YIELD AND QUALITY RESPONSE OF TOMATO AND HOT PEPPER TO PRUNING

BY

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ABSTRACT

The effect of source-sink relationships on the performance of tomato and hot pepper was investigated in glasshouse experiments by pruning tomato trusses and hot pepper fruit from plants trained to a single stem. The objectives were to characterize the effect of time, method and intensity of pruning on the yield and quality of tomato and hot pepper. Pruning at anthesis as compared to pruning at fruit-set had little effect on yield and fruit quality of both crops. Yield per truss increased steadily with intensity of pruning in tomato, due to increase in fruit size and fruit number per truss. Thus, total yield was not affected by pruning. In hot pepper fruit size increased with intensity of pruning but total yield was significantly reduced and total plant dry mass depressed at higher source : sink ratios (two and three fruit pruned out of a total of six). Occurrence of fruit disorders such as blossom-end rot and fruit cracking increased with increasing source: sink ratio. Pruning of one truss in tomato and one fruit in hot pepper gave the best fruit quality in terms of fruit size, pericarp thickness and freedom from defects, without decreasing total and marketable yield.

Removing a middle truss of tomato (third truss) gave the highest yield as compared to removing the youngest truss (sixth truss) or the oldest truss (first truss). The yield increase (relative to the control) in the remaining individual trusses tended to decrease with increasing distance of the trusses from the pruned truss. In hot pepper removal of the youngest fruit (sixth fruit) resulted in the highest yield in comparison to removal of the middle fruit (third fruit) and the oldest fruit (first fruit). The quantity of yield increase in the remaining individual fruits had no consistent trend regarding the relative distance of the fruits from the pruned fruit.

Two pruning methods were tried on hot pepper and tomato to compare yield and fruit quality. The first method involved pruning of the first three consecutive trusses of tomato and the first three consecutive fruit of hot pepper out of a total of six. The second method involved pruning of three alternating tomato trusses or hot pepper fruit. Yield and yield components did not differ significantly for the two methods, but pruning alternate trusses of tomato and fruit of hot pepper reduced occurrence of fruit disorders.

Key words: tomato, hot pepper, yield and yield components, fruit quality, pruning.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Tomatoes (*Lycopersicon esculentum*) and hot peppers (*Capsicum frutescens*) are popular vegetable crops in Eritrea and in many parts of the world. Tomato, in particular, is an important vegetable crop worldwide and has a variety of uses. Ripe tomato fruit is consumed fresh and utilized in the manufacture of a range of processed products such as puree, paste, powder, ketch-up, sauce, soup and canned whole fruit. The unripe green fruit are used for pickles and preserves. Moreover, tomato extracts have been used in traditional medicine to treat ulcers, wounds, hemorrhoids, burns and edema during pregnancy (FAO, 1996).

Hot pepper fruit are used to spice the bland flavor of staple foods and as a coloring and flavoring agent in sauces, soups, processed meats, snacks, candies, soft drinks and alcoholic beverages, either in the ground form or as an oleoresin (concentrated extract). The chemical compound present in this crop - capsaicin - is used to make 'pepper sprays' used for personal protection. Capsaicin also has medicinal properties and can be included in analgesic creams to treat shingles and provide pain relief for arthritis patients. Medicinal products containing capsaicin can also be used to relief neuralgia, diabetic neuropathy and post surgical pain (Morgan & Lennard, 2000).

Hot peppers and tomatoes belong to the same botanical family, Solanaceae (Van Veldhuizen, 1986). They are herbaceous, warm season crops, which are annual in temperate regions, but can produce continuous growth in tropical areas (Morgan & Lennard, 2000). Determinate and indeterminate growth types exist. In the indeterminate varieties, once flowering starts it continues throughout the life of the plant and it is unlikely that total fruit yield will be limited by the number of fruit formed. This increase in fruit number increases the potential for competition between fruit and the consequent reduction in fruit size (Van Ravestijn & Molhoek, 1978). Different cultural methods can be used to manipulate the fruit size. Most of these methods, however, entail chemicals that may not be acceptable to the consumer. A non-chemical method is by pruning some of the flowers or young fruit. However, removing potential fruit will influence the sink in the sink-source interaction, and thus the partitioning of assimilates. Furthermore, if pruning is not done at the appropriate level, time, and using suitable methods, fruit disorders, yield loss and inhibition of dry matter production may result.

Pruning of some of the flowers or fruit from crops like tomato and hot pepper results in assimilate re-distribution to the remaining fruit, increasing their size. The extent of re-distribution of assimilates to the remaining fruit appears to depend mainly on the sink-strength of fruit (which varies with the age of fruit) and on the transport pathway (Kinet & Peet, 1997). Thus, an overview of the characteristics of the fruit and the transport pathway is worthwhile in an effort to understand the functioning of the intricate source-sink system.

