# Chapter 4

## Effects of mulch, manure, and water regime on carrot yield

### 4.1 Introduction

Soil temperature and moisture have been shown to be critical edaphic factors for plant growth and productivity. It has been reported that a change in soil temperature as small as $1^{0}C$ can influence the growth of corn seedlings (Walker, 1969). Temperature may also affect the geotrophism of roots (Mosher and Miller, 1972).

It has been documented that soil temperature affects germination and seedling emergence of carrots (Richards *et al.*, 1952; Hegarty, 1973), the colour (Barnes, 1936), the length of storage roots (Barnes, 1936; Bradley *et al.*, 1967;Thompson, 1969), and the ratio of growth rates of roots to that of the leaves (Stanhill, 1977). Barnes (1936), and Stanhill (1956, 1977) reported that high soil moisture content (26% to 34%) resulted in bigger storage roots compared to low soil moisture content. High soil moisture levels have been found to result in less secondary root growth and fewer split and forked carrot roots (Stanhill, 1956; Orzolek and Carroll, 1978).

Mulching, through its reduction of daytime soil temperature and soil moisture conservation, has been reported to have beneficial yield effects. Mulches, have been reported to increase the yield of maize and cowpea (Maurya and Lal, 1981), potatoes (Midmore *et al.*, 1986), cabbages (Tumuhairwe and Gumbs, 1983a.b), watermelons (Ghawi and Battikhi, 1986), pineapples (Ekern, 1967), and other vegetable crops (Harris,1965; Knavel and Mohr, 1967).

Results of studies on the effects of different types of mulch on the yield of different crops, have been widely documented. Hanks *et al.* (1961), Schales and Sheldrake (1966), Grewal and Singh (1974). Tripathi *et al.* (1985), and Vander Zaag *et al.* (1986) have reported that organic mulches, particularly straw, have more beneficial effects on soil temperature and moisture, than other mulches. Due to cost and convenience factors, polyethylene mulches have been widely used in vegetable crop production (Wells and Loy. 1985). Such mulches have been found to have beneficial effects on early seedling emergence. crop maturity, and total crop yields (Clarkson and Frazier, 1957; Schales and Sheldrake, 1966; Shadbott *et al.* , 1962; Fordham and Biggs, 1985). Polyethylene mulches have also been reported to reduce total irrigation water demand (Ghawi and Battikhi, 1986).

Organic matter has been reported to have important effects on soil physical properties. Cation exchange capacity, stability of granules, rate of water infiltration, and porosity of soils, have been found to significantly increase following the addition of organic materials (Baver, 1930). Organic matter is frequently applied as animal manure in vegetable crop production (Jenkins, 1935; Salter and Williams, 1963; Salter *et al.*, 1967; Ohu *et al.*, 1985; Fordham and Biggs, 1985).

The use of either organic or polyethylene mulches combined with irrigation, has been reported to result in increased yields in crops such as maize, potatoes, and sugarcane (Prihar *et al.*, 1979), and watermelons (Ghawi and Battikhi, 1986). However, no such information is available on carrots. In addition, little information is available on the effects of animal manure on carrots.

The present study was conducted in the glasshouse, where carrots were grown in polystyrene boxes with 21 plants per box. Three types of mulches (e.g. rice straw, white and black polyethylene sheets) and unmulched soils, two manure applications, and two watering regimes were assigned as treatments. The aims of the experiment were :

1. to study the effects of mulch, manure, and water regime on the yield of carrots.
2. to study modifications of soil temperature and moisture resulting from the application of mulch and irrigation.

## 4.2 Materials and methods

### 4.2.1 Treatments and experimental design

The treatments, which were applied in combination,were as follows:

4 mulches (bare, rice straw, white and black plastic)

× 2 horse manure applications (with and without manure)

× 2 watering regimes (high and low regime)

This experiment was designed in a split-plot, in which the two watering regimes were assigned as the main-plots, while the four mulch treatments and the two manure applications were allocated as the sub-plots. This resulted in a total of 16 treatment combinations, which were replicated three times to give a total of 48 boxes.

As for the experiment reported in Chapter 3, this experiment was conducted in the glasshouse of the Department of Agronomy and Soil Science, University of New England, Armidale, from April 1 until July 15, 1986.

### 4.2.2 Soil and carrot variety

The same type of soil and variety of carrot was used in this experiment as those in the experiment reported in Chapter 3, were used in this experiment. The soil was air dried and sieved before being packed into the boxes. Forty-eight kg of air dried soil was packed to a depth of 18 cm in a polystyrene box of size 52.5 × 33.5 cm, to obtain a bulk density of 1.40 Mg $m^{-3}$. This bulk density was chosen to represent an optimum level, based on the results of the experiment reported in Chapter 3.

### 4.2.3 The treatments

Chopped rice straw at a rate of 5.5 t oven dry $ha^{-1}$ (108.5 g air dry $box^{-1}$), and white and black polyethylene (plastic) sheets of 12.5 mm and 15.0 mm thickness respectively, were used as mulches. Horse manure was applied at a rate of 15 t oven dry $ha^{-1}$ (177.6 g air dry $box^{-1}$). Inorganic fertilizer was applied as basal nutrients to all boxes. The amount of nutrients applied in this experiment was based on that used in the experiment reported in Chapter 3. An amount of 150 kg N $ha^{-1}$ was applied as basal application with other nutrients, while another 80 kg N $ha^{-1}$ was applied as side dressing 30 and 44 days after planting. Details of rates of elements and of chemicals applied, are presented in Appendix B.2.

The two watering regimes, which were determined as in the experiment reported in Chapter 3, were imposed 55 days after planting. In the high and the low water regime, plants were watered to field capacity, when the moisture contents reached 70% and 30% of the field capacity respectively.

### 4.2.4 Management

Fertilizers and air dried manures were mixed uniformly throughout the soil prior to compaction. Soil compaction was carried out by placing a 16 kg portion of soil into the box, and gradually compacting with a metal rammer to a depth of 6 cm. This procedure was repeated three times to give a total soil depth of 18 cm. A selective herbicide " treflan " with an active ingredient of 400 g $l^{-1}$ (40% w/v) trifluralin, was applied 7 days before planting to supress weed growth (Swarbrick, 1980). The herbicide was incorporated and uniformly mixed with 6 cm top layer of soil in each box. During compaction of the soil three copper-constantan (type T) thermocouples were placed in one box of each treatment at soil depths of 0 (soil surface), 5 cm, and 15 cm, to monitor the soil temperatures. These thermocouples were then connected to a CR5 Data Logger (Anon., 1977). It was only possible to monitor temperatures in one replicate, because of the limit of 50 input channels in the recorder. The additional two thermocouples were used to monitor the air temperature. Before planting the pre-germinated seeds, the moisture content of the soil in all boxes was brought to field capacity, by watering the boxes to a predetermined weight. Eight monitor boxes, which were in wooden framed, were selectively assigned to represent eight treatment combinations. Using a jack, the monitor box was lifted and weighed on a digital balance, and watered to a predetermined weight as presented in Appendix B.3. Mass of water applied to the monitor box, was then converted to a volume of water and this amount was added to other boxes of the same treatment.

Forty-two pre-germinated carrot seeds with the radicles only as long as the seed coats (the same determinations as used in the experiment reported in Chapter 3), were planted in three rows in each box, on April 6, 1986. Two seeds were planted per hole. Immediately after planting, all boxes were covered with shade cloth for seven days to protect young seedlings from direct sunlight.

The mulch treatments were applied eight days after planting, by which time 90% of the seedlings had emerged. The straw mulch, was placed on the soil surface, to obtain approximately 100% coverage. The white and black plastics were slit along the plant rows for ease of watering and to allow enlargemence of the plant crown.

Twenty days after planting, the seedlings were thinned into one seedling per hole.

### 4.2.5 Soil moisture and temperature measurement

Apart from weighing, gravimetric soil moisture content was also determined to monitor the soil moisture. Soil samples were taken one and four days after watering for the high and the low water treatments respectively. Using a small core, samples of the soil between rows were taken at three depths (0-5 cm, 5-10 cm, and 10-15 cm) with three replicates for each treatment. Samples were then placed in small glass containers and dried in a microwave oven for 20 minutes, after which time the moisture content was determined.

Temperatures were recorded in every two hours during the experiment. A maximum and minimum thermometer and a thermohygrograph were also placed in a screen, which was located in the experimental area, to check the readings of the thermocouples. The thermocouple readings were recorded on both a cassette recorder and a printer attached to the CR5 Data Logger. The readings recorded on the cassette were then transferred to a computer, on which the means of daily maximum and minimum temperatures were computed. Since no replication of the temperature measurement was possible, these data were not statistically analysed. In this thesis, only the means of daily temperatures during two weeks after planting (the early growth stage) and two weeks before harvesting (the late growth stage) are presented.

### 4.2.6 Data collection

Yield data was obtained after harvesting all plants 100 days after planting. At this time, 21 plants were dug and washed, and these were used to determine the fresh weight of the storage roots and tops, and the length and diameter of storage roots. The procedures used for these measurements, and for the shape index and the storage root : tops fresh weight ratio are outlined in Chapter 3.

The total amount of water applied to each treatment was recorded throughout the experiment. The weight of the fresh storage roots produced per unit of water applied, was used to compute water use efficiency (g fresh weight per l water applied) (Ritchie, 1974; Begg and Turner, 1976).

### 4.2.7 Data handling

The effects of mulch, organic manure, and watering regime on yield parameters, and on the shape index as a quality parameter, were tested by analysis of variance using the University's computer programme NEVA (Burr, 1982). The difference among means was tested using Duncan's multiple range test.

