Factors Affecting the Early Production of Processing Tomatoes

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Abstract

A field experiment was conducted on the Karapoti brown sandy loam soil during the 1995-96 season on the Horticultural Field Plots at the Plant Growth Unit, Massey University. The objective of the research was to study the effect of black plastic mulch with fertigation and fabric row covers on crop growth, yield, quality and maturity of processing tomatoes (*Lycopersicon esculentum* Mill. cv. Cleo).

The rowcover (RC) treatment advanced by 2 days both the date of first flowering and 50% flower opening compared with no RC. There were no RC effects on growth during the first 8 weeks in the field. RC reduced the yield and number of factory grade fruit at optimum harvest. Thus the treatment was detrimental. These results suggested that the use of floating covers during early summer in New Zealand will cause fruit setting to be reduced by high temperatures (>30°C). Bad weather delayed planting and resulted in relatively short use of the RC. If planting had taken place three weeks earlier, as planned, then RC may have improved earliness and not had a detrimental effect on yield. These results confirmed that the timing of rowcover application is critical for its successful use.

The nutrient concentrations in leaves of mulched plants maintained higher levels of N P K during establishment. During the period of the fruit swelling (28-91 days after transplanting) the nutrient levels in the leaves fell markedly. The leaf analysis data in this experiment suggests that N and P had an important role in improving early growth and fruit set and as a result increased fruit number and yield.

The results of this study showed that black plastic mulch plus fertigation provided for improvements in the early growth (relative growth rate) and development (number of flower clusters) and yield of total, red and factory grade fruit for the processing tomato cv Cleo. The optimum harvest time occurred 114 days after transplanting. Fertigation made a major contribution to the increase in yield. With cultivar Cleo the number and yield of factory grade and red fruit followed a normal distribution curve. This showed that advancing or delaying harvest by one week significantly reduced yield and it is suggested that the timing of harvest of processing tomatoes is more crucial than is commonly believed. A technique to predict the optimum harvest date for processing tomatoes should be developed.

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CHAPTER ONE

Review of the Literature

1.1 Introduction

All plant species in nature have their specific life cycles which they follow during they growth and development and reproduction. They are constantly challenged by environmental conditions as well as pathogenic microorganisms. Thus plants not only have to acclimatise themselves to the environment but also they must resist pathogenic microorganisms and insects. Plant acclimatisation and resistance to pathogenic microorganisms are features of survival. Plants possessing these features are not eliminated through competition or selection and they increase gradually in quantity. Environmental factors, such as moisture, nutrient elements, light intensity and temperature all provoke responses from plants that can modify the morphological and physiological characteristics of the plant as well as their reproduction performance. Humans grew plant products which are rich in nutrients as in our food or fruit by means of supplying optimal growing condition for the growth and development of plants. As with higher plants, there are several growing stages for the tomato plant, such as seed germination, emergence of seedlings, vegetative growth, flowering, fruit setting and maturity of the fruit. At each growth stage, the tomato plant may require different environmental conditions to meet their requirements for growth and development. Temperature represents an important environmental factor essential for the metabolic and cellular functions of the tomato plant (Table 1.1 , Aung, 1979). The rates of many physiological processes are determinated by temperature and may be manifested in subsequent morphological changes. The vegetative and reproductive responses are strongly modified by temperature alone, or in conjunction with other environmental factors of light, gas composition, mineral nutrients, and moisture.

It is a prerequisite for acquiring superior quality and high yield of fruit to have an understanding and knowledge of the environmental requirements of tomato plants for normal growth and development. This detailed knowledge of the vegetative growth of tomatoes provides the opportunity (a) to increase growth and ultimately yields; (b) to minimise the duration of the vegetative phase and the cost of the production; (c) to optimise the growth and the use of energy (d) to improve fruit production further. Similarly a better understanding of pollination and fertilisation processes should enable improved fruit set in adverse condition. In this review the origin, characteristics, growth, development and production of tomato plants will be briefly discussed. In the latter case processing tomatoes are of particular interest.

1.2 General growth pattern of the tomato plant

1.2.1 Characteristics of the tomato plant

The tomato belongs to the Solanaceae family and the genus Lycoperisicon. The tomato is a warm-season crop, but despite its susceptibility to frost, it can be grown successfully from equator to 65° of northern latitude (Taylor,1986).

Tomato plant is a perennial plant although it often grown as an annual. The tomato plant possesses a vigorous tap root with extensive fibrous roots. Tomato stems are solid and hairy (Figure 1.1), rooting at nodes. Its main stems are covered with setae and it has oil glands, but the older stems lignified. Tomato leaves are plume-like multiforliage (Figure 1.2), 15-30 cm x 10-25 cm with petioles 3-6 cm long. Tomato flowers are in cymes or racemes of 4-12 and are borne opposite or between leaves.

The yellow-petalled flower encloses an ovary similar in shape to that of the ripe fruit and is surrounded with a style surrounded by stamens. The stamens open via internal slits and fertilise the stigma automatically. The stigma does not normally emerge from the staminal cone. Tomatoes are therefore considered as being self-fertilising. Tomato fruit is a flesh berry with 2-9 loculi, orange, yellow or red when ripe. Fruit shape varies widely between varieties and can be flat or rounded, smooth or ribbed, elongated or pear-shaped (Figure 1.3) and 2-15 cm in diameter. The tomato seeds is small and hairy, kidney-or pear-

Table 1.1 The optimal growing temperatures of tomato at different developmental stages (adopted and modified from Aung, 1979)

Developmental stages	Optimal temperatures *	Reference
Seed germination	26-32 °C	Thompson, 1974
Cotyledon expansion	16-20°C	Calvert, 1957
Seedling apex enlargement	15°C	Hussey, 1963
Seedling growth	25-26°C	Cited by Aung, 1979
Stem elongation	30/17°C, day/night	Cited by Aung, 1979
	27/19-20°C, day/night	Cited by Aung, 1979
Axillary shoot growth	35/18°C, day/night	Abdelhafeez and Verkerk, 1969
	26/22°C, day/night	Cited by Aung, 1979
Root growth:		
Intact seedling	26-32°C	
Older plants	27/13-22°C, day/night	Cited by Aung, 1979
Excised in vitro	20-33°C	Cited by Aung, 1979
Leaf initiation	25°C	Calvert, 1957; Hussey, 1963
Leaf node reduction	10-14°C**	Lewis, 1953
Flower formation	13-14°C**	Lewis, 1953
Anthesis	13-14°C**; 26/22, day/night	Asahira, 1976; Lewis, 1953
Pollen formation	20-26°C	Cited by Aung, 1979
Pollen germination	22-27°C	Abdalla and Verkerk, 1968
Pollen tube growth	22-27°C	Abdalla and Verkerk, 1968
Stylar extension	30-35°C	Abdalla and Verkerk, 1968
Fruit-set:		
Intact plant	18-20°C	Cited by Aung, 1979
Excised in vitro	20-22°C	Cited by Aung, 1979
Fruit ripening	24-28°C	Cited by Aung, 1979

* The temperature responses are modulated by light intensity, mineral nutrient and moisture levels.

** Low temperature provided to seedlings for short duration of two weeks or less followed by growth at higher temperatures.

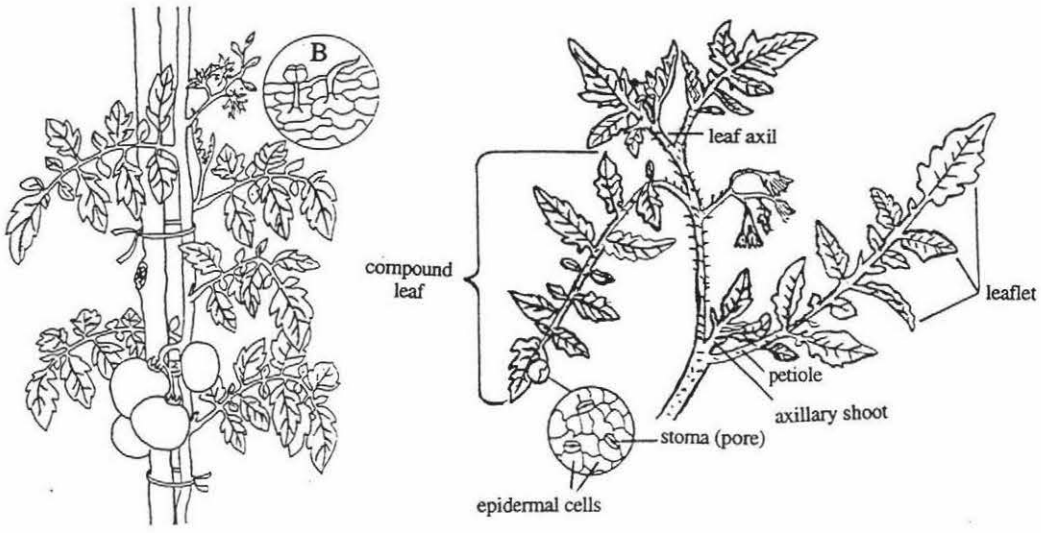

Figure 1.1 General appearance of the tomato (*Lycopersicon esculentum*) plant. A represents simple and glandulous hairs as seen under a hand-lens (after Messiaen, 1994); B represents structure of leaves and branches; C represents the appearance of shoots (Anon, 1990)

shaped, light brown and 3-5 mm × 2-4 mm. It has an approximate weight of 1000 seeds for 2.5 g. The tomato seeds will retain their viability at normal temperatures and at a fairly wide range of relative humidity, thus tomato seeds store well (Messiaen, 1994).

1.3 Growth and development of the tomato plant

Tomatoes pass through several stages in the course of their growth during a season: seedling establishment (Figure 1.4), vegetative growth, followed by the flowering and fruiting stages. Tomato flowering starts 50-65 days after sowing. First flowers are found at the seventh to tenth node. There are 45-55 days between the first anthesis of the flower and the ripening of the corresponding fruit and therefore 90-120 days between sowing and the first harvest (Messiaen, 1994).

Depending on the capacity of the shoot system for continued sympodial development the tomato cultivars are classified as determinate or indeterminate (Atherton and Harris, 1986). Determinate cultivars of tomato produce branching systems of limited growth and

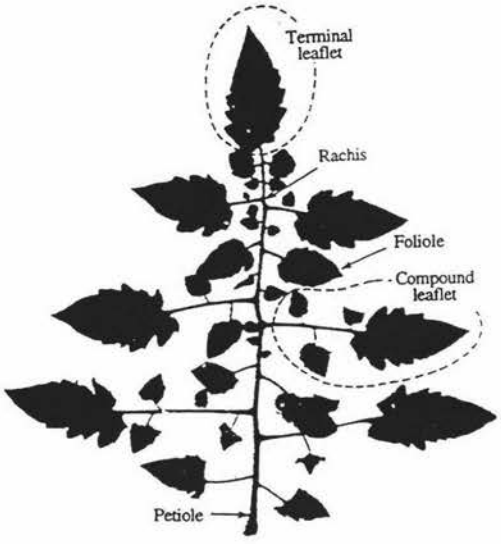

Figure 1.2 A typical tomato leaf--plume-like multiforliage (after Picken et al, 1986)

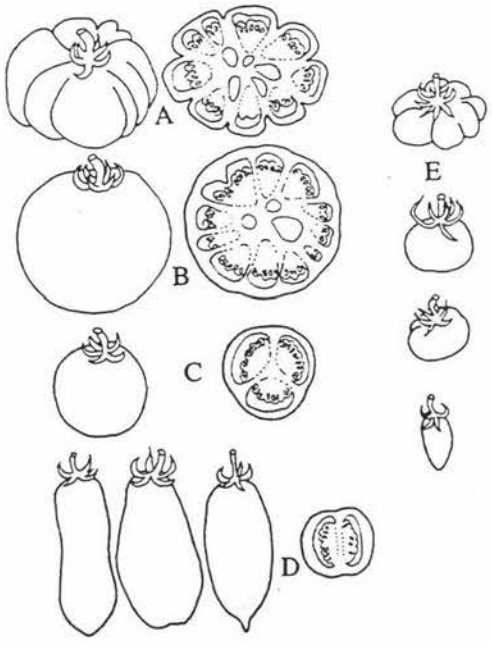

Figure 1.3 Different shapes of tomato fruit:

A: early varieties with flat, ribbed fruit; B: later varieties with large fruit; C: Anglo-Dutch type; D: elongated fruit; E: typical cherry tomato *Lycopersicon esculentum* var. *cerasiforme* (after Messiaen, 1994)

develop in the form of a bush. Indeterminate cultivars of tomato produce branching systems that grow indefinitely and have a growth habit that is prostrate or scandent.

For determinate cultivars of tomato, the growing point in the axil of the last-formed leaf of the primary shoot may be transformed into an inflorescence without the initiation of

further leaves (Figure 1.5b, cited from Atherton and Harris, 1986). Since no new leaves or axillary buds are initiated, extension of the shoot axis is halted with the formation of the inflorescence.

The limited extension of the main axis of the shoot system in determinate cultivars is associated with the outgrowth of all or most of the lateral buds on the primary shoot. These give rise to lateral shoot systems which, like the primary system, go though limited extension. Axillary buds on laterals and sub-laterals may repeat this pattern of development.

In an indeterminate cultivar after the primary shoot has formed a terminal inflorescence, the extension of the shoot axis continue through the growth of a series of lateral shoots that together constitute the primary sympodium (Figure 1.5a). Each shoot normally yields three leaves and a terminal inflorescence.

The extension of the primary sympodium is through the growth of the bud in the axil of the last-formed leaf of the preceding shoot. The bud that caused extension of the sympodium exhibits a type of growth distinct from that of buds at other nodes. As the shoot grows out, the inflorescence above it is pushed to the side and the stem of the lateral shoot becomes continuous with the stem of the shoot from which it has grown. The bud grows out united to the basal part of the petiole of the leaf that subtends it, so that the leaf appears to be extended up with the growth of the shoot and comes to occupy a position above rather than below the inflorescence.

1.4 Young plant

1.4.1 The leaf and flower initiation

1.4.1.1 Early growth and development

The termination of seed germination is characterised by the straight hypocotyl and horizontal cotyledons. If the seedling is dissected at this stage 2-3 leaf primordial and an

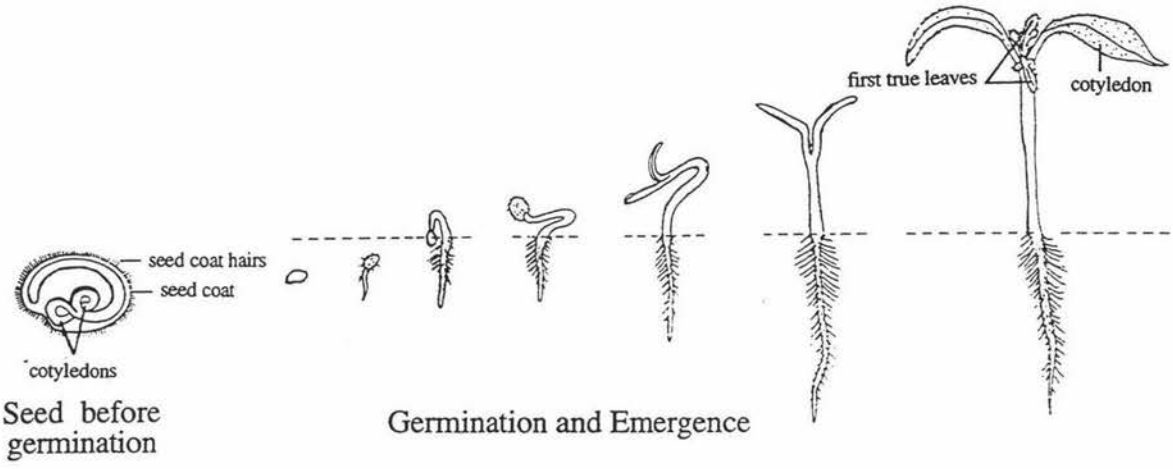

Figure 1.4 Tomato seedling establishment (Anon, 1990)

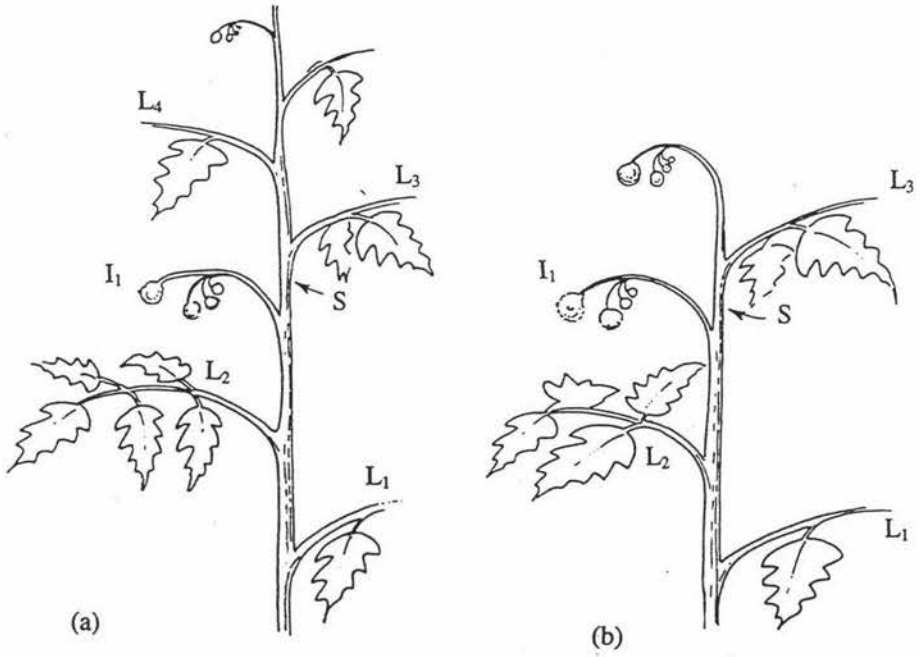

Figure 1.5 Tomato cultivars of indeterminate (a) and determinate(b) type
(after Atherton and Harris, 1986). The leaves, L1, L2, and L3 are initiated before the initiation of the inflorescence, I_1. Growth of the shoot system continues via a lateral sympodial shoot (S) which grows out united to the basal parts of the leaf (L_3) that subtends it. Hence the leaf (L_3) comes to occupy a position above the inflorescence. In the indeterminate cultivar (a) extension of the shoot axis continues through a series of sympodial shoots, each producing three leaves and a terminal inflorescence. In the determinate cultivar (b) extension is ceased when the sympodial shoot produces an inflorescence but no leaves or axillary growing points.

apex or growing point can be observed. Sequentially, a succession of leaf initials are formed round the growing point before any differentiation to reproductive development takes place. The size of the apex gradually increases as new leaves are produced. Flower differentiation and development in the tomato begins soon after cotyledon expansion (Aung, 1979). The apex continues to increase in size until it becomes transformed from a vegetative apex to an individual flower. The inflorescence of tomato is thus formed terminally on the shoot and floral initiation is preceded by enlargement and flattening of the shoot apex (Hussey, 1963). The first-formed flower of the cymose inflorescence originates at the apex and a lateral growing point that arises below the first flower develops into the second flower. A succession of flowers is developed from lateral growing points in this manner until the inflorescence is complete. The procedures are shown in Figure 1.6. During the development of the floral laterals, their basal regions become aligned to form the main axis of the inflorescence from which the pedicels of the individual flowers diverge. The form of the mature inflorescence is raceme-like with the youngest flowers at the distal end (Atherton and Harris, 1986).

There is the competition for available assimilates between the developing leaves and the apex. If these leaves are removed at an early stage the growth of the apex is stimulated and the time of flower initiation is hastened with a reduction in the number of leaves before the first truss. This effect is most obvious when the temperature is high but is less apparent with low temperatures (Calvert, 1965).

1.4.1.2 Effect of temperature and light on leaf and flower production

1.4.1.2.1 Effect of temperature and light on leaf production

In general, rates of leaf or leaf primordial production increase with temperature and daily irradiance, and are constant in a constant environment (Calvert, 1959; Hussey, 1963; Kinet, 1977). If the air temperature is high during the early period of growth, the number of leaves which form before the first truss will be greater than if the temperature is low. This is because the rate of development of the apex is slow at high temperature, while leaves are being produced rapidly (Calvert, 1965). If the temperature is low enough a

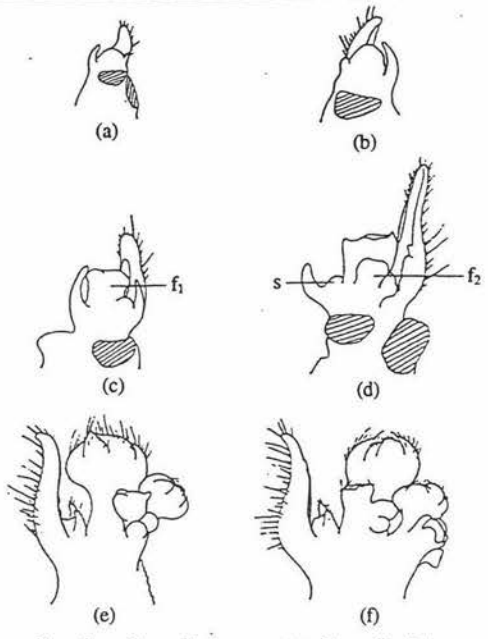

Figure 1.6 Early stages in the development of an inflorescence of tomato

(a) vegetative shoot apex; (b) apex with enlarged apical dome prior to flower initiation; (c) first flower primordium (f_1) forming; (d) second flower primordium (f_2) visible at base of first primordium; lateral buds that will continues growth of sympodium forming in leaf axil; (e) differentiation of flowers in simple, unbranched inflorescence; (f) differentiation of flowers in branched inflorescence. Cross-hatched area represent scars left by removal of leaf primordium (after Atherton and Harris, 1986).

minimal leaf number (7 - 8 leaves varying with variety) is formed. Calvert (1957) found that during a period beginning at cotyledon expansion and ending approximately nine days later, tomato seedlings can be vernalised. Thus the number of leaves to the first inflorescence is minimised with low temperature and maximised with high temperature.

Calvert (1959) found light intensity had the smallest effect on leaf number when the temperature was low (13°C) and the smallest response to temperature occurred when the light intensity was high (1 000 lumens/sq. ft.). The number of leaves produced before the first inflorescence was influenced by the intensity of photoperiodic light, high light intensities causing low leaf numbers and vice-versa. The rate of leaf production increased with the light intensity but leaf number decreased. The rate of leaf production increased with temperature and leaf number also increased. Thus response of new leaf and flower buds to light intensity is in the same direction, but temperature produces opposing effects. Hussey (1963) reported that at 15°C the rate of leaf production increased as light increased from 400 to 800 foot candles, but not from 800 to 1600 foot candles. At 25°C

the rate continued to increase. The rate of leaf production in young plants is relatively independent of daylength.

1.4.1.2.2 Effect of temperature and light on flower production

1.4.1.2.2.1 Temperature

There is no evidence to indicate that day and night temperatures have different effects on inflorescence initiation and it appears that average diurnal temperature is an important factor in controlling flowering. Low temperature increased and high temperature decreased the number of flowers (Calvert, 1957). The effect of high temperature on flower initiation depend on the interaction of the temperature and light intensity. If the light intensity is high, then the adverse effects of high temperature on apex enlargement is less marked and flower initiation could occur quite rapidly, though the temperature effect on leaf number would be evident. The lower the light intensity, the greater the delaying effect of high temperature (Calvert, 1965).

Phatak, *et al.* (1966) reported that with high temperatures the rate of apical enlargement is slow and the developing leaves taking a greater share of the available assimilates at the expense of the growing point. This results in an increase in the number of leaves before the inflorescence and the development of an unbranched truss. With low temperature the converse case takes place, this results in a minimal leaf number and a branched truss. Aung (1979) reported that the developmental stage is critical in the response of seedlings to low temperature induction of flower production and early flowering.

Seed vernalisation at 5°C or less has no effect on flowering of the tomato. However, tomato seedlings are thermo-sensitive and can be vernalised to flower earlier and produce a greater number of flowers on a inflorescence. Provided tomato seedlings are after the cotyledons expansion stage, a temperature of 14°C in comparison with 25°C or 30°C increases the numbers of flower in the inflorescence. The low temperature effects are reflected in greater flower number (Charles and Harris, 1972), and fewer leaves preceding the first inflorescence. Similar results were reported by Calvert (1959), who found that plants grown at 15°C in growth cabinets initiated flowers up to 13 days earlier than those grown at 25°C. Previously, Calvert (1957) found that the number of leaves

subtending the first inflorescence was also reduced at lower temperatures with a minimum number of about 6 or 7 leaves formed at 10°C. At this temperature anthesis was delayed.

In a experiment on the effect of top and root temperature on flowering, Phatak, *et al.* (1966) found that top temperatures determined the position, as to node number, of the first inflorescence, while root temperatures influenced the number of flowers in the first inflorescence, the flower number was not affected by top temperatures but was modified by the root temperatures. Low top temperatures (10°C to 12.8°C) significantly decreased the number of nodes below the first inflorescence in comparison with higher temperature (15.6°C to 18.3°C up to 21.1°C). Conversely, at 10°C to 12.8°C root temperatures, the flower numbers were significantly increased in comparison with 15.6°C to 18.3°C or 18.3°C to 21.1°C. Aung (1979) reported that during the thermo-sensitive period, a shoot temperature of 10-13°C determinates the morphological position of the first inflorescence and a root temperature of 10-13°C controls the number of flowers on the inflorescence.

Each inflorescence has a temperature-sensitive period where low temperature promotes greater flower production and this varies with cultivar. The interval between the thermo-sensitive phases for the first three inflorescence is 1 week. For example, The sensitive period for the low temperature effect on the first inflorescence of "Kondine Red" is between the 8th and 12th day after cotyledon expansion. For "Spartan Hybrid", the thermo-sensitive period for first inflorescence is the 2nd week after cotyledon expansion, and for the 2nd inflorescence the 5th week (Aung, 1979). When ten-day old seedlings were exposed to 15.5°C during the day and 10°C at night, the flower number on the 1st, 2nd and 3rd inflorescence were increased after the 3rd, 4th and 5th week of treatment, respectively. Relatively high temperature diminished flowering. For example, a high temperature of 26°C day and 22°C at night under phytotron conditions decreased flower numbers in the first inflorescence of tomato cultivars "Epoch" and "Fireball", compared to 22°C day/18°C night or 18°C day/14°C night.

Hussey (1963) reported that in plants grown at 25°C, defoliation of the first two leaves was followed by rapid enlargement of apex and earlier flower initiation, the number of

leaves produced before flowering being reduced to that in plants grown at 15°C. At 15°C, removal of first two leaves only slightly increased rate of apical enlargement, and did not influence the time to flower and number of leaves. The first two leaves at 25°C were using a much higher proportion of assimilate translocated from the cotyledons than at 15°C, suggesting at higher temperatures, the first two leaves compete strongly with the shoot apex for supplies of assimilate.

1.4.1.2.2.2 Light

Light intensity is another factor that is important to inflorescence initiation. Under a low light regime flowers fail to open (Leonard and Kinet, 1982) and Atherton and Harris (1986) reported much research that shows that low irradiance encountered during the early seedling growth delays inflorescence initiation. The effects of light were greater at high temperatures (25°C) than at lower temperatures (15°C). Calvert (1959) found that reducing the illuminant level from 10000 to 2500 lux delayed flower initiation by up to 29 days and allowed up to approximately 7 more leaves to be produced before the inflorescence was initiated. Solar radiation influences flowering time through its effects on the time of inflorescence initiation and on the rate of flower development. In generally, the effects of photoperiod on tomato flowering initiation is slight (Atherton and Harris, 1986).

Calvert (1964) found that differences in leaf number to the first inflorescence observed in tomatoes grown in greenhouse, at different time of the year, were largely attributable to differences in daily light integral rather than to photoperiod. The inhibiting effect of night-break lighting treatment on flower initiation in short-day plants was not marked in tomato. Atherton and Harris (1986) reported that in some cases the increase of far-red component of radiation may increase the number of leaves to first inflorescence, but reduced the time to opening of the first flower. Wittwer (1963) reported that the tomato had been considered a photoperiodically-indifferent or a day-neutral plant with respect to flowering by previous researchers. However, he found that the effects of short day exposure of tomato seedlings during the critical period of flower formation, for the first inflorescence, compliment the effects of low temperatures and high light intensities. The effect is opposite to that induced by high temperatures, an extended photoperiod of low

light intensity, or gibberellin. Thus he suggested that the tomato was a facultative short day plant.

1.4.1.2.2.3 Growth regulators

Abortion of the first inflorescence of the tomato takes place when plants are grown under low light levels (Leonard, *et al.* 1983). Abortion may be prevented by treating the inflorescence, soon after its macroscopic appearance, with a mixture of a cytokinin and gibberellin (Leonard and Kinet, 1982; Leonard, *et al.* 1983). The research of Leonard and Kinet (1982) indicated that the abortion of the inflorescence of plant grown under insufficient light may be due to a deficiency of both cytokinins and gibberellins, as cytokinins were required for floral development soon after the macroscopic appearance of the inflorescence and exogenous gibberellins were required for development of flowers to anthesis. That cytokinins play a major role in the control of the early stages of reproductive development in tomato, is demonstrated by the lack of cytokinins in the inflorescences of plant grown under adverse light conditions. This result was supported by the findings of Menary and Staden (1976), who reported that ten days of phosphorus deficiency resulted in a decrease in the number of flowers in the first inflorescence, and this effect on flower number was accompanied by a decrease in the cytokinin activity of the root exudate. Thus they suggested that phosphorus stress may be influencing flower number through its effect on the supply of endogenous cytokinins to shoots. Leonard, *et al.* (1983) suggested that there is a competition for assimilates between vegetative and reproductive growth because removal the young leaves located above the inflorescence promoted inflorescence development. Thus a possible mechanism by which growth substances favour the development of the inflorescence in tomato could be through the redirection of the flow of assimilates. Their study on enhanced inflorescence development in tomato by use of growth substances used the distribution pattern of ^{14}C-assimilates to demonstrate that after treating the inflorescence with a mixture of a cytokinin and gibberellin, the photosynthetic rates of the young mature leaf (which feeds the developing inflorescence) and the proportion of ^{14} C-assimilates exported from the source leaf were not influenced, but the pattern of ^{14} C-assimilates distribution was altered. Assimilate supply to the treated inflorescence increased concomitantly with a decrease in the ^{14}C import into the apical shoot, reflecting a competition between these

two plant parts. The increased assimilate accumulation in the treated inflorescence was apparent 1 day after the first application of the mixture of a cytokinin and gibberellin.

