	20.98	9.19	6.12	8	13.96	19.53	9.82	15.14	12.93	9.02	12.38
Time of day	1	154.01	180.[illegible]	202.89	209.31	114.24	83.23	1	189.73	242.91	94.18	227.14	213.86	147.93	299.54
Time x treatment	4	13.36	13.75	20.92	22.79	9.38	3.96	4	12.21	14.51	5.71	15.38	13.37	9.59	10.33
Sub error	5	1.76	2.29	0.46	0.56	0.39	0.26	4	0.50	0.18	0.85	0.42	1.82	[illegible].12	0.3[illegible]
Total	19	17.69	20.37	25.28	10.11	12.44	8.18	17	20.72	26.93	11.71	24.20	22.24	15.23	[illegible]

Appendix II: **Soil Temperature**

15cm Analysis of variance

6/12/76
Time in weeks

Mean Square

	df	1	2	df	3	4	5	df	6	7	8	df	9
Treatment	4	26.95	24.98	4	24.16	34.07	42.42	4	47.76	48.99	36.60	4	53.[illegible]
Main error	4	2.41	1.68	5	3.47	4.03	2.91	9	3.53	3.05	2.00	10	2.2[illegible]
Main total	8	14.68	13.33	9	12.67	17.38	20.47	13	17.14	17.19	12.64	14	16.86
Time of day	1	10.09	3.12	1	4.23	10.51	8.59	1	1.68	4.96	28.81	1	27.[illegible]
Time x treatment	4	0.24	1.13	4	0.26	0.74	0.98	4	0.26	0.55	2.44	4	2.[illegible]
Sub error	4	0.15	0.46	5	0.35	0.36	0.29	9	0.35	0.26	1.00	10	1.86
Total	17	7.59	6.83	19	6.37	9.04	10.43	27	8.47	8.63	7.85	29	[illegible]

25th March, 1977

	df	10	11	12	13	14	15	16
Treatment	4	35.29	30.52	35.11	21.30	33.58	28.28	15.08
Main error	5	0.36	1.58	2.43	0.31	1.72	1.30	1.67
Main total	9	15.33	14.44	16.95	9.37	15.88	13.29	7.63
Time of day	1	3.37	12.80	0.16	3.20	3.45	19.21	26.22
Time x treatment	4	0.14	1.04	0.54	0.60	0.44	[illegible]2	8.22
Sub error	5	0.28	2.21	0.87	0.97	0.15	0.71	1.25
Total	19	7.83	7.79	8.38	5.27	7.84	7.56	5.[illegible]7

Appendix III Analysis of variance soil temperature one metre depth

Time weeks	df	6/12/76				Mean Square				
		1	2	3	4	5	6	7	8	9
Treatment	4	9.30	6.16	7.31	6.93	7.13	7.29	6.03	11.91	15.62
Main error	5	2.83	2.52	1.49	2.12	1.61	2.03	1.08	1.42	2.15
Main total	9	5.70	4.14	4.08	4.26	4.06	4.37	3.28	3.64	8.14
Time of day	1	6.73	2.53	0.58	0.02	0.19	0.37	0.03	2.25	0.97
Time x treatment	4	0.60	0.52	0.09	0.15	0.23	0.06	0.17	1.15	0.42
Sub error	5	0.63	0.55	0.11	0.24	0.18	0.01	0.41	0.20	0.44
Total	19	3.35	2.35	2.01	2.11	2.03	2.10	1.70	3.29	4.11

	df	10	df	11	12	df	13	df	14	15 8/3/77
Treatment	4	15.33	4	15.18	19.21	4	17.99	4	27.01	21.87
Main error	3	1.38	2	5.5	0.94	3	0.85	4	3.11	0.81
Main total	7	9.57	6	11.95	13.12	7	10.64	8	15.06	11.34
Time of day	1	0.60	1	1.02	0.29	1	2.67	1	0.11	2.31
Time x treatment	4	0.21	4	0.55	1.48	4	0.46	4	0.15	0.12
Sub error	3	0.82	2	0.40	0.25	3	0.46	4	0.14	0.31
Total	15	4.70	14	5.41	6.1	15	5.36	16	7.61	5.92