# 4.3 Results

## 4.3.1 Yield and quality

The four yield parameters studied and statistically analyzed were the fresh weight of storage root and of tops,the length of storage root,and the ratio of storage root:tops fresh weight. Carrot shape, as a quality parameter,was also measured and statistically analyzed.

### a. Storage root fresh weight

The effect of the mulch × manure × water regime interaction on the storage root fresh weight was highly significant (P<0.001,Table 4.1)

Table 4.1: The effect of mulch, manure and water regime on storage root fresh weight (g plant$^{-1}$)

| Mulch | Low water regime | | | | High water regime | | | |
|---|---|---|---|---|---|---|---|---|
| | No manure | | With manure | | No manure | | With manure | |
| Bare | 40.78 | *bcde*† | 49.13 | *bcde* | 49.51 | *bcde* | 53.39 | *bcde* |
| Straw | 44.19 | *de* | 62.39 | *ab* | 69.90 | *a* | 57.87 | *abc* |
| White P. | 53.55 | *bcde* | 49.20 | *bcde* | 53.44 | *bcde* | 61.98 | *ab* |
| Black P. | 52.88 | *bcde* | 46.80 | *cde* | 56.42 | *bcd* | 62.15 | *ab* |

†Data followed by the same letter are not significantly different (P > 0.05)(Duncan's multiple range test).

In the low water regime, yields in mulched treatments were not significantly higher than in the bare treatment, in either the manure or no manure treatment. The weight of carrot storage root under the straw mulch in the presence of manure, was significantly higher than under the black plastic mulch. The presence of manure significantly increased the storage root weight under the straw mulch, but only in the low water regime.

### b. Tops fresh weight

The effect of the mulch × manure interaction on tops fresh weight was significant ($P< 0.05$), Table 4.2).

Table 4.2: The effect of mulch and manure on carrot tops fresh weight (g plant$^{-1}$)

| Mulch | Manure treatment | |
|---|---|---|
| | No manure | With manure |
| Bare | 27.9 *b*† | 32.3 *a* |
| Straw | 32.8 *a* | 32.6 *a* |
| White P. | 33.9 *a* | 31.9 *a* |
| Black P. | 33.0 *a* | 31.6 *a* |

†Data followed by the same letter are not significantly different($P> 0.05$)(Duncan's multiple range test).

Under all mulches in the no manure treatment, the tops fresh weight was significantly higher than the bare treatment. The white plastic in the no manure treatment, resulted in the highest tops fresh weight (33.9 g plant$^{-1}$), and the lowest (27.9 g plant$^{-1}$) was in the bare soil with no manure. This difference was significant ($P< 0.05$).

The tops fresh weight was not significantly different among mulches(straw, white and black plastics) in either the presence or absence of manure. The application of manure significantly increased the tops fresh weight (from 27.9 to 32.3 g plant$^{-1}$) only in the bare treatment.

### c. Storage root:tops fresh weight ratio

There was a significant effect of the mulch × manure × water regime interaction ($P< 0.05$) on the storage root:tops fresh weight ratio (Table 4.3).

The ratio of storage root:tops fresh weight recorded in the straw and plastic mulches, in either the high or low water regime with or without manure, was not different from the ratio recorded in the bare treatment.

Table 4.3: The effect of mulch, manure and water regime on storage root:tops fresh weight ratio.

| Mulch | Low water regime | | High water regime | |
|---|---|---|---|---|
| | No manure | With manure | No manure | With manure |
| Bare | 1.43 *b*† | 1.54 *ab* | 1.82 *ab* | 1.65 *ab* |
| Straw | 1.53 *ab* | 1.97 *a* | 1.94 *a* | 1.73 *ab* |
| White P. | 1.68 *ab* | 1.54 *ab* | 1.49 *ab* | 1.97 *a* |
| Black P. | 1.68 *ab* | 1.55 *ab* | 1.66 *ab* | 1.90 *a* |

†Data followed by the same letter are not significantly different ($P > 0.05$)(Duncan's multiple range test).

The highest storage root:tops fresh weight ratio (1.97) was recorded under the straw mulch in the low water regime, and from the white plastic in the high water regime. both in the presence of manure. The lowest ratio (1.43) was found in the bare soil with no manure in the low water regime.

The ratio was not significantly different among mulches, in either the manure or no manure treatment in each water regime. The application of manure had no significant effect on the storage root:tops fresh weight ratio, under each mulch treatment in each water regime.

### d. Storage root length

The effect of the mulch × manure × water regime interaction on the storage root length was highly significant ($P < 0.01$,Table 4.4).

The longest storage root (14.1 cm) was found in both the straw mulch and the bare treatment, in the presence of manure in the low water regime. This 14.1 cm length was significantly different from that under the white plastic (12.4 cm), but was not different from the length under the black plastic mulch (12.9 cm).

Mulch treatments had no significant effects on the storage root length, in either the manure or no manure treatment in the high water regime. There was no significant effect of mulches on the storage root length in the no manure tratment, in the low water regime. The shortest storage root (12.1 cm) was recorded under the black plastic mulch, in the no manure treatment in the high water regime.

Table 4.4: The effect of mulch, manure and water regime on storage root length (cm).

| Mulch | Low water regime | | High water regime | |
|---|---|---|---|---|
| | No manure | With manure | No manure | With manure |
| Bare | 12.7 *abc*[†] | 14.1 *a* | 13.3 *abc* | 13.8 *ab* |
| Straw | 13.1 *abc* | 14.1 *a* | 13.5 *abc* | 12.7 *abc* |
| White P. | 13.5 *abc* | 12.4 *bc* | 12.2 *c* | 13.4 *abc* |
| Black P. | 13.3 *abc* | 12.9 *abc* | 12.1 *c* | 12.8 *abc* |

[†]Data followed by the same letter are not significantly different ($P > 0.05$)(Duncan's multiple range test).

The application of manure did not result in any significant effect on the storage root length in any mulch treatment, in either water regime.

#### e. Carrot shape

There was no significant effect of any treatment on carrot shape (Appendix B.1). The cylindricality (C) value was found to vary from 0.58 to 0.67, suggesting that the carrot shapes were between conical and cylindrical.

### 4.3.2 Soil temperatures

#### a. Early growth stage

Daily soil temperatures during the early growth stage, differed at different soil depths according to treatments applied (Figures 4.1[a,b], 4.2[a,b], Appendices C.1[a,b], C.2[a,b], C.3[a,b], C.4[a,b]). Mulches affected soil temperatures considerably at the soil surface , but this effect was reduced at the lower depths. This is clearly shown in the diurnal fluctuations in the different treatments, at the soil surface (Figures 4.1[a], 4.2[a], Appendices C.1[a], C.2[a]. At all depths the straw mulch in both the presence and absence of manure, reduced the maximum soil temperatures compared to the bare treatment. However, the straw also maintained higher soil temperatures during the night.

In the high water regime in the absence of manure, the straw mulch reduced maximum soil temperatures by 4.3$^0$C at the soil surface, 4.5$^0$C at 5 cm depth and 2$^0$C at 15 cm depth, compared to the bare treatment (Figure 4.1[a,b], Appendix C.3[a]). Compared to temperatures under the black and white plastic, the straw mulch reduced the maximum temperature at the soil surface by 11.9$^0$C and 8.3$^0$C respectively.(Figure 4.1[a]). With the application of manure, maximum temperatures at the soil surface under the straw, bare soil and black plastic mulch in the high water regime, was increased by 4.9$^0$C, 1.7$^0$C and 1.2$^0$C respectively (Appendix C.1[a]). However, it decreased 1.1$^0$C under the white plastic.

Under the low water regime, the pattern of soil temperatures under the different mulches at different depths, tended to be similar to those under the high water regime (Figure 4.2[a,b], Appendices C.2[a,b], C.3[b], C.4[b]).

The maximum and minimum soil temperatures under mulches and the bare treatment at the soil surface, were recorded at 1300 and 0700 hours respectively (Figures 4.1[a], 4.2[a], Appendices C.1[a], C.2[a]). The maximum temperatures at 5 cm and 15 cm depths, were recorded at 1500 and 1700 hours respectively, but the minimums at these depths were similar to those at the soil surface (Figures 4.1[b], 4.2[b], Appendices C.1[b], C.2[b], C.3[a,b], C.4[a,b]).

### b. Late growth stage

The soil temperatures during the late growth stage showed a different pattern from those during the early stage (Figures 4.1[c,d], 4.2[c,d], Appendices C.1[c,d], C.2[c,d], C.3[c,d], C.4[c,d]). Diurnal fluctuation in soil temperatures was small, especially under the low water regime. The maximum soil temperatures varied depending on treatments and soil depths. The maximums were recorded at 1500, 1700 and 1900 hours at the soil surface, 5 cm and 15 cm depths respectively. The minimum soil temperatures at all depths were recorded at 0700 hours.

Under the high water regime, the straw mulch with no manure gave the lowest maximum and minimum temperatures at the soil surface (Figures 4.1[c]. In the presence of manure these temperatures were slightly higher than the bare treatment, but lower than the plastic mulches (Appendix C.1[c]). A somewhat similar pattern of soil temperatures occured at lower soil depths (Appendices C.1[d], C.4[c]).

In the low water regime, mulches with manure treatments resulted in a very small difference in maximum and minimum soil temperature at all depths, than the bare treatment (Appendices C.2[c,d], C.4[d]). At 5 cm and 15 cm depths, the straw mulch with no manure treatment resulted in the lowest maximum and minimum soil temperatures (Figure 4.2[d], Appendices C.3[d]).