(2-Chloroethyl) trimethylammonium chloride (CCC) is another growth regulator affecting the formation and abortion of flowers in the first inflorescence of tomato. Abdul, *et al.* (1978) found that CCC and GA_3 had contrasting effects on the appearance of the plants and on the number of flowers in the first inflorescence. Plants treated with CCC had darkgreen foliage, short internodes and thick stems and reduced growth in terms of dry weight of the shoot and an increased number of flowers in the first inflorescence. Those treated with GA_3 had pale green foliage, long internodes and thin stems and showed an increase in the dry weight of the shoot and reduced the number of flowers in the first inflorescence. When GA_3 was applied in combination with CCC the effects of CCC were reduced. They also found that an application of CCC reduced the incidence of flower abortion in the first inflorescence when plants were grown at a high temperature with low light. This again could be explained by a change in the pattern of distribution of assimilates.

The formation of flowers is a prerequisite for the formation of fruit and delays in flowering can lead to delay in fruit production. Thus, differences in the rate of flower formation can lead to differences in fruit production at particular stages in the growth of the crop. Short-term increases in yield may be associated with the formation of an unusually large number of flowers within an inflorescence or with a high rate of initiation of successive inflorescences. This may be only benefit when high yields are required early, such as early production of fresh tomato for the early spring market. If such increase in a fruit production occur, correlative growth inhibitions of further developing fruits may result in a reduction of yield at a later stage (Fisher, 1977; Slack and Calvert, 1977). An increase in the number of flowers initiated increases the potential for competition between fruits and as a consequent reductions in fruit size (Atherton and Harris, 1986).

1.4.1.2.2.4 Nutrients

Nutrient uptake is continuous during growth and development of the tomato plant (Halbrooks and Wilcox, 1980) if no drastic limiting factor appears. Mineral absorption

rhythms during the life of a tomato plant show low absorption during the pure vegetative stage, an increase when the first trusses appear, a marked increase during the overlapping time of 'flowering - fruit setting - early fruit swelling', and a fall during fruit ripening (Dumas, 1990). Dumas (1990) reported that the highest uptake rates occurred between 40 and 70 days after planting.

Nitrogen affects vegetative growth and fruit production more than any other nutrient. Nitrogen surplus can be as unfavourable as deficiency especially in a mechanical harvest context or with respect to towards fruit quality by decreasing size, colour and solid content (Dumas, 1990). Dumas (1990) found that the daily uptake during flowering was 4.3, 0.7 and 8.3 kg/ha, for N, P and K and that it was all the more intense because mechanical harvest uses cultivars with concentrated fruit set. Fisher (1969) and Adams *et al.* (1973) found that low levels of nitrogen resulted in delayed opening of the flowers. Shortage of nitrogen can give rise to an increase in the incidence of flower abortion under some conditions (Atherton and Harris, 1986). Bar-Yosef (1977) suggested that in sandy soils 140 N mg l^{-1} is an optimum concentration of the solution for nutrient uptake. This must be varied according to growth stages, with 100 ppm as a threshold value and 300 ppm as the maximum level (Bar-Yosef and Sagiv, 1982).

Phosphorus is necessary to growth and development with positive effects on the number of flowers, earliness of ripening and concentration of yield and on fruit quality (coloration, vitamin C content). Phosphorus deficiency can be observed as a purple colour when the second true leaf appears a few days after seedling emergence (Dumas, 1987). At emergence, soil P availability is most important at a time when the root system is small. Dumas (1990) reported that growth and development rates greatly increased with the amount of P mixed in the 0-22 cm layer from emergence to the appearance of the first trusses and that for P it is most important from the plant establishment phase until first trusses formation. It can be supplied successful using moderate amounts of placed P (at least a fifth of what could be recommended when mixing P into the ploughed layer). Dumas (1987) reported that phosphorus availability and taking easiness are important for the very young plant to enhance flowering precocity. His research showed that high availability of phosphate had a favourable effect on the maturation earliness (a few days) and grouping, which is good for machine harvest and that there are

more favourable influence when using superphosphate than when using ammonium phosphate. Menary and van Staden (1976) reported that when tomatoes grown in solution culture were deprived of a phosphorus supply for 10 days, anthesis was delayed by 7 days and the number of flowers that opened in the first inflorescence was reduced from 7 to 3.

Potassium is considered to have a great influence on fruit quality through the ripening processes. It improves coloration by increasing pigmentation. 'Blotchy ripening' is associated with K deficiency (Dumas, 1990). Sufficient K increases solid content, surgars, acids, carotene, lycopene and keeping quality. Growing plants at 1000 K mg l^{-1} gives intensive red colour fruit (Borkowski and Szwonek, 1986). Bingham and Cumbus (1991) studied the effect of low temperature on the growth and potassium requirement of young tomato plants. They reported that the critical concentration of potassium for shoots, defined as the concentration in the tissue associated with 90% of maximum shoot dry weight, was increased at root temperatures of 15°C and 30°C compared with 24°C. The critical concentration of potassium represents that tissue concentration at which vacuolar potassium has reached a minimum and below which loss from the cytoplasm occurs. They suggested that the higher concentrations of potassium at low root temperature may represent a real increase in requirement for the element at the physiological level. As the concentration of potassium in the tissue declines, the cytoplasm is initially buffered at the optimum concentration by potassium from the vacuole, and metabolic activity is sustained. A reduction in cytoplasmic potassium would limit metabolic activity and consequently growth. Differences in requirement for potassium between species or cultivars may result from differences in the amount of potassium retained in the vacuole for osmotic and electrostatic charge balance. They concluded that under situations of a limited K supply, root temperature appears to have little influence on any of the parameters governing efficiency of utilisation of K by tomato plants, but when supplies are suitable, root-cooled plants maintain a higher concentration in the shoots than controls, which may reflect an increase in the K requirement of shoots. The slower rate of growth at low root temperature cannot be attributed to a deficiency of K as concentrations in the tissue in their experiment were in the range optimum for growth.

1.4.1.3 Flower development

The elongation of the pedicel and the axis of the inflorescence occurs during the development of the flowers. Between each flower and the axis an abscission zone is formed which can be recognised by a slight angulation of the pedicel and a localised swelling of the tissues. Separation of the flower at the abscission zone may occur before or after the flower opens. Retention of part of the pedicel by the harvested fruit can be undesirable in tomatoes grown for processing and there is interest in a 'jointless' character which renders the fruit more likely to separate at its juncture with the pedicel (Atherton and Harris, 1986).

Abnormalities in the development of the flowers, such as (a) unusual elongation of the style; (b) fascination of the style; (c) impaired viability of ovules; (d) abnormal development of the stamen (e) defects in endothelium, are a potential cause of failure of pollination and of fruit set at high temperature (39°C day, 22°C night) (Picken, 1984). Reasons for flower drop at high temperature are diverse (Abdalla and Verkerk, 1968), including (a) viability and effectiveness of pollen produced, (b) rate of pollen tube growth, (c) drying of the style, (d) extension of the style beyond the stamen tube resulting in lack of pollination and rapid disintegration of the embryo sac. Pick and Dempsey (1969) found that in some genotypes and under some conditions, unusual elongation of the style may signify that the stigma becomes exerted beyond the anther cone so that self-pollination is unlikely to take place. Abnormal stamen development can implicate splitting of the staminal cone, defects in the endothelium that can interrupt the dehiscence of the anthers (Rudich et al, 1977) and failure to produce viable pollen (Atherton and Harris, 1986).

1.4.2 Earliness

Earliness is an important characteristic where tomatoes must be grown during a short season or tomatoes are grown for processing. An early maturing tomato crop advances and extends the harvesting season and thus is of great significance in machine harvesting (Malone, 1981). Earliness is a quantitatively inherited character influenced by

environmental factors such as climate and cultural practise. In other words, breeding selection for this character on a season basis is very difficult (Malone, 1983). Malone (1983) reported that the main defect of the tomato cultivars used by New Zealand industry is their lack of earliness. An early cultivar is Castlong, but a cultivar that matured two weeks earlier than Castlong would be welcomed by the processing industry as it would allow harvesting to commence two weeks earlier, thus extending the harvesting season.

1.5 Growth analysis of young plants

Growth analysis is a useful technique in horticultural research. Growth analysis can be carried out (a) to show that one particular environment or management practice is or is not more suitable for a particular plant than others; or b) to compare the performances of different species or varieties grown under the same conditions; or c) to explore and qualify the growth of a new experimental subject. There are two approaches to plant growth analysis, the classical approach and functional approach. In the classical approach, the course of events is followed through a series of relatively infrequent, large harvests with much replication of measurements. In the functional approach, involving fitted growth curves, harvests supplying data for curve-fitting are smaller (less replication of measurements), but more frequent (Hunt, 1982). The best fitting polynome for the relation between natural logarithms of total dry weight of the plant (g, DM), total dry weight of the leaves (g, Lw) and total plant leaf area (cm^2, A) with time can be calculated (Heuvelink, 1989). Heuvelink (1989) proposed the relationship $\ln DW = a + b \times t + c \times t$ ($c \neq 0$), for DW as a function of time, and $RGR = b + 2 \times c \times t$. Where parameter a represents logarithm of the dry weight at $t = 0$, parameter b represents RGR at $t = 0$ and parameter c reflects the degree of curvature in progressions of ln DW. If c equals zero this equation is the simple exponential relationship. Causton (1991) suggested that if there are many harvests, such as ten or more, the functional methods of growth analysis may be used to compute the derived quantities of interest, but where only a few harvests can be taken, the functional approach can easily give misleading results and the classical approach of calculation must be used.

RGR, SLA, LAR, NAR (or ULR), LWR, LAI are the most common used in growth analysis of individual plants. The formula for their calculation are expressed as follows (Hunt, 1978).

The relative growth rate (RGR, g g^{-1} $week^{-1}$) is defined as the increase in plant weight per unit of plant weight per unit of time.

In the classical approach:

$$RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

Where W_1 and W_2 are the dry weights at times T_1 and T_2, respectively, and (T_2-T_1) is the time interval studied.

In the functional approach (Hunt, 1982; Smeets and Garretsen, 1986.):

$$RGR(t) = \frac{1}{W}\frac{dW(t)}{d(t)}$$

The net assimilation rate (NAR, g m^{-2}) is a measure of the ability of the leaves to produce a net gain in weight per unit area of leaf.

In the classical approach:

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{\ln A_2 - \ln A_1}{A_2 - A_1}$$

Where A_1 and A_2 are the leaf areas at time T_1 and T_2, respectively.

In the functional approach:

$$NAR(t) = \frac{1}{A}\frac{dW(t)}{d(t)}$$

Where A is the leaf area.

The leaf area ratio (LAR, m^2 g^{-1}) is defined as the ratio of total leaf area to whole plant dry weight. LAR represents the ratio of photosynthesising to respiring material within the plant (Hunt, 1978). It can be calculated by:

In the classical approach:

$$LAR = \frac{A_2 - A_1}{W_2 - W_1} \times \frac{\ln W_2 - \ln W_1}{\ln A_2 - \ln A_1}$$

In the functional approach:

$$LAR(t) = \frac{A(t)}{W(t)}$$

RGR can be separated into an assimilatory component (NAR) and a morphological component (LAR) (Heuvelink, 1989), i.e.:

$$RGR = LAR \times NAR$$

Specific leaf area (SLA, $m^2\ g^{-1}$) is the mean area of leaf displayed per unit weight. In a sense it is a measurement of leaf density or relative thickness:

In the classical approach:

$$SLA = \frac{A}{Lw}$$

where Lw is leaf weight.

In the functional approach:

$$SLA(t) = \frac{A(t)}{Lw(t)}$$

The leaf weight ration (LWR, $g\ g^{-1}$) is an index of the leafiness of plant on a weight basis:

In the classical approach:

$$LWR = \frac{Lw_2 - Lw_1}{W_2 - W_1}$$

In the functional approach:

$$LWR(t) = \frac{Lw(t)}{W(t)}$$

LAR can be considered as the results of SLA times LWR (Heuvelink, 1989). i.e.:

$$LAR = SLA \times LWR$$

Considerable research work using growth analysis of young tomato plants has been carried out (Bruggink and Heuvelink, 1987; Pardossi, *et al.*, 1988; Heuvelink, 1989;

Smeets, and Garretsen, 1986; Nieuwhof, *et al.*, 1991). Relative growth rate, leaf area ratio, specific leaf area, and leaf weight ratio decreased with time. The change in net assimilation rate was small (Nieuwhof, *et al.*, 1991; Smeets, and Garretsen, 1986).

The decrease in RGR with time was mainly due to the decreases in LAR (Smeets, and Garretsen, 1986) or due to decreases in LWR, which implies a relative increase of non-assimilating tissue (Nieuwhof, *et al.*, 1991). Decreases of NAR and SLA may contribute to decreases of RGR at later growth stages (RGR = NAR × LAR = NAR × SLA × LWR, Nieuwhof, *et al.*, 1991). The effects of night temperatures on RGR, NAR, LAR, SLA and LWR has also been studied by some researches. Smeets, and Garretsen (1986) and Nieuwhof, *et al.*, (1991) found that RGR, LAR and SLA were lower and LWR slightly higher at low night temperatures, but NAR was hardly affected. The low RGR at lower night temperatures was mainly due to a lower SLA. Differences between genotypes for NAR, LAR, SLA and LWR have been reported (Nieuwhof, *et al.*, 1991; Smeets, and Garretsen, 1986), but not for RGR (Smeets, and Garretsen, 1986). Smeets, and Garretsen (1986) found that as the differences between genotypes for RGR were relatively small, genotypes with a relatively high NAR had a low LAR, while genotypes with a low NAR had a high LAR.

LAR and SLA were positively (Nieuwhof, *et al.*, 1991; Smeets, and Garretsen, 1986; Heuvelink, 1989), while NAR and LAR, and NAR and SLA were negatively correlated (Nieuwhof, *et al.*, 1991; Smeets, and Garretsen, 1986). There were positive correlations between RGR and LAR, and between RGR and SLA (Heuvelink, 1989). Heuvelink (1989) suggested that differences in RGR under different temperature regimes are almost completely related to differences in leaf thickness. He concluded that growth reduction at an inverse temperature regime (day temperature lower than night temperature) compared to constant temperature regime was due to the development of thicker leaves at the inverse temperature regime. Thicker leaves led to less light interception per unit leaf weight and thus to growth and development reduction, thus changes in RGR due to temperature regime are mainly caused by changes in LAR and not by in NAR. No large temperature effects on NAR are found because net photosynthesis of tomato leaves at 0.03% CO_2 is not greatly influenced by the temperature. Changes in LAR were mainly caused by changes in SLA, and thus by differences in leaf thickness (1/SLA). For young

tomato plants LWR was insensitive to temperature (Heuvelink, 1989). SLA is in general more sensitive to environmental change (Bruggink and Heuvelink, 1987; Heuvelink, 1989).

1.6 Roots of the tomato plant

Roots anchor the plant to the soil, absorb and translocate water and nutrients, synthesise and transport growth regulators and other organic compounds and provide a sink for carbohydrates from the shoots. The tomato root consists of a cortex of parenchyma cells, phloem, protoxylem and metaxylem. The xylem forms a cylinder in the centre of the root, with two lateral wings (diarch). The phloem completes the vascular tissue, filling out the space between the wings and forming a cylinder. Lateral roots arise from pericyclic cells behind the growing root tip and grow through the cortex. The xylem is usually tetrarch with four wings resembling a four-cornered star. Adventitious roots, similar in structure to the laterals, develop under favourable conditions from the stem, particularly near the base. They are also initiated in profusion on the underside of horizontal portions of the stem, enabling the plant to reroot in nature, although if they are suspended in air they do not usually elongation (Picken *et al.*, 1986).

Shoots are dependent on roots for growth regulators, such as abscisic acid (ABA), cytokinins and gibberellins, and absorption of water and mineral nutrients. When the root system is damaged severely enough to reduce water and mineral absorption, shoot growth is inhibited (Kramer and Boyer, 1995). Genetic differences in root growth do exist among tomato varieties (Gulmon and Turner, 1978). The research of Gulmon and Turner (1978) found that there was a strong correlation between root length and shoot growth that was similar for all varieties, however, the way in which the varieties achieved the particular root length varied markedly, for example, a variety could have many short secondary roots whereas another variety had fewer, more branched secondary roots.

Many factors, such as water supply and nutrition, soil salinity, oxygen supply to the roots and waterlogging, and root temperature, influence the growth and development of

tomato roots. High humidity may encourage aerial adventitious root growth and promote root extension. The development of the roots is decreased by pruning the axillary shoots (Aung, 1979).

Root growth is low at 5°C, and increases nearly linearly with increased temperature up to a maximum close to 25°C. Further increases in root zone temperature cause rapid decline in root production. The optimum root zone temperature varies among species and cultivars, for example, 26°C to 34°C for tomato root production (Miller, 1986). Miller (1986) reported that the optimum soil temperatures for maximum root growth is generally lower than the optimum soil temperatures for maximum shoot growth, and that the required optimum soil temperatures is usually highest at germination and then decreases with time. Abdelhafeez et al (1971) reported that roots grown at low soil temperatures were comparatively thicker, more white and less branched than those from higher soil temperatures.

1.7 The mature tomato plant

1.7.1 Introduction

Understanding the relationship between vegetative and reproductive growth of the tomato and knowing the factors affecting this relationship is the key for improvement and enhancement of tomato fruit production. Vegetative and reproductive growth take place simultaneously. Root growth of tomato is reduced during fruiting (Kramer and Boyer, 1995). Once fruits start to growth, the rate of vegetative growth slows to a minimum. Root net growth ceases 4 weeks after first anthesis and leaf growth is greatly reduced when the total fruit growth rate reaches a maximum (Hurd, *et al.*, 1979). In a fruiting plant the growth of fruit places an added demand on the root and shoot system for both mineral nutrients and for photosynthates. As fruit grow and subsequent fruit are set, this demand would be expected to increase and to become increasingly competitive with vegetative growth and between fruit (Fisher, 1975; Cooper, 1972).). The growth of

the tomato fruit depends mainly on its import of carbon. The rate of import is determined by the availability of assimilates and the competition with other sinks, which may depend upon the metabolic activity of the fruit (Heuvelink and Bertin, 1994). Photosynthetic efficiency is one of the major genetic determinants of high productivity in a crop. This determines its ability to produce high levels of photosynthates over a wide range of environmental conditions and to efficiently transport and partition a high proportion of those assimilates into economically important organs. If a crop plant is not able to allocate a major proportion of the fixed carbon into yields, high photosynthetic rates would not translate into increased food production.

1.7.2 Fruit set

1.7.2.1 Introduction

Fruit set is a key factor in the production of tomatoes. The fruit yield of a tomato plant is determinated by both the number and weight of individual fruit. Therefore, high yields of tomatoes depend on proper fruit set and development. After the commencement of flowering, the ovarian tissues, comprising the fruit organ of the tomato, already possess a great number of cells, which will be reflected in the mature fruit. Wolf and Rudich (1988) reported that in processing tomatoes, anthesis of most flowers takes place during the second week of flowering. They found that although the proportion of fruit set is lower during the second week of flowering than during the first week, the major part of the fruit number yield comes from these fruits. In a research on flower and fruit development in processing tomatoes, Julian (1990) found that flowering commenced 40 days and ceased 88 days after transplanting, and the peak of the number of flowers opening per day was 28.5 days from commencement of flowering. For the number of flowers opening per day which produced fruit, the peak occurred at 21.5 days from commencement of flowering and for flowers which produced fruit ceased after a total of 38 days.

The processes involved in fruit-set are (Stevens and Rudich, 1978; Picken, 1984): 1) production of viable pollen and development; 2) pollination--transfer of pollen to the

stigma; 3) germination of the pollen grains; 4) growth of the pollen tube down the style; 5) ovule production and 6) fertilisation-- the union of the male gamete with a viable ovule; and 7) fruit initiation. All of these processes are temperature sensitive. In the research of Charles and Harris (1972), they found that at low temperatures poor fruit-set is caused primarily by poor pollen viability and probably also slow pollen tube growth, because if the growth of tube is slow during pollen germination, the ovules may deteriorate before the pollen tube reaches the ovule. At high temperatures poor fruit set is due primarily to the high stigma level in the anther cone, which decreases the opportunity for pollen to reach the stigma. High temperature susceptibility depends largely on the stage of development of flowers (Sugiyama, *et al.*, 1966): flower buds 9-5 days before anthesis and flowers 1-3 days after anthesis being highly susceptible; flower buds 1-3 days before anthesis being rather tolerant to high temperature.

Pollination and fertilisation are decisive processes in fruit set because final fruit weight is generally related to seed number (Ho and Hewitt, 1986). Night temperatures of about 16-20°C are considered adequate for most cultivars, below 13°C then pollination and fertilisation are severely affected (Tindall, 1983). Low viability of pollen (due to low light and low temperature) and poor transfer of pollen may be the principle causes of poor fruit set (Rudich *et al*, 1977).

1.7.2.2 Pollen production and development

1.7.2.2.1 Effects of temperature on pollen development

There is evidence that high temperatures are detrimental for pollen production. Rudich, *et al* (1977) found that even a few hours of high temperature (over 40°C), at the critical stages of gametogenesis, can adversely affect the viability of ovules and the production, dehiscence and transfer of pollen. Sugiyama, *et al.* (1966) and Picken (1984) reported that in normal stamens, meiotic division of microspore mother cells occurred 9 to 8 days before anthesis, but pollen grains were liberated about 7 days before anthesis. When flower buds in which cell divisions were occurring (i.e. 9 to 8 days before anthesis) were treated with high temperature (40°C), the degeneration of pollen tetrads was induced. Thus many pollen grains after liberation from the treated flower buds were empty.

Anthers treated 3 to 7 days before anthesis contained 50% - 20% empty grains. Injury to pollen was still severe when plants were exposed to high temperature five days before anthesis, when pollen grains were developing, but there was little injury to mature pollen when plants were treated between 3 days and 1 day before anthesis (Picken, 1984). Pollen viability can also be reduced by extreme temperatures, which adversely affect its subsequent germination. For example, Stevens and Rudich (1978) found that the percentage of germinating pollen grain is greatly reduced at temperatures outside the range of 5-37°C, and night temperatures below 13°C caused the formation of abnormal or empty pollen grains resulting in no fertilisation (Kemp, 1965). Stevens and Rudich (1978) found that pollen production and fruit setting ability was greatly reduced and dehiscence impaired in many genotypes with high temperature of 38°/27°C.

1.7.2.2.2 Effect of light on pollen development

When tomato plants grew under very poor light conditions (in a greenhouse in the UK winter at 20°C day and night) there was a reduction in carbohydrate supply and meiosis was abnormal in some pollen mother cells. Even within one locule of an anther there were some grains which had stared to develop normally, but then degenerated. When normal microspore development had ceased at an early stage, the pollen grain at anthesis was shrunken and irregular. These grains were probably viably until just before anthesis, but that viability was lost in response to carbohydrate stress at this time (Picken, 1984).

1.7.2.3 Pollination

Several hundred pollen grains may be released from an anther loculi when the anther dehisces 1 or 2 days after anthesis. At dehiscence in the tomato the anthers open to allow the pollen grains to fall on to the stigma, either by degradation of the middle lamella of the epidermal cells, or by degradation of the entire epidermal cell walls or by mechanical rupture of the epidermis due to the hygroscopic action in a layer of fibrous cells in the anther wall (Hayward, 1938). Once pollen grains adhere to the stigma, pollen tubes start to grow within one hour and can reach the micropyle of the ovule within twelve hours at 25°C (Dempsey, 1970).

At higher humidity pollen tends to remain inside the anthers, whereas at lower humidity it may not adhere to the stigmatic surface (van Koot and van Ravestijn, 1962). If the relative humidity is below 70% or the temperature is outside the range 17°-24°C, the adherence of pollen on the style may be reduced. In the range between 50 and 90%, the effects of relative humidity are small (Kretchman, 1968) and it may not be possible to dissociate them from the effects of other factors such as irradiance and temperature.

Pollination can be adversely affected by abnormalities in flower structure (Section 1.4.1.3). Successful transfer of pollen grains to the stigma is dependent on the length of the style. The length of the style is both genetically determined and affected by growing conditions (Rudich *et al*, 1977). It has also been observed that the number of pollen grains retained by the stigma was higher at 24°C and 17°C than at higher or lower temperatures (van Ravestijn, 1970).

In practice, poor pollination is regarded as a major cause of incomplete fruit set and undersided fruits. Improving methods of the pollination to achieve a high percentage of fruit set in greenhouses include daily vibration by an 'electric bee', tapping, air-blasting or hose-jetting on the inflorescence. In the field, extreme temperatures, such as high temperature at night (over 26°C) or during the day (over 40°C) and low temperature (below 10°C) at night are most damaging (Rudich *et al*, 1977).

1.7.2.4 Germination of Pollen Grains

Pollen shown to be germinable in optimum conditions may not germinate under adverse conditions. The time taken for pollen to germinate depends on the temperature and has been shown to vary from 0.5 h at 37.5°C, 1 hours at 25°C, 5 hours at 10°C, to 20 h at 5°C (Picken, 1984; Ho and Hewitt, 1986). Germination was severely decreased at temperatures above 37-38°C (van Ravestijn, 1970) or below 5°C (Dempsey, 1970). Neither light intensity nor relatively humidity (at least over the range from 50-90%) appeared to affected germination. Pollen germination in vitro was best at 27°C (Abdalla and Verkerk, 1968), the best temperature range for pollen germination was 21°-27°C and for fruit set 18°-24°C (Kemp, 1965).

1.7.2.5 Pollen tube growth

Pollen tube growth in tomato can take about 12 h to 50 h after pollination, depending on temperature, for example, at 20°C, the longest pollen tubes were shown to have already reached the micropyles only 12 h after pollination (Picken, 1984). Stevens and Rudich (1978) and Picken (1984) reported that the growth rate of the pollen tube increases with temperature between 10°C and 35°C, but is reduced outside this range. Tube growth of pollen at high temperatures (35°/25°C--day/night temperatures) was slower than for normal temperatures (22°/18°C) (Abdalla and Verkerk, 1968). At temperatures below 10°C pollen tube growth may be too slow to effect fertilisation (Dempsey, 1970). With hand pollinated with viable pollen during the day or in the evening, pollen tubes reached the base of the style in 6 hours, but took 12 h if pollinated in the early morning (Picken, 1984).

1.7.2.6 Ovule production

Picken (1984) reported that megaspore meiosis in the tomato occurred about 1 day after meiosis of the microspore mother cells at 20°C, and that it is rare for all viable ovules to be fertilised because, even with heavy pollination, additional pollen was still able to increase the number of seeds in a fruit. Light and high temperature can influence ovule development. Low light may reduce the size of flowers and ovules, but there is little information about ovule viability. However under low winter light conditions, abnormal flowers with incomplete petals, stamens and pistils are frequently observed on the first two inflorescences and ovule development in such flowers ceased before or soon after formation of the embryo sac (Veselova, 1977).

Exposure to 40°C for 3 h on two successive days impaired ovule viability in plants otherwise grown at 20°C. If flowers were exposed to high temperatures 7-9 days before anthesis, at about the time of meiosis in the ovule mother cells, poor ovule viability occurred, which was a prime cause of poor fruit set (Picken, 1984).

1.7.2.7 Fertilisation

Pollen must adhere to the stigmatic surface in order to achieve fertilisation. Fertilisation will occur once the nuclei from the pollen tubes penetrate viable ovules (Ho and Hewitt, 1986). Fertilisation by nuclei from the first pollen tubes occurred 18 h after pollen germination in summer light conditions at 20°C and a number of the ovules were fertilised within 30 h of pollination (Iwahori, 1966). The bi-nucleate endosperm was observed after 48 h and eight- nucleate endosperm after 96 h. A two-celled pro-embryo was seen after 96 h and a ten-celled pro-embryo after 120 h (Picken, 1984).

Fertilisation may not however take place if the ovule has already deteriorated due to high temperature at the megaspore mother cell stage, about 9 days before anthesis. Fertilisation is not greatly affected by growing conditions, although the endosperm can deteriorate at high temperature (40°C) between 24 and 96 hours after pollination. The number of fertilised ovules is determined by the number of germinating grains and by the successful growth of the pollen tube reaching the micropyles of the ovules. When plants were grown at 20°C and exposed to 4 h at 40°C between 24 to 96 h after pollination, degeneration of the endosperm and, less frequently, damage to the pro-embryo was seen (Iwahori, 1966).

High temperature seemed to be harmful not only to pollen germination and tube growth, but also to fertilisation and fertilised eggs (Sugiyama, *et al.*, 1966). The critical temperature range for pollen germination, tube growth, and fertilisation was 15°-18°C (Kemp, 1965). Abdalla and Verkerk (1968) reported that at high temperatures of 35/25°C flower drop was increased and only 50% of the fruit developed on the first two inflorescences. This effect of the high temperature may be reversed by application of CCC. Abdalla and Verkerk (1970) reported that when CCC was applied to the soil at the start of flowering, it reduced flower drop, increased fruit-set and development, and decreased the competitive restriction of fruits in the first inflorescence at the high temperature. Charles and Harris (1972) found that low fruit-set when temperature was less than 12.8°C (same day and night temperatures) was due mainly to poor pollen viability and germination, and to a lesser extent to high stigma position in the antheridial cone; and that when temperature was more than 26.7°C (same day and night

temperatures), the high level of the stigma in the antheridial cone was the main factor reducing fruit-set, but low stigma receptivity was also a factor in some cases.

1.7.3 Fruit growth and development

1.7.3.1 Fruit structure and characteristics

A tomato fruit is a berry consisting of seeds within a fleshy pericarp developed from an ovary (Figure 1.7). Fruit of tomato (*Lycopersicon esculentum* Mill.) usually possess two to several carpels. Tomato fruits consist of skin with pericarp walls (called flesh) and placenta and locular tissue including seeds (called pulp). The pericarp which arises from the ovary wall is composed of an epicarp, a parenchymatous mesocarp with vascular bundles and a single-celled layer of endocarp lining the locular. Ho and Hewitt (1986) reported that the epidermal cells in green fruit tend to have less starch than the inner parenchymatous cells. Most of the cell division in the pericarp occurs during the first week after anthesis. The number of cell layers of the pericarp increase from 8 to 30.