Appendix IV: Analysis of variance soil temperature at two metres depth

Time weeks	df.	1 (6/12/76)	2	3	4	5 (Mean Squares)	6	7	8	9	10 (11/2/77)
Treatment	4	0.48	0.45	2.00	0.84	1.30	0.57	0.98	1.13	2.79	3.31
Main error	5	2.92	0.29	0.34	0.30	0.51	0.14	0.12	0.51	0.12	0.37
Main total	9	1.84	0.36	1.08	0.54	0.66	0.33	0.50	0.78	1.31	1.68
Time of day	1	3.04	0.02	0.22	0.29	0.01	0.24	0.72	0.03	1.74	0.09
Time x treatment	4	0.25	0.12	0.29	0.07	0.16	0.08	0.12	0.29	0.33	1.46
Sub error	5	2.65	0.15	0.14	0.03	0.07	0.05	0.07	0.53	0.90	0.14
Total	19	1.78	0.24	0.62	0.29	0.46	0.20	0.32	0.57	1.02	1.14

Appendix V: Analysis of variance soil moisture 1976

Date		df	Mean Square 0-15cm	60cm	120cm
13/5/76	Block	3	10.94	2.43	8.56
	Treatment	4	83.14	32.10	10.37
	Error	12	3.64	2.50	3.05
3/6/76	Block	3	2.17	2.40	1.69
	Treatment	4	65.06	13.97	4.63
	Error	12	4.46	3.71	4.80
14/6/76	Block	3	2.49	3.46	3.39
	Treatment	4	45.48	10.58	3.79
	Error	12	5.20	3.49	2.67
24/6/76	Block	3	6.76	4.59	4.58
	Treatment	4	91.97	13.61	6.97
	Error	12	8.00	5.31	2.10
2/7/76	Block	3	10.29	4.78	3.41
	Treatment	4	74.00	14.61	3.63
	Error	12	6.53	5.69	4.00
13/7/76	Block	3	5.86	8.54	4.09
	Treatment	4	25.66	9.24	2.94
	Error	12	11.42	5.54	1.93
23/7/76	Block	3	14.44	0.70	3.33
	Treatment	4	27.10	6.18	2.85
	Error	12	6.67	1.45	1.66
2/8/76	Block	3	2.32	4.97	3.52
	Treatment	4	25.93	11.78	4.95
	Error	12	4.02	2.34	2.53
22/8/7	Block	3	6.41	3.75	3.98
	Treatment	4	32.20	11.22	4.69
	Error	12	2.74	1.06	1.42
21/9/76	Block	3	0.87	1.00	7.90
	Treatment	4	41.39	7.87	9.13
	Error	12	3.53	1.40	1.89
1/10/76	Block	3	1.46	3.30	6.42
	Treatment	14	29.07	3.45	3.26
	Error	12	6.48	1.60	1.97
12/10/76	Block	2	1.00	0.65	1.76
	Treatment	4	74.88	1.02	2.20
	Error	8	6.08	0.40	1.68

Appendix VI: Variation of soil moisture with depth analysis of variance 1976

Mean Square

Source	df	Date 13/5	3/6	14/6	24/6	2/7	13/7	23/7	2/8	12/8	21/9	1/10	df	12/10/76
Block	3	5.94	5.17	9,98	11.34	8.62	17.26	10.75	6.28	8,59	5.02	3.80	2	1.98
Mulches(m)	4	89.28	55.43	48.81	85.08	67.69	30.81	22.34	34.3	37.14	48.41	23.45	4	36.33
Total	19	22.75	18.54	18.47	26.11	22.44	17.11	9.71	11.47	10.31	13.68	8.37	14	12.71
Depth (D)	2	114.33	116.18	211.96	77.74	207.89	208.57	204.54	202.89	243.64	160.16	323.84	2	209.58
M x D	8	12.51	10.36	34.76	55.85	10.48	2.61	4.78	3.86	1.55	4.17	4.79	8	20.[illegible]
Pooled (EMS)	12	3.80	4.32	3.79	5.14	5.41	6.29	3.26	2.96	1.74	2.27	3.35	8	[illegible]

Appendix VII: Variation of soil moisture with mulch analysis of variance 1977

		Mean Square									
Source	df	Data 12/1	11/2	4/3	14/3	24/3	15/4	df	2/2	22/2	5/5
Block	3	20.67	0.36	65.32	0.45	6.86	2.56	2	1.45	7.99	3.67
Mulches(m)	4	122.52	42.18	99.29	89.13	87.09	22.91	4	52.92	30.29	12.50
Total	19	32.31	12.20	43.42	22.58	24.10	7.94	14	20.76	11.58	6.38
Depth(D)	2	13.43	37.53	0.19	59.37	32.21	14.48	2	46.48	41.82	39.91
M X D	8	7.74	2.96	8.52	2.08	9.34	0.54	8	0.65	2.04	0.28
Pooled EMS	12	4.60	2.84	10.91	4.46	5.68	2.75	8	6.75	1.73	3.99