### 4.3.3 Total water applied and water use efficiency

#### a. Total water applied

The effect of the mulch × manure × water regime interaction on total water applied during the experiment was significant (P< 0.001, Table 4.5). Total water applied to plants under mulches, in both the manure and no manure treatments at the high water regime, was significantly less than that applied to the bare treatment.

Table 4.5: The effect of mulch, manure and water regime on total water applied (l).

| Mulch | Low water regime | | High water regime | |
|---|---|---|---|---|
| | No manure | With manure | No manure | With manure |
| Bare | 54.10 *h*† | 63.60 *fg* | 114.20 *a* | 99.70 *b* |
| Straw | 51.70 *h* | 57.00 *gh* | 81.70 *c* | 81.20 *c* |
| White P. | 53.43 *h* | 51.47 *h* | 65.83 *ef* | 74.50 *cde* |
| Black P. | 52.10 *h* | 50.47 *h* | 71.30 *def* | 79.43 *cd* |

†Data followed by the same letter are not significantly different (P> 0.05)(Duncan's multiple range test).

At the low water regime, there were no significant effects of mulches in the absence of manure on the total water applied. In the presence of manure, plastic mulches significantly reduced the total amount of water applied, compared to the bare treatment. However, this total amount was not significantly lower than that applied to the straw mulch treatment.

Manure treatment had no significant effect on the total water applied to any mulch treatment, in each water regime. The application of manure, significantly decreased the total water applied to the bare treatment in the high water regime, but increased that applied to the bare soil in the low water regime.

### b. Water use efficiency

There was a significant ($P< 0.01$) effect of the mulch $\times$ manure $\times$ water regime interaction on the plant water use efficiency (Table 4.6). The straw mulch resulted in the highest water use efficiency, in the manure treatment under the low water regime. The water use efficiency under this straw mulch,was significantly higher than that under the black plastic mulch, but was not different from the efficiency under the white plastic mulch.

In the no manure treatment in this low water regime, plastic mulches resulted in significantly higher water use efficiency than the bare treatment, but was not different from that under the straw mulch.

In the high water regime, mulches significantly increased the water use efficiency in both the presence and absence of manure. However, there were no differences in water use efficiency among mulches.

Manure had no significant effect on the plant water use efficiency, under either the mulches or the bare treatment in the high water regime. In the low water regime, the manure treatment significantly increased the plant water use efficiency only under the straw mulch.

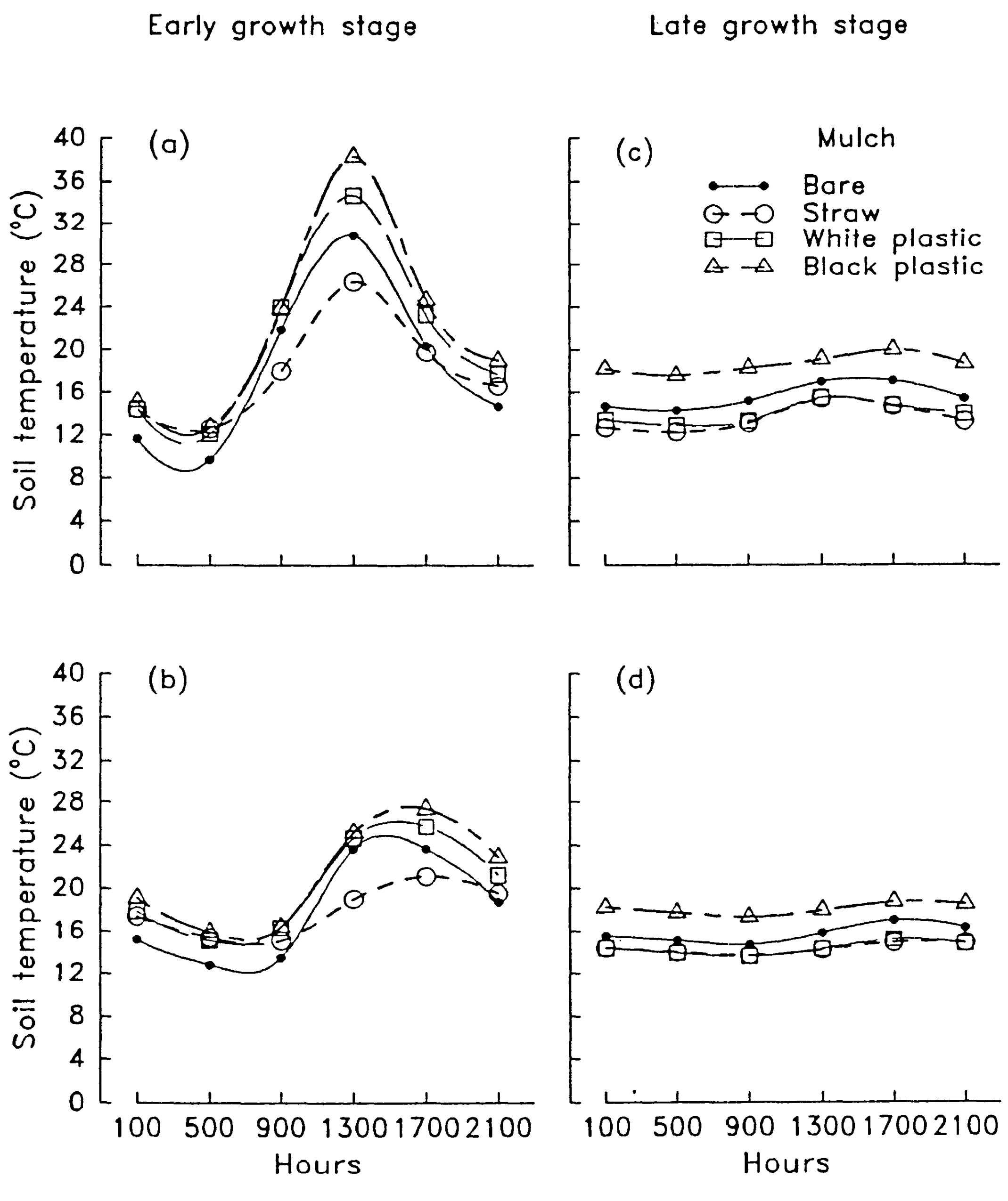


Figure 4.1: Soil temperatures at the surface and 5 cm depth in the no manure-high water treatment at early [a,b] and late growth stage [c,d].

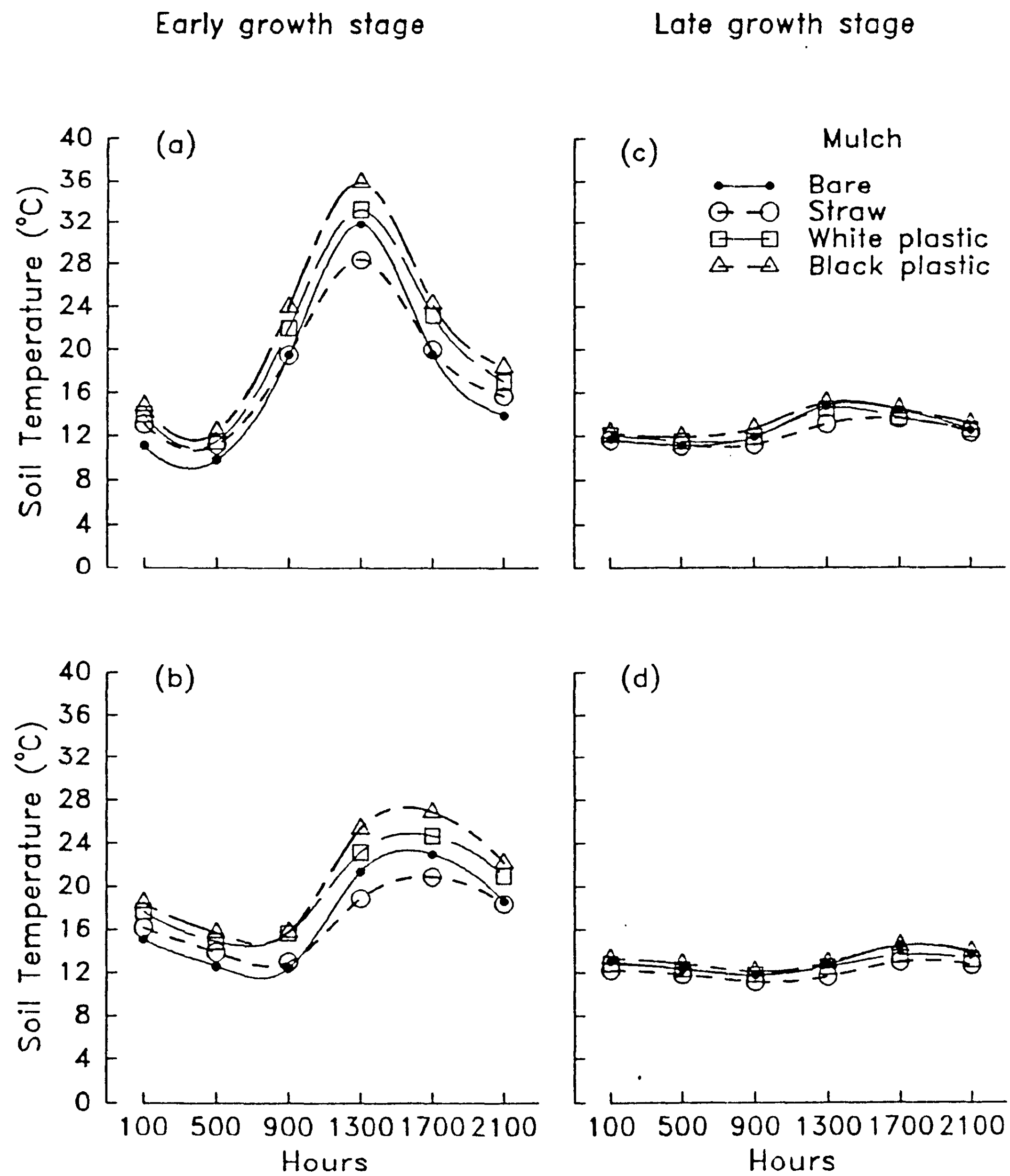


Figure 4.2: Soil temperatures at the surface and 5 cm depth in the no manure-low water treatment at early [a,b] and late growth stage [c,d].