The fruit epicarp is composed of the outer epidermal layer plus two to four layers of thin-walled hypodermic cells with collenchyma-like thickenings. The epidermis is covered by a thin cuticle which is composed of a layer of cutin covering the epidermal cells and an overlaying cuticle. The genotypic differences in pericarp and epicarp anatomy are relevant with economically important characteristics. For example, the easy peeling characteristic is related to both the disintegration of parenchyma cells and more intercellular air spaces below the hypodermis, whereas the crack resistance of the 'sticky peel' mutant is associated with a highly elastic skin which may be due to the absence of the hypodermis (Ho and Hewitt, 1986).

Wolf and Rudich (1988) reported that growth of tomato fruit is characterised by cell division during the first week after anthesis, followed by cell elongation for the next 6-7 weeks. Fertilisation of the ovules indicates the commencement of fruit growth for seeded tomato fruit. The time required for a fertilised ovary to develop into a red ripe tomato

fruit is between 7 and 9 weeks, depending on cultivar, position on a truss and the environment (Ho and Hewitt, 1986).

1.7.3.2 Physical changes during fruit growth and development

During the early stage of fruit development, the placenta (Figure 1.7) starts to expand into the locules to envelop the seeds within the first 10 days and occupies the whole locular cavity in the following few days. In immature fruits, the placental tissue is firm, but as the fruits mature, the cell walls begin to break down, and the locular tissue of mature green fruit is jelly-like. At later stages, intracellular fluid may accumulate in the locules (Ho and Hewitt, 1986). Ho and Hewitt (1986) reported that there are two major branches of the vascular system in tomato fruits, one expanding from the pedicle through the outerwall of the pericarp and the other passing through the inner and radial walls to the seeds. Generally the vascular system is a closed network with very few blind endings.

The rate of fruit growth is slow during the first stage, accelerates during the second and declines in the third. The early slow growth results from cell division and initial cell enlargement, whereas the following rapid growth is entirely due to cell enlargement (Ho and Hewitt, 1986). Many researches in fruit development showed that growth rate and physical changes occurred with fruit growth. Although the absolute growth rate is low initially, the relative growth rate of fruit volume increases sharply to a maximum of 0.8 ml ml^{-1} day^{-1} by the end of the first week and then declines logarithmically over the rest of the growth period (Ho and Hewitt, 1986). While the cumulative growth rate increases over the rapid growth period, the daily import rate of carbon diminishes from 140 mg to half this value as the fruit increases from 20% to 90% of its final carbon content (Walker and Ho, 1977a). The cessation of assimilate import occurring about 10 days after the first change of colour is caused by the formation of the abscission layer between the calyx and the fruit.

Fruit swelling dose not always follow fertilisation and fertilised fruit sometimes abscise or temporarily cease to swell (Davis *et al*, 1965). Ceasation of growth in fertilised fruits

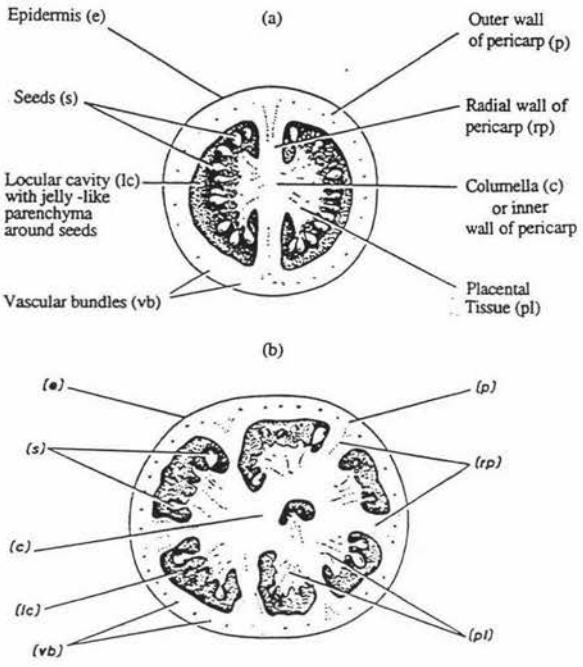

Figure 1.7 Anatomy of tomato fruits with (a) bilocular or (b) multilocular structure (after Ho and Hewitt, 1986)

is occasionally induced by adverse environments such as high temperature and high light. It can also be induced by competition with other fruits. The distal fruits of an truss are smaller than the proximal (Bangerth, 1989) and the last fruit may be slow or may fail to swell, due to competition with its neighbours for assimilates. Sometimes all of the fruits on a truss show a delay in swelling under conditions of severe competition with other trusses of fruits (Hurd *et al*, 1979).

The final size of a tomato fruit is closely correlated with the number or weight of seeds (Picken, 1984; Imanishi and Hiura, 1977) and the number of the locules (Imanishi and Hiura, 1977;) within a cultivar. For different cultivars, the ovule number per pistil varies from 250-1000 and the proportion of ovules developing into seeds varies from 20% to 50% with a higher proportion when there are fewer ovules (Mihailov, 1975). There is a significant correlation between seed number and final fruit weight within a cultivar, but the relationship is different among trusses of the same crop or under different growing conditions (Rylski, 1979).

1.7.3.3 Chemical changes during fruit growth and development

The dry matter content, which is expressed as a percentage of fruit fresh weight, decreases as increasing amounts of water are accumulated. Prior to fertilisation, dry matter accounts for 17% of the ovary weight. Once the fruit starts its growth, the dry matter content declines to less than 10% by 10 days and then to 5-7% by 20 days,

remaining at this level to maturity. The carbon content, which is based on a percentage of dry matter content, does not change substantially but remaining at about 39% throughout. Potassium (K) together with nitrogen (N) and phosphorus (P) account for more than 90% of the total mineral content. During fruit development, both P and N reduce slightly, whereas K remains constant (Ho and Hewitt, 1986).

Sugars (mainly glucose and fructose) account for about half of the dry matter or 65% of the total soluble solids of a ripe tomato fruit. Hewitt and Stevens (1981) found that the content of total soluble solids was positively related to the ratio of leaf area to fruit number, but inversely related to fruit yield (Stevens and Rudich, 1978). Much researches support this view (Stevens, 1979; May, *et al.*, 1990). When fruiting starts, the content of reducing sugar increases from 0.1% of ovary fresh weight to 2% of the fruit fresh weight within 2 weeks and then to 3.5% at ripening. The sugar content is higher in the wall than in the locules (Winsor *et al,* 1962).

The rate of starch accumulation during the rapid growth period has a great influence on the final content of total soluble solids (Ho, *et al.*, 1983b). The maximal starch content accounts for 20% of the dry matter 25-30 days after anthesis (Tanaka, et al, 1974a; Ho, *et al.*, 1983b). Starch starts to decompose when the fruit absolute growth reaches its maximum and the starch content is about 1% dry matter at the mature green stage (Ho, *et al*, 1983b) or 0.03% fruit fresh weight at ripening. The organic acid content based on a percentage of fruit fresh weight, increases during fruit development and the pH of the sap of a mature green fruit is about 4. The organic acids in a tomato fruit are composed mainly of citric and malic acids and accounts for 13% of the dry matter. Malic acid prevails during early growth whereas citric acid account for only 25% of the total acidity (Davies, 1961).

1.7.4 Possible mechanisms of fruit set and development and parthenocarpy formation

Fruit set is triggered off by hormones contained in pollen grains and fruit development is stimulated by hormones synthesised mainly of seeds (Mapelli *et al.*, 1978). There is

evidence of hormones, such as auxin, gibberellins, being involved in fruit set and development (Ho and Hewitt, 1986; Mapelli *et al.*, 1978; Gustafson, 1960). The exogenous auxin content of seeds reaches a peak about 7 days after anthesis, which corresponds with the start of fruit swelling. A second peak was observed after 30 days. In a research on the effects of activities of growth regulators on tomato fruit set and development, Mapelli *et al.* (1978) found similar results, with peaks of auxin occurring at 10 and about 27 days after anthesis. Auxin and gibberellin were also present in the first week after anthesis and their activities are involved in fruit setting. High auxin activity was observed only in seeded fruits 20-40 days after anthesis, and it was probably synthesised by seeds. Exogenous auxins are used to increase flowering and fruit set. Gibberellin activity is present, corresponding to the change in fruit development from the mature green to pink stages.

Parthenocarpy in tomato can arise naturally or be induced artificially. Natural parthenocarpy results from genetic causes and may be obligatory or facultative. Obligatory parthenocarpy is as a result of genetic sterility and requiring vegetative propagation; whereas the expression of facultative parthenocarpy is dependent upon environmental conditions. The size of parthenocarpic fruit is smaller than normal fruit (Picken, 1984; Mapelli *et al.*, 1978). The smaller size of parthenocarpic fruits can be attributed to a lower cell enlargement. Mapelli *et al.*(1978) reported that gibberellin and auxin activity rise in parallel with pollination and fertilisation, which in tomato occurred 2 days and 6 days after anthesis respectively. A threshold concentration was necessary for parthenocarpic fruit development. They also found that the auxin peak, in both parthenocarpic and normal fruit corresponded to the end of cell division and the initiation of cell enlargement. . In normal tomatoes, gibberellin and auxin peaks are clearly present at 20 and 27 days after anthesis respectively. In parthenocarpic fruits, auxin activity increase very slowly until ripening, which may be attributed to the degeneration of ovules (Ho and Hewitt, 1986; Mapelli *et al.*, 1978). Gibberellin activity in the first week after anthesis was higher in mutant than in normal fruits, indicating that gibberellin activity may be involved in the setting of parthenocarpic fruits.

1.7.5 Effect of environmental factors on fruit set, growth and development

1.7.5.1 Temperature

Fruit-set is usually poor when the temperature is either relatively low or high (Kuo *et al*, 1979). The critical factor in tomato fruit-setting is the night temperature (Tindall, 1983). The optimum night temperature for fruit set is in the range of 13-24°C in most cultivars (Anon, 1990; Schaible, 1962). Schaible's (1962) study showed that when night temperatures were over 17°C, fruit size declined as night temperatures increase. The optimum day temperature for fruit set is in the range of 13-26.7°C (Charles and Harris, 1972). Fruit-set was greater at 24°C than 16°C. When the average maximal day temperature is above 32°C, and average minimal night temperature is above 20°C, fruit set is low. Many cultivars suffer severe blossom drop when exposed to day/night temperatures of 26/20°C and temperatures of 30/20°C prevent fruit set (Stevens and Pudich, 1978; Malone, 1981).

Walker and Ho (1977b) found that for fruit having 30% of final their size, the rate of carbon import by cooled fruits (5°C) was far lower than by control fruits (25°C), Fruits at 35°C accumulated carbon at a significantly higher rate than those at 25°C. They reported that under fruit temperatures of either low (5°C) or control (25°C), starch and the non-starch insoluble residue were directly related to the carbon translocation rate. The rate of starch and the non-starch insoluble residue accumulation increased as the rate of carbon import increased, and were therefore higher in the control (25°C) than in the cooled fruits (5°C). A simplified scheme of carbon metabolism in the fruit consisted of initial hydrolsis of imported sucrose and subsequent utilisation of hexoses in respiration or in the further conversion (from hexoses to carbohydrates, amino acids, such as aspartic acid and glutamic acid, and organic acids, such as malic acid and citric acid), starch and insoluble residue were the major products (Walker and Ho, 1977a). The effect of fruit temperature on translocation was due to modification of the fruit's carbon metabolism (Walker and Ho, 1977b). The enhanced import rates in fruits maintained at 35°C were associated with less sucrose accumulation, implying greater rates of sucrose hydrolysis; hexoses accumulated more than in controls (25°C), but there was a net loss

of reserve material due to the breakdown of starch at the higher temperature. The change in the rate of assimilate import by fruit temperature can be attributed to affecting the rates of respiration and starch synthesis within the fruit (Walker and Ho, 1977b; Walker and Thornley, 1977). Temperature also influences the rate of pigment synthesis during ripening, and thus uneven pigmentation can be caused by a localised temperature effects on a fruit (Koskitalo and Ormord, 1972). A diurnal variation of at least 5-6°C, within the range of 21-27°C , is necessary for optimum growth and development; this is partly related to the maintenance of a suitable carbohydrate/nitrogen balance in the plant and the functioning of the auxin regulatory system in stimulating both growth and fruit setting (Tindall, 1983).

Temperature also influences the transport of assimilates in a plant. As fruit temperature can affect the rates of respiration and starch synthesis in the fruit and thus it also alter the rate of assimilate import. When temperatures are below 12°C, plant growth is seriously hindered (Yoshioka *et al.*, 1977; Tindall, 1983), and both the export of assimilate from the leaves (Yoshioka *et al.*, 1977) and the absorption of nutrients by the roots (Tindall, 1983; Moorby and Graves, 1980) is greatly decreased. More assimilates are transported to fruiting trusses at the expense of roots at an air temperatures of 30°C/24°C (day/night), whereas more are transported to roots at the expense of fruiting trusses at 17°C/12°C. In consequence, plants grown at 17°C/12°C are small, but more dry matter is accumulated in the lower part of the stem and roots. When day temperatures are constantly at 18°C, high night temperatures of 18°C increase import by the fruit, whereas low night temperatures of 8°C increase import by the stem and roots (Ho and Hewitt, 1986).

1.7.5.2 Light and CO_2

Both the size and the total soluble solids content of tomato fruit are strongly affected by solar radiation. When the light level is low during the early growing season, the proportion of hollow fruits in the first few trusses is high and the dry matter of the fruit is also low. Conversely, when the solar radiation is high both dry matter and sugar content of the fruit are high. There are direct light effects on fruit metabolism, such as on CO_2

fixation (Davies and Cocking, 1965), protein synthesis and pigment synthesis(Ho and Hewitt, 1986). CO_2 enrichment increases fruit yield by increasing the number and weight of fruit in greenhouse, but the chemical composition of the fruits in commercial crops is not markedly affected. Madsen (1976) reported that there is a slightly increase of sugar and potassium with a decreased titratable acidity and lowered contents of nitrogen and phosphorus in fruit enriched with CO_2.

1.7.5.3 Water and nutrients

1.7.5.3.1 Water

Wolf and Rudich (1988) reported that water stress shortened the duration of fruit growth and accelerated ripening. High water stress during plant development can seriously reduce yield. Thus water stress reduced fruit size mainly as a result of a shorter fruit growth period. In a research of moisture stress as it affects yield, soluble solids and viscosity with processing tomatoes, May *et al.* (1990) found that soil moisture depletion levels of 40% and 60% in the top 1.2 m gave rise to minimal yield losses and significant increases in percent solids, however depletion levels over 60% resulted in serious yield losses. Yields were highest on the 20-day cut-off (terminating irrigation 20 days prior to harvest) and decreased with the 60-day cut-off. They suggested that through a good moisture stress management program, one can maintain yield, while increasing solids without decreasing viscosity and being easier for grower to manage (May *et al.*, 1990).

Smajstrla and Locascio (1994) found that the main effect of deficit irrigation was a reduction in the amount of the highest-quality extra-large fruit because the total number of fruit per acre tended to decrease with larger irrigation deficit (45%). Extra-large and marketable fruit yield were reduced up to 31% and 13%, respectively. Irrigation is a necessary production practice as total marketable fruit yield was doubled by irrigation, while yields of the highest-value extra-large fruit were tripled by irrigation (Smajstrla and Locascio, 1994).

Locascio *et al* (1985) report that the frequency of water application had no influence on total fruit yield, while the water quantity applied had a greater influence on fruit production than the number of daily application. In the research of growing tomatoes

with polyethylene mulch by Locascio *et al* (1989), they found that tomato water requirement is about 0.5 time pan evaporation on the fine sandy soil, but between 0.5-1.0 time pan on the fine sandy loam soil. The response of early fruit yield to water quantity depends on growing region and soil type or the interaction between them and year. Wolf and Rudich (1988) stated that water deficit takes place in the plant when the transpiration exceeds absorption, and is accompanied by an inhibition of growth and development. They found that the damage to plant production mainly takes place when turgor pressure falls and cell elongation ceases. As the turgor pressure continues to falls, stomata close and photosynthesis declines. Continuous stress is accompanied by impairment of enzymatic activities and changes in assimilate partitioning, hormone activities and cell metabolism. Fruit size can also be manipulated by controlling the electrical conductivity of the nutrient solution in water culture, such as with the nutrient film system (Ho and Hewitt, 1986).

1.7.5.3.2 Nutrients

Potassium accounts for over 85% of the cation in tomato fruit (Hobson and Davies, 1971). The level of potassium supply affect the acidity, colour and shape of fruit. Davies and Winsor (1967) reported that increasing supply of potassium fertilisers significantly increased the titratable, total and combined acidities, potassium content and specific conductivity of the expressed fruit juices Potassium accumulation is proportional to that of the dry matter in tomato fruits. This relationship varies according to the level of potassium supply and the growing conditions. Ho and Hewitt (1986) reported that with a high potassium supply, the acidity increases and the colour and shape of the fruits improve, while at low potassium supply, the growth period of a tomato fruit is shortened and the maximum climacteric respiration is intensified. Potassium concentration certainly affect the metabolism of the imported assimilates in the fruit although the promoting effect of potassium on the import of assimilates is debatable.

Nitrogen applications significantly depressed the sugar content of the fruit, but potassium and phosphorus had little effect. The effects of nitrogen were no so pronounced and with respect to acidity, potassium content and specific conductivity, were affected by the level of potassium applied (Davies and Winsor, 1967).

Phosphorus reduced the acidity potassium content and specific conductivity, particularly at low potassium levels (Davies and Winsor, 1967).

1.7.5.4 Effect of defoliation and removal of floral buds (or trusses) on fruit load

It is well known that there are competition effects between fruit trusses on a tomato plant. Slack and Calvert (1977) investigated the effect of removing individual truss on tomato yield. They found that removing a truss gave rise to yield increases on some of the remaining trusses both above and below the one removed, the largest increases occurring on the trusses adjacent to the removed truss with successively smaller increases on the more distant ones. The total yield from plants reduced to 9 trusses varied from 91% to 99% of the yield from the control plants with 10 trusses, depending on the position of the truss removed. Accordingly, they suggested that most of the translocated material received by a truss was derived from the leaves in its immediate vicinity. Also that the removal of a truss sink results in apical and basal movement of the available assimilate to the remaining trusses, perhaps through the internal and external phloem. Previous findings of Bonneman (1965, as cited by Slack and Calvert, 1977) supported this suggestion. Many studies on the effects of flower and foliage removal on the subsequent development of tomato plants indicated an inverse relationship between fruit load and vegetative growth. Veliath and Ferguson (1972) observed the effect of deblossoming on fruit yield and earliness in tomato, found that deblossoming of a determinate cultivar after 4, 5 and 6 truss stages significantly increased average fruit weight and yield. Removal of late formed flowers tended to delay maturation of fruits, which was probably due to increased vegetative growth and the larger size of the remaining fruits.

1.7.6 Photosynthesis

Green plants are able to absorb the energy in sunlight and subsequently convert it into chemical energy, which they then store for future use as organic carbon compounds. The light-driven anabolism of carbon dioxide is termed photosynthesis (Foyer, 1984). Green

parts of tomato plants are essentially solar collectors where chlorophyll and other specialised molecules capture the energy of sunlight. In photosynthesis, the energy is used to combine water from the soil with CO_2 from the air to form carbohydrates (sugar and starches, Figure 1.8; Anon, 1990), Oxygen from the water molecules is released into the air. The carbohydrates may be used immediately in the metabolism of the plant, they may be modified and stored as starch to be used later, or they may be concentrated in certain parts of the plant, such as the fruit. Carbohydrates are used as building blocks for many other compounds; these include structural compounds like cellulose as well as pigments and flavour compounds. The rate of photosynthesis is affected by many exogenous (such as light intensity, CO_2, temperature, etc.) and endogenous (such as anatomical structure, chlorophyll content, etc.) factors.

In tomatoes there may not be a causal relationship between chlorophyll content and carboxylation efficiency (CE), but these two characteristics are closely related (Augustine *et al*, 1976). Leaf thickness was greater in the high carboxylation efficiency genotypes than in the intermediate CE cultivars, and differences in the rate of photosynthesis between genotypes were positively correlated with specific leaf weight and CE. The high CE genotypes had much greater percent air space in the palisade tissue and much longer palisade cells than the intermediate CE cells. Conversely the number of palisade cells cm^{-2} was much less in the high CE genotypes, indicating that differences in gaseous diffusion potential may in part account for genotypic differences in CE (Augustine *et al*, 1979). Augustine *et al* (1979) observed that a positive relationship existed between CE and

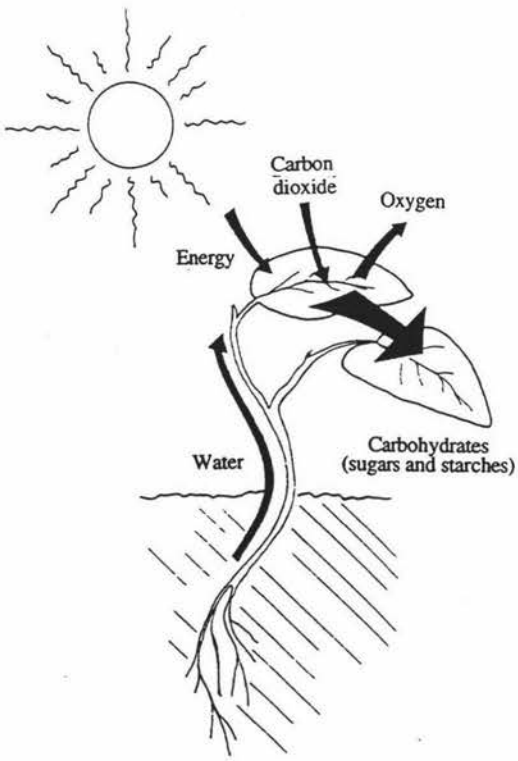

Figure 1.8 Illustration of photosynthesis

RGR for various tomato genotypes, but that a high RGR may not always coincide with a high photosynthetic activity.

Heuvelink and Buiskool (1995) reported that negative feedback control of photosynthesis caused by small sink demand was governed by accumulation of assimilates (either sugars or starch, so-called end-product inhibition) and hormonal mechanisms, influencing, for example, stomatal or mesophyll resistance. In a research with tomato genotypes under low light intensity and low night temperature, van de Dijk and Maris (1985) found that the photosynthesis on a leaf area basis was not affected by the night temperature. Net photosynthesis on a fresh weight basis was lower under the lower night temperature. The average rate of net photosynthesis was low due to low light intensity and seven-fold higher values have been found for tomato under high light intensity by previous researches (van de Dijk and Maris, 1985). van de Dijk and Maris (1985) reported that variation of net photosynthesis in tomato under optimal conditions, where light intensity and temperature were not limiting plant growth, was not related in any way to dry matter production. They ascribed this to changes in other characters of the plant, such as leaf area ratio, rate of dark respiration, rate of decrease in net photosynthesis as the leaf ages and different rates of net photosynthesis at different stages of development. Gosiewski, *et al* (1981) found that the rate of photosynthesis may exceed the rate of transport of the formed assimilates towards the growing points elsewhere in the plant with field-grown tomato at high light intensities. In this situation accumulation of assimilates within the leaf may occur, which in turn may reduce net photosynthesis via an increase in photorespiration and /or a closing of the stomata. A genotype with a more favourable internal transport system of assimilates might maintain a steady rate of photosynthesis for a longer period. They reported that the decline in net photosynthesis may be due to an increase in photorespiration, however, some results have indicated that in tomatoes at a high CO_2 concentrations (1474 mg m^{-3}) that CO_2 absorption at 20% and at 1% O_2 is almost the same. The decrease in photosynthesis could be due also to a closure of stomata as a result of water stress. The relatively stable rate of tomato photosynthesis may be connected with continuous growth of vegetative organs, even during rapid growth of tomato fruits. Tanaka, *et al* (1974b) reported that tomato leaf is itself one of the most important acceptors for its own assimilates. When plants do not form fruits, the photosynthates are deposited in the leaves, causing their

thickening, and also in the stem, which under ordinary conditions, did not act as a so strong sink. Tanaka (1974a, c) concluded that in tomato plants the photosynthetic potential of the whole plant exceeds usually the current demand for assimilates for both growth of vegetative organs and development of fruits.

According to many research results, Starck *et al* (1979) suggested that photosynthesis is not controlled by the reproductive sink per se, it may be affected by plant growth regulators produced by fruits or other organs. The effect of fruits on hormonal balance in leaves has been observed in plants. For example, leaves in close proximity to developing fruits contain much less ABA and have a lower stomatal resistance than leaves distant from the fruits. An increased level of ABA and phaseic acid as a result of fruit removal has been observed in many plants. An Increase of cytokinin and decrease of gibberellin content in leaves of plants deprived of fruits was reported by some researchers (Starck *et al,* 1979). In tomato the mechanism controlling photosynthesis by product inhibition as well as by hormones deserves more study.

1.7.7 Assimilate distribution

In tomatoes, the main labile assimilate is sucrose, which accounts for 90% of the ^{14}C exported by the leaves (Walker and Ho, 1977a). The sucrose is transported along the phloem from the leaves or other sources to the fruit or other growing organs. Assimilate distribution to the various growing organs is determined by the relationship and the physical link between the suppliers and the receivers of assimilates (Ho and Hewitt, 1986). Khan and Sagar (1967) reported that in the tomato there were two phloem systems to deal with different directions of transport, and from this it would follow that each leaf, is exporting upwards in the internal phloem and downwards in the external phloem, would be in ready communication with every sink. A growing leaf imports assimilates through the internal phloem and export them through the external phloem. It also changes from a net importer to a net exporter. When the first truss is flowering, the younger leaves above the inflorescence export chiefly to the roots, while the inflorescence is supplied chiefly by the older leaves below. At fruiting, the truss import assimilates through both the internal and external phloem from leaves both below and

above (Ho and Hewitt, 1986). Khan and Sagar (1967) found that the first truss was a major sink for assimilates from all the leaves and the direction of export of materials by a leaf was primarily determinated by the position of the first truss. The leaves closest to this truss were its most important suppliers. The middle group of leaves supplied more carbon to the roots than did the lower group. Significant quantities of radioactive carbon were recovered from stems and more of this came from lower and upper leaves than from leaves close to the first truss. Both sucrose and starch are the important products of carbon fixation in tomato leaves. While starch is stored in the chloroplast, sucrose is either stored in or exported immediately from the mesophyll cells. Reduction in sink demand immediately reduces the export of sucrose and the demobilisation of starch and causes an increase in the accumulation of these two assimilates. The sucrose level would be maintained via hydrolysis and the surplus assimilate would be mainly stored as starch and hexoses. If the assimilate production is far higher than the sink demand, then the accumulation will be increased (Ho, *et al*, 1983a). Partitioning of assimilates between various fruits is determined by the strength of the different sinks (fruits) and the ability of the source leaves to supply the assimilates.

1.7.8 Partitioning of dry matter in tomato

The economic yield of a tomato crop is determined by the accumulation of fresh weight in the harvestable organs. Accumulation of fresh weight is to a great extent determined by accumulation of dry weight (Heuvelink and Bertin, 1994). Dry weight accumulation in the harvestable organs depends on the total among of assimilates available for growth (determined by photosynthesis and respiration) and on the dry-matter distribution among the plant organs (Heuvelink and Bertin, 1994). Most of the fruit dry matter is derived from leaf assimilates. Therefore, fruit growth is mainly determined by the import rate of leaf assimilates (Ho and Hewitt, 1986). Cooper (1972) observed partitioning of dry matter by tomato plant between roots, stem, cotyledons, leaves and reproductive tissue under greenhouse condition. He found that the proportional partitioning between component organs of the plant is controlled by a mechanism that is independent of the growth rate of the plant. The control of partitioning was such that initially it increased the proportion of the dry matter going to the leaves and stem and reduced the proportion

going to the cotyledons and roots. Almost immediately after flower initiation this pattern of distribution was altered, in that the proportion going to the leaves ceased to increase further and began to decline slowly. However, flower initiation did not coincide with any change in the steadily increasing proportion going to the stem or in the decreasing proportion going to the cotyledons and roots. Only leaf growth was affected. Consequent changes which took place in the control of partitioning coincide with the beginning of rapid ovary swelling. Firstly, the proportion of the dry matter going to the stem, which up to rapid ovary swelling had been increasing, started to decrease (Cooper, 1972). Secondly, the slow reduction in the proportion of dry matter going to the leaves decreased at a faster rate. However, ovary swelling did not coincide with any change in the steadily decreasing proportion going to the roots. Only leaf and stem growth were affected.

1.7.9 Source and sink relationships and their effects on tomato production

Crop plants are highly integrated systems consisting of multiple sources and sinks. The partitioning of assimilates between their sites of production in photosynthesising leaves and their sites of utilisation in harvestable region is a major determinant of crop yield (Giaquinta, 1983). Prochazka (1992) suggested that usually the source is an net exporter, such as mature young leaves from which sucrose and other substances are exported after being loaded into the phloem. While sinks are net importers, such as young leaves, apex, meristems, roots, individual fruit and storage organs, which are well often defined organs having a reproductive or storage function, and which import substances from the source. In the sinks substances are unloading from the phloem and used for growth and storage. Sink regions play a central role in determining assimilate distribution patterns (Wolswinkel, 1985). Photosynthesis of leaves is strongly influenced by sink demands because when the sink demand is low, sucrose builds up in the leaves, causing a product inhibition of photosynthetic reactions (Salisbury and Ross, 1992). Ho and Baker (1982) classified different sinks according to the nature of sink, the possible unloading pathway and the postulated control system involved (Ho and Baker, 1982). They described tomato fruit as a starch-sugar sink.

The improvement of yield can be made possible by improving both dry-matter production in the leaves and accumulation of dry-matter by harvestable organs (Ho, 1988). Fruit growth results mainly from the import of assimilates from the leaves (Wolf and Rudich, 1988). In crop production, there is either source- or sink-limiting situations or simultaneously there is source-limiting and sink-limiting situations. The higher photosynthetic capacity of crops is mainly achieved by increasing the light-intercepting area of leaves. By increasing the number of leaves and attaining a larger individual leaf area so that the leaf area index can become optimum. The higher dry matter accumulation capacity of harvestable organs have been achieved mainly by increasing either the number of organs or the size of individual organs. Daie (1985) reported that under either source- or sink-limiting conditions, sink strength is a major determinant of translocation rate, so that similar-sized fruits have similar import rate. Constant sink demand caused heavy loss of carbon even from leaves with minimal rates of carbon fixation. Sink strength determines assimilate allocation rather than assimilate availability or vascular connection between the source and sink. A rapidly growing sink produces a steeper gradient between source and sink, and it thus competes at advantage relative to a weaker sink. Hormones interact to modify the movement of assimilates towards activity sink regions.