1.2 ASSIMILATE PARTITIONING AND SINK STRENGTH

In a model developed by Heuvelink and Marcelis (1989), dry matter distribution is primarily regulated by the sink-strength of the various organs. When the available assimilates equal or exceed the total sink strength of the plant, the growth rates of the vegetative parts and the individual fruit or clusters occur at the potential rates. However, when the amount of available assimilates is less than the total sink strength, the assimilates are distributed between leaves, stem, roots and fruit according to their individual sink strengths relative to the total sink strength.

The sink strength of an organ can be quantified by the potential growth rate of a sink, that is, the growth rate under conditions of non-limiting assimilate supply (Marcelis & Heuvelink, 1999). Potential growth rate is a dynamic parameter that may change with developmental stage or temperature. In tomato, a developing inflorescence is a weaker sink for assimilates than the expanding leaves, but a truss with growing fruit is a stronger sink than young leaves and roots. The potential sink strength of the inflorescence increases from flowering to fruiting stage. The priority between sinks for assimilates changed from roots > young leaves > inflorescence in a flowering plant to fruit > young leaves > flowers > roots in a fruiting tomato plant (Ho, 1988) .

Similarly, an actively growing pepper fruit is believed to be a stronger sink than a flower or maturing fruit (Ali & Kelly, 1992). However, in growth analysis studies done by Marcelis and Baan Hofman-Eijer (1995), the sink-strength of pepper fruit was hard to determine. This was due to the occurrence of fruit deformation and blossom-end rot when fruit were grown under non-limiting assimilate supply.

The sink-strength of tomato fruit also varies depending on the position of the truss on the stem and position of the fruit within the truss. Lower trusses and proximal fruit have higher sink strength than upper trusses and distal fruit. Bangerth and Ho (1984) associated this with the variation in the number of cells that fruit from various positions of the plant attain at anthesis. Besides, Bertin (1995) has reported that, within one inflorescence, the vascular area of the rachis was reduced at the inflorescence extremities, which could contribute to the restriction of assimilates to distal fruit, rendering them weaker sinks.

Changes in sink-strength can be attributed to the growth pattern of the fruit. Cumulative fruit growth in tomato is expressed in the form of a sigmoid curve. An initial two-week period of slow absolute growth is followed by 3-5 weeks of rapid growth up to the mature green stage and finally a period of slow growth for two further weeks. Cell division is limited to the early slow growth phase (Monselise *et al*., 1978). In peppers, however, cell division predominates in the period before anthesis of the flower, during which the basic structure of the ovary is determined, including the number of carpels to be found in the mature fruit, followed by cell enlargement after flowering. The hierarchy of sink-strength in the sinks of different type and/or age determines the extent to which they will compete or dominate one another (Bangerth, 1989).

1.2.1 Competition

In the partitioning of dry matter in fruiting vegetable crops, development of the fruit is an important event bringing about a significant change in sink load. From the time of their inception, fruit may account for as much as 90% of the total increase in dry weight of pepper and tomato plants (Nielson & Vierskov, 1988). Thus, an uncontrolled increase in the demand for assimilates due to fruit production could lead to a surplus of slowly growing fruit of poor quality (Schapendonk & Brouwer, 1984). This is due to competition among the fruit as well as between the fruit and the vegetative plant parts for available assimilates.

Competitive limitations on the growth rates of fruit begin as increasing numbers of fruit mobilize nutrient supplies for their growth. Since the pattern of such mobilization is mainly determined by the sink strength (Schapendonk & Brouwer, 1984), which in turn is determined by the age (developmental stage) of the sink, earlier formed fruit inhibit the growth of younger fruit and flowers in many plant species. Ali and Kelly (1992) demonstrated the limitations exerted by older fruit at the lower fruiting nodes on younger fruit of the third and fourth nodes, and the negative consequences on their size in sweet pepper plants. At the time when the lower fruit were actively mobilizing assimilates and nutrients for their growth, those on the upper nodes were at a less competitive flower bud stage.

Ali and Kelly (1992) reported that the stress of competition might be attributed to deprivation of the necessary growth factors for cell division in the buds because most of the assimilates would be diverted to the growth of the metabolically more active sinks in the older fruit. Consequently, the rate of cell multiplication would be lower and result in smaller buds. These small buds eventually result in a small potential fruit size because the number of cells at the bud stage is a basis for fruit growth by cell expansion at the later stages. Histological investigation by Ali and Kelly (1992) revealed less cell multiplication activity and formation of fewer cell tiers in the ovary wall of flower buds and small fruit under competition stress, than those under no competition.