Table 4.6: The effect of mulch, manure and water regime on water use efficiency (g storage root FW $l^{-1}$ water applied).

| Mulch | Low water regime | | | | High water regime | | | |
|---|---|---|---|---|---|---|---|---|
| | No manure | | With manure | | No manure | | With manure | |
| Bare | 15.88 | *e*† | 16.19 | *de* | 9.06 | *f* | 11.25 | *f* |
| Straw | 18.04 | *bcde* | 22.97 | *a* | 18.04 | *bcde* | 14.97 | *e* |
| White P. | 20.93 | *ab* | 20.17 | *abc* | 17.05 | *cde* | 17.40 | *cde* |
| Black P. | 21.17 | *ab* | 19.43 | *bcd* | 16.67 | *de* | 16.36 | *de* |

†Data followed by the same letter are not significantly different ($P > 0.05$)(Duncan's multiple range test).

## 4.4 Discussion

The weight of carrot storage roots under the straw mulch in the high water regime, was significantly higher ($P < 0.01$) than in the bare soil and under the plastic mulch treatments (Table 4.1). Similar benefits of straws were described by Stephenson and Schuster (1946) and Jacks *et al.* (1955). These authors found that straw was the best mulch in conserving soil moisture, while Greb (1966) found a 49% reduction in evaporation of water from a wet soil surface under the straw mulch compared to a no straw treatment. Unger and Parker (1968) also reported a similar result. Midmore *et al.* (1986) found that organic mulch at a rate of 4 - 6 t $ha^{-1}$ resulted in increased soil water retention.

The effectiveness of the straw mulch in conserving soil moisture has also been reported by other researchers (Alderfer and Merkle, 1943; Turk and Patridge, 1947; Moody *et al.*, 1963 and Lal, 1974a). The advantage of straw mulch in increasing plant water use efficiency, was reflected in a 26% increase in corn yield in the experiment of Khera *et al.* (1976). Other researchers have reported similar increases (Jones *et al.*, 1969 and Prihar *et al.*, 1979). Higher moisture was found in the 0 to 7.5 cm soil layers (Chaudhary and Prihar, 1974) or in the upper 15 cm layer (Schales and Sheldrake, 1966), under straw mulch compared to bare soil. In the experiment of Midmore *et al.*, 1986, 5.3%, 3.5%, and 2.2% higher soil moisture was recorded at

5 cm, 10 cm, and 20 cm depth respectively in mulched compared to bare plots. A similar result was reported by Simpson and Gumbs (1986a), and Tumuhairwe and Gumbs (1983a,b).

In the results of the present experiment, the straw mulch in the no manure treatment in the high water regime, increased carrot storage root fresh weight by 41% compared to the bare treatment (Table 4.1). There was also an increase in water use efficiency (Table 4.6).

Aeration effects were not measured in the present experiment, but Tukey and Schoff (1963) found a higher $O_2$ : $CO_2$ ratio of 3.8 : 1 in soil under the straw mulch compared to a bare soil. These researchers also found increases in the available phosphorus in the soil under the straw. Jacks *et al.* (1955) and Jones *et al.* (1969) measured a higher infiltration rate under straw mulch, while Stephenson and Schuster (1946) observed higher soil organic matter under this mulch.

Maximum soil temperatures at all depths, especially at the early growth stage recorded in the present experiment, were lower under the straw mulch than under all other treatments (Figures 4.1[a,b], 4.2[a,b], Appendices C.1[a,b], C.2[a,b], C.3[a,b], C.4[a,b]). Compared to plastic mulches, Hanks *et al.* (1961) recorded the lowest temperature at all depths under a straw mulch treatment. Grewal and Singh (1974) reported that a decrease in maximum temperature of 1.5$^0$C and 3.5$^0$C was recorded at 10 cm depth under a mat and *Pennisetum* stalk mulch during Autumn and Spring respectively. Under polyethylene mulches the maximum temperature increased by 1.4$^0$ and 2.2$^0$C respectively. Tripathi *et al.*, (1985) recorded a maximum soil temperature of 28$^0$C under paddy straw mulch, compared to 32.9$^0$C on a bare soil, at early sowing. Schales and Sheldrake (1966), working with muskmelon, found that straw mulch decreased maximum soil temperature by 4.4$^0$C to 6.7$^0$C under a straw mulch, while a reduction in maximum soil temperature of 2.6$^0$C to 6.3$^0$C was observed at the 5 cm depth under the straw mulched corn by Chaudhary and Prihar (1974). Allmaras and Nelson (1971) reported a decrease in mean daily temperatures up to 2$^0$C at 5 cm depth, under a straw mulch. A difference of 8$^0$C was found between the straw and unmulched soil in the initial crop growth stage by Lal (1974a). Lower temperatures under straw mulch have also been reported by McCalla and Duley (1946), Hanks *et al.* (1961),Kohnke and Werkhoven (1963), and Moody *et al.* (1963).

A significant negative correlation was found to exist between total yield of potatoes and maximum soil temperature in the experiment of Prihar *et al.* (1979). Epstein (1966) found that root and tuber growth in potatoes was maximal when the soil temperature in the 10-20 cm layers was in the range of $9^0$C to $22.4^0$C, and that no tubers were formed at a temperature of $29^0$C. Vander Zaag *et al.* (1986) reported that a 50% increase of potato yields was obtained from treatments with straw mulches during the wet season in the Philippines. This greater yield was associated with reduced daily maximum soil temperature by $2^0$ to $4^0$C under the rice straw mulch. Tripathi *et al.* (1985) recorded a greater emergence of wheat seedlings in straw mulched plots, compared to that on bare soils. This was associated with $3.2^0$ to $4.4^0$C lower maximum and with $3.6^0$C higher minimum soil temperatures under a straw mulch than on a bare soil. Maduakor *et al.* (1984) also concluded that longer and bigger yam tubers were found in organic mulch plots than on bare soils. Increased soil moisture and decreased maximum soil temperature recorded at 5 cm depth was associated with the greater yield. A similar result was reported by Chaudhary *et al.* (1985).Tunmhairwe and Gumbs (1983a) found that the mean whole plant weight, and cabbage head fresh weight, increased significantly under organic mulches.

In the present experiment, a reduction in the maximum soil temperature by $4.5^0$C at 5 cm depth as a result of straw mulch, was in the range of that found by Chaudhary and Prihar (1974), and was lower than that found by Lal (1974a). Chaudhary and Prihar (1974) measured the soil temperature under approximately 6 t $ha^{-1}$ of straw mulch, at the subtropical field condition in Punjab, India, while Lal's observations (1974a) were made under a 4 t $ha^{-1}$ of straw mulch, at the humid tropical condition in Ibadan, Africa. In the present study, the soil temperature was measured under 5.5 t oven dry $ha^{-1}$ of straw mulch, in the glasshouse at a latitude of $30^0$S from the Autumn to Winter. At the late growth stage as the canopy covered most of the soil surface, the soil temperature in the bare treatment was not very different from the mulches. Moody *et al.* (1963), Voorhees *et al.* (1981), Maurya and Lal (1981), and Midmore *et al.* (1986) reported that the effect of mulch on soil temperature is more pronounced at the early growth stage of crops. As the canopy develops the difference in soil temperatures between mulched and bare soils becomes smaller. The results of the present experiment are in agreement with those of Moody *et al.* (1963), Voorhees *et al.* (1981), Maurya and Lal (1981), and Midmore *et al.* (1986). The soil temperature at this growth stage contrasts to that at the early growth stage. During this late period, air and soil temperatures decreased as Winter approached (Figures 4.1[c,d], 4.2[c,d], Appendices C.1[c,d], C.2[c,d], C.3[c,d], C.4[c,d]). These conditions are most likely the cause of the lower reduction in the maximum soil temperature recorded in the present study, than that observed by Lal (1974a). The reduction is similar to that recorded by Chaudhary and Prihar (1974).

The high albedo, and great insulating capacity, which is due to lower thermal conductivity as stated by Kohnke and Werkhoven (1963), and due to the fibrous material of the straw mulch (Tukey and Schoff, 1963), resulted in this mulch being more effective in lowering the maximum soil temperature than any other forms of mulch used.

Under the plastic mulches, in the no manure treatment in the high water regime, the storage root fresh weight was 24 to 31% lower than the weight under the straw mulch (Table 4.1). Tukey and Schoff (1963) found lower aeration under plastic sheets than under fibrous materias such as straw mulches. Significantly lower potato yield (33%) was recorded under polyethylene mulch, due to higher maximum soil temperature, compared to millet stover mulch (Prihar *et al.*, 1979). The results of the present experiment are in agreement with those of Tukey and Schoff (1963) and Prihar *et al.* (1979).