Tomato fruit yield is a function of net assimilation rate of tomato plant (Ho, 1980). The rate of import into individual fruit appears also to be regulated by the metabolism of the fruit. Ho (1980) reported that the import into tomato fruits would be regulated by the sink strength of the fruit as well as the availability of the translocated assimilate and the resistance of the conducting tissue. The top tomato fruits at the tip of the truss may have lower potential sink strength as well as higher translocation resistance than the basal fruits because they were smaller than those developing earlier at the base of the truss (basal fruits). Such differences in the growth, which as a measure of apparent sink strength among fruits, persists even when the supply of assimilate is non-limiting and competition factors have been removed. This result suggests that the tomato production is sink limited. However, in a research on competition effects between fruit trusses of the tomato plant, Fisher (1977) found that the presence of subsequent trusses resulted in the reduction of both fruit number and mean fruit weight in a particular truss, which could be attributed to competition among trusses for available assimilates. The existence of such

competition effects demonstrates that yield is being limited by assimilate supply (i. e. source limited). He also found that as the fruit load increased, total dry-matter production increased, which could be attributed to as sink strength increased the net assimilation rate increased. In conclusion, fruit yield of tomatoes can be limited simultaneously by lack of both source and sink strength.

Wolf and Rudich (1988) suggested that sink strength, which expresses the ability of a particular plant organ to accumulate assimilates, is determined by the size and the activity of the sink. Sink activity can be expressed as the rate of dry weight increase per unit weight of sink tissue. They reported that the source supply exceeds the sink requirements in indeterminate tomatoes. However, determinate processing tomatoes have been selected to have concentrated fruit set and smaller leaf area, making it unlikely that there is an excess of source supply. Early-setting fruits appear to be stronger sinks than later ones, as reflected in their higher rates of dry-weight accumulation. However, it could be that the strength of the sink results from the larger size of the early fruits or from their greater sink activity. This may be explained by Bangerth's (1989) "Primigenic dominance" theory. He suggested that the earlier developed sink inhibits later developed organs because the polar IAA export of the earlier developed sink inhibits the IAA export of the later developed sinks and polar IAA export has been assumed as essential for a growing organ. Wolf and Rudich (1988) reported that an increase in size of the tomato fruit is accompanied by a proportionally greater reduction in its sink activity, giving rise to an overall decline in sink strength. When sink activity was expressed as the rate of dry weight accumulation per unit dry weight of fruit, no difference were found between the various fruits, suggesting that the greater sink strength exhibited by earlier fruits can be mainly ascribed to their larger size and they also have a longer period of growth.

Heuvelink and Buiskool (1995) reported that increased source activity, resulting from increased daily light integral in the summer, may allow an increase of the number of sinks, resulting from reduced flower and fruit abortion and an increase in side-shoots. However, the number of fruits per truss is rather constant during a large part of the season and truss appearance rate and fruit growth period are hardly influenced by sink-source ratio. Sink-source ratio can be manipulated by increasing or decreasing sink

strength (demand for assimilates) or source strength (supply of assimilates, i.e. crop photosynthetic rate), sink strength was decreased by pruning of fruit or truss. In commercially grown crops, fruits may grow larger at a small sink-source ratio than at a large ratio. At a small sink-source ratio, vegetative growth and leaf area were higher, whereas specific leaf area was reduced, i.e. leaves were thicker. When the number of fruits per truss was imposed by fruit pruning, tomato fruits grown on plants with 7 fruits per truss (source-limited fruit growth) reached only 70% of final dry weight of fruits grown on plants with one fruit per truss (sink-limited fruit growth). Increased source activity may increase leaf thickness, it may lead to strongly curled leaves, thus reducing light interception, or it may decrease leaf photosynthetic rate. They concluded that dry matter production was not affected by the sink-source ratio, whereas dry matter distribution between fruits and vegetative parts was greatly influenced. Plant development (number of visible leaves) was not influenced by the sink-source ratio. The effects of sink-source ratio on dry matter production per unit intercepted radiation and probably on leaf photosynthetic rate in commercial tomato production can be ignored.

1.7.10 Fruit maturation and ripening

1.7.10.1 Ripeness classes of tomato fruit

As colour is a indicator of tomato ripeness, several subjective evaluating scales and colour charts have been developed for classifying ripeness stages of tomatoes. Grierson and Kader (1986) introduced some classes of tomato ripeness included in the US standards (Table 1.2 and Table 1.3). These classes are used in the production of both fresh market and processing tomatoes.

Table 1.2 Ripeness Classes of Tomatoes

Score	Class	Description*
1	Green	Entirely light- to dark-green, but mature
2	Breaker	First appearance of external pink. Red or tannish-yellow colour; not more than 10%
3	Turning	Over 10% but not more than 30% red, pink or tannish-yellow
4	Pink	Over 30% but not more than 60% pinkish or red
5	Light-red	Over 60% but not more than 90% red
6	Red	Over 90% red; desirable table ripeness

* All percentages refer to both colour distribution and intensity (Grierson and Kader, 1986).

Table 1.3 Maturity Classes of Green Tomatoes

Score	Class	Description based on internal examination	Average number of days to reach the breaker stage at 20°C
1	Immature green (grass green)	Nor jelly-like material in any of the locules; seed are cut by a sharp knife upon slicing the fruit	>10
2	Particular mature green	Jelly-like material formed in at least one, but in less than all locules; seeds are well development	>5 to 10
3	Typical mature green	Jelly-like matrix in all locules: seeds are not cut by a sharp knife upon slicing the fruit	>1 to 5
4	Advanced mature green	Typical mature green with some internal red coloration	1

1.7.10.2 Changes in physiology and chemical composition during fruit ripening

1.7.10.2.1 Changes in chemical composition during fruit ripening

The transformation of a tomato fruit from the mature green to the fully ripe stage involves markedly changes in colour, chemical composition, aroma, flavour and texture (Grierson and Kader, 1986). The conversion of the mature green tomato into a red ripe fruit involves many complicated sequences of essential biochemical reactions (Stevens, 1979). In the process of ripening, changes of chemical composition produce the following: (a) The green chlorophyll pigments are degraded, and the yellow-orange carotenoid ß-carotene and red lycopene pigments are synthesised. *a*- and ß-carotene

reach peak concentrations at the breaker and light-red stage while red colour of ripe fruit is because of the subsequent rapid accumulation of lycopene (Grierson and Kader, 1986). The biosynthesis of these pigments are light and temperature dependent. Carotenoid and red lycopene development is promoted by red light and inhibited by far-red, indicating the process was under phytochrome control. (b) Starches are degraded, and glucose and fructose are produced. (c) The soluble pectins are increased resulting from wall softening and degradation. (d) Flavour and aroma compounds are produced. (e) The ratio of citric acid to malic acid is increased. Citric acid concentration increases to a maximum at the mature-green stage and maintains at this level during ripening, whereas malic acid concentration decrease. As a result, the ratio of citric acid to malic acid increases from 0.8 to 1.7 in the entire fruit during ripening and citric acid accounts for well over 50% of the total acidity in a ripe fruit (Davies and Hobson, 1981). (f) The concentration of glutamic acid is increased, and (g) Breakdown of the toxic alkaloid α-tomatin take place. Grierson and Kader (1986) suggested that many factors, such as irradiance, genotype and potassium nutrition during fruit growth, and temperature during ripening, influence colour, acidity and sugar content.

1.7.10.2.2 Changes in physiology during fruit ripening

Tomato fruit undergo a climacteric rise in respiration and ethylene production prior to attaining the red-ripe stage (Edwards, *et al.*, 1984). The physiological changes during fruit ripening has been well reviewed by Grierson and Kader (1986). The main physiological changes of tomato fruit during ripening is a stimulation of respiration and an increase in ethylene synthesis. Production of ethylene is associated with ripening of climacteric fruit, senescence, and plant response to stress under natural conditions (Farag and Palta, 1993). In intact, healthy tomato fruit, an increase in ethylene production (to 2-10 nl g^{-1} h^{-1}) only takes place at the initiation of the respiratory climacteric. Thus an increase in the synthesis of CO_2 and ethylene are normally the first indications of the onset of ripening. According to many researchers of biochemical reactions during fruit ripening, Grierson and Kader (1986) concluded that ripening was made up of a number of distinct processes and that they all tend to take place at the same time. The rise in endogenous ethylene production in climacteric fruit may actually cause the respiration increase and play an important role in ripening. Commercially, the best method for stimulating ripening is to treat harvested mature-green fruit with ethylene gas (Grierson

and Kader, 1986; Edwards, *et al.*, 1984) or to spray plants before harvest with the synthetic ethylene-generating compound ethephon (2-chloroethsulphonic acid, also called ethrel). Ethephon is an aqueous formulation that decomposes to ethylene and is widely used to maximise the yield of ripe tomato fruits in once-over harvesting operations (Farag and Palta, 1993).This chemical is absorbed by the plant and at *pH* 4.1 and above it breaks down to produce ethylene. Generally ethephon is applied some days before mechanical harvest of field-growth tomatoes or to end-of-season greenhouse crops (Grierson and Kader, 1986). When ethephon is applied to either the leaves or the fruit, ethephon promoted ripening of tomato fruit occurs (Splittstoesser and Vandemark, 1972). In the light of ethephon promoted ripening, when applied only to the leaves, Splittstoesser and Vandemark (1972) suggested that substances (ethephon) controlling fruit ripening were transported from the leaves along with the photosynthate and that ethephon triggers a maturation mechanism which effects the ripening process, but not ripening itself. The major disadvantages of ethephon (ethrel) are that ethephon induces chlorophyll degradation in leaves and stems (Splittstoesser and Vandemark, 1972) and it also causes some defoliation from the 2500 ppm or higher doses (Splittstoesser and Vandemark, 1972; Bussell and Dallenger, 1972).

1.7.11 Fruit quality for processing

1.7.11.1 Fruit quality attributes

Tomato Juice and other processing tomato products and tomato fruit contain significant amounts of several nutrients necessary for human nutrition (Malone, 1981). The major nutrients of tomatoes are vitamins A and C. Vitamin C activity in tomatoes is present as reduced ascorbic acid at 25 mg per 100g and it is therefore possible to meet all our vitamin C requirements from the tomato. Tomatoes are also a good source of vitamin A which is present as carotene. Tomato juice and fresh ripe tomatoes contain 1000 international Units of vitamin A per 100g. Tomatoes contain small amounts of B complex vitamins. Of the minerals present, tomatoes contain significant amounts of iron. Stevens (1979) reported that vitamin-C content was related to fruit size and shape a well as to locular content, and depends on the amount of light hitting the fruit and the amount

of fruit surface exposed to the light. Smaller-fruited cultivars tend to have higher vitamin-C contents. The vitamin-C was highest near the skin and in the locular tissue. High-pigment gene results in 25-50% increase in vitamin-A content and an increase in both lycopene and β-carotene, whereas the crimson (old gold) gene results in about a 25% reduction in vitamin-A content and an increase in lycopene content (Stevens, 1979; Stevens, 1994).

Tomato fruit usually contain from 7-8.5 % total solids (Malone, 1981 and 1983).Of which about 1% is skin and seeds (insoluble solids), and 4.0% - 4.6%. is soluble solids. Glucose and fructose comprise 50% - 60% of tomato solids with the total sugar content varying from 3.1% - 3.5%. The polysaccharides in tomatoes constitute about 0.7% of tomato juice, of which 50% are pectins, 25% are cellulose and 25% are xylans. The acid in tomato is almost entirely citric (Malone, 1981). An improvement in solids content of tomatoes would increase the recovery of tomato products during processing and also reduce the input of energy required to recover those products. The factors determining fruit quality for processing are fruit firmness, colour, soluble solids, and pH.

1.7.11.2 Fruit firmness and soluble solids

Fruit need to be firm enough to be able to withstand the rigours of machine harvesting and the sequentially processing stages. Both soluble solids and insoluble solids are important components of processing tomatoes. Soluble solids are important in product recovery, while insoluble solids are important in fruit firmness, viscosity and vine storage (Malone, 1981). There is a strong positive relation between fruit firmness and viscosity or consistency. This is because thick walls result in increased firmness and normally also increased alcohol insoluble solids. The viscosity potential of tomatoes is determined mainly by the content of alcohol insoluble solids which including the pectins and cellulose. Therefore thick walled, firm fruit tend to have higher viscosities than thin walled juicy tomatoes. This high viscosity is very important to processors that sell products, which have consistency as an important quality characteristic, such as sauce (Malone, 1981). Percentage of solids and viscosity influence the cost of processing and the final quality of product. High solids tomatoes produce more products per ton and

reduces the evaporation cost for paste. Viscosity influence the thickness of the paste. Moisture stress reduces yield and increases solids. This high solids can result from moisture stress and stress reduces yields (May *et al.*, 1990). May *et al.* (1990) reported that terminating irrigation a period prior to harvest can have the same moisture stress effect on yields and solids. Yields were highest on the 20-day cut-off and decreased with the 60-day cut-off. Percent solids responded opposite to yields. More days of water cut-off resulted in higher percent solids. Viscosity showed no difference from the 20-day to 40-day cut-off, but a significant decrease in viscosity from 40-day to 60-day cut-off. The best viscosity was at 20-day to 40-day cut-off with the poorest viscosity at the 60-day cut-off. A high solid tomato resulting from high moisture stress will yield more paste per ton, but this paste could be of a poorer quality.

1.7.11.3 Tomato colour

Fruit colour is an important quality criterion of both processed and fresh market tomatoes because the consumer notices colour first, and this observation often provides preconceived feelings about other quality factors such as flavour or aroma. Colours make a favourable initial impression with a standard and familiar colour being what the consumer both wants and expects to see. For tomatoes and tomato products the degree of colour quality often represents the measure of total quality (Gould, 1992).

Colour in the tomato is a result of the presence of carotenes and carotenol (Gould, 1992). The carotenoid pigments derive their names from carotene are polyene compounds of a yellow to red colour. The most abundant carotenoid of the tomato is lycopene, which comprises approximately 83% of those pigments present. The colour quality of tomatoes depends on the total amount of carotenoid pigments present and the ratio of lycopene : β-carotenoid, which are known to be controlled by a number of genetic factors. The 'high crimson' types, for example, developed in the Philippines, have an intense red colour which is controlled by a monogenic recessive factor og^c (Lee and Robinson, 1980; Malone, 1981). However, the crimson types have depressed β-carotenoid which means less vitamin A. These types are not desirable when tomatoes are important in providing vitamin A in the diet (Malone, 1981). High colour is due to an

increase of lycopene and a reduction in β-carotenoid. This means that the nutritional value of the tomato is reduced. The actual reduction depends on the parental background and differs for different cultivars.

Ho and Hewitt (1986) report that the colour of fruit was improved with a high potassium supply. Gould (1992) reported that the carotenoid content may be partially destroyed under the conditions of the low water percentage of tomato products, heating, the presence of metallic ions (Cu^{2+}, Fe^{3+}), or the presence of oxygen. Because tomato products discolour with reducing lycopene, lycopene destruction should be prevented.

The term pH is the symbol for hydrogen-ion concentration. The hydrogen-ion concentration of a food is a controlling factor in regulating many chemical and microbiological reactions (Gould, 1992). The pH of a solution is a measurement of the free hydrogen ion H^+ concentration. pH is a quality control check that will assist in the prevention of spoilage. It is one of the more important factors accounting for flavour changes in many products.

There are two principal methods used to measure pH. One is the colorimetric method, which depends on the used of an indicator solution that produces a characteristic colour at a given pH. The other method used to measure pH is to determine the potential developed between two electrodes when immersed in a solution. The most useful type used is the glass-calomel system and an associated potential-measuring device. This device measures the voltage development between the glass electrode and the calomel electrode. The voltage is a measure of the H^+ activity and each change of 1 pH unit corresponds to a change of 0.059 volt. The scale of the electric meter is calibrated in terms of pH rather than millivolts. In the case of tomatoes, extraction of liquid by means of a hand-operated juicer will provide sufficient liquid to make the pH determination. Gould (1992) suggested that the most important factors affecting the actual pH values of a product are (1) cultivars, (2) maturity, (3) seasonal variations due to growing condition, (4) geographical areas, (5) handling and holding practices prior to processing, (6) processing variables and (7) salt.

In the canning of foods, the actual pH is the most important factor affecting the sterilisation times and temperatures. Fruits with high pH are not adapted to processing because of the increased time for sterilisation (Iwahori and Lyone, 1970). The lower the pH value, the higher the amount of acidity in the food, the lower the degree of heat required for sterilisation. Gould (1992) reported that a pH of 4.6 is the dividing line between acid and non-acid foods. This usually means that with a product having a pH of 4.6 or less, that the germination of bacterial spores from organisms (such as *Clostridium botulinum*) will be inhibited after proper sterilisation.

In New Zealand, processing tomatoes are used in the manufacture of pulp and paste, while some is canned whole (whole peel). Fruits for whole peel should weigh 50-60, be of pear or elongate shape for ease of packing, peel readily, remain firm and exhibit a deep red colour after removal from the can. Larger fruits are used for the paste process. High solids (higher than 5%) and low pH (less than 4.5) are also necessary (Malone, 1981).

1.8 Processing tomato production

1.8.1 The general requirements of climate and cultivation for the tomato crop

The tomato is warm-season plant and grows under wide range of climatic and soil conditions. The tomato thrives best when the weather is clear and rather dry and the temperatures are uniformly in range of 18 to 30°C. Fruit size does not increase when temperature is higher than 35°C. High temperatures together with high humidity favour the development of foliage diseases. Hot, dry winds cause the flowers to drop (Guold, 1992).

Level fields with uniform soil conditions and good drainage, and large enough for a minimum number of turns for mechanical equipment are preferred for the production of processing tomatoes. Well-drained, fertile soils with a good moisture-retaining capacity and high level of organic material are required, although many cultivars are tolerant to a

wide range of soil conditions. Slightly acid conditions, with the pH range of 6.0 to 6.5 are optimal for growing tomatoes (Gould, 1992; Tindall, 1983) For example, soils used for the production of processing tomato should be loams, clay loams and silt loams. Soils with a pH of 5.0 or less, require an application of 1 or 2 tons of finely ground limestone to raise the pH to an optimum level between 6.0 to 6.5. Fields with high weeds population and high residual nitrogen and possible herbicides residues should be avoided. Supplying the lime and the fertiliser (organic and manure fertiliser) before cultivation according to soil test results is the most simple, effective and economical method of meeting the crop nutrient requirements. Ploughing should be done as deeply as the soil will permit. Beds are used for growing tomatoes because beds make for more uniform ripening of fruit, provide better drainage following heavy rains, and increase yields (Guold, 1992). Beds should be as flat as possible. Generally, the beds should be 1.37m to 1.68m apart between centres to accommodate field and harvesting equipment, and single or double rows are used. The single row of tomatoes should be grown in the centre of the bed with the plants 25.4cm to 35.6cm apart in the row. With twin rows, tomato plants should be 50.8cm to 66.0cm apart with plants 30.5cm to 40.6cm in the row (Guold, 1992). Crop rotation is very important for the protection of soil structure and the maintenance and balance of soil nutrients, and soybeans, sugar beets, wheat and beans are good preceding crops for processing tomatoes in USA. The time of transplanting tomato seedlings or direct-seed tomatoes in the field is dependent on weather and soil conditions. Gould (1992) pointed that tomato growth is impaired by temperatures below 10°C, with chilling injury occurring close to 4°C. When soil temperature reach to 14°C or more for 3 successive days, planting may begin. Temperatures that fall below 13°C or rise above 35°C for several hours when flowers are opening usually give rise to poor fruit set. The height of transplants should be kept at 8-10 cm before the transplanting (Trindall, 1983). There are many chemical and non-chemical methods to control transplant heights of tomato plants, such as DIF (the difference between daytime and night-time temperatures) (Carlson, 1990), brushing (Latimer and Beverly, 1993), nutrient deficiency (Carlson, 1990) and red light (Decoteau and Friend, 1991). After transplanting, crop management, such as weed control, disease and insect control should be performed throughout the growing season. Irrigation and fertilisation are also necessary for the successful production of tomatoes.

Processing tomatoes grown for destructive mechanical harvesting are harvested when 65% to 75% of the fruit are red-ripe (Edwards, *et al.*, 1984). The ethylene-releasing compound ethephon is sometimes used to enhance uniformity of fruit coloration and rate of tomato fruit ripening, induce mature green fruit to ripen, and increase the yield of ripe fruit for mechanical harvesting (Kwon and Bradford, 1984; Kwon and Bradford, 1987). The compound is applied when 5 to 30% of fruits are red and pink and there are sufficient mature green fruit to give the desired yield.

1.8.2 Production area and Product lines in New Zealand

Processing tomatoes are an important crop in New Zealand. The major production regions are Hawkes Bay and until recently Gisborne (Nichols and Bussel, 1980) and a very small quantity is produced in the Bay of Plenty (Burgmans, 1984). Yields of the processing tomatoes fluctuate from year to year because the major characteristics of the New Zealand climate are its unpredictability (Nichols and Bussel, 1980). It can be marketed as sauce, pulp, puree, juice, ketchup or whole canned (whole peel) fruit.

1.8.3 Cultivars--their characteristics

The most important characteristic of a successful processing-tomato cultivar is a high yield potential (Stevens, 1979). A machine-harvested cultivar must have a concentrated fruit set. Firm-fruited cultivars have become increasingly important in the processing-tomato industry. One of the most striking characteristics of these firm-fruited cultivars is that they remain in good physical condition for several weeks after they have reached full red colour. Stevens (1979) reported that firm-fruited cultivars have high levels of the alcohol-insoluble components of the fruit, a thicker outer pericarp, and a smaller locular area. The rate of breakdown of the cell-wall material did not differ between these cultivars. The firmness was greater at all stages of fruit ripening and senescence. Another important characteristic to achieve full use of the fruit is easy of removal from the vine. If the fruit can be removed too easily, tomatoes will be shattered leaving many fruits on the ground during harvest, while if the fruit is removed from the plants with difficulty, then a

high percentage of fruit will be left on the vine after they have gone through the shakers. For tomato plants, one of the greatest limitation of a concentrated fruit load is blossom shedding due to stressful conditions during peak fruit-setting period. High temperatures may cause blossom drop, resulting in a split fruit-set (Stevens, 1979). Stevens (1979) reported that this problem had been solved by developing the high temperature tolerant cultivars, which can continue to set fruit despite high-temperature stress. Also, genotypes with high-temperature fruit-set capability set fruit better under low-temperature conditions. Disease, insect and disorder resistance are indispensable characteristics of a successful processing tomato cultivar. Processing cultivars should satisfy the following quality indices (Gould, 1992): (a) fruit size should be uniformly less than 90 g, but more than 50 g, (b) total solids content should be in the range of 5.5-8.5%, (c) soluble solids content (Brix reading) should be in the range of 4.4-7.5% (preferable), (d) acid (citric) content should reach minimum of 0.35% and up to 0.55%, (e) pH values should be preferably 4.2 or less for all fruits with a maximum of 4.4 (Stevens, 1979).

1.8.4 Establishment methods

1.8.4.1 Establishment process

Crop establishment is a very important step in the production of processing tomatoes, because crop establishment can affect time of maturity, compactness of maturity, uniformity of product and yields of crops. Crop establishment can be defined as total seedling emergence less post-emergence losses and could be said to be reached when plants have achieved four to six true leaves (Wright, 1986). Wright (1986) suggested that crop establishment may be usefully divided into three phases: the crop emergence phase, the self thinning phase, and final establishment phase (Figure 1.9).

In the crop emergence phase, germination of seeds leads to crop emergence in which plant number increase rapidly over a short period. However, not all the seeds which have been sown will germinate and some will germinate but not emerge, thus the number of initial emergence will be less than the number of seeds sown. A self thinning phase

generally takes place after the emergence phase when plant population falls. The severity of this self-thinning will depend upon the crop and the initial competition it encounters. Following the self thinning phase, seedling populations (plant numbers) then tend to be relative stable, this phase is regarded as the final establishment phase and crop establishment can be said to have been completed. After crop establishment individual plants may continue to die because of pests diseases or accidents but these should be regarded as post-establishment losses.

Once seed is sown in the field it is exposed to range of complex and uncontrollable conditions. Before germination can occur, a seed must imbibe water from the surrounding soil (Wright, 1986). A number of treatments have been developed, such as seed hardening or advancing and seed priming. The technique of hardening or advancing involves soaking seed for 24 hours and then slowly drying it for 48 hours with 3 cycles and the seeds are then dried and sown at some later date. For some treated seeds hardening or increased the number of cells in the embryo, and the seedlings were larger at any particular stage after emergence in comparison with untreated seeds (Anon, 1993).

1.8.4.2 Seed priming

The basic process of priming is to commence germination of the seed in an aerated solution of a high molecular weight compound (polyethylene-glycol, PEG) of sufficient osmotic strength or to use osmoticums such as salts (KNO_3, Haigh *et al.*, 1986) to prevent visible germination (Bradford, 1986). The high osmotic strength acts to control the entry of water into the seeds. The seed can be kept in this conditions for periods of up to several weeks, then rinsed and redried to the original water content. This technique is based upon controlled hydration of seeds to a level that permits pre-germinative metabolic activity to proceed (Bradford, 1986). This osmoconditioning process does not result in radicle emergence and so the seeds can be dried down and stored temporarily until planting (Wolfe and Sims, 1982). The purpose of washing and drying seeds is to enable the seeds to be sown using a normal drill. After priming, viable seeds were all at

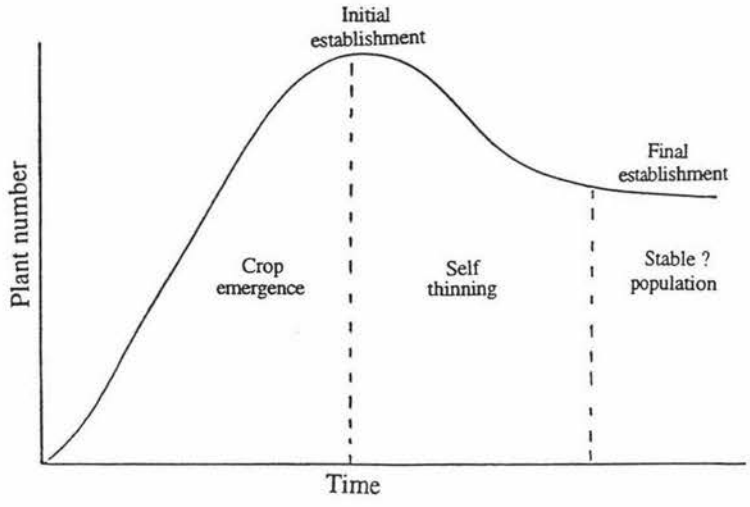

Figure 1.9 Schematic representation of the changes in crop establishment over time

the same stage of development and the seedlings emerged more rapidly than normal seeds , and all at the same time. Priming results in the hydration of seeds in an osmotic solution that permits the preliminary processes of germination, but not the final phase of radicle emergence (Haigh *et al.* 1986). Osmotic condition or priming of seeds has been shown to give rise to more rapid and uniform germination at suboptimal temperatures in the laboratory and greenhouse (Alvarado *et al.*, 1987; Barlow and Haigh, 1987). Priming did not affect the final germination percentage (Alvarado *et al.*, 1987). Seedlings from primed seeds maintained greater average plant dry weights, leaf areas, and ground cover percentages than untreated seedlings throughout the preflowering period due to early emergence rather than to an increased relative growth rate. The early growth advantage from seed priming did not improve earliness or soluble solids content of fruit (Alvarado *et al.*, 1987). In research on the effects of osmoconditioning and fluid drilling of tomato seed on emergence rate and final yield, Wolfe and Sims (1982) found that osmoconditioning process reduced the times to 50% germination by 6.6 days and that the fluid-drilled PEG treatment also had a dramatic effect, giving rise to a higher percentage of mature fruit than the control at harvest and no effect on total yield. This finding is supported by research of Barlow and Haigh (1987). A reduction in the growing season of only a few days can have economic impact for commercial growers in the tomato processing industry. Also, more rapid seedling establishment decreased risks associated with early crop development (Wolfe and Sims, 1982). Seed priming of tomato appears to provide a convenient method of enhancing crop emergence from cold soils (15-16°C), therefore providing growers with greater flexibility in sowing dates (Barlow and Haigh, 1987).

1.8.4.3 Establishment methods

1.8.4.3.1 Introduction

There are three methods of establishing vegetable crops: (a) direct seeding, (b) bare root transplanting, and (c) cell transplanting. The cell transplanting method is the main establishment way adopted by commercial production of processing tomatoes in New Zealand.

1.8.4.3.2 Direct seeding

The advantages of direct-seeding are (a) reduced cost per unit area; (b) less chance of the introduction of diseases; (c) greater flexibility of variety selection, and plant population (Gould, 1992); (d) better maturity characteristics. The problem of direct-seeding method is related to poor weed control caused by lack of suitable herbicides and low and widely spread emergence of seedlings caused by the environmental conditions at sowing and the variability in quality between different seed lots.

1.8.4.3.3 Bare root transplanting

With bare root transplanting, the plants are raised in a seed bed outdoors (such as processing tomatoes, lettuce etc.) or in seedling boxes in a greenhouse (fresh market tomatoes, celery, lettuce). Then plants are dug from the seed bed or removed from the boxes to be transplanted in the field with a mechanical transplanter (Anon, 1993).

The advantages of bare root transplanting are more economic utilisation of space and provision of improved growing conditions. The disadvantages of bare root transplanting are (a) the root damage which occurs at transplanting, (b) the lack of growth control of seedlings in the field bed and (c) it is wasteful of seed.