Significantly less total water was applied to the soil under the plastic mulches than that applied to the soil under the straw mulch (Table 4.5). Due to the non-fibrous nature of plastic mulches (Tukey and Schoff, 1963), the water loss from the soil surface could be reduced to a greater extent under the plastic than under the straw mulch. Ekern *et al.* (1967) concluded that an impermeable barrier provided by a polyethylene film on a soil surface prevents heat flows into and vapor evaporation from the soil. This resulted in higher amount of soil moisture maintained under the plastic mulches. However, the storage root fresh weight recorded in the plastic mulch treatment, was lower than the weight in the straw mulch treatment (Table 4.1), while water applied to the soil under the plastic was less than that in the straw mulch treatment (Table 4.5). This resulted in no significant difference in water use efficiency between the plastic and straw mulch treatments (Table 4.6). The difference between the results of the present experiment and that of Anon. (1986) was due to differences in crop species, site of the experiment, and the treatments applied. In the experiment of Anon. (1986), tomatoes and aubergines were grown in the field, with and without plastic mulch. In the experiment reported here, carrots were grown in pots, in a glasshouse, under plastic, rice straw, and without mulch.

In the high water regime, the application of manure did not increase the storage root fresh weight in either the bare or the mulch treatments (Table 4.1). Salter and Williams (1968) concluded that the primary cause of increased vegetable yield in the farm manure treatment they used, was the supply of nutrients by the manure rather than in a better moisture condition. In the present experiment, a total of 230 kg N $ha^{-1}$, 200 kg P $ha^{-1}$ and 131 kg K $ha^{-1}$ were applied together with other nutrients to all treatments. This amount of nutrients should have been sufficient for the plant growth, hence the manure effect is thought not to be due to nutrients. The water infiltration of a soil is increased by incorporating manure to that soil (Alderfer and Merkle, 1943). Jenkins (1935) indicated that farm-yard manure ploughed in to a soil improved the soil aeration and structure. The horse manure applied in this present experiment, due to its fibrous texture, probably improved the soil physical properties more than its nutrient supply. This is in agreement with the results of Jenkins (1935), and Alderfer and Merkle (1943). The finding of no differences in water use efficiency between the manure and no manure treatment (Table 4.6), agreed with the conclusion of Salter and Williams (1968), especially in the high water regime where the soil moisture was always adequate for plant growth.

In the low water regime, mulches had no effect on the storage root fresh weight of carrot, in either the manure or no manure treatment (Table 4.1). Jacks *et al.* (1955)

and Hanks *et al.* (1961) found that the effect of mulch in reducing evaporation, was less pronounced in infrequently irrigated soils than under frequently irrigated conditions. Voorhees *et al.* (1981) concluded that differences in albedo between mulched and bare soils decreased as the soil moisture decreased. Hanks *et al.* (1961) concluded that in the bare treatment in a subhumid condition, the soil surface dried within a few hours after the rain and formed a "soil mulch", which was more effective in decreasing water vapor flow than a straw or gravel mulch. The result of the present experiment is supported by that of Jacks *et al.* (1955), Hanks *et al.* (1961), and Voorhees *et al.* (1981).

In the absence of manure in the low water regime, there were no significant differences in the storage root fresh weight of carrot among the mulches (Table 4.1). This is associated with no differences in the water use efficiency among the mulches (Table 4.6). The application of manure in the low water regime, increased the storage root fresh weight, only under the straw mulch (Table 4.1). The infiltration rate of water was not measured in the present study, but Jacks *et al.* (1955) reported that the infiltration rate of water under the straw mulch was greater than under the bare treatment, which was probably due to an increase in the number of soil macro pores as biotic activity increased. Schales and Sheldrake (1966) found lower infiltration rates of water in the upper 15 cm under the plastic mulches than under the straw mulch. Incorporation of manure into a soil, significantly increased the infiltration rate of water after the soil was wetted to field capacity, as was concluded by Alderfer and Merkle (1943). In this present experiment, the application of manure to the soil in the straw mulch treatment in the low water regime, presumably resulted in greater increases in the infiltration rate of water. This might have contributed to the higher storage root fresh weight under the straw mulch (Table 4.1), which is associated with increasing the water use efficiency (Table 4.6).

In the low water regime, the straw mulch in the manure treatment resulted in significantly

higher storage root fresh weight than the black plastic mulch (Table 4.1). Schales and Sheldrake (1966) reported that soil temperatures were 2.8$^0$C higher under a black plastic than on bare soil. Clarkson (1960) also reported a similar increase under black plastic. The increase could be up to $8^0$ - $12^0$C at 5 cm depth, during a hot season (Jacobsohn *et al.,* 1980). The unfavourable condition for plant growth under the black plastic mulch in this present experiment, which might be due to the poor aeration (Tukey and Schoff, 1963) and to higher maximum soil temperature (Prihar *et al.*, 1979; Clarkson, 1960; Schales and Sheldrake, 1966), resulted in lower water use efficiency under the black plastic compared to the straw mulch (Table 4.6). Since the storage root fresh weight under the black plastic was lower than that under the straw mulch (Table 4.1), while the storage root length was not significantly different (Table 4.4). it seems that the storage root under the black plastic was thinner than under the straw mulch. Under the white plastic mulch, the storage root appeared to be thicker than under the straw mulch, as the storage root length was significantly shorter (Table 4.4), whereas the storage root fresh weight was not different.

The shape of the carrot storage root was determined from the length, diameter and the fresh weight of the storage root (Thompson, 1969). Barnes (1936) and Stanhill (1977) found that both the length and diameter of carrot storage root were much affected by the soil temperatures. This finding was supported by Saini *et al.* (1981). The results found in this present study, indicated that there were no significant differences in carrot shape under the treatments applied (Appendix B.1). This is most likely due to small differences in soil temperatures at the late growth stage.

Tops fresh weight of carrot grown under mulches, both in the manure and no manure treatment, was significantly ($P < 0.05$) higher than in the bare treatment (Table 4.2). Barnes (1936) concluded that increased soil moisture resulted in higher carrot tops fresh weight. The higher tops fresh weight under the mulches in the present experiment, was probably due to higher soil moisture under the mulches compared to the bare treatment. However, this higher tops fresh weight and higher storage root fresh weight did not always result in higher storage root : tops fresh weight ratio. Barnes (1936) stated that the ratio of the storage root : tops was not necessarily correlated with either the storage root or tops fresh weight. Saini *et al.* (1981) concluded that this ratio was stable and least influenced by the environment.

In the present experiment, the storage root : tops fresh weight ratio under the straw mulch in the no manure at the high water regime, was not significantly different from the bare soil and the plastic mulch treatments (Table 4.3). However, the fresh weight of storage root between those same treatments were significantly different ($P < 0.01$, Table 4.1). This was probably due to the stability of this ratio. The result found in the present experiment is in agreement with that documented by Barnes (1936) and was supported by Saini *et al.* (1981). In the present experiment, the highest storage root : tops ratio (1.97) recorded under the straw mulch in (Table 4.3), is somewhat similar to the ratio of 1.84 found by Barnes (1936) 100 days after planting.

# Chapter 5

## General discussion and conclusions

Soil physical conditions have been reported to have significant effects on the market value of carrots (Barnes, 1936; Thompson, 1969; Orzolek and Carroll, 1978; White, 1978; Strandberg and White, 1979). Literature indicates that yield and quality of carrot storage roots decrease significantly in compacted soils (Olymbios and Schwabe, 1977; Strandberg and White, 1979; Millette *et al.*, 1981; Taksdal, 1984; Bunyan, 1985). High soil temperature and low soil moisture conditions are reported to be the cause of low yield and quality of carrots (Barnes, 1936; Salvestrin, 1984), and poor soil aeration is also associated with this decrease (Olymbios and Schwabe, 1977).

Studies on other crops indicate that there are significant effects of soil bulk density and water regime, and of mulching and irrigation interactions on yield of those crops (Maurya and Lal, 1979; Simpson and Gumbs, 1983a; Tumuhairwe and Gumbs, 1983b). However, there is little information on the effect of these interactions on carrots.

Experiments reported in this thesis were conducted to study the effects of soil bulk density, moisture, and temperature on carrot yield and quality. The interaction of bulk density and moisture was examined in the first experiment (Chapter 3), and that of soil moisture and temperature through the effect of mulching was studied in the second experiment (Chapter 4).

Barnes (1936), Chipman (1959), Thompson (1969), and Benyamin and Wren

(1978) reported that carrot storage root weight increased with time. The results of the experiment reported in this thesis agreed with these findings.

Previous studies have reported that carrot yield was significantly reduced in compacted soils. The work of Olymbios and Schwabe (1977) indicated that carrot yield decreased significantly at soil bulk density of 1.45 Mg $m^{-3}$. A reduction of 33% and 19% of storage root and tops weight respectively was recorded at this bulk density. The results reported in this thesis (Chapter 3), showed that the effect of soil bulk density was significant on all parameters measured. Carrot yield generally decreased with increased bulk density. The optimum bulk density in terms of yield, size, and carrot shape was 1.40 Mg $m^{-3}$ in both water regimes. At this bulk density the void ratio and the total porosity was favourable for carrot growth. The highest yield (92.30 g $plant^{-1}$), and an acceptable shape and size of storage roots was obtained at this bulk density, in the high water regime. At 1.25 Mg $m^{-3}$ the fresh weight and the length of storage roots was not significantly different, but the size was smaller than at 1.40 Mg $m^{-3}$. In contrast, at 1.55 Mg $m^{-3}$, the storage roots were significantly shorter, while the size and the fresh weight was not different from at 1.40 Mg $m^{-3}$. However, all parameters measured in this experiment were significantly decreased at 1.70 Mg $m^{-3}$. High mechanical impedance to the root growth at this highest bulk density was believed to be the cause of the reduction. A 69% and 83% reduction in storage root fresh weight was recorded at this highest bulk density, in the high and the low water regime respectively. A high force, greater than 5.5 MPa., had to be exerted by carrot plants to penetrate and develop in the soil compacted to 1.70 Mg $m^{-3}$. This resulted in 0.91 and 1.56 cm of storage root length being recorded above the soil surface, in the high and the low water regime respectively. A similar result was reported by Olymbios and Schwabe (1977).