1.8.4.3.4 Cell transplants

A cell transplant is a seedling raised in a greenhouse in a discrete volume of media. In New Zealand processing tomatoes, lettuce, asparagus, and brassicas have all been established by this method and plastic trays are commercial used. Cell volumes vary from

5-35ml. The media used is peat based with sand added The fertilisers used contain N, P, K plus Mg and lime or dolomite and trace elements. The advantages of cell transplanting are (a) reduction in the amount of expensive seed (such as hybrid seed); (b) production of a uniform line of plants; (c) more likely to achieve the desired plant density; (d) reducing the early disease; (e) aiding the early planting of frost tender crops; (f) controlling readily plant height when transplanting has to be delayed by adverse field conditions; This is an important consideration for processing tomatoes; and (g) improving the yield and maturity characteristics (Anon, 1993). However, Davis (1992) found that there was no difference in maturity or yield between bare root and cell transplants.

1.8.5 Plant density

Successful mechanical harvesting of processing tomatoes requires high yields and concentrated maturity. Different plant spacings can be used to increase yields and hasten fruit maturity. Plant spacings consist of two major factors: density and arrangement (Frost and Kretchman, 1988). Fery and Janick (1970) have demonstrated that higher plant densities are needed to achieve the same maximum yields using a single harvest than when using multiple harvests. In a research of plant density by direct seeded tomato with constant rectangularity of 1.0, Nichols *et al.* (1973) concluded that the production of processing tomatoes for mechanical harvesting could be successfully achieved by direct seeding the tomato with a square planting pattern at densities over 40 plants m^{-2} (400 000 plants ha^{-1}). At this density the need for vine storage of ripen fruit was minimised, because all of the plants tend to mature at same time. Fery and Janick (1971) reported that the timing of harvesting was affected by the response of tomatoes to population pressure. They found that marketable yield increased asymptotically with increasing density for early harvests, but peaked at intermediate densities with mid-season and late harvests. Researches conducted at Levin and Hastings by Bussell *et al.* (1975) further demonstrated that when chlorethephon was used to promote ripening before harvest, the percentage of process grade fruit at all densities was similar, and consequently the need to use very high densities for uniform ripening was reduced. Therefore the utilisation of chlorethephon to assist ripening allows any plant densities in

excess of 30000 plants/ha to provide the highest single harvest yield which can be acquired from a crop grown in a single or twin rows. Nassar (1986) carried out field experiments to study the effect of plant density, nitrogen level and planting pattern on yield and quality of tomato. Their results showed that fruit quality was significantly influenced by N rate, but not by either planting pattern or plant density. Fruit length and diameter, and average fruit weight all increased with increases in the nitrogen level. Also, there was a positive correlation between fruit TSS% and N level. Maximum yields were attained at 297 kg N ha^{-1} (120kg N $acre^{-1}$) associated with a plant density of 89000 plants ha^{-1} (36 000 plants $acre^{-1}$). The efficiency of N rates to increase early, marketable and total yields, increased with increasing plant densities.

Frost and Kretchman (1988) reported that an increase in plant density often gave rise to increased early and total marketable fruit per unit area, and that as densities increased, yield per plant, fruit size (Nichlow and Downes, 1971), and number of fruit per plant decreased (Frost and Kretchman, 1988; Smith *et al.*, 1992). These decreases were likely because of the reductions in trusses per plant, flowers per truss, and percentage fruit set. The increase in total yield was associated with increases in vine yield, early green yield and decreases in yield per plant. Researches in photomorphogenesis suggested that the response of close-spaced plants are regulated by phytochrome. The fundamental function of phytocrome is to perceive natural changes in light quality (Smith and Morgan, 1983). Kasperbauer and Karlen (1986) reported that close-spaced seedlings of wheat received higher far-red/red light ratios than wide-spaced plants due to the larger amount of far-red reflected from green leaves of the more numerous nearby plants. Therefore close-spaced plants developed fewer tillers (or branches) than wide-spaced seedlings under field conditions and phytochrome served as a sensing mechanism that detected the level of competition from other plants. A similar response was observed by Kasperbauer(1994), who found that the red paint used to changes the surface colour of plastic mulches reflected a higher far-red/red light ratio, and tomato plants partitioned more photoassimilate to shoots, including fruit. Plants that were closer together and received the higher far-red/red ratios had the higher shoot/root biomass ratios, the longer internodes and the fewer branches. Plants that received the higher far-red/red ratios in the field as well as those in controlled environments partitioned higher percentages of the new photosynthate to growing stems, and less to branches or new root growth, which

resulted in the reduction in trusses per plant, flowers per truss, and percentage fruit set. This is a reasonable and instinctive adaptive response of plants to population pressure because the far-red/red ratio would be sensed as an indicator of competition, and plants with longer stems would have a greater probability of keeping some leaves in sunlight above competitors and surviving long enough to produce the next generation (Kasperbauer, 1994). Nevertheless, although under high density individual plants developed fewer fruit due to fewer branches per plant, the increased ripe fruit yields were primarily a function of the larger number of plants per unit area because the dry matter production per unit area either increased with high density or remained constant (Frost and Kretchman, 1988).

Double rows provided a higher plant density and more upright vine while maintaining spacings suitable for mechanical harvesting. Double rows generally increased yields in comparison with single rows, but this increase depended upon cultivar (Frost and Kretchman, 1988; Smith *et al.*, 1992) and moisture conditions (Smith *et al.*, 1992).

1.8.6 Nutrition and irrigation

1.8.6.1 Nutrients

"Tomatoes will grow moderately well over a range of levels of each nutrient. Manipulation of the nutrient supply is, however, essential in achieving the high yields of good quality fruit needed for profitable production" (Adams, 1986). Demand for mineral nutrients is high at the seedling stage of plant development. This high nutrient requirement is in part thought to be the result of the high relative growth rates of young plants. It has been found that there was a close correlation between relative growth rate and the uptake of potassium and phosphorus by tomatoes (Widder, 1989). A close relationship was found to exist between nitrogen content and relative growth rate by Fisher and MacKay (1990).

Applications of high-analysis fertilisers at the time of transplanting have been shown to stimulate early growth and fruit maturation. The availability of both phosphorus and nitrogen is thought to be critical for vigorous vegetative growth of transplanted tomato seedlings (Widders 1989).

Nitrogen is an essential component of proteins and is a fundamental building material of the cells. Nitrogen, as a constituent of all enzymes, is involved in metabolic processes throughout the plant. Nitrogen influences the quality and the date of maturity of the tomato crop. Adequate nitrogen can ensure tomatoes produce sufficient foliage for photosynthesis (Gould, 1992). Nitrogen deficiency gives rise to spindly and stunted growth, the leaves become small and yellow-green in colour, and few fruit are formed (Adams, 1986). High rates of nitrogen result in lower soluble solids and more blotchy ripening (grey wall), more yellow eye, and poor machinability (Gould, 1992). If the tomato plant has too much readily available nitrogen in the early growing season, it is likely to stimulate excessive vegetative growth and to delay setting and maturing of fruit (Nicklow and Downes, 1971). Gould (1992) reported that late application was harmful because they may cause prolonged growth with late fruit and/or split sets. Nicklow and Downes (1971) found that the addition of either preplant nitrogen or sidedressed nitrogen caused a decrease in fruit size due to higher nitrogen levels promoting the development of more trusses per plant, which gave rise to a greater fruit load per plant and smaller fruit size. When 1 tonne of fruit and canopy of tomatoes is produced, about 1.8 kg of actual nitrogen is required by the plant (Geisenberg and Stewart, 1986).

Phosphorus affects the quality of tomato fruit in several ways, (1) phosphorus prompts vigorous root growth, which accounts for a better utilisation of the nutrients in the soil, (2) phosphorus hastens the efficiency of the plant by stimulating a sturdy stem and healthy foliage and (3) phosphorus increase yields (Gould, 1992). Phosphorus deficiency results in dwarfed and spindly growth, the leaves remain small and stiff, and purple tints develop on the undersides. When phosphorus deficiency occurs on soils with a high capacity for fixing phosphorus or at a low temperature (<14°C) in the root zone, phosphorus may be translocated from the oldest leaves to new leaves to maintain new growth (Adams, 1986). Soil temperature, type and compaction, pH of soil all influence availability of phosphorus. Types and timing of phosphorus fertiliser application varies

with soil type, pH, plant size and stage of development and irrigation system used. For example, in medium and heavy soils, 40-50% of the phosphorus fertiliser should be preplanted to a depth of 30-40cm, while the rest would be applied in the upper 10-15cm of the soil and by rotovator together with nitrogen and potassium fertilisers (Geisenberg and Stewart, 1986).

Sims (1975) suggested that placement of a starter phosphorus fertiliser is very important for processing tomato production, because during the early sowings, the soil temperatures may be cool (under New Zealand condition below 12 to 16°C). Absorption of phosphorus by the tomato plants at these low temperatures was very poor and, and consequently, the plants remain very stunted, purple in colour and phosphorus-deficient. Placement of phosphorus underneath the seed overcome this difficulty. A small band about 2.5cm directly below the seed at the time of sowing proved satisfactory (Sims, 1975). Phene *et al.* (1990) reported that daily injection of P through fertigation system in addition to conventionally banded P under the seeds at planting significantly increased the yield of tomatoes.

The main function of potassium appears to be that of a regulator for many of the metabolic processes in the cells, including protein synthesis (Adams, 1986; Gould, 1992), nitrogen metabolism, carbohydrates metabolism and translocation, regulating stomatal movement and cell sap concentration, and as an enzyme activator (Gould, 1992). The tomato plant takes up and utilises a large amount of potassium. Potassium content of leaves is higher (3-4%) during the vegetative stage of the plant, and decrease during fruiting period. In fact, more potassium is absorbed than any of the other mineral. Sufficient potassium may improve fruit quality. Blotchy ripening is an economically important fruit disorder influencing productivity in the tomato whole-pack industry. This disorder involves the failure of the inner pericarp tissue of the tomato fruit to colour and soften normally during ripening. Processing tomato fruits with blotchy ripening characteristically possess discoloured areas of white or yellow tissue which may be visible externally (Dick and Stattuck, 1987). Dick and Stattuck (1987) found that potassium treatments up to 624 and 590 kg ha^{-1} decreased the incidence of blotchy fruit of processing tomatoes. Cultivars affected the efficiency of potassium treatments in mediating blotch susceptibility occurred.

Potassium deficiency slightly restricts growth and causes yellowing of the margins of the upper and middle leaves. The yellowing spreads to the other leaves and eventually becomes brown, which may occur rapidly in hot weather (Adams, 1986). Potassium deficiency results in poor lycopene development in the fruit and concentrated in the fruit as they approach maturity. Insufficient K supply decreased the number of fruits and thereby fruit yield due to either flower development or fruit set having been reduced (Ho and Hewitt, 1986). A heavy fruit load may produce such a stress on the plant that potassium deficiency symptoms occur (Gould, 1992).

In general, for most of soils, 500-1000 kg of KCl or K_2SO_4 would be needed to raise the level of available potassium to near optimum. If potassium is applied in irrigation systems, potassium nitrate is convenient, especially under low soil temperature conditions (Geisenberg and Stewart, 1986).

Calcium is a cementing agent in the cell walls and plays a vital role in maintenance and modulation of various cell functions (Adams, 1986; Palta, 1996). Therefore calcium is very important in plant growth and development. Calcium is an integral part of the cell wall where it provides stable, but reversible, intramolecular linkages between pectic molecules, resulting in cell wall rigidity. In addition, calcium stabilises cell membranes by bridging phosphate and carboxylate groups of phospholipids at the membrane surface. Presence of extracellular Ca^{2+} increases bonds between the cell wall and plasma membrane. Ca^{2+} is a nontoxic mineral nutrient and plant cells can tolerant high concentration of extracellular Ca^{2+}. It is known that maintenance of a certain level of membrane Ca^{2+} could mitigate the injurious impact of freeze-thaw stress, biotic stress and heat stress in some crops (Palta, 1996). Under cases of excessively low humidity, most of water in the xylem is drawn into the mature leaves to maintain the transpiration rate. Consequently, little calcium reaches the actively growing tissue (root and shoot tips, expanding young leaves and immature fruit) and they become deficient. However, during night, water and calcium transport into the low- or non-transpirating tissues follows an increase of humidity (Adams, 1986). When calcium deficiency occurs (on acid soils or peats), the leaves develop interveinal yellowing and the margins turn brown the growing

point soon dies and the fruit become black around the stylar scar. If the pH level of soils is below 5.6, 1.0-3.0 tons of limestone might be needed (Geisenberg and Stewart, 1986).

Magnesium is a nutrient that is essential to chlorophyll formation in the plant and plays an important non-specific role in the process of phosphate transfer. It also acts as activator for certain enzymic reactions. The main functions of micronutrients and symptoms of their deficiencies have been discussed by Adams (1986) in detail. Boron is involved in the regulation of carbohydrate synthesis. Iron is a constituent of cytocromes and of the non-haem iron proteins that are involved in photosynthesis, and is also an essential component of peroxidase enzymes. Manganese is required as an activator for many enzymes and is involved in photosynthesis. Lack of these minor elements might occur in tomato plants especially under low or very high pH conditions in peat or sandy soils. A commercial mixture of minor elements added into irrigation water is the most common method for supplying minor elements (Geisenberg and Stewart, 1986).

1.8.6.2 Irrigation

Irrigation plays an important role in providing for uniform maturity and an adequate supply of water is necessary during early plant growth, fruit set, and fruit elongation periods. If water stress occurs during any one of these stages, optimum uniformity of fruit maturity connot be achieved (Gould, 1992). Once the fruit has reached the final size, the water is only required for maintenance of plant growth. Irrigation in the later growing season should be avoided after the crop has reached an advanced stage of maturity in order to prevent fruit rots and cracks and decreasing total soluble solids (Gould, 1992). The more water, the higher the yield and the lower the TSS. The termination of the irrigation prior to harvest in processing tomatoes has to be decided considering the influence of the irrigation on fruit quality, especially TSS content, and also on the possible danger of fruit rot. (Sanders *et al.*, 1989; Rubino and Tarantine, 1988). This would be more critical with overhead sprinkler irrigation.

There are mainly three types of irrigation in practice: furrow, overheat sprinkler and drip irrigation (also called trickle irrigation). They have respective advantages and disadvantages.

The advantage of furrow irrigation is the low initial cost compared with other systems. The shortcoming is the low water use efficiency in comparison with other irrigation systems. The amount of water applied depends on the volume of water running in the furrows, the duration of the water run and the inclination of the furrow. Furrow irrigation is applicable to medium and heavy soils.

Overhead sprinkler has the advantage of the relatively easy layout of the system. Sprinkler may be installed permanently at suitable position or sprinkler can be moved manually and can also be installed as a travelling system. They can be moved in the field either along the rows from one station to another or the irrigation lines can be moved sideways. The major disadvantages of overhead sprinkler are: (a) that the efficiency of sprinkler irrigation system is subjected to water pressure and wind velocity, (b) that this irrigation promotes free moisture conditions which provide good environments for diseases, such as early and late blight, grey leaf spot, bacterial speck and bacterial spot (Geisenberg and Stewart, 1986).

Drip (trickle) irrigation has been demonstrated to be the most efficient. Its advantages are as follows. (1) It is independent of wind velocity and that the water flow can be mediated by suitable pressure regulators, (2) The infiltration of water into the soil can be controlled to the optimum depth and moisture level, (3) Irrigation can be applied at any time of the day with nearly 100% efficiency and (4) The biggest advantage of this irrigation system is that fertilisers, herbicides, systemic fungicides or pesticides can be applied through the irrigation system, the so-called fertigation system (Geisenberg and Stewart, 1986).

1.8.6.3 Fertigation

Drip irrigation systems provide an efficient method to supply fertiliser to most vegetable crops (Hochmuth, 1994). Hochmuth (1994) suggested that drip irrigation systems must be designed properly for supplying fertiliser (fertigation) to vegetables so that water and nutrients are placed in the proper position in the root zone and that the amount of water and nutrients are correctly calculated to minimise the chances of excess or inadequate amounts of these inputs. N and K are the most often-applied nutrients to be successfully injected through drip irrigation systems. Fertigation provides a system to supply the N and K requirements of the crop in a scheduled fashion during the season. P can also be successfully injected through drip irrigation systems. Locascio *et* al. (1989) reported that growing tomatoes with polyethylene mulch increased the amount of applied N recovered by trickle-irrigated tomatoes and increased yield over non-mulched tomatoes. Tomatoes has responded with increased production with N and K injected into the irrigation water in contrast to all applied preplant. Locascio *et* al.(1989) explained that a major effect of applying N and K with the drip system may be to maintain N and K concentrations in the plant relatively late in the season, thereby resulting in increased fruit size and yield later in the season than where all N and K was applied preplant.

1.8.7 Harvesting

The optimum time of harvesting can be predicted based on the maximum percentage of red ripe useable fruit. In any growing area, soil type, cultivar, irrigation practise, date of planting, maximum and minimum temperatures, rainfall, stress conditions, all influence the number of days of ripening and the date of harvest. Some firms estimate their date of harvest counting the number of days after full bloom (60 days ± depending on the variations among different cultivars, maximum and/or minimum temperatures, rainfall) (Gould, 1992). Geisenberg and Stewart (1986) suggested that under optimum climatic conditions and given that no major plant diseases or pests damage the plant foliage, then the optimum time to start harvesting a field would be when 90% of the fruit is red or pink. Cultivars with good vine-storage characteristics could be harvested over about 5-10 days without any markedly weight loss. However, if the leaves were damaged and the

fruit unprotected, harvest should start earlier to prevent the loss of marketable fruit and the increase of cull fruits. Fruits will last 25-35 days after full ripening so that 90-95% of the fruit harvested at one time can be used for processing. This contrasts with the works of Julian (1990) and Davis (1992) who all found a potential loss of 10 - 15 t ha^{-1} with a consequence of loss of potential profit due to harvesting one week earlier or later than the optimum harvest date.

The quality of the fruit supplied to the processing plant will be specified usually in the contract between the grower and the processor. The quality indices include colour, percentage of green and pink fruit, mould, impurity (material other than tomato) over-ripeness, calyx on the fruit, worms, worm-injury, peelability, TSS measured in Brix (Geisenberg and Stewart, 1986).

1.8.8 The use of tomato fruit ripening agents in tomato production

Ethephon is used to promote greater uniformity of ripening in mechanically harvested processing tomatoes (Mutton, 1978). The effects of exogenously supplied ethephon on promoting tomato ripening are documented (Iwahori and Lyons, 1970; Splittstoesser and Vandemark, 1972; Gongora, 1987; Ohta *et al.*, 1992; Kaynas *et al.*, 1992). In research on the use of ethephon in tomato ripening, Gongora (1987) found that the most effective treatment of ethephon was 2-3 litres ha^{-1} supplied when 5-15% of fruits had reached maturity, followed by harvesting 10-12 days later. Sprayed ethrel (ethephon) at 100 or 200 ppm promoted uniform fruit colouring on the truss of cherry tomatoes and hastened their ripening (Ohta *et al.*, 1992). Ohta *et al.* (1992) also found that both ethephon treatments increased Brix values and at 100 ppm decreased fruit cracking to less than 10%. Kaynas *et al.* (1992) reported that preharvest ethrel application shortened the ripening period by 8-10 days compared with the control, depending on dose and cultivar.

The timing of ethrel applications (per cent ripe at starting the ethrel treatment), varieties (Bussell and Dallenger, 1972), moisture stress (Bussell, 1973; Mutton, 1978), and cultivars (thin- or thick-walled) (Bussell and Halligan, 1982) may influence the effectiveness of ethrel treatment on tomato ripening. Bussell and Dallenger (1972) found

that (1) if ethrel was applied when more than 25% of the fruit was ripe, there was no increase in proportion or yield of ripe fruit compared with untreated plants, and when 15% of the fruit was ripe, it gave the better results, (2) ethrel treated tomatoes took at least 3 weeks to ripen at lower temperatures before the maximum proportion or yield of ripe fruit was achieved and (3) in some varieties, ethrel not only hastened ripening but also markedly increased single harvest yields, but in some varieties this did not occur.

Moisture status is an important consideration where ethephon is used to hasten ripening. Ethephon and moisture stress both hastened the ripening of fruit, Increasing levels of ethephon promoted a greater acceleration of ripening than increasing levels of moisture stress (Mutton, 1978).

Bussell (1973) reported that in New Zealand during dry conditions in the field, ethephon treatment did not hasten ripening unless there was at least 12 mm of rain in one fall in the period from 10 days before to 7 days after treatment. Mutton's research in Australia (1978) supported this result, Mutton found that the greatest increase took place where plants were moderately stressed and sprayed with 250 ppm ethephon, or where plants were kept continuously stressed and sprayed with 500 ppm ethephon. Bussell and Halligan (1982) demonstrated that tomatoes, of both thin- and thick-walled cultivars, should be treated routinely with ethephon before harvest under New Zealand conditions to promoting ripening. These results showed that treatment with chlorethephon of cultivars with thin fruit walls accelerated and concentrated ripening, whereas with the cultivars with thick fruit walls it accelerated ripening and increased the time that the maximum yield of process-grade fruit could be achieved.

The inhibiting effect of exogenous application ethephon or ACC on the development of flowers and inflorescences also is reported by Kinet and Hachimi (1988), who found that exogenous application ethephon or ACC stopped the development of flowers and inflorescences and they finally abscised. In some cases all of flowers or the inflorescence aborted causing the failure of the entire truss. The effectiveness of this was highest 9 days before anthesis. Early sprayed ethephon could give rise to the increase of the total yield (Tremblay and Perron, 1991), the mean yield and the mean fruit weight (Dimri *et al.*, 1988) in tomato.

More recently, some natural lipids, such as lysophosphatidylethanolamine (LPE) have been used as tomato fruit ripening agents. Farag and Palta (1993) conducted research to compare the effect of this compound with ethephon on hastening the ripening and on the defoliation of both processing and fresh-market tomatoes. Their results suggest that a natural lipid, lysophosphatidylethanolamine can enhance ripening and shelf life of processing and fresh-market tomato fruit, and that LPE may be able to mitigate the possible undesirable effects of ethephon on foliage and fruit storability, LPE can also enhance shelf life of vine-ripe fruit. Farag and Palta (1993) reported that LPE enhanced ethylene production in fruit tissue, inhibited the activity of polygalacturonase extracted from tomato fruit, and retarded tomato leaf senescence. They further suggested that LPE may able to maintain fruit quality by keeping the fruit respiration low, by inhibiting the activity of enzymes involved in fruit softening, and by retarding senescence.

1.8.9 Improvement of earliness

Improvement in earliness of processing tomatoes can be of benefit for both growers and processors. Namely, for growers, earliness improvement advances harvesting time, extends harvesting period and makes more manageable the tomato season. For processors, it means more efficient in-plant operation because of an early start to the season and in climates such as New Zealand this means more efficient use of capital.

Cultivars, site selection, plastic mulches and rowcovers have been used to advance earliness of vegetable crops. By utilisation of cultivars with a succession of maturities, particularly early cultivars, the earliness can be improved and the undesirable peak of delivery can be reduced and spread out (Gould, 1992). The use of plastic mulches with vegetable crops such as cucumbers, squash, tomatoes, peppers, eggplant, muskmelons watermelon, sweetcorn has achieved a significant increase in earliness, total yield, and quality (Lamont, Jr., 1993).

CHAPTER TWO

Introduction and Materials and Methods

2.1 Introduction

Processing tomatoes are an important crop in New Zealand. A major problem of the New Zealand industry is the short growing season which results in tomatoes only being able to be harvested for a period of about 10 weeks. This means that expensive processing plant, such as evaporators and specialised harvesting machinery, are not used as efficiently as in tomato processing industries overseas. If the season could be advanced by even a week then this would be considered a significant improvement by the industry in New Zealand.

Black plastic mulch (BPM) has been widely used in the production of fresh market tomatoes and many other crops. The beneficial responses of tomatoes to BPM, such as higher total yield, earlier production and better fruit quality, have been reviewed by Abdul-Baki *et al* (1992). Floating (fabric) row covers allow growers to plant vegetable crops 1-2 weeks earlier than normal and they should be left on for 4-6 weeks, depending on the crop (Mansour, 1984). Row covers combined with BPM increased both earliness and total yields of muskmelon in New England as compared to those grown on BPM alone (Loy and Wells, 1982, Wells and Loy, 1985). Studies with BPM have often combined the mulch treatment with fertigation, which is provided via a drip irrigation line lain down below the mulch (Abdul-Baki, *et al.*, 1992; Bhella, 1988; Decoteau *et al.*, 1989). Although, these techniques have been used to enhance fruit production and advance the earliness of other vegetable crops, they have not been fully investigated with processing tomatoes. The identification of early cultivars and early sites for planting are the only techniques that have been used so far in this country.

The objective of this experiment was to study the effect of black plastic mulch with fertigation and fabric row covers on crop growth, yield, maturity and quality of processing tomatoes.

2.2 Materials and Methods

2.2.1 Introduction

Seed of the cultivar Cleo was supplied by Cedenco Foods Ltd of Gisborne. Cleo was the earliest cultivar used by Cedenco. The plants were established as cell transplants (section 2.2) with the experiment being conducted during the 1995-96 season on the Horticultural Field Plots at the Plant Growth Unit, Massey University. The soil type is a Karapoti brown sandy loam. It is known that this soil type has an available soil moisture (ASM) content of 60mm/30cm.

The research area was subsoiled, ploughed and then rotary-hoed. A 500 kg nitrophoska (12-10-10, a mixture of NH_4NO_3, $(NH_4)PO_4$ and KCl) base fertiliser was applied down the line of the rows. This application was based on the results of a soil test (Appendix 1). Slightly raised beds were prepared along the line of the rows. The black plastic mulch plus T-tape was lain prior to transplanting.

2.3 Production of cell transplants

The seeds were sown on 12 September 1995 in cell trays, which had 198 cells each of 16 ml volume. The medium used for the production of transplants was as follows:

Sphagnum peat moss (sieved)	60 litres
Dolomite lime	0.180 kg
AG lime	0.180 kg
Micromax (trace elements)	0.036 kg

One seed was sown per cell, The seed was germinated on a heated (22°C) capillary bench in a greenhouse. Seven days after seed sowing the trays were transferred to a wire mesh bench so that the roots would be air pruned. The heating system maintained a minimum air temperature of 13°C with ventilation at 21°C. A nutrient liquid feed was applied manually to the cell transplants 2-3 times per week (Appendix 2). The seedlings were watered as judged necessary for their size and prevailing weather conditions.

2.4 The treatments and experimental design

The treatments were:

- Black plastic mulch plus fertigation (BPM)
- Rowcover (RC)

These were combined factorially to give the following four treatments:

1. Control (Bare ground)
2. BPM
3. RC
4. BPM plus RC (BR)

The black plastic mulch was standard mulch film, 1 meter wide and 50 microns thick. T-tape with emitters at 20 cm spacing was lain below the plastic mulch. Fertigation was supplied 3 times per week (Monday, Wednesday and Friday) from establishment until 24 days before the final harvest. A 100 ppm N, 34 ppm P and 100 ppm K feed was applied after diluting a stock solution 100 times. The nutrient ingredients used to make the stock solution was as for the cell transplant liquid feed (Appendix 2).

The rowcover used was a light polyester fabric (Trade name: "Evolution") 1.7m wide and 38 µm thick, which was supported at 2 m interval by wire hoops and buried along the edges with soil.

A squirrel data logger was set up one week after transplanting. Four probes were buried 10 cm deep in the soil, while another four probes were mounted, with the protection of plastic cups, 15cm above ground. Recording was at 30 minute intervals for the following periods: 8 - 14 November, 25 - 30 November and 1 - 20 December 1995.

To study the effect of the treatments on the growth and development of young plants, four destructive harvests were taken during the crop's first 8 weeks in the field. These plants were used in a growth analysis study. Seven destructive harvests were made over the period that the fruit matured to study fruit maturity patterns.

A Split-plot design was used with BPM and RC treatment combinations as the main plots with harvests as the split-plot. There were four replications. Each replication had four main plots and in each main plot there were two series of plants. Series 1 was the plants for the growth analysis study and series 2 was the plants for the study of the fruit maturity pattern. In series 1 there were four plots each of four plants and in series 2 there were seven plots each of fifteen plants. There were two guard plants between the plots. A plan of the experiment is detailed in Appendix 3 and Appendix 4.

For series 2 in block II, each subplot was reduced to 7 plants due to herbicide damage (Arsenal 250A, isoprophylamine salt) (Harrington, 1996). The symptoms were first seen one week after transplanting and became more serious with time.

2.5 Transplanting of seedlings in the field

The cell transplants were planted into the field 52 days after sowing on 3 November, 1995. Seedlings were planted 20 cm apart in the row with the rows at 1.5 m centres (33 333 plants ha^{-1}). Plants were irrigated at transplanting and also one week after transplanting.

The depth of transplanting was a little higher than the height of cell media. The floating rowcovers were set up immediately after transplanting on the RC plants. Fertigation was applied three times per week irrespective of rainfall via the fertigation system with treatments BPM and BR. Floating rowcovers were taken off 6 weeks after transplanting.

2.6 Crop Management

The main weed species in experimental area were red root (*Amaranthus* spp.), night shade (*Solanum nigrum* L.), white clover (*Trifolium repens*), dock (*Rumex obtusifolius*) and plantain (*Musa* sp.). Weed control was carried out manually throughout the growing season. Pesticides were sprayed regularly at appropriate intervals. The applications of pesticides are detailed in Appendix 5.

2.7 Data collection and analysis

2.7.1 Growth and development of young plants

Observations on flowering was made with the series 2 plants. The date of the first flower opening and when first anthesis had been completed for 50% of the plants were recorded on a plot basis.

Water deficits during growing season (Appendix 6) were calculated from the differences between total weekly water loss in crop field (mm) and total weekly rainfall (mm) using meteorological records for an adjacent CRI site (Appendix 7). This was done to determinate when the unirrigated plants were moisture stressed.

Plate 1 General view of the experiment on 11 December 1995

(From left: row 4-bare ground, row 5-BPM+RC, row 6-RC, row 7-BPM, row 8-guard plants)

Plate 2 Comparison of plant growth of the different treatments

6 weeks after planting

Data for the study on the growth and development of young plants using growth analysis was collected from plants of series 1. There were four harvests at two week intervals covering the 8 weeks immediately after transplanting. The first harvest was two weeks after planting. At each harvest the fresh and dry weight of stem, petioles and leaves were determined and the leaf area was measured with a LI-COR Area Meter Model LI-3100. This data was collected on a plot basis.

For each plot ln dry weight per plant (lnW), ln leaf area per plant (lnLA), and ln leaf dry weight per plant (lnLW) were calculated. From the parameters of these elementary growth curves per plot, the relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) were derived using the functional approach to growth analysis (Hunt, 1982). A two factor Randomised Complete Block Design was used to perform the ANOVA at each harvest. Data were analysed using the MSTAT-C statistical package.

2.7.2 Leaf nutrient analysis and TSS, fruit yield and fruit maturity pattern determination

2.7.2.1 Leaf nutrient analysis

Samples of young leaves plants from the control and BPM treatments were collected for nutrient analyses at 2-week intervals from two weeks after transplanting till the end of experiment. Leaves were collected on the basis of four leaves per plot from each of the replicates and then the samples were bulked together. For this purposes the third leaf down from the top of the plant was sampled and dried in a forced-air oven at 70-80°C for 48 hours and kept in plastic jars with lids. At the end of the experiment, all leaf samples were dried in the oven at 70°C for 24 hours and then ground in a laboratory DFH 48-Grinder through a 1mm mesh sieve.

The contents of K, Mg and Ca were analysed by atomic absorption spectrophotometry. N and P content were analysed by using the Kjeldahl and a spectrophotometric methods, respectively.

2.7.2.2 TSS measurement

The TSS of ripe fruit was determined by using a Brix meter at harvest 4 and harvest 5. For this purpose, 10 ripe fruits which were uniform in size and colour were collected, after determining the fruit fresh weight. The ten fruits were cut into quarters (stem to blossom end) and opposite wedges from 10 fruits were mixed homogeneously using a blender. Blended samples were centrifuged to make clarified juice. Samples of clarified juice were poured into small vials. A few drops of clarified juice were used to determine the TSS of red fruits using an Abbe refractometer.

2.7.2.3 Fruit yield

The number and weight of rotten, green, coloured and red fruit were determined for each plot at each harvest. The data were analysed by using the MSTAT-C statistical package.

2.7.2.4 Mature plant growth

At harvest 5, the fresh and dry weight of stem, petiole and leaves of 3 plants from each plot in each replicate was determined and the leaf area measured with a LI-COR Area Meter Model LI-3100.

2.7.2.5 Fruit maturity pattern

The predicted normal distribution curves of weight of factory grade and red fruit with or without BPM were simulated by using the modified method of Nichols (1965, Appendix 8).

CHAPTER THREE

Results

3.1 Growth and development of young plants

The black plastic mulch plus fertigation treatment (BPM) significantly affected a number of growth parameters (Figure 3.2 - 3.4) and dry matter accumulation (Figure 3.1), while the use of rowcovers had little effect on the growth of the plants during their first 8 weeks in the field (Table 3.1), although there was a small increases in dry matter accumulation in the first 2 weeks with rowcovers (14 -28 days after transplanting, data not shown). The relative growth rate (RGR) over the 8 week period was higher for BPM plants (Table 3.2 and Figure 3.1). The net assimilation rate (NAR) of BPM plants, which increased over the 8 week period, increased at a slower rate than for the unmulched plants (Figure 3.2) but the leaf area ratio (LAR) decreased at a slower rate with BPM (Figure 3.3). The specific leaf area (SLA) increased at a slower rate with BPM (Figure 3.3). The leaf weight rate (LWR), which was greater, decreased faster (Figure 3.4).

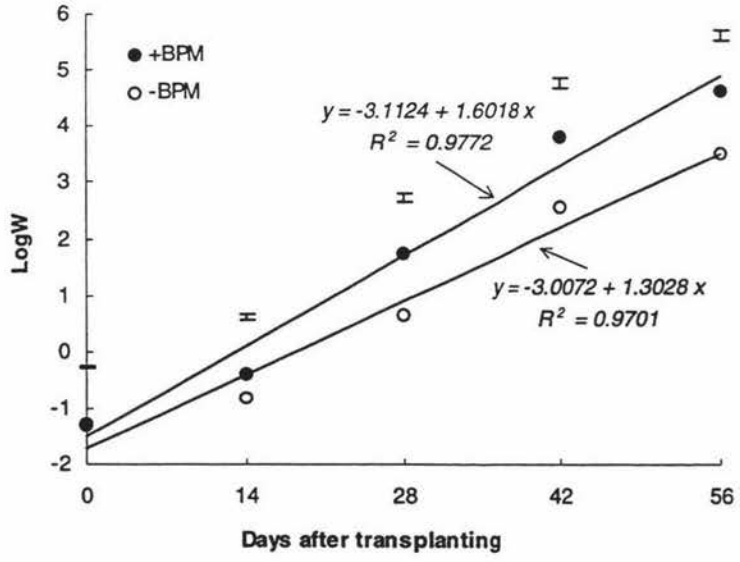

Figure 3.1 Dry matter accumulation based on logarithm with BPM and no BPM plants over first 8 weeks in the field

There was no effect of RC on RGR and LAR, SLA (Table 3.1). Rowcover plants however had a lower NAR at the first 2 harvests and a lower LWR at the final harvest.

Table 3.1 Growth analysis parameters with or without RC

	LAR ($m^2 g^{-1}$)			NAR ($g m^{-2}$)			LWR ($g g^{-1}$)			SLA ($m^2 g^{-1}$)		
Days	+RC	-RC	P	+RC	-RC	P	+RC	-RC	P	+RC	-RC	P
0	122.66	112.73	ns	0.011	0.013	**	0.606	0.572	ns	202.33	198.56	ns
14	108.96	106.66	ns	0.013	0.014	*	0.553	0.547	ns	196.06	195.18	ns
28	97.07	101.13	ns	0.014	0.015	ns	0.506	0.524	ns	190.45	192.50	ns
42	86.73	96.07	ns	0.016	0.016	ns	0.464	0.502	ns	185.45	190.47	ns
56	77.70	91.45	ns	0.019	0.017	ns	0.425	0.482	*	181.03	189.08	ns

* represents significant difference at P=0.05; ** represents significant difference at P=0.01; ns represents no significant difference

Table 3.2 Effect of BPM and RC on the average RGR ($g g^{-1}$ $week^{-1}$) over the first 8 weeks in the field

	with	without	significance
BPM	1.602	1.303	**
RC	1.399	1.505	ns

** represents significant difference at P=0.01; ns represents no significant difference

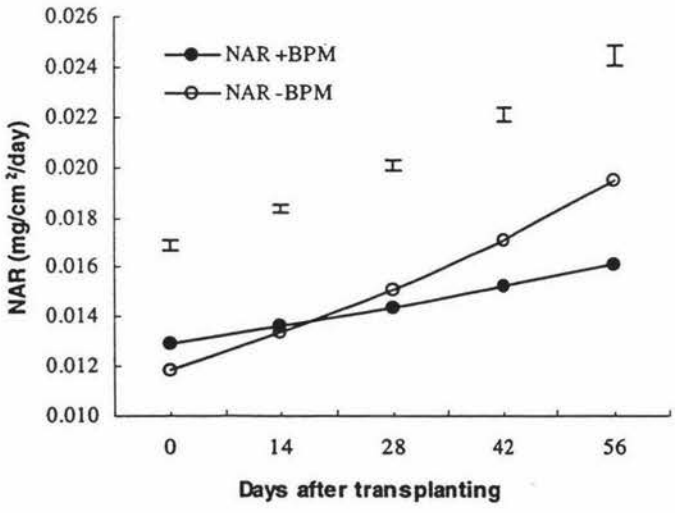

Figure 3.2 Net assimilation rate of tomato young plants with or without BPM (Vertical bar represents SEM at different harvests)

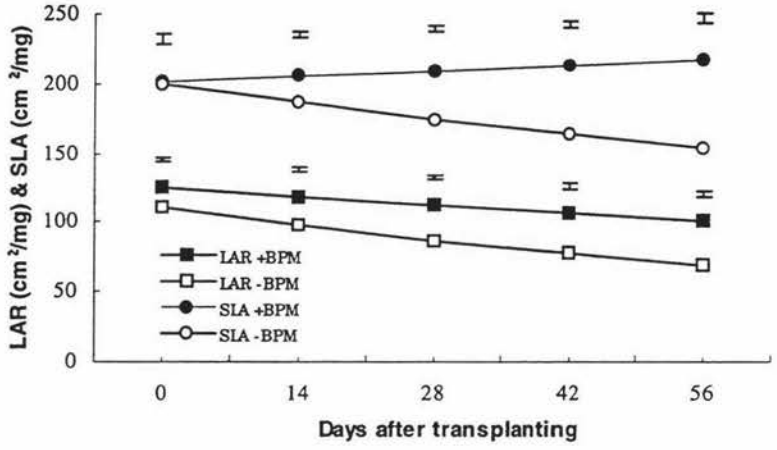

Figure 3.3 Leaf area ratio and specific leaf area of tomato young plants with or without BPM (Vertical bar represents SEM at different harvests)

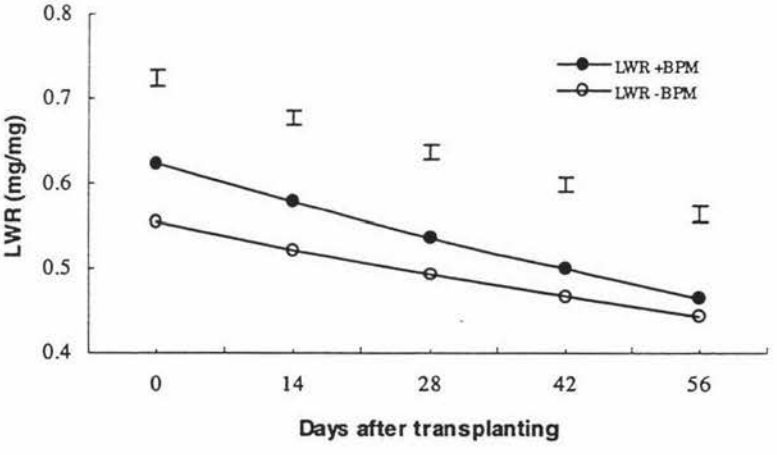

Figure 3.4 Leaf weight ratio of tomato young plants with or without BPM (Vertical bar represents SEM at different harvests)

Major differences were the effect of the BPM on RGR which was the result primary of the higher LAR. The initial increase in NAR soon disappeared due probably to natural shading of the larger BPM plant.

The increased LAR of BPM plant was due to the higher LWR's and also higher SLA's. RGR was constant and NAR increased over time which were due to a steady improving radiation and temperature environment, while LAR slightly fell over time.

3.2 Observations on timing of flowering and numbers of flower clusters, main stems, and fruit

The Black plastic mulch plus fertigation had no effect on the date of the first flower or 50% flower opening (Table 3.3), but the RC treatment significantly advanced by 2 days both the date of the first flowering and 50% flower opening compared with no RC.

Table 3.3 Effects of treatments on the date of the first flower and 50% flower opening

Treatments	Days after transplanting	
	First flowering	50% flower opening
Without BPM	28.2	31.6
With BPM	27.5	30.8
Significance	ns	ns
Without RC	28.9	32.2
With RC	26.8	30.2
Significance	**	**

** represents significant difference at P=0.01
ns represents no significant difference

The black plastic mulch plus fertigation did not affect the number of main stems, but increased the number of flower clusters, flowers and fruit per plant at both 56 and 112 days after transplanting compared with the no BPM treatment (Table 3.4). RC increased the number of main stems and the number of fruit compered with no RC at 56 but not at 112 days after transplanting.

Table 3.4 Effect of treatments on number of main stems, flower clusters and fruits per plant

Treatments	56 days after transplanting			112 days after transplanting		
	Number of main stems	Number of flower clusters	Number of fruit	Number of main stems	Number of fruit trusses	Number of fruit
Without BPM	6.25	19.88	13.34	7.50	25.13	75.63
With BPM	7.25	36.63	27.13	9.00	47.75	158.63
Significance	ns	**	*	ns	**	**
Without RC	7.50	30.88	13.50	8.50	34.88	111.75
With RC	6.00	25.63	27.00	8.00	38.00	122.50
Significance	*	ns	*	ns	ns	ns

* represents significant difference at P=0.05; ** represents significant difference at P=0.01; ns represents no significant difference

3.3 Temperature data

The average daily soil and air temperature during the early growing season and heat unit accumulations (base 10°C) over this growing period are shown in Table 3.5. The average daily soil temperature is highest under BPM, following by RC and lowest for BPM + RC, whereas the average daily air temperature and average heat unit accumulation is highest under RC, followed by BPM + RC. The use of BPM mainly affects soil temperature and the fabric rowcover mainly influences air temperature, while the use of BPM plus RC decreased slightly soil temperature in comparison with other treatments in this experiment.

Table 3.5 The average daily temperature for soil and air for 9-14, 25-30 November and on 1-20 December 1995 and average heat units accumulations (base 10°C) during these periods

	Soil				Air			
	Control	BPM	BPM + RC	RC	Control	BPM	BPM + RC	RC
Temperature(°C)	17.99	18.53	17.91	18.38	16.98	17.64	17.87	18.20
AHUA*	-	-	-	-	7.09	7.72	7.98	8.33

*:Average heat unit accumulations during recorded period when tomato plant has a base temperature of 10°C.

The daily average temperature and heat unit accumulations for soil and air on 9 - 14, 25 - 30 November and on 1 - 20 December 1995 are shown in Appendix 9.

3.4 Leaf nutrient levels

The seasonal variation in N (Figure 3.5a) and P (Figure 3.5b) leaf nutrient levels were similar for the control and BPM. The magnitude of the variation in the concentration of N and P of control plants was less than for BPM with the lowest value at 91 days after transplanting and the highest value at 112 days after transplanting. The concentrations of N and P for the BPM plants increased markedly from 14 to 28 days after transplanting and then decreased rapidly until 56 days after transplanting. The seasonal variation of K (Figure 3.5c) concentration was similar to that of N and P except at 70 days after transplanting for the control plants when they reached their lowest K concentration and the

BPM plants reached a high value. The amplitude of the variation in K was less than for N and P.

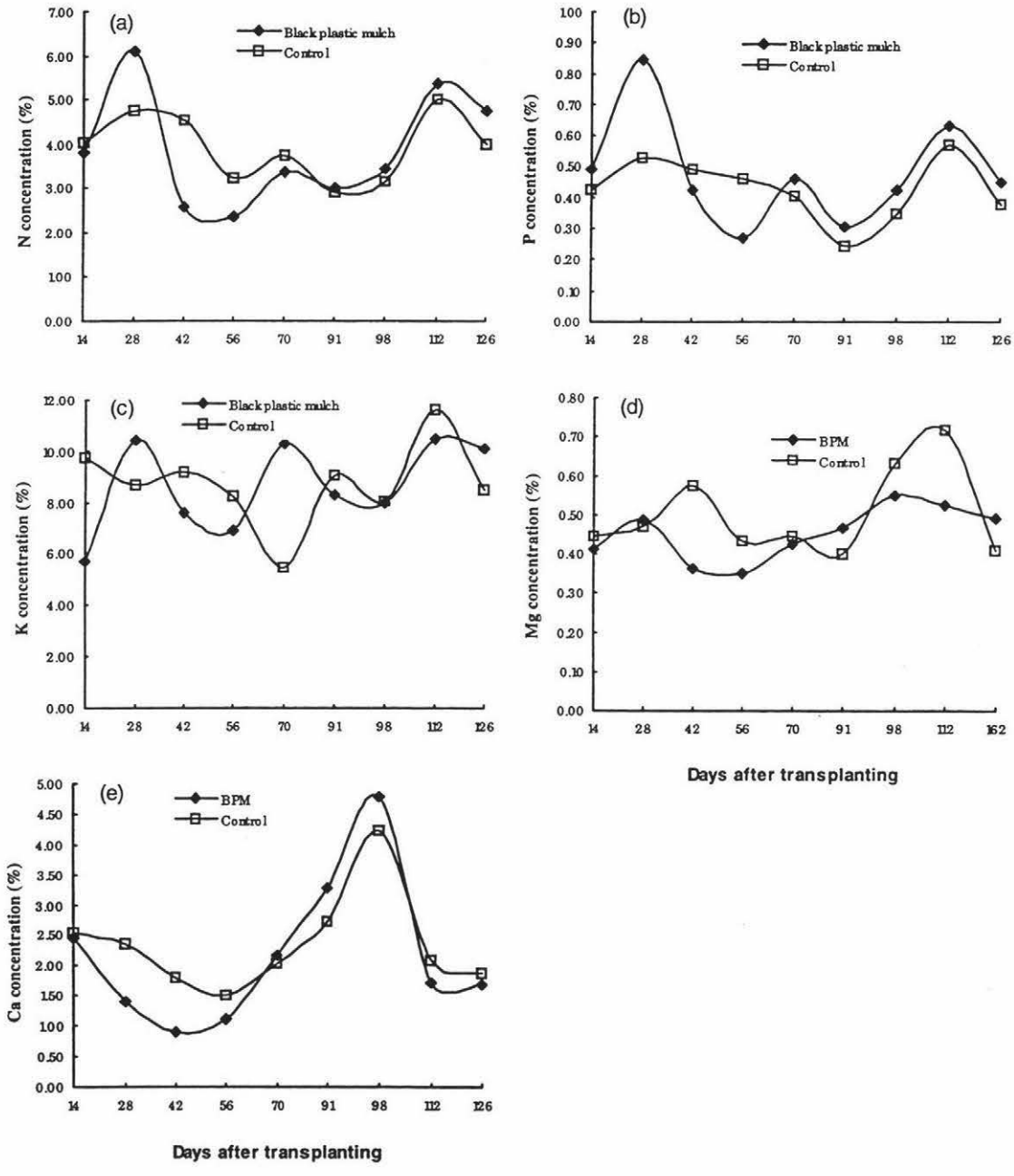

Figure 3.5 (a) Nitrogen (b) phosphorus (c) potassium (d) magnesium and (e) calcium concentrations (g/g) in leaves in control and BPM plants over the growing season

The seasonal variation in Mg for BPM was initially similar to that of N, P and K (Figure 3.5d). It increased initially and then decreased to 56 days. For much of growing period the control plants maintained the higher Mg level.

The leaf Ca level decreased to 42 - 56 days for both treatments and then increased to 98 days before decreasing (Figure 3.5e). The control plants had the higher Ca level from 14 - 56 days and BPM plants had the higher Ca level from 70 - 105 days (Figure 3.5e).

3.5 Total soluble solids (Brix)

BPM reduced total soluble solids of the tomato at 107 days after transplanting but not at 114 days after transplanting (Table 3.6). There was no effect of RC on total soluble solids at either 107 or 114 days after transplanting.

Table 3.6 Brix readings of ripe fruit

Treatment	Brix readings	
	107 days after transplanting	114 days after transplanting
With BPM	4.475	4.525
Without BPM	4.612	4.550
Significance	*	ns
With RC	4.563	4.612
Without RC	4.525	4.462
Significance	ns	ns

* represents significant difference at P=0.05
ns represents no significant difference

3.6 Growth of Mature Plant at 114 days after transplanting

The partitioning of plant dry weight is presented in Table 3.7. Possibly due to the small sample size no significant differences were found. The trend was for BPM to be better than without BPM and without RC to be better than RC.

Table 3.7 Plant dry weight (t ha^{-1}) partitioning at 114 days after transplanting (harvest 5)

	Leave	Stem+flower	Total vegetative tissue	Total fruit	Total plant
With BPM	1.45	1.30	2.75	6.59	9.34
Without BPM	1.34	0.86	2.20	4.95	7.15
Significance	ns	ns	ns	ns	ns
With RC	1.21	0.97	2.18	4.91	7.09
Without RC	1.58	1.19	2.77	6.63	9.40
Significance	ns	ns	ns	ns	ns

ns represents no significant difference

3.7 Fruit Yield

3.7.1 Effect of rowcover on earliness and total yield

There was an interaction between rowcovers and harvests. The trend for both weight and number of factory grade fruit was for RC to be greater for harvests 2 and 3 and then fall below no RC for the remaining harvests (Figure 3.6a, b). Significant difference in weight ($P<0.05$) and number ($P<0.05$) of factory grade fruit only occurred at harvests 4, 5 and 6 where no RC gave the higher yield and number of fruit. Similar responses occurred with the coloured and red fruits (data not shown). There were all so differences at later harvests for total yield but not number of fruit (Figure 3.6c,d)

The conclusion reached based on the data in Figure 3.6 is that using RC did not affect earliness but decreased yield at most of the later harvests.

3.7.2 Effect of BPM on earliness and total yield

The effect of BPM on the weight and number of fruit in each of the five grades of fruit are shown in Figure 3.7 - 3.11. The coloured and red grades were combined together to give the factory grade. There were significant interactions between BPM and harvests for the yield and number of fruit for all grades except for total number and yield of fruit. The

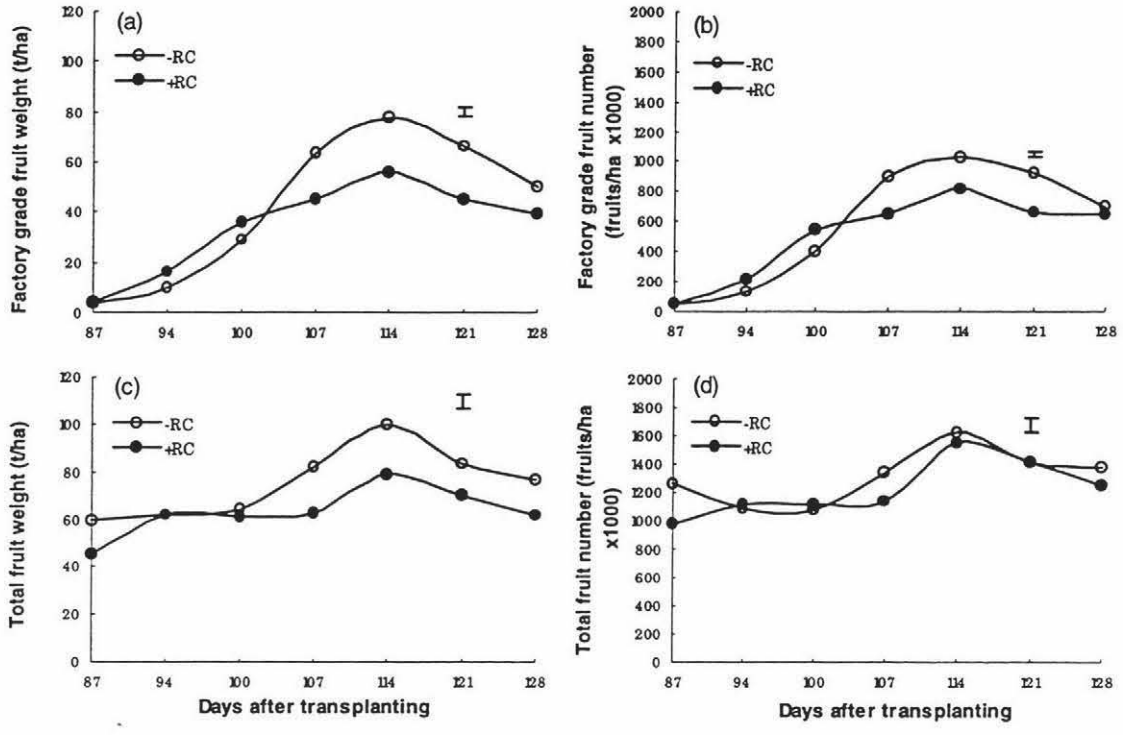

Figure 3.6 The weight and number of factory grade fruit (a, b) and total fruit (c, d) with and without RC over the harvesting season (Vertical bars represent overall SEM).

levels of significance was green ($P<0.001$), coloured ($P<0.001$), red ($P<0.001$), rotten ($P<0.05$) and factory grade ($P<0.01$). BPM plants had a greater weight and number of green fruits than no BPM plants at first three harvests (Figure 3.7). The number and weight of green fruit decreased to a low level at 107 days after transplanting with the weight and number of fruit for BPM and no BPM being similar. As fruit matured, the change in colour occurred gradually. Coloured, red and factory grade fruit increased in both number and weight with time and reached its peak at 107 days after transplanting for coloured fruit (Figure 3.8) and at 114 days after transplanting for both red (Figure 3.9) and factory grade fruit (Figure 3.11). For harvests at 94-107 days for coloured and harvests from 94 days for red and factory grade fruit BPM maintained a higher number and weight of fruit. Numbers and weights of rotten fruit increased with time and BPM maintained the higher number and weight of fruit (Figure 3.10).

BPM increased the total yield ($P<0.01$) and number ($P<0.01$) of fruit. This data can be seen in Figure 3.14 - 3.15. BPM maintained its advantage at all harvest dates.

The size of various grades of fruit including the mean across all grades (total) was calculated from data on fruit number and weight. There were no significant differences in fruit size between treatments (data not show). The size of the total, red and factory grade fruit remained constant with time, but the size of green and coloured fruit tended to decreased with time (Figure 3.12).

Based on the data for factory grade fruit (Figure 3.11) BPM did not advance the maturity of the crop.

3.7.3 Pattern of fruit ripening

The pattern of fruit ripening for all maturity grades for both fruit weight and number based on the data collected from all treatments, is presented in Figure 3.13. Figure 3.7 - 3.11 presents similar information for the BPM treatments on an individual grade basis. As the data for number and weight of fruit is similar in Figure 3.13 only the data for fruit weight will be reported here. As the yield of green fruit fell to 107 days after transplanting so the yield of coloured, red and factory grade fruit increased. Green fruit yield did not fall away completely, but was maintained at a low level from 107 - 128 days. The yield of coloured fruit was never high and peaked a week before the red and factory grade fruit yields peaked. This peak which gave a maximum yield at 114 days after transplanting was distinct. The yield of rotten fruit increased as the season progressed. Total yield increased to a maximum at 114 days and then decreased.

Figure 3.14 - Figure 3.15 present data for BPM and no BPM. These figures are similar to Figure 3.13 expect that the data is drawn from Figure 3.7 - 3.11. The fruit ripening patterns are as described for Figure 3.13.

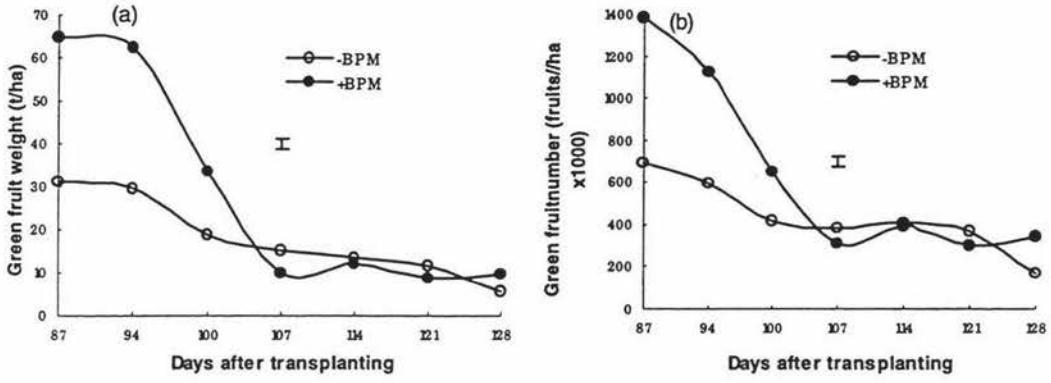

Figure 3.7 Effect of BPM and no BPM on (a) weight and (b) number of green fruit per hectare (Vertical bar represents overall SEM)

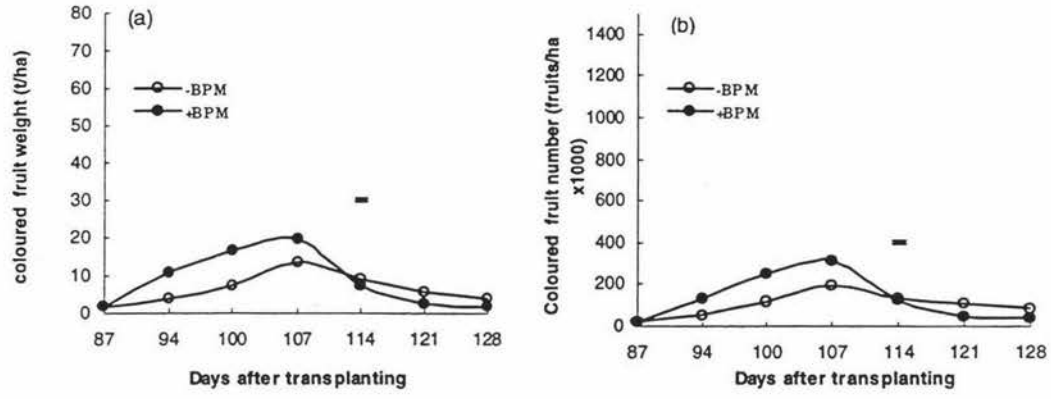

Figure 3.8 Effect of BPM and no BPM on (a) weight and (b) number of coloured fruit per hectare (Vertical bar represents overall SEM)

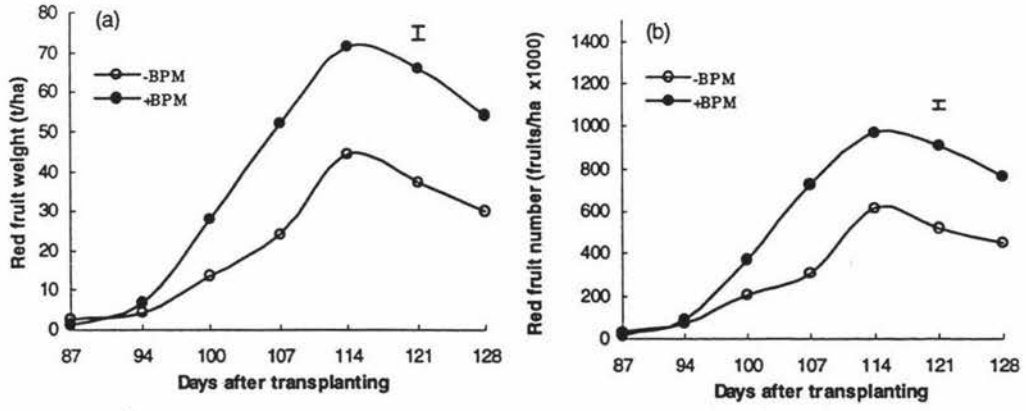

Figure 3.9 Effect of BPM and no BPM on (a) weight and (b) number of red fruit per hectare (Vertical bar represents overall SEM)