Maurya and Lal (1979) concluded that the rate of crop root elongation was low at high bulk density under low soil moisture conditions. In this present experiment, low yield was recorded at the highest bulk density of 1.70 Mg $m^{-3}$ in the low water regime, and the yield was always higher in the high than in the low water regime. Barnes (1936). Henkel (1970); and Cavalchini (1972) have also reported that the highest carrot yield was obtained under high moisture conditions. At no stage in this present experiment, was the effect of bulk density × water regime interaction on the weight and the length of storage root significant.

Literature has shown that mulching has beneficial effects in modifying soil temperature, conserving soil moisture, and increasing water use efficiency. The effectiveness of straw mulch in modifying soil temperature has been reported by Alderfer and Merkle, 1943; Turk and Patridge, 1947; Moody *et al.*, 1963; Schales and Sheldrake, 1966; Jones *et al.*, 1969; Lal, 1974a; Prihar *et al.*, 1979; Maurya and Lal, 1981; Tumuhairwe and Gumbs, 1983a; Midmore *et. al.*, 1986; Simpson and Gumbs, 1986a; Vander Zaag *et al.*, 1986). Other researchers have documented the adventage of this mulch in conserving soil moisture (Stephenson and Schuster, 1946; Jacks *et al.*, 1955; Greb, 1966; Unger and Parker, 1968; Allmaras and Nelson, 1971; Tumuhairwe and Gumbs, 1983a,b; Tripathi *et al.*, 1985; Midmore *et al.*. 1986; Simpson and Gumbs, 1986 a; Vander Zaag *et al.*, 1986), and in increasing water use efficiency (Khera *et al.*, 1976). In the experiment reported in Chapter 4, rice straw mulch applied at a rate of 5.5 t oven dry $ha^{-1}$, resulted in significantly increased the fresh weight of carrot storage roots under high moisture conditions. Increased water use efficiency and lower maximum soil temperature are believed to be the factors that resulted in this increase. The highest yield (69.90 g $plant^{-1}$) was recorded in this straw mulch treatment in the high water regime. This yield was 41% higher than that in the bare treatment. The straw mulch resulted in 4.5$^{0}$C reduction in maximum soil temperature at 5 cm depth and a 99% increase in water use efficiency. Effect of this straw mulch in reducing maximum soil temperature was more pronounced at the early growth stage. Similar findings were reported by Moody *et al.* (1963), Voorhees *et al.* (1981); Maurya and Lal (1981), and Midmore *et al.*(1986).

The yields of other crops have been reported to increase under plastic mulches (Schales and Sheldrake, 1966; Anon., 1986; Ghawi and Battikhi, 1986). However, in the present experiment carrot yield was lower under plastic mulch than under straw mulch. Alderfer and Merkle (1943) concluded that incorporation of manure into a soil significantly increased the infiltration rate of water, while Jacks *et al.* (1955) reported that this rate was greater under straw mulch than in bare soils. The results reported in Chapter 4 showed that the application of horse manure (15 t oven dry $ha^{-1}$) resulted in significantly higher carrot yield in the straw mulch - low water treatment. This increase, which was 41% higher than in the no manure treatment, was associated with 27% increase in water use efficiency. The higher infiltration rate of water is believed to be the factor contributed to this increase.

Soil compaction and moisure conditions have been reported to have significant effects on carrot shape (Barnes, 1936; Olymbios and Schwabe, 1977; Strandberg and White, 1979; Salvestrin, 1984; Taksdal, 1984). The results of the present experiment (Chapter 3), which were in agreement with those of other studies, showed a decrease in cylindricality (C) with increased soil bulk density. The effect of water regime and the interaction of these factors on carrot shape was also significant. More conical carrot storage roots were found at high bulk density and low moisture conditions. However, muches had no significant effect on carrot shape (Chapter 4).

As a source of vitamin A, carrot is an important vegetable to be developed in the tropics. In this region, adverse environmental conditions are believed to result in low yield and quality of this crop. The need to increase the production and improve the quality of carrots in tropical regions is becoming more important.

In the tropics, raindrop impacts and the existence of gravel horizons in some upland soils, are believed to be the cause of high bulk density of these soils (Panabokhe and Quirk, 1957; Lal, 1978). High mechanical impedance to crop root development is associated with low crop yield in this region (Babaola and Lal, 1977 a,b). High soil temperature (> $30^0C$) at 5 cm depth during the growing season (Lal, 1975; Prihar *et al.*, 1979; Tumuhairwe and Gumbs, 1983a; Vander Zaag *et al.*, 1986), and a shortage of water in the dry season, particularly in areas with no irrigation (Tumuhairwe and Gumbs, 1983b), are other factors which result in reduced yield of crops in the tropics.

Studies indicate that straw mulch has succesfully increased the yield of some temperate vegetables grown in the lowland areas in the tropics (Tumuhairwe and Gumbs, 1983a,b; Midmore *et al.*, 1986; Vander Zaag *et al.*, 1986). The use of vegetative mulches in maintaining soil structure in the tropics have been reported by Lal (1975), and Falayi and Lal (1979). Simpson and Gumbs (1986b) recorded the highest maize yield when mulch from the previous crops without tillage was maintained on the soil surface.

Rice is the major agricultural crop in South East Asia, and a huge of rice straw is usually burned or left in the field after treshing (Anon., 1978), hence there is generally a readily availability of straw in this region (Vander Zaag *et al.*, 1986). This mulch could be used to improve the yield and quality of root vegetables such as carrots. However, field experiments are needed to evaluate the effects of this mulch on the yield and quality of carrots grown in the field. These studies should be conducted in experiments where the effects of mulches and other agronomic practices are combined.

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# Appendices

# Appendix A

## Experiment 1

## A.1 Particle size distribution of the soil

Appendix A.1 Particle size distribution and moisture content of the soil used in the first and the second experiments

Particle size distribution :

2 mm - 212 $\mu$ : 73 %
212 mm - 50 $\mu$ : 10 %
50 $\mu$ - 20 $\mu$ : 4 %
20 $\mu$ - 5 $\mu$ : 4 %
5 $\mu$ - 2 $\mu$ : 1 %
<2 $\mu$ : 8 %

Soil moisture content : 2.41 %

## A.2 Bulk density

Appendix A.2 Mass of air dried soil, amount of water added, and moisture content for each bulk density produced

| Bulk density ($Mg\ m^{-3}$) | Air dried soil ($g\ pot^{-1*}$) | Water added ($g\ pot^{-1}$) | Compaction | Moisture content ($g\ g^{-1}$) |
|---|---|---|---|---|
| 1.25 | 5655.6 | - | tapped | 0.024 |
| 1.40 | 6318.3 | - | rammed | 0.024 |
| 1.55 | 7025.3 | 200 | rammed | 0.052 |
| 1.70 | 7688.0 | 400 | rammed | 0.076 |

1. *pot area : 176.6 $cm^2$
2. soil depth : 25 cm
3. volume of soil : 4418.4 $cm^3$

# A.3 Rates of elements and chemicals applied

Appendix A.3 Rates of elements and chemicals applied in the first experiment

| Element | Rates of elements ($kg\ ha^{-1}$) | Chemicals |
|---|---|---|
| N | 545.13* | $NH_4NO_3 + Ca(NO_3)_24H_2O + (NH_4)H_2PO_4$ |
| P | 259.42* | $KH_2PO_4 + (NH_4)_2HPO_4$ |
| K | 130.80* | $KCl + KH_2PO_4$ |
| S | 47.99 | $MgSO_47H_2O$ |
| Ca | 45.01 | $Ca(NO_3)_24H_2O$ |
| Mg | 22.08 | $MgSO_47H_2O$ |
| B | 1.49 | $H_3BO_3$ |
| Zn | 2.99 | $ZnSO_47H_2O$ |
| Cu | 2.99 | $CUSO_45H_2O$ |
| Mo | 0.15 | $Na_2Mo_42H_2O$ |
| Mn | 2.99 | $MnSO_44H_2O$ |
| Fe | 4.25 | Fe sequestrene |

*An amount of 149.99 kg N $ha^{-1}$, 59.96 kg P $ha^{-1}$, and 90.03 kg K $ha^{-1}$, was applied as basal nutrients. Another 395.14 kg N $ha^{-1}$, 199.46 kg P $ha^{-1}$, and 40.77 kg K $ha^{-1}$ was given periodically from 38 days after planting until the last harvesting time, with a week alternate application in the forms of $NH_4NO_3$, $(NH_4)H_2PO_4$, $(NH_4)_2HPO_4$ or aquasol.