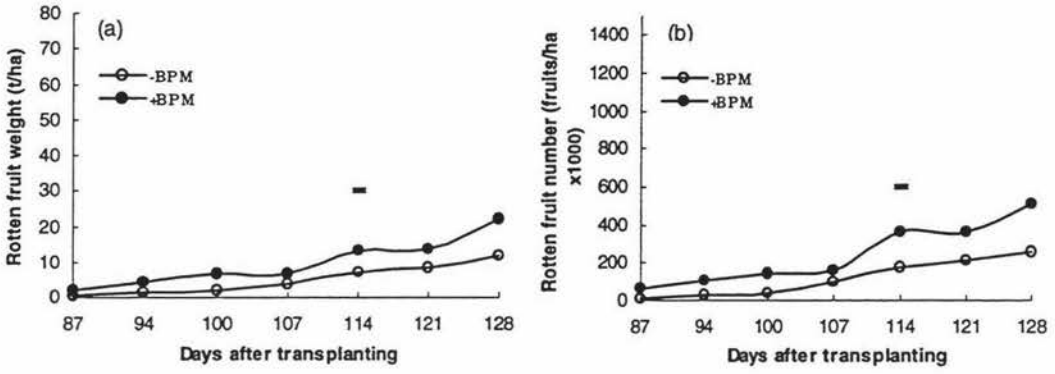

Figure 3.10 Effect of BPM and no BPM on (a) weight and (b) number of rotten fruit per hectare (Vertical bar represents overall SEM)

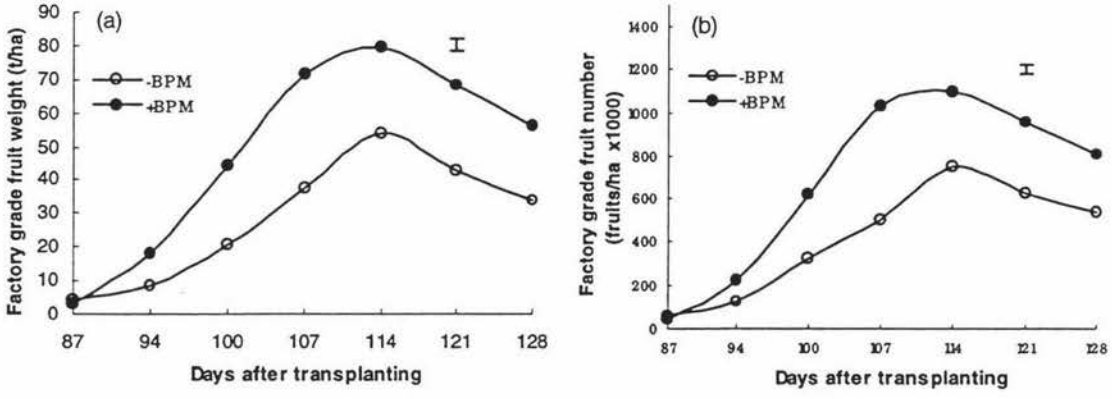

Figure 3.11 Effect of BPM and no BPM on (a) weight and (b) number of factory grade fruit per hectare (Vertical bar represents overall SEM)

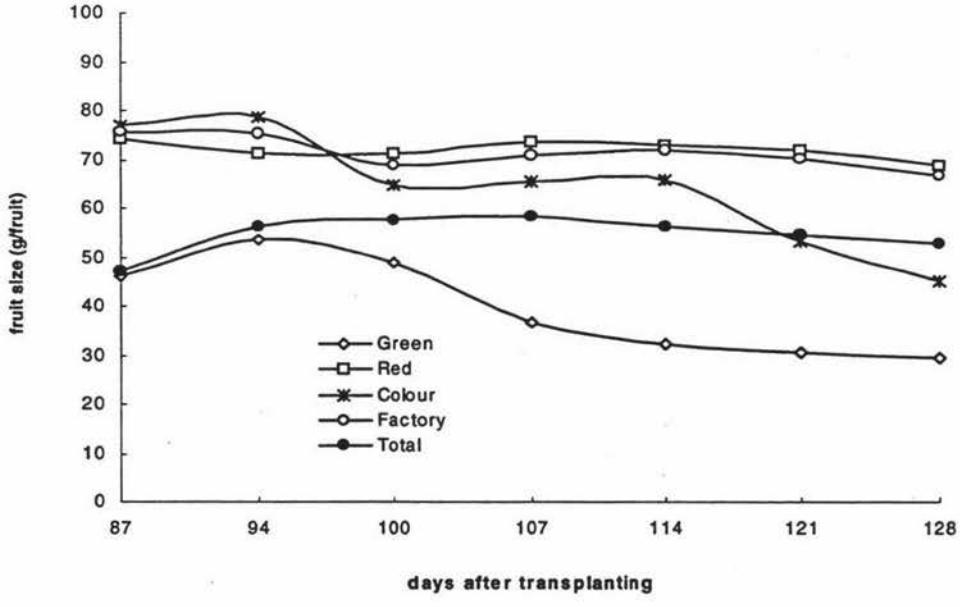

Figure 3.12 Size variation of the various grade of fruit over the growing season

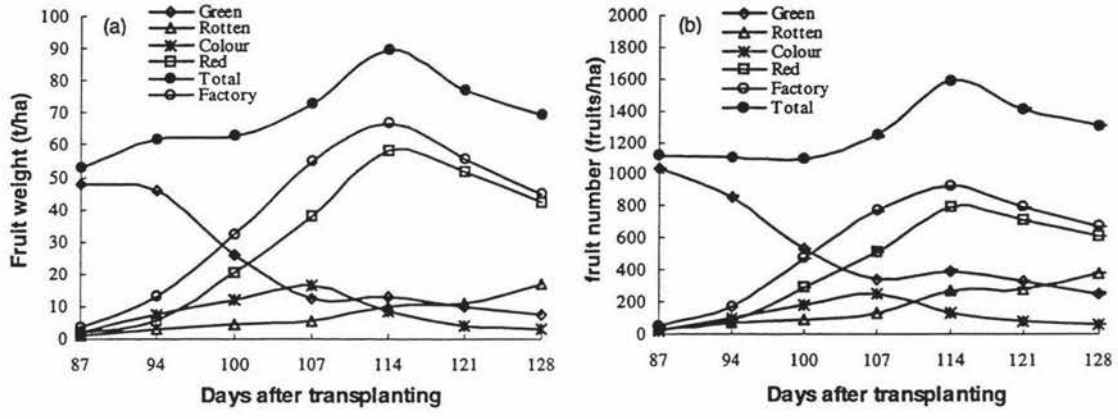

Figure 3.13 The fruit ripening pattern over the growing season for the whole experiment: (a) based on weights and (b) based on numbers

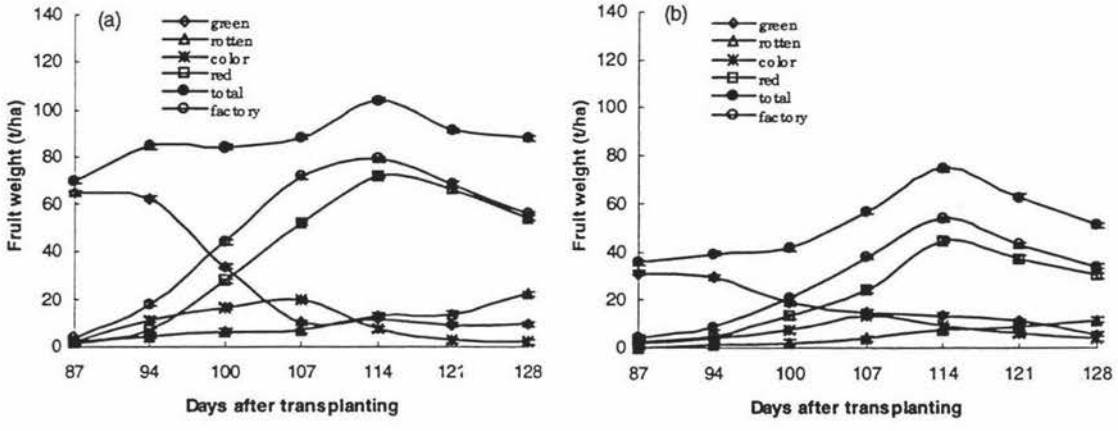

Figure 3.14 Weight of fruit per hectare for (a) BPM (b) no BPM

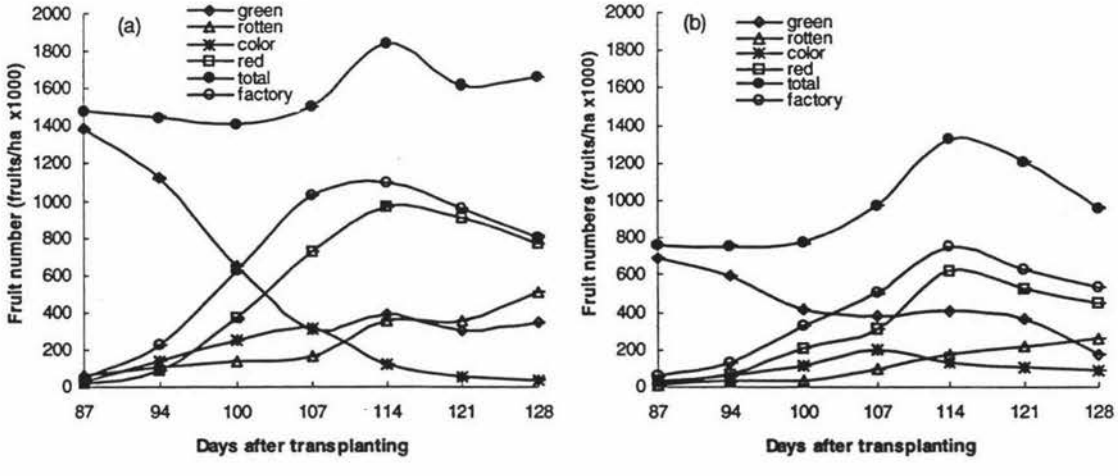

Figure 3.15 Number of fruit per hectare for (a) BPM (b) no BPM

3.8 Predicted normal distribution curves

The weight and numbers of factory grade and red fruit and their predicted normal distribution curve were generated and shown in Figure 3.16 - 3.17. The results of normal distribution curve statistics are tabulated in Appendix 11, and the maximal values for number and yield of fruit, and their timings and variances for red or factory grade fruit are tabulated in Appendix 12.

There were significant differences in yield of factory grade and red fruit between treatments with and without BPM ($P< 0.01$, Figure 3.16). The highest yield of factory grade and red fruit occurred at 114 days after transplanting where yields of 79 and 72 t ha^{-1} with BPM and 54 and 44 t ha^{-1} without BPM were achieved, respectively.

The actual yield distributions of factory grade and red fruit were slightly skewed to the right compared with the predicted normal distribution curves due to the morphological characteristics of Cleo tomato, which is a indeterminate cultivar and has a second fruit set late in the season (Figure 3.16).

The shapes of numbers of factory grade and red fruit and their predicted normal distribution curves are similar with that for yields (Figure 3.17). The highest numbers of factory grade and red fruit were all reached at 114 days after transplanting.

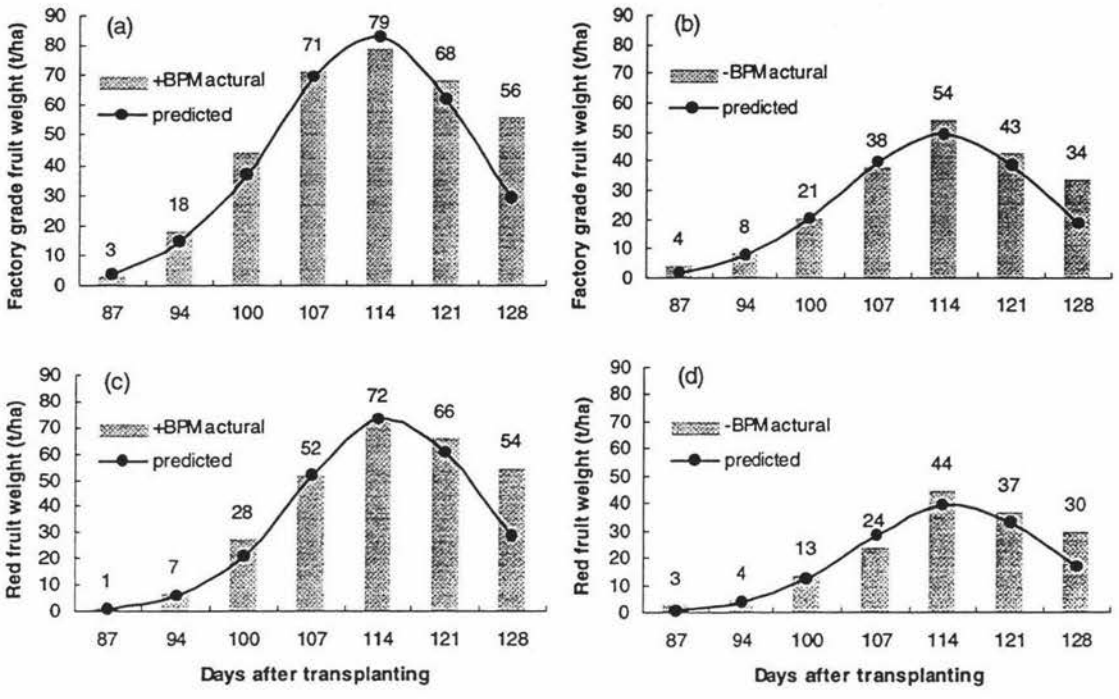

Figure 3.16 Yield of red and factory grade fruit and their predicted normal distribution curves for treatments (a, c) with BPM and (b, d) without BPM

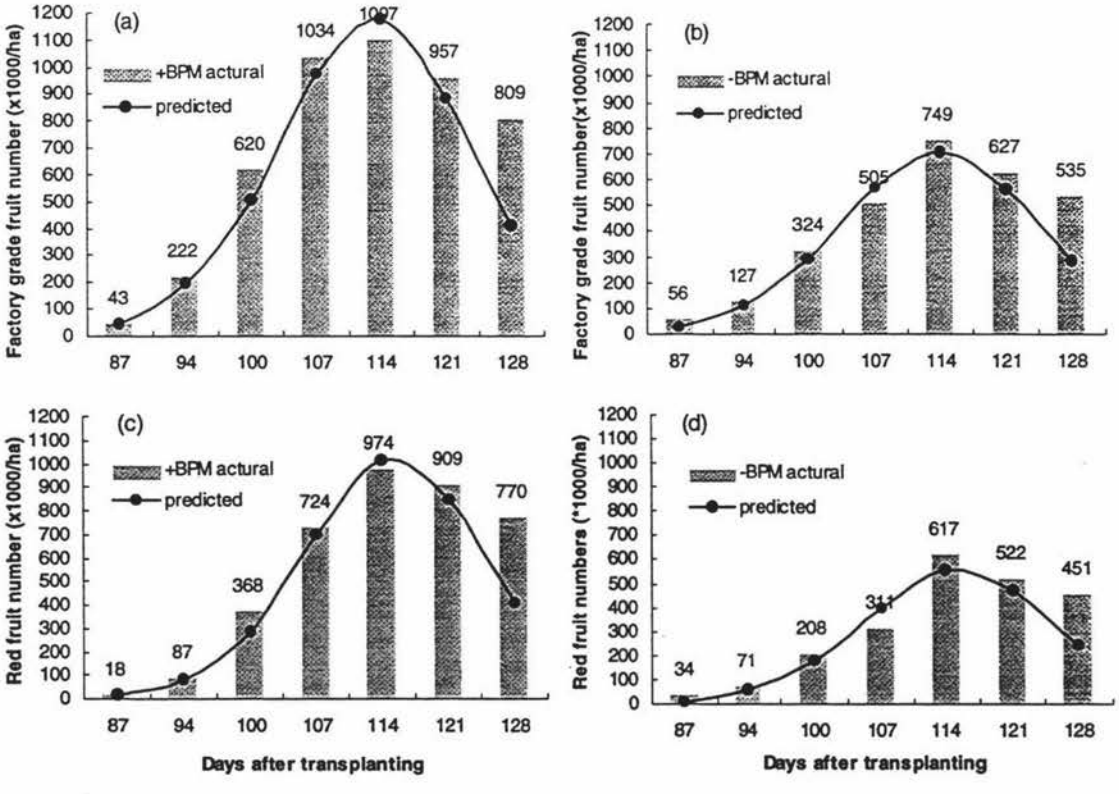

Figure 3.17 Number of factory grade and red fruit and their predicted normal distribution curves for treatments (a, c) with BPM and (b, d) without BPM

CHAPTER FOUR

Discussion

4.1 Growth and development of the young plant

The study of the growth and development of the young plant covered the crops first eight weeks in the field. The black plastic mulch plus fertigation treatment (BPM) significantly affected the early growth and development of Cleo plants. Mulch colour induces morphogenetic response in plants as they bring about a change in far-red/red ratio received by plants. Far-red/red ratio is important in the phytochrome regulation of plant physiological processes (Decoteau *et al.*, 1986). Thus far-red/red ratio plays a major role in assimilate partitioning during growth and influences plant adaptation to competition from other plants (Kasperbauer, 1988). The ratio acts through the phytochrome system to regulate stem elongation, leaf shape and thickness, chloroplast concentrations and development, photosynthetic efficiency and photosynthate partitioning among shoots, roots and developing fruits (Kasperbauer, 1987; Bradburne *et al.*, 1989).

The effect of mulch colour affecting the plant light environment has been well documented. Plants grown in sunlight over black plastic mulch had fewer axillary shoots (branches) and were taller than plants grown over white plastic mulch. The black plastic mulch surface reflected less total light and less blue light, but a higher ratio of far-red/red light (Decoteau *et al.*, 1988). Thomas (1981) reported that increasing the blue component of white light was associated with shorter internodes, smaller leaf areas and reduced relative growth rate. Light reflected off the plastic mulch surface can alter the plant light environment sufficiently to modify photosynthetic rate and/or light stimulus of morphogenetic development (Decoteau *et al.*, 1989). Leaves which developed on plants that received a high far-red/red ratio at the end of the daily photosynthetic period, grew longer and narrower than those that received a low far-red/red ratio at the end of each

day. The petioles were longer as were the stem internodes. In addition, leaves that received the higher far-red/red ratios were thinner, had a higher chlorophyll a/b ratio, and a higher concentration of light-harvesting chlorophyll protein (Bradburne *et al.*, 1989; Kasperbauer, 1994) and were more efficient photosynthetically. i.e. they fixed more CO_2 per mass of leaf tissue even through they did not differ on a leaf area basis. A higher far-red/red ratio leads to a longer stem with fewer branches and a more efficient photosynthetic system. This adaptive response would favour survival by increasing the probability of keeping some leaves in sunlight above competing plants and perhaps by having leaves that are more efficient in utilising light within the plant canopy (Kasperbauer, 1994). Decoteau *et al* (1989) reported that lighter-coloured mulches (silver and white) surfaces reflects more total photosynthetic light, but with a lower ratio of far-red/red light, which acts through the phytochrome system within a plant, than the other mulches. The increase in SLA of the mulched plants in the present experiment can be therefore explained by their leaves received higher far-red/red ratio by using BPM.

There were no effects of time on RGR in this experiment for both with BPM and no BPM (Section 3.1). Reason for constant relative growth rate maintained throughout the first eight weeks in the field was due to improving environment plus exponential growth of young plants and due to the indeterminate growth habit of Cleo tomato cultivar. These are inconsistent with findings of previous research (Smeet and Garretsen 1986). They found that the decrease in RGR with time was in part due to the decrease in LWR. The lower RGR of the no BPM plants, compared with BPM, is mainly attributed to a lower LAR which was due to a lower SLA (thicker leaves), which results in less light interception per unit leaf weight, and thus a reduction in growth and development (Heuvelink, 1989). The maintenance of constant RGR over the whole growth period is related to changes in NAR , LAR, SLA and/or LWR ($RGR = NAR \times LAR = NAR \times SLA \times LWR$). For the BPM plants, the higher constant RGR with time was due to a higher LAR which was the results of both a higher value in LWR and SLA with time, which was however not so greater for no BPM plants, where there was a increase in NAR and decreases in both SLA and LWR. This implies that thicker leaves were developed (Heuvelink, 1989) and the non-assimilating tissues were relatively increased (Nieuwhof *et al.*, 1991) with no BPM.

For both BPM and no BPM plants, RGR was near constant (Figure 3.1 and Table 3.2) over first eight weeks after transplanting because plants were growing exponentially.

The BPM plants maintained a higher relative growth rate than the no BPM plants (Table 3.2) so producing larger plants due to improved growing conditions. These improved environmental conditions included changes in the light, temperature and efficient utilisation of water and nutrients. Data on water deficits (Appendix 6) during growing season shows that during the period November 1995 to February 1996 significant crop moisture stress would have occurred on a number of occasions from mid December onwards. The alleviation of this stress by the fertigation treatment would have improved early growth and would have ensured sufficient moisture to maintain fruit size of the increased number of fruit set by the BPM treatment. It is suggested that the fertigation component was a major factor in the response to BPM. Improved nutrient and water availability would be important factors for growth and development. The leaf analysis data in this experiment (Section 3.4) suggests that N and P had an important role in improving early growth and fruit set and as a result increased fruit number and yield. N and P concentrations were higher in the leaves of the BPM plants compared to control for all but the period when the fruit were swelling (28-91 days after transplanting). Nutrient levels in leaves have been observed to fall over this period (Peck, 1996). As the mulched crop had the highest yield this may explain why, over the fruit swelling period, leaf nutrient levels fell further for these plants than for the unmulched plants.

With both BPM and no BPM, NAR increased with time, and with no BPM the increase in NAR with time was more marked, which is related to changes in an assimilatory component and may be attributed to the cultivar characteristics of Cleo tomato. For BPM plants, large plant size with luxuriant foliage led to natural shading and resulted in that NAR increased more slowly compared with no BPM plants. This implies that for Cleo tomato plants as their vegetative development progresses from young to mature the carbon-assimilatory capacity of the leaves increases gradually.

With both BPM and no BPM, LAR (Figure 3.3) and LWR (Figure 3.4) decreased with time. With no BPM SLA also decreased with time. This agrees with the research of Nieuwhof *et al.* (1991) and Smeets and Garretsen (1986). LAR represents the ratio of

photosynthesising to respiring material within the plant. BPM plants produced the thinner leaves in comparison with no BPM plants, as SLA increased with time. These leaves received the higher far-red/red ratios (as discusses above) and are more efficient in using light and going on photosynthesis. Thus LAR of BPM plants decreased slower.

With BPM, SLA increased with time, which may be attributed to morphological changes caused by using BPM. This is supported by research of Challa and Schapendonk (1984). They found that LWR was not much influenced by light level, while SLA (leaf thickness) was strongly influenced by light level. Hunt (1982) also concluded that of SLA and LWR, SLA was more sensitive to environmental change.

With BPM plants, significant higher dry matter accumulations (Figure 3.1) were obtained in comparison with no BPM plants during first 8 weeks in the field. This was due to the improvement of nutrients and water supplying and to the increase of photosynthetic efficiency. This is supported by data of growth analysis in this experiment and the report of Kasperbauer (1994).

RC plants accumulated the slight higher dry matter in comparison with no RC plants at first 2 weeks, which may in part be due to the increase in air temperature in this period.

4.2 Observations on timing of flowering and number of flower clusters, main stems and fruit

BPM had no effect on the time of flowering (Table 3.3). The responses of BPM plants in terms of increasing the number of flower clusters and fruit per plant at 56 and 112 days after transplanting (Table 3.4) could be ascribed in part to the microclimatic changes caused by BPM. Decoteau *et al* (1989) reported that the morphological development of young tomato plants was altered by subtle changes in the wavelength composition of light reflected from various colours of polyethylene surfaces. Soil surface or mulch colour can affect the reflected far-red/red light ratio sufficiently to influence photosynthate partitioning and biomass distribution within growing seedlings

(Kasperbauer, 1994). For example, tomato plants that received a higher far-red/red ratio grew longer stems and had fewer branches (Decoteau *et al.*, 1989) and had a more efficient photosynthetic system. Black mulch has been shown to affect flowering of tomato and mulching increased number of clusters and flowers in tomato (Vandenberg and Tiesser, 1972). In this experiment there was positive effects of BPM on the number of flower clusters and thus flowers per plant, and consequently, mulching significant increased fruit numbers per plant. This was possibly a photomorphogenetic response induced by using BPM. These results indicate that black plastic mulch *per se* affect the number of clusters, flower and fruit could in part be phytocrome stimulated brought about by the changes in plant microclimate, such as spectral balance and quantity of light.

In addition, it is possible that the higher soil temperature (Table 3.5) and smaller fluctuations in soil temperature under BPM (data not shown) would favour root growth and nutrient absorption as would the improved nutrient supply provided by fertigation. Air temperature data shows that air temperatures in the canopy of tomato plants grown with BPM was on average 0.7°C higher than with control plants. This implies that plants grown with BPM were subjected to more favourable temperatures than those grown in bare ground. Mulching also reduces the amount of water lost by evaporation from the upper soil layer (Rudich, 1979). Rudich (1979) also found that using BPM increased the soil temperature and the growth of roots and increased the availability of phosphorus, and consequently improved the growth of shoots. This is supported by results of growth analysis in this experiment. Fertigation applied adequate nutrients for early growth and development of tomato plants, which is vital to later growth and development.

4.3 Leaf nutrient analysis

Nutrient absorption is continuous during growth and development of the tomato plant. When the nutrient availability in a soil where plants are grown is high, then the requirements of plants are satisfied over their whole growth. If soil nutrient availability of mobile elements is limiting, then the needs for fruit development can be met in part by translocation from the vegetative portions rather than by root absorption. Limited absorption of non-mobile elements, such as Ca and Mg (Halbrooks and Wilcox, 1980),

due to drought, cannot be compensated for by translocation. Thus knowledge of plant nutrient absorption patterns can provide fertiliser application programs necessary for optimum production.

Results of leaf analysis show that BPM plants had higher uptakes of N, P and K from 14-28 days after transplanting (Figure 3.5) to meet the substantial nutrient requirements during establishment in the field and subsequently vigorously vegetative growth. It is supported by the results of this experiment, where the BPM plants maintained a higher relative growth rate (Section 3.1) and produced larger plants (Plate 2) than the other treatments and that BPM plants obtained significant higher fruit yields than no BPM plants (Section 3.7.2). From 28 to 56 days after transplanting plants were setting and swelling fruit, and concentrations of N nutrients decreased in leaves due to demands of the fruit (Peck, 1996). Therefore with BPM plants, because there were more fruit, more N was needed. The effect of P on the tomato plant is to prompt vigorous root growth, which provides a better utilisation of the nutrients in the soil, stimulating a sturdy stem and healthy foliage and increasing yields (Gould, 1992). Thus during 28 - 56 days after transplanting a large amount of P was required for vigorous root growth and fruit swelling. Therefore P would have been mainly transplanted to roots and fruits and the content of P in the leaves decreased. After fruit swelling ceased at about 70 days, the content of N and P in leaves increased again from 91 to 112 days after transplanting. For no BPM plants, a relatively steady amount of N and P were required prior to 70 days after transplanting. This could be attributed to smaller plants and less fruits caused by a reduced supply of nutrients and water stress which would limit the uptake of nutrients by roots.

Soil P availability is particularly important at the time when the root system is establishing. Dumas (1990) reported that growth and development rates increased with the amount of P mixed into the 0-22 cm layer of soil. Dumas (1987) reported that phosphorus availability enhanced flowering precocity.

Potassium maintains enzyme structure, is important in protein synthesis through its role in binding mRNA to ribosomes, and assists with the maintenance of electrostatic balance and turgor within the cell together with other cations (Shuman, 1994). K recycling occurs within the plant to facilitate the upward transport of NO_3^- from root to shoot.

When K^+ is in short supply the high mobility of this element ensures that the K^+ ion provides a balancing charge for NO_3^- uptake. In addition, NO_3 reductase activity was stimulated by an increased supply of K in the nutrient medium and if plants were not adequately supplied with K^+, NO_3 reduction may be affected (Kirkby *et al.*, 1981). The availability of metabolic substrates to the root has a controlling effect on K uptake and transport into the xylem stream (Widders and Lorenz, 1982). Widders and Lorenz (1982) suggested that ontogenetic changes in the growth rate of the plant, which reflect changes in the availability of metabolites, could be correlated with the rates of K transport to the shoot. They found that the high net rates of K accumulation primarily contributed to fruit development and that the rate of K accumulation in the fruit approximated the net accumulation in the entire aboveground portion (combined vegetative shoot and fruit tissues) from 90 days after planting. Therefore in this experiment, the occurrence of low leaf K concentrations during fruiting appears to be related to a large fruit set and the preferential partitioning of K into fruit tissues (Widders and Lorenz, 1982) during 28-56 days after transplanting (80-108 days after sowing). This is also supported by research of Widders and Lorenz (1982), who reported that the initiation of fruiting occurred 65 to 75 days after planting and at 125 days after planting over 65%, 75-80% or over 90% of fruits were matured depending on differences in cultivars. The differences in the leaf K content between mulched and unmulched plants before 91 days can be in part explained by differences in when the fruit placed their demands for K. With unmulched plants, the lowest leaf K content occurred at 70 days after transplanting and was probably due to the K redistribution from vegetative tissues to the fruit. After 91 days, disappearance of the differences in leaf K content may be due to the plants producing similar amount of new leaves in both the mulched and unmulched series and their being little demand from the fruit.

The lower levels of Mg and Ca in the leaves of the BPM plants over the 14 - 70 day period may be due to demands that fruit growth and development placed on these nutrients. However, these nutrients were not supplied by the fertigation system.

N, P and K concentrations in young mature leaves for the control and BPM plant at the time when the first fruit mature (94 days) are compared with published data (Clarke *et al*, 1986) (Table 4.1).

Table 4.1 N, P and K concentrations in young mature leaves

Nutrient	Published data	Control	BPM	comment
N	3.0-6.0	3.0	3.4	normal
P	0.50-0.80	0.32	0.42	low
K	2.5-4.0	7.8	7.8	high
Ca	4.0-6.0	4.2	4.8	normal
Mg	0.60-0.90	0.64	0.53	low

In conclusion, BPM plus fertigation maintained higher levels of N P K in the leaves early in the life of the crop. Fruit development lowered these levels. Later in the life of the crop there were similar N P K levels in the leaves between BPM and control.

4.4 TSS measurement

Total solids and water make up the composition of the tomato fruit (Gould, 1992). A direct reading of the tomato juices is the most common method of predicting the solids content using a refractometer. The refract meter reading (Brix) is not a true sugar reading but it is the measure of total soluble solids (TSS) in the tomato.

Numerous factors are known to influence °Brix. Water availability and nutrient availability appear to be the main agronomic factors, which cause soluble solids concentrations to vary (Dumas *et al.*, 1994). Vural *et al.* (1994) suggested that the high Brix values is probably a result of high nitrate fertilisation and water stress after fruit set and before harvest. Our Brix data confirmed the finding of Vural *et al.* (1994). For BPM plants total soluble solids of the tomato was reduced at 107 days after transplanting but not at 117 days after transplanting (Table 3.6). Thus the adequate water supply via the fertigation increased yield but decreased solids. Fertigation was discontinued 104 days after transplanting and by 117 days after transplanting there was no difference in Brix between mulched and unmulched plants. This result is supported by the research of May *et al.* (1990). May *et al.* (1990) found that high solids can result from moisture stress. They reported that terminating irrigation prior to harvest can result in moisture stress effecting yields and solids. Yields were highest on the 20-day cut-off and decreased with the 60-day cut-off. More days of water cut-off resulted in higher percent solids.

However, a high solid tomato resulting from high moisture stress will yield more paste per ton, but this paste could be of a poorer quality.

4.5 Growth of mature plant 114 days after transplanting

There were no significant effects on the partitioning of dry weight at 114 days after transplanting (Table 3.7). This was the time of maximum fruit yield and was despite differences in growth, favouring BPM after 8 weeks in the field (Section 3.6). The lack of significance may by more a result of the small plant harvested from each plot (Section 3.6) rather than a lack of a treatment effect. Thus the trend of the data in Table 3.7 is in the expected direction. In each comparison BPM produced the greater dry weight.

4.6 Effect of rowcovers on crop growth and yield

When rowcovers are used, light, soil and air temperature, humidity and air movement are all modified (Motsenbocker and Bonanno, 1989). Wells and Loy (1985) reported that one layer of fabric cover protects tomatoes and pepper from frost to about -3°C, whereas 2 layers protect from frost -6°C. Mansour (1984) indicated that row covers provide only a small amount of frost protection, approximately 1° to 4°F. However, they can more than double the heat units accumulated over a four- to six-week period. Floating covers will allow growers to plant 1-2 weeks earlier than normal and they should be left on for 4-6 weeks, depending on the crop. With fresh market tomatoes, a three-week covering period might be too short to provide any benefit, so a five- or six-week covering period is more appropriate. The beneficial effects of rowcover have been attributed to providing enhancement of plant growth and protection against frost, insects, birds, animals. It can help growers to overcome land and climate adversities to achieve the purpose of early production (Motsenbocker and Bonanno, 1989). In 1995, the experiment was planted on 3 November, which due to bad weather, was three weeks later than planned. During the period of November 1995 the meteorological records for an adjacent CRI site show that mean daily minimum air

temperature (°C) range was 8.3-10.6°C, the mean daily maximum air temperature range was 16.3-19.4°C, and the mean daily 10 cm soil temperature range was 13.4-15.6°C (Appendix 7). Early yield was not improved by the use of rowcovers (Figure 3.6). An important factor in this lack of response was the fact that bad weather delayed planting and temperatures after planting were reasonable so that any potential benefit caused by using rowcovers was lost. The positive effect of the RC treatment in advancing flowering and 50% flower opening by 2 days (Table 3.3) can be attributed to the changes in soil and air temperature, which were modified by RC treatment. However, there were no RC effects on earliness or RGR over first 8 weeks in the field (Table 3.2). The relatively short use of the RC treatment may explain this lack of response, although the reduced NAR (Table 3.1) of the RC treatment during the first 2 weeks after planting out might suggest that the temperatures at times were too high.

These results suggest that rowcovers only should be used for early Spring production or to prevent late frost damage. This is supported by the results of Wells and Loy (1985) who reported that row cover (RC) provides enhancement of plant growth and protection against frost. RC reduced the yield and number of factory grade fruit at optimum harvest (Figure 3.6, 114 days after transplanting) shows the treatment was in fact detrimental. Thus the late use of the rowcover reduced yields by reducing fruit numbers. This could be explained by the higher temperatures that would occur midday, reducing fruit set and thus fruit numbers and yields. The works of Rudich *et al* (1977) supports this conclusion. Further support for this suggestion is provided by the data collected on fruit numbers at 56 days after transplanting (Table 3.4). Here the RC treatment increased fruit numbers, but at 112 days this advantage had been lost. This suggests that it was the later setting of fruit that was affected by high temperatures.

These results indicate that by using floating covers during early summer fruit setting was reduced by high temperatures (>30°C). This occurred on 3 December, for example, which was during the intensive flowering stage (Table 3.3). Plants experienced under rowcovers enhanced high temperatures for 6 to 9 hours (data not shown). Rudich, *et al* (1977) found that even a few hours of high temperature (over 40°C), at the critical stages of gametogenesis, can adversely affect the viability of ovules and the production, dehiscence and transfer of pollen. With RC treatment on 3 December, there were indeed 2

hours of high temperature (over 40°C) were recorded. This result shows that the timing of rowcover application is critical for its successful use.

This conclusion is supported by the finding of Wells and Loy (1985) who reported that the excessive temperature during the early period of the growing season can reduce yields drastically for tomatoes and pepper. A similar result also was obtained with muskmelon by Motsenbocker and Bonanno (1989). They found that the use of a perforated rowcover resulted in lower total marketable yields than with the spunbonded rowcover and that excessive air temperatures with perforated rowcover resulted in reduced marketable yield.

4.7 Effect of BPM on yield and earliness of crop

From 87 to 94 days after transplanting for both BPM and no BPM the weight of green fruit is constant (Figure 3.7a) but its number decreases (Figure 3.7b). This indicates that fruit size is still increasing while green fruit numbers were falling (Figure 3.12). The yield and number of green fruit with BPM plus fertigation is about twice the yield with no BPM, which could be attributed to warmer soil temperatures, reduced water vapour loss and nutrient leaching caused by BPM, which results in earlier flowering (not in this experiment), more total flowers, and greater subsequent growth (Vandenberg and Tiessen, 1972). Nutrient and water applications by the fertigation system during early growth increased nutrient availability and improved water-use efficiency, which again increased plant growth and development and fruit setting (Bhella, 1988). The increase in fruit numbers suggests that improved conditions for early growth and development were provided by the BPM treatment. This is supported by BPM effect on RGR (Section 3.1) and flower cluster number (Section 3.2). It is suggested that the fertigation component was a major factor in the response to BPM. Thus improved nutrient and water availability would have made a major contribution the response to the BPM treatment.

Early-setting fruits appear to be stronger sinks than later ones, as reflected in their higher rates of dry-weight accumulation (i.e. in their faster increase in fruit size). From physiological point of view, sink strength determines assimilate allocation rather than

assimilate availability (Daie, 1985). A rapidly growing sink, which resulted from, for example using BPM plus fertigation, will produce a steeper gradient between source and sink, and it thus competes at advantage relative to a weaker sink, this will increase the net assimilation rate (Fisher, 1977).

From 87 - 94 days after transplanting, the number and weight of coloured, red and rotten fruit (Figures 3.8 - 3.10) were very low for both with BPM and no BPM. This suggests that during this week fruits had almost completed swelling. From 94 days after transplanting, sharp reductions in number and weight of green fruit and sharp increases in number and weight of coloured and red fruit with BPM and no BPM occurred. Minimal values of green fruit and maximal values of red fruit was obtained at 107 and 114 days after transplanting, respectively. The significant differences between BPM and no BPM for both number and weight of green fruit were maintained as the fruit matured from green to red and finally to rotten fruit. However, during this period differences for both number and weight of coloured fruit between BPM and no BPM were not significant. The peak for coloured fruit in weight and number were reached a week earlier than red fruit at 107 days after transplanting. It seems that changes in colour to red stage finished within one week. It suggested with this cultivar that when the peak for coloured fruit weight and number were reached the optimum harvest time would commence about one week later. There was a slight increase in green fruit yield at 114 days due to the Cleo cultivar continuing to set fruit throughout the season.

The maximum yield of red and factory grade fruit occurred at 114 days after transplanting (Figure 3.9 and 3.11, respectively). This was time for both with BPM and no BPM. There was therefore no effect of BPM on earliness.

4.8 Pattern of fruit ripening

Some discussion of this topic took place in Section 4.6 Effect of BPM on yield and earliness of crop. In that section Figures 3.7 - 3.11 were considered. In the present

section Figure 3.13 - 3.15 will be considered. These Figures bring together the various maturity grades into single graphs for the respective treatment data sets.

Total yield averaged across all treatments (Figure 3.13) and for the BPM and no BPM treatments (Figure 3.14) peaked at 114 days. The sharp increase from 87 - 94 days could have been due to the green fruit increasing in size. This is supported by the data on fruit size in Figure 3.12 where over this period the only fruit to increase in size were the green and total classes. Also Figures 3.15 show fruit numbers were constant over this period.

The increase in total yield from 107 - 114 days would be due to increased fruit numbers of green fruit. It was at 107 days that green fruit number levelled off. In Section 4.6 this was suggested to be due to late setting fruit. The fall in total fruit yields and fruit numbers from 114 days would be due to the increasing number of rotten fruit.

The change from green to coloured to red was as was to be expected and was discussed in Section 4.6. There were no treatment effects on fruit size. The data for the mean fruit size over all treatments for the full fruit ripening period was very constant (Figure 3.12). This was to be expected as once the fruit is mature green no further increases in fruit weight occur and fruit just changes colour as it matures. The decrease in size of green fruit from 100 days and coloured fruit from 114 days would be due to late setting fruit.

4.9 Predicted normal distribution curves

The predicted normal distribution curves fitted the raw data well (Figures 3.16 - 3.17). These results suggest that the optimal harvest date of Cleo tomato in this experiment was 114 days after transplanting. If harvesting was carried out one week earlier or later than this optimal harvest date, then the yield of factory grade fruit would be reduced by up to 8 - 11 t ha^{-1} with BPM and up to 16 - 11 t ha^{-1} without BPM. In earlier research on flower and fruit development in processing tomatoes, similar results were obtained by Julian (1990) when growing different cultivars of processing tomatoes. Davis (1992), when comparing the performance of bare-root and cell transplants, reached a similar conclusion. This also agrees with a research on the effect of delayed harvest on the yield

and quality of processing tomatoes in Turkey. Yoltas *et al.* (1994) found that with processing tomatoes, which were harvested using 3 successional harvests, that delaying each harvest by up to 15 days reduced fruit yield. These results suggest that the timing of harvest of processing tomatoes is far more critical than is commonly believed. Result of is a further indication that processing tomato fruit do not hold on the vine as long as commonly believed. That such a relationship exists can only be determined in experiments where successional destructive harvests are carried out. This is not normally done because of the large amount of extra work involved in data collection. It could be possible to develop a predictive model based on data of this type, for example in this study the optimum harvest date was 7 days after the peak yield of coloured fruit (Figures 3.8 and 3.11).

CHAPTER FIVE

Conclusions

An important objective of the experiment was to improve earliness. Neither the use of rowcovers or black plastic mulch affected earliness. RC failed to do this due to late planting. Thus further research is required to assess the potential of row covers as the present project failed adequately to test this hypothesis.

The results of this study demonstrate that black plastic mulch plus fertigation provides improvements in the growth (relative growth rate) and development (number of flower clusters) and yield of total, red and factory grade fruit for the processing tomato cv Cleo. Fertigation made a major contribution to the increase in yield by limiting water and nutrient stress. Further improvements were achieved by the black plastic mulch enhancing root zone temperatures and improving the supply and efficiency of absorption of nutrients and water so producing larger sized plants and greater yields. The mulch also provides for changes in the spectral balance and quantity of light, so increasing photosynthetic efficiency and photosynthate partitioning to developing fruits.

There is a problem with mulching and mechanical harvesting of processing tomatoes. The mulch will interfere with the harvesting process. One approach would be to use degradable polyethylene sheets.

Ethylene (ethrel or ethephon) is widely used to maximise the yield of ripe tomatoes (Farag and Palta, 1993). Ethephon triggers a maturation mechanism which effects the ripening process, but not ripening itself (Splittstoesser and Vandemark, 1972). It was not used in the present experiment, but it is not considered its use would have changed the conclusions researched.

In this research the approach to watering and feeding was simplistic. Application of N and K should follow the nutrient uptake pattern of a crop and should use soil and leaf

analysis, including quick tests, to fine tune nutrient management. Further work in this area is required.

Processing tomatoes grown in New Zealand are likely to have their yield improved by the use of fertigation to ensure an adequate supply of nutrients and for eliminating water stress. The use of drip irrigation would also improve water-use efficiency, and minimise nitrate pollution in the ground water.

With cultivar Cleo the number and yield of factory grade and red fruit followed a normal distribution curve and reached their peaks at 114 days after transplanting. Advancing or delaying the time of harvest decreased yield. It is suggested that the timing of harvest of processing tomatoes is far more crucial than is commonly believed and techniques to predict the time of optimum harvest should be developed.

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Appendices

Appendix 1 Required target nutrient values of MAF (Clake et al, 1986) and the results on soil test of Karapoti brown sandy loam soil

	pH	Olsen P	K	Ca	Mg
MAF	5.3-6.7	35-45	14	>10	10-12
Results	5.9	91	18	11	32

Appendix 2 Liquid feed for seedlings grown in the greenhouse (also as a stock solution for application of nutrients in the field after concentrating 100 times)

Fertilisers	kg/100L	ppm
NH_4NO_3	0.0137	N 100
monoammonium phosphate	0.0133	P 30
KNO_3	0.0256	K 100

Appendix 3 Plan of experiment (series 1) for growth analysis of young plants

Block I				Block II				Block III				Block IV			
treatments (main plots)				treatment (main plots)				treatment(main plots)				treatment (main plots)			
1	3	4	2	3	2	1	4	2	3	4	1	1	3	4	2
H2	H2	H4	H2	H4	H2	H1	H3	H2	H3	H3	H4	H2	H3	H4	H2
H4	H3	H3	H4	H2	H4	H4	H2	H1	H4	H4	H3	H1	H4	H1	H4
H3	H1	H2	H3	H1	H1	H2	H4	H3	H2	H1	H2	H3	H2	H2	H3
H1	H4	H1	H1	H3	H3	H3	H1	H4	H1	H2	H1	H4	H1	H3	H1

NB: Treatment 1: Bare Ground; Treatment 2: Black Plastic Mulch (BPM);

Treatment 3: BPM + Rowcover; Treatment 4: Rowcover

H1, H2, ..., H4: represents Harvest 1, Harvest 2, ..., Harvest 4, respectively, which were subplots.

4 Plants were harvested at each harvest.

Appendix 4 Plan of experiment (series 2) for fruit yield and maturity pattern

Block I				Block II				Block III				Block IV			
treatments (main plots)				treatments (main plots)				treatments (main plots)				treatments (main plots)			
1	3	4	2	3	2	1	4	2	3	4	1	1	3	4	2
H2	H1	H1	H2	H5	H4	H7	H2	H6	H3	H4	H2	H6	H6	H1	H1
H7	H4	H3	H7	H4	H1	H6	H5	H2	H1	H7	H1	H4	H3	H3	H3
H1	H2	H5	H3	H1	H3	H4	H6	H3	H5	H3	H7	H3	H7	H7	H4
H4	H5	H7	H5	H7	H2	H2	H7	H5	H4	H2	H5	H5	H2	H5	H6
H6	H3	H4	H4	H3	H7	H5	H1	H1	H6	H1	H3	H2	H5	H4	H5
H3	H7	H6	H1	H2	H6	H3	H4	H4	H7	H6	H6	H7	H4	H2	H2
H5	H6	H2	H6	H6	H5	H1	H3	H7	H2	H5	H4	H1	H1	H6	H7

NB: Treatment 1: Bare Ground; Treatment 2: Black Plastic Mulch (BPM);

Treatment 3: BPM + Rowcover; Treatment 4: Rowcover;

H1, H2, ..., H7 represents Harvest 1, Harvest 2, ..., Harvest 7, respectively.

15 or 7 plants were harvested at each harvest.

Appendix 5 The applications of pesticides

Dates of application	Pesticide	Dose
14/11/95	Mancozeb	150-200g/100 litres of water
30/11/95	Mancozeb	150-200g/100 litres of water
12/12/95	Mancozeb	150-200g/100 litres of water
23/1/96	Benlate	2 kg/700-1100 litres water
31/1/96	Ridomil	2.5 g/litre of water
15/2/96	Manzate 200	150-200g/100 litres of water
22/2/96	Manzate 200	150-200g/100 litres of water

Appendix 6 Water deficits during the experimental periods (1 October, 1995 to 30 February, 1996)

Weeks	Total weekly Pan Evaporation in pasture(mm)	Total weekly water loss in crop field(mm)	Total weekly Rainfall (mm)	Total weekly water deficit (mm)
1-7/10/95	13.1	10.5	36.3	0
8-14/10/95	9.7	7.8	62.3	0
15-21/10/95	16.7	13.4	13.5	0
24-28/10/95	18.5	14.8	0.0	14.8
29-30/10/95	10.7	8.6	27.5	0
1-7/11/95	18.9	15.1	27.6	0
8-14/11/95	23.4	18.7	19.2	0
15-21/11/95	24.4	19.5	19.6	0
24-28/11/95	26.9	21.5	34.8	0
29-30/11/95	8.2	6.6	1.2	5.4
1-7/12/95	32.2	25.8	trace	31.3
8-14/12/95	28.0	22.4	3.7	50
15-21/12/95	41.3	33.0	15.4	67.6
24-28/12/95	30.1	24.1	75.5	0
29-30/12/95	14.7	11.8	6.4	5.4
1-7/01/96	39.2	31.4	0.0	36.8
8-14/01/96	27.1	21.7	33.7	24.8
15-21/01/96	40.0	32.0	0.0	56.8
24-28/01/96	38.4	30.7	17.2	70.3
29-30/01/96	13.8	11.0	0.0	81.3
1-7/02/96	38.3	30.6	47.9	64
8-14/02/96	32.6	26.1	2.7	88.6
15-21/02/96	22.6	18.1	56.8	0
24-28/02/96	29.2	23.4	21.3	2.1
29-30/02/96	5.1	4.1	0.0	6.2

N.B. For Karapoti brown sandy loam of soil used in this experiment, the available soil moisture (A.S.M.) is 60 mm/30 cm. Irrigation should occur when 50% of the available soil moisture has been lost, i.e. 30 cm. The weekly total water loss from the crop (mm) is 80% total weekly pan evaporation.

Appendix 7 Meteorological records at an adjacent CRI site, Palmerston North during October, 1995 to February , 1996

Week:	Total weekly Rainfall(mm)	Total weekly Pan Evaporation. (mm)	Mean daily minimal air temperature(°C)	Mean daily maximal air temperature(°C)	Mean daily 10 cm soil temperature (°C)
1-7/10/95	36.3	13.1	10.6	18.2	13.6
8-14/10/95	62.3	9.7	7.1	14.9	11.9
15-21/10/95	13.5	16.7	7.3	14.9	11.7
24-28/10/95	0	18.5	9.0	18..2	13.5
29-30/10/95	27.5	10.7	9.3	18.4	14.5
1-7/11/95	27.6	18.9	8.3	16.3	13.4
8-14/11/95	19.2	23.4	10.6	19.4	15.3
15-21/11/95	19.6	24.4	8.9	17.9	15.2
24-28/11/95	34.8	26.9	8.8	18.7	14.7
29-30/11/95	1.2	8.2	9.3	18.9	15.6
1-7/12/95	trace	32.2	14.0	23.00	18.90
8-14/12/95	3.7	28	13.6	22.40	18.40
15-21/12/95	15.4	41.3	11.4	21.30	17.10
24-28/12/95	75.5	30.1	13.6	21.3	17.7
29-30/12/95	6.4	14.7	14.3	21.1	17.4
1-7/01/96	0	39.2	14.5	23.3	19.2
8-14/01/96	33.7	27.1	15.7	24.8	20.6
15-21/01/96	0	40	14.8	22.8	19.4
24-28/01/96	17.2	38.4	13.5	20.8	18.5
29-30/01/96	0	13.8	14.1	23.9	18.6
1-7/02/96	47.9	38.3	15.3	24.2	19.5
8-14/02/96	2.7	32.6	15.1	23.8	19.3
15-21/02/96	56.8	22.6	14.6	22.3	19.7
24-28/02/96	21.3	29.2	10.3	20.6	15.5
29-30/02/96	0	5.1	11.0	23.2	18.0

Appendix 8 The calculation of the moments and parameters, the simulation of normal distribution curve

In order to calculate the predicting values of normal distribution curve, the following equation is used (Nichols, 1965):

$$F_N(x) = \frac{\alpha}{\delta\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\delta^2}} \quad (1)$$

Where F_N (x) is predicting fruit yield at time x after transplanting, μ is the meantime to produce total fruit yield, $\alpha = 2\pi$. multiples total fruit yield, δ is the standard deviation, δ^2 is the variance, π =3.1416.

In equation (1), The function values (fruit yield) is decrease progressively as the increase of negative exponential power ($-\frac{(x-\mu)^2}{2\delta^2}$) because $e^0 = 1$, $e^{-0.1} = 0.90$, $e^{-0.2} = 0.82$,... $e^{-1} = 0.37$, etc.. In other words, when the time x = the meantime μ to produce total fruit yield, the crop reaches its maximum fruit yields. Therefore, the maximal values of this function (*Ymax*) can be calculated by following equation:

$$Y\max = \frac{\alpha}{\delta\sqrt{2\pi}} \quad (2)$$

For normal distribution curve statistics, the following 4 moments and 4 parameters are calculated (Nichols, 1965):

$$V_1 = \frac{\Sigma(fx)}{\Sigma f} = \mu \quad \text{(1st moment)} \quad (3)$$

$$V_2 = \frac{\Sigma\left(f(x-\mu)^2\right)}{\Sigma f} = \delta^2 \text{ (variance)} \quad \text{(2nd moment)} \quad (4)$$

$$V_3 = \frac{\Sigma\left(f(x-\mu)^3\right)}{\Sigma f} \quad \text{(3rd moment)} \quad (5)$$

$$V_4 = \frac{\Sigma\left(f(x-\mu)^4\right)}{\Sigma f} \quad \text{(4th moment)} \quad (6)$$

The 2 remaining parameters (skewness and kurtosis) can be calculate from these moments.

$$\text{Skewness } (\theta) = \frac{V_3}{(V_2)^{3/2}} \tag{7}$$

$$\text{kurtosis } (\gamma) = \frac{V_4}{(V_2)^2} \tag{8}$$

For normal distribution curve $\theta = 0$, and $\gamma = 3$.

The 'k' statistics of Fisher can be calculated as follows in order to determine the significance of these parameters:

$$k_1 = V_1 \tag{9}$$

$$k_2 = \frac{N}{N-1} V_2 \qquad (N = \alpha) \tag{10}$$

$$k_3 = \frac{N^2}{(N-1)(N-2)} V_3 \tag{11}$$

$$k_4 = \frac{N^2}{(N-1)(N-2)} \times \left[\frac{(N+1)V_4 - 3(N-1){V_2}^2}{N-3} \right] \tag{12}$$

Two statistics (g_1 and g_2) can be then calculated from these 'k's:

$$g_1 = \frac{k_3}{(k_2)^{3/2}} \tag{13}$$

$$g_2 = \frac{k_4}{(k_2)^2} \tag{14}$$

For a normal distribution, both g_1 and g_2 are equal to zero.

The standard errors of g_1 and g_2 are:

$$\text{s.e. } g_1 = \frac{6N(N-1)}{(N-2)(N+1)(N+3)} \tag{15}$$

$$\text{s.e. } g_2 = \frac{24N(N-1)^2}{(N-3)(N-2)(N+3)(N+5)} \tag{16}$$

Appendix 9 The daily average temperature for soil and air on 9-14, 25-30 November and on 1-20 December 1995 and heat unit accumulations (base 10°C) during these periods

	Soil				Air			
Date	BG	BPM	BR	RC	BG	BPM	BR	RC
09/11	15.1	16.0	15.9	15.8	15.7	16.1	16.9	16.4
10/11	16.2	16.5	16.3	16.5	15.7	16.2	17.5	17.1
11/11	15.7	16.5	16.2	16.2	15.6	16.0	16.3	15.9
12/11	15.6	16.1	15.8	15.8	14.6	15.1	16.3	15.7
13/11	16.2	16.7	16.5	16.3	15.7	16.2	19.4	18.2
14/11	17.2	18.1	17.7	17.2	15.9	16.4	19.6	18.3
15/11	15.8	18.0	17.4	16.1	10.4	10.7	10.4	10.1
25/11	17.2	17.9	16.9	17.4	18.4	19.5	19.3	19.5
26/11	16.6	17.5	16.5	17.1	14.0	14.6	14.4	14.6
27/11	15.3	15.8	15.0	15.9	12.0	13.2	13.2	13.7
28/11	14.7	15.6	14.9	15.5	12.4	13.6	13.3	13.9
29/11	15.5	16.2	15.4	16.1	14.9	16.8	16.6	17.6
30/11	16.3	17.2	16.3	16.8	16.3	17.4	17.2	17.6
01/12	17.2	18.0	17.1	17.7	17.6	19.0	18.8	19.6
02/12	18.3	18.8	17.9	18.7	18.8	20.3	19.8	20.9
03/12	19.4	19.9	18.9	19.8	20.8	22.7	22.4	24.0
04/12	21.4	21.7	20.4	21.4	20.8	21.9	22.0	22.8
05/12	20.6	21.3	20.0	20.5	18.7	19.3	19.2	19.4
06/12	20.7	20.9	19.7	20.4	21.0	22.4	21.8	24.1
07/12	20.7	21.2	20.1	21.0	18.5	19.3	19.1	20.2
08/12	19.6	20.2	19.3	20.1	18.2	18.8	18.5	18.9
09/12	18.5	19.3	18.5	19.1	16.1	16.6	16.3	17.1
10/12	17.9	18.4	17.8	18.6	17.8	19.1	18.2	20.6
11/12*	20.0	19.9	19.4	20.5	20.8	21.2	21.2	22.1
12/12	20.5	20.5	19.9	20.9	20.3	20.3	20.5	20.9
13/12	20.8	20.8	20.3	21.2	21.0	21.1	21.2	21.5
14/12	20.5	20.8	20.3	21.1	17.6	17.8	17.9	17.7
15/12	19.0	19.4	19.0	19.5	17.4	17.2	17.8	17.8
16/12	19.8	19.8	19.5	20.3	17.6	17.5	17.8	17.9
17/12	18.9	19.3	19.0	19.7	13.9	14.0	14.2	14.0
18/12	17.5	17.8	17.6	17.9	16.0	16.3	16.7	16.2
19/12	17.1	17.8	17.6	17.5	16.0	16.0	16.4	16.4
20/12	17.8	17.9	17.9	17.9	19.7	19.2	19.9	20.1
HUA**	263.7	281.6	260.9	276.4	233.9	254.7	263.4	275.0

*:Floating rowcovers were taken off on 11/12/1995;

**:Heat unit accumulations where a base temperature of 10°C was used.

Appendix 10 Growth analysis parameters with and without BPM

Harvest	RGR			LAR			SLA		
weeks	+BPM	-BPM	P	+BPM	-BPM	Pro	+BPM	-BPM	P
0	1.602	1.303	0.002	125.000	110.392	0.0105	201.713	199.176	ns
2	1.602	1.303	0.002	118.166	97.454	0.0016	205.064	186.175	0.0275
4	1.602	1.303	0.002	111.821	86.378	0.0007	208.630	174.313	0.0003
6	1.602	1.303	0.002	105.927	76.874	0.0006	212.420	163.505	0.0000
8	1.602	1.303	0.002	100.446	68.704	0.0006	216.445	153.668	0.0001

Harvest	LWR			NAR		
weeks	+BPM	-BPM	P	+BPM	-BPM	P
0	0.623	0.554	0.0291	0.013	0.012	ns
2	0.578	0.523	0.0324	0.014	0.013	ns
4	0.537	0.494	ns	0.014	0.015	ns
6	0.499	0.467	ns	0.015	0.017	0.0199
8	0.464	0.442	ns	0.016	0.019	0.0055

Appendix 11 The moments, parameters and statistics for normal distribution curves

Parameters	Fruit weight (t/ha)		Fruit numbers (× 1000/ha)	
	red fruit	factory fruit	red fruit	factory fruit
Means	115.06	113.32	115.19	113.51
Variance	9.60	10.24	9.66	10.26
Skewness	-0.43	-0.30	-0.44	-0.29
Kurtosis	2.58	2.35	2.55	2.32
V_1	115.06	113.32	115.19	113.51
V_2	92.16	104.91	93.25	105.31
V_3	-383.12	-320.00	-398.31	-317.19
V_4	21873.26	25887.62	22184.47	25683.24
k_1	115.06	113.32	115.19	113.51
k_2	92.58	105.30	93.28	105.33
k_3	-388.46	-323.57	-398.71	-317.44
k_4	-3483.86	-7071.37	-3894.70	-7581.13
g_1	-0.0010	-0.0006	-0.0010	-0.0005
g_2	-0.4064	-0.6377	-0.4476	-0.6833
s.e.g_1	0.0272	0.0219	0.0020	0.0016
s.e.g_2	0.1077	0.0870	0.0079	0.0062

Appendix 12 The maximal values for number and yield of fruit, and their timing and variances for red and factory grade fruit

		maximal					maximal		
		numbers	time	spread			yield	time	spread
-BPM	red	556.51	115.15	19.94	-BPM	red	39.96	115.06	19.57
+BPM	red	1018.67	115.22	18.94	+BPM	red	73.82	115.06	18.99
-BPM	factory	705.13	113.91	20.78	-BPM	factory	49.33	113.67	20.46
+BPM	factory	1177.96	113.27	20.35	+BPM	factory	83.26	113.12	20.49
-RC	red	881.60	115.92	18.36	-RC	red	65.79	115.89	18.28
+RC	red	702.69	114.36	20.21	+RC	red	48.86	114.04	20.09
-RC	factory	1057.91	114.08	19.53	-RC	factory	77.22	114.07	19.47
+RC	factory	834.00	112.86	21.53	+RC	factory	56.27	112.40	21.54