# Appendix B

## Experiment 2

### B.1 Effect of mulch, manure, and water regime on carrot shape

Appendix B.1 The effect of mulch, manure, and water regime on carrot shape

| Mulch | Low water regime | | High water regime | |
|---|---|---|---|---|
| | No manure | With manure | No manure | With manure |
| Bare | 0.63 *a*[†] | 0.62 *a* | 0.65 *a* | 0.64 *a* |
| Straw | 0.58 *a* | 0.63 *a* | 0.67 *a* | 0.66 *a* |
| White P. | 0.63 *a* | 0.61 *a* | 0.66 *a* | 0.65 *a* |
| Black P. | 0.59 *a* | 0.59 *a* | 0.61 *a* | 0.63 *a* |

[†]Data followed by the same letter are not significantly different ($P > 0.05$)(Duncan's multiple range test).

## B.2 Rates of elements and chemicals applied

Appendix B.2 Rates of elements and chemicals applied in the second experiment

| Element | Rates of elements ($kg\ ha^{-1}$) | Chemicals |
|---|---|---|
| N | 230.00* | $NH_4NO_3 + Ca(NO_3)_2 4H_2O + (NH_4)H_2PO_4$ |
| P | 200.00 | $KH_2PO_4 + (NH_4)_2HPO_4$ |
| K | 130.00 | $KCl + KH_2PO_4$ |
| S | 47.99 | $MgSO_4 7H_2O$ |
| Ca | 45.01 | $Ca(NO_3)_2 4H_2O$ |
| Mg | 22.08 | $MgSO_4 7H_2O$ |
| B | 1.49 | $H_3BO_3$ |
| Zn | 2.99 | $ZnSO_4 7H_2O$ |
| Cu | 2.99 | $CuSO_4 5H_2O$ |
| Mo | 0.15 | $Na_2MO_4 2H_2O$ |
| Mn | 2.99 | $MnSO_4 4H_2O$ |
| Fe | 4.25 | Fe sequestrene |

*An amount of 150 kg N $ha^{-1}$ was applied as basal nutrients and another 80 kg N $ha^{-1}$ was applied as side dressing 30 and 44 days after planting.

## B.3 Weights of monitor boxes

Appendix B.3 The weights of eight monitor boxes (High and Low water regime)

| Treatment | Weight (kg) at s.m.c. | | |
|---|---|---|---|
| | 70% FC* | 30% FC* | FC* |
| High water regime | | | |
| Bare - No manure | 59.6 | - | 61.6 |
| Straw - No manure | 61.8 | - | 63.8 |
| White P. - With manure | 59.5 | - | 61.6 |
| Black P. - With manure | 60.2 | - | 62.3 |
| Low water regime | | | |
| Bare - With manure | - | 56.7 | 61.5 |
| Straw - With manure | - | 59.1 | 63.9 |
| White P. - No manure | - | 58.9 | 63.7 |
| Blak P. - No manure | - | 57.1 | 61.9 |

*Soil moisture content (s.m.c.):

at field capacity (FC) : 0.154 kg $kg^{-1}$
at 70% FC : 0.108 kg $kg^{-1}$
at 30% FC : 0.046 kg $kg^{-1}$

# Appendix C

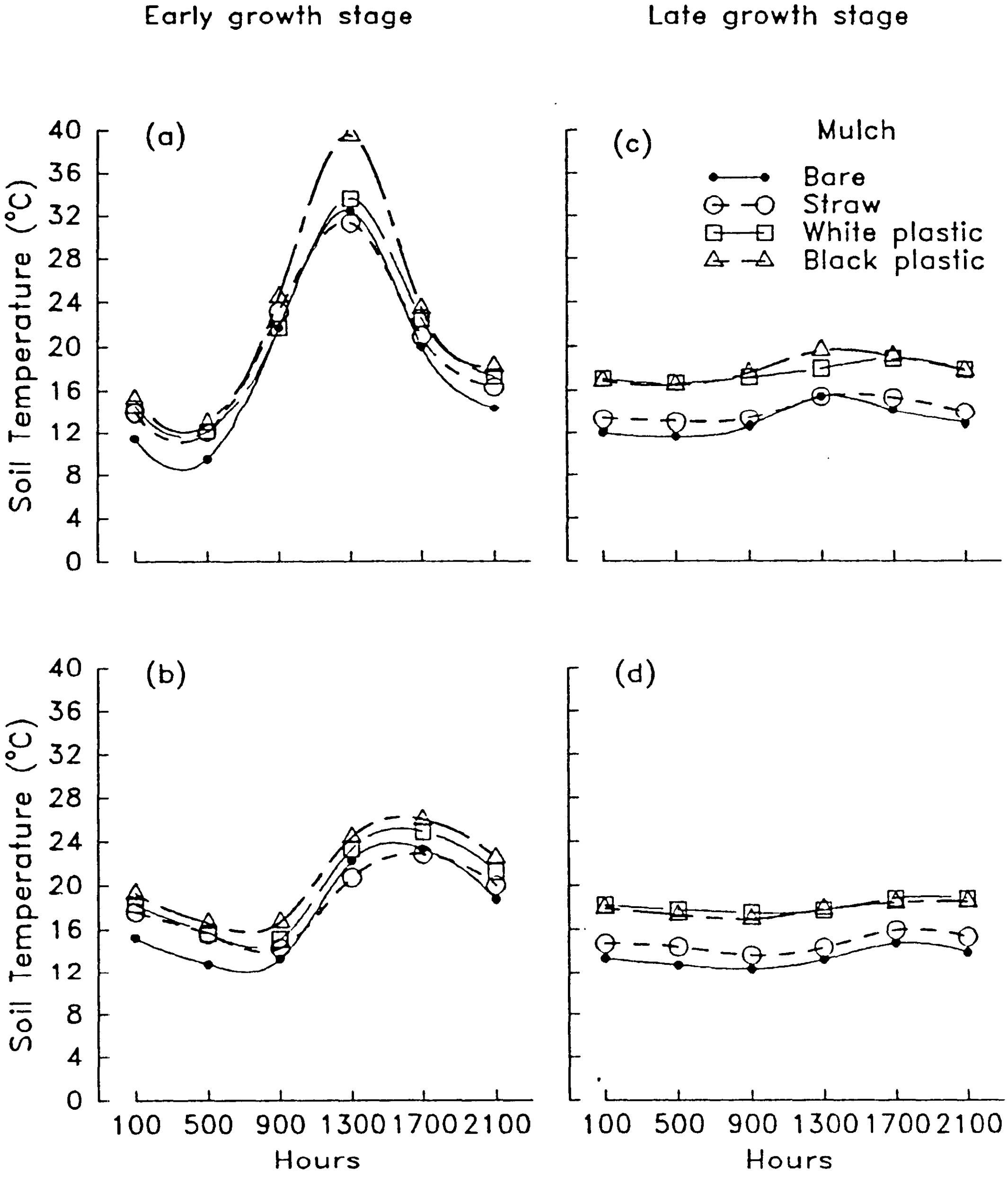
Soil temperature

C.1 Soil temperatures at the surface and 5cm depth in the manure - high water treatment

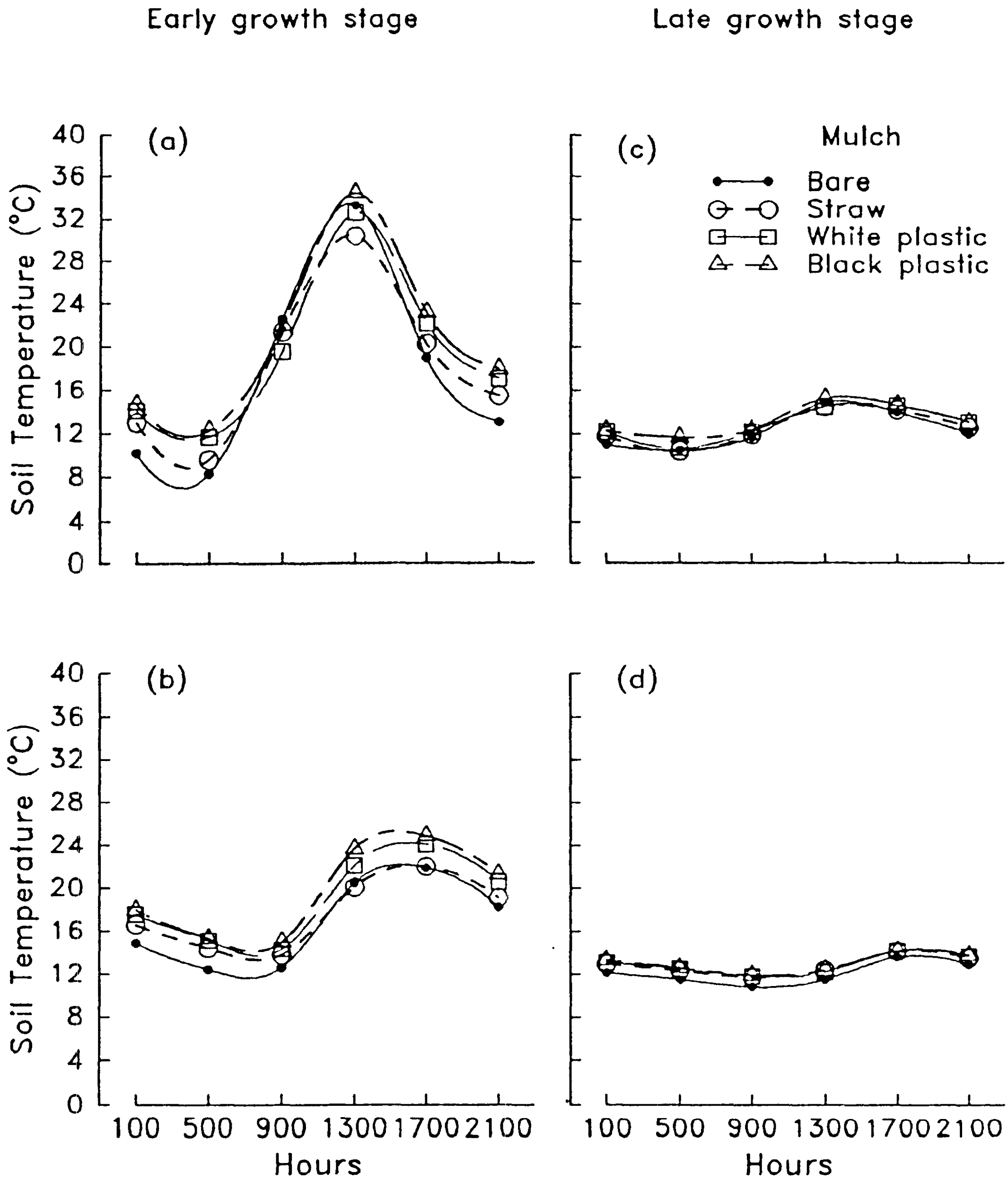
C.2 Soil temperatures at the surface and 5cm depth in the manure - low water treatment

C.3 Soil temperatures at 15 cm depth in the no manure - high and low water treatment

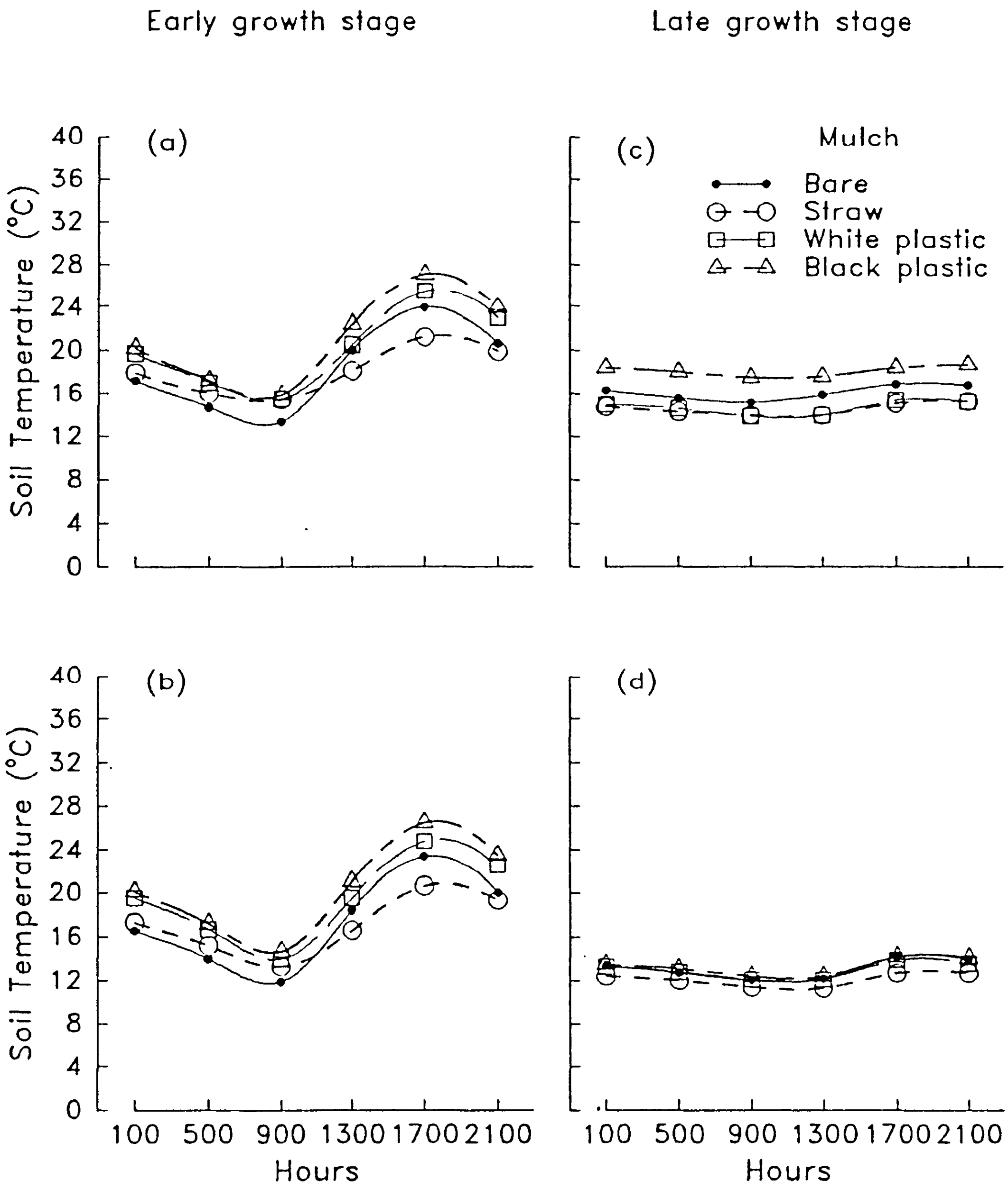
C.4 Soil temperatures at 15 cm depth in the manure - high and low water treatment



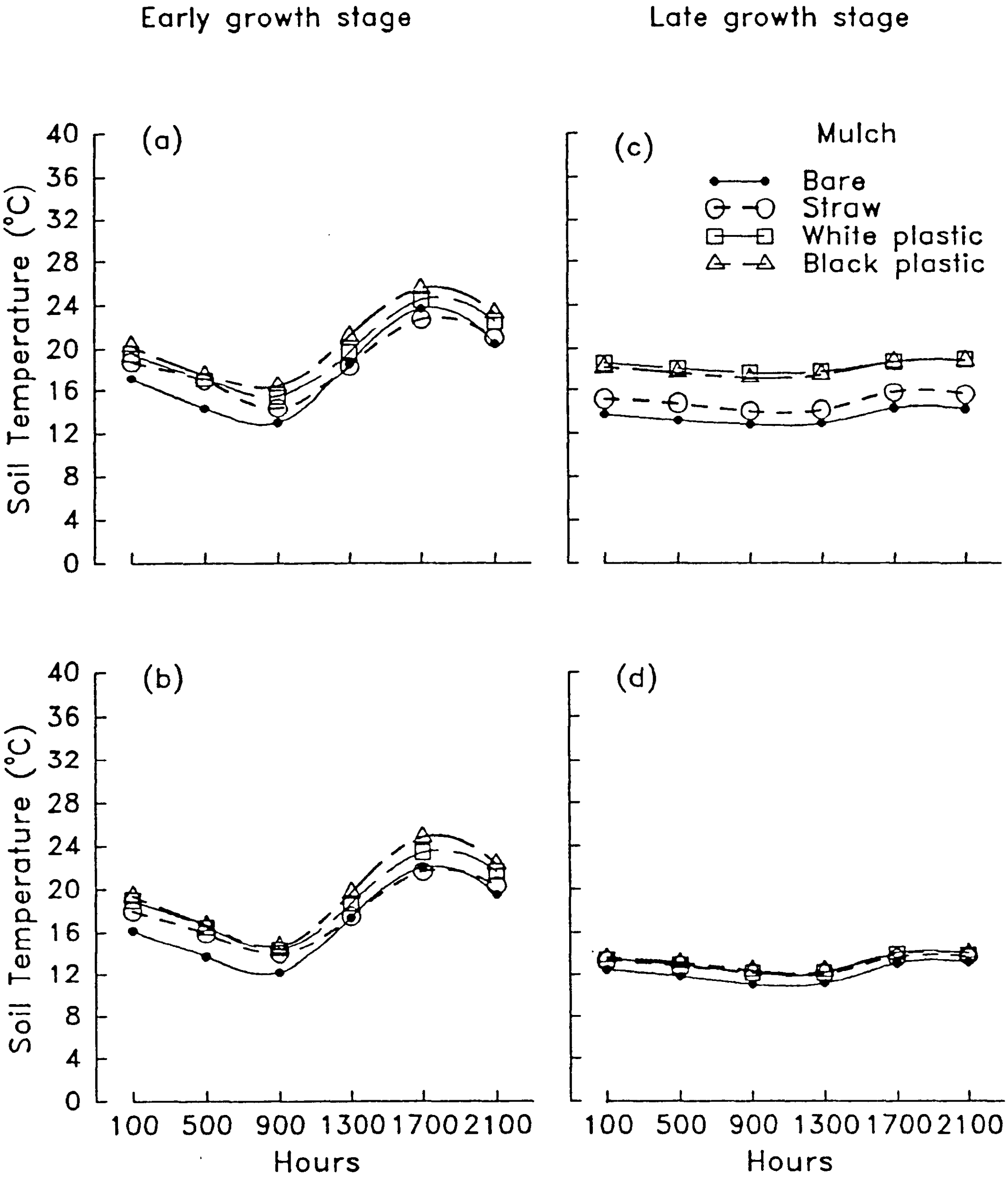

Appendix C.1 Soil temperatures at the soil surface and 5 cm depth, in the manure - high water treatment at early [a,b] and late growth stage [c,d].




Appendix C.2 Soil temperatures at the soil surface and 5 cm depth, in the manure - low water treatment at early [a,b] and late growth stage [c,d].




Appendix C.3 Soil temperatures at 15 cm depth in the no manure - high and low water treatment at early [a,b] and late growth stage [c,d].




Appendix C.4 Soil temperatures at 15 cm soil depth in the manure - high and low water treatment at early [a,b] and late growth stage [c,d].