1.2.2 Dominance

As fruit are important sinks for assimilates, the effect of earlier formed fruit are probably not only mediated through assimilate availability, but also hormonal control (Ruiz & Guardiola, 1994) or a combination of these factors (Schapendonk & Brouwer, 1984).Generally, a clear distinction between dominance and competition for a limited assimilate supply is difficult to make. Frequently, dominance can be observed very early in the ontogeny of fruit/sinks where in many cases competition for assimilates is less likely, because of the low demand of small sinks for assimilates (Bohner & Bangerth, 1988). In some instances, elimination of the dominating organs during these early stages lead to a yield over-compensation of the remaining sinks (Ojehomon, 1970), indicating that assimilate availability was not limiting. Therefore dominance was most likely the reason for the depressed growth of these organs. Dominance of the first formed fruit may be exercised in several ways, which include a pressure gradient, sink development sequence, growth inhibitors and seed number.

1.2.2.1 Pressure gradient

Earlier formed fruit may constitute a stronger sink for assimilates, due to a higher pressure-gradient between sink and source (Bangerth & Ho, 1984). This gradient may be in part mediated by the action of growth hormones such as auxins and cytokinins active in the growing fruit. However, levels of extractable auxins in the fruit have not correlated well with relative fruit growth (Ho *et al*., 1982; Bohner & Bangerth, 1988).

1.2.2.2 Sink development sequence

A hypothesis reviewed by Bangerth (1989) stated that the sequence of sink development might establish the dominance effect. 'Primigenic dominance' was suggested to describe this kind of correlative inhibition in which earlier developed sinks inhibit later developed organs. Results in the same study show that the polar indole acetic acid (IAA) export of the earlier developed sink inhibits the IAA export of later developed sinks. This inhibition occurs at the junctions where auxin streams from various sinks meet. It is suggested that this depressed IAA export of the subordinated fruit/ sink acts as the signal that leads to inhibited development.

Recently, Bertin *et al*. (2002) studied the growth of tomato fruit in plants grown under a limiting and non-limiting supply of carbon assimilates. Where the supply was limiting, a decrease in cell number from proximal to distal fruit within a truss was observed. This was, however, not the case when the supply was not limiting. The gradient in cell number from proximal to distal fruit was steep in the upper trusses, but was not significant on the lower trusses, indicating that this gradient largely depended on the level of competition during floral development.

1.2.2.3 Growth inhibitors

Another possible way in which dominance could be maintained by tomato fruit may be through the production of a growth inhibitor such as abscisic acid (ABA). ABA content of competing tomato fruit has, however, not shown any relationship with fruit growth inhibition (Ho *et al*., 1982; Bohner & Bangerth, 1988).

1.2.2.4 Seed number

In many species, including peppers and tomatoes, fruit size has been reported to be positively correlated with seed number (Stephenson *et al*., 1988). Apart from stimulating growth of a fruit, the seed number was also found to increase the inhibitory effect of the fruit on growth of later developing fruit. Fruit with low and medium seed numbers seem to be far less capable of inhibiting younger fruit with high seed numbers than *vise versa*. Thus, it was concluded that differences in seed number among developing fruit could override the dominance of the first fruit. Stephenson *et al.* (1988) predicted that reductions in seed number would reduce the dominance of the first fruit. Consequently, first-fruit dominance is nearly absent from parthenocarpic plants; where as seeded lines of the same species exhibit strong first-fruit dominance (Cantliffe, 1974).

Seeds are well known to be rich sources of plant growth regulators (Hedden & Hoad, 1985). Sjut and Bangerth (1984) reported that auxin production and export by a fruit is predominantly confined to the seeds. As the result of this auxin export, seeds of a fruit may affect competition between fruit, either by increasing the sink strength (competitive ability to attract assimilates) of the fruit, or by suppressing the sink strength of other fruit (Bangerth, 1989). In the first situation, an increase in seed number of the first fruit may reduce growth of the second fruit because of competition for limited assimilate supply, while in the second situation, growth reduction is due to hormones produced by older fruit (dominance).

In line with this, the effect of seed number on inhibition of later- developed fruit was studied by varying the pollen load on the stigma of sweet pepper flowers (Marcelis & Baan Hofman-Eijer, 1997). Fruit-set of the second flower was reduced by the application of a high pollen load to the first flower, even when the first fruit aborted before it had accumulated much dry matter. This indicates that growth inhibition of the second fruit by seed number of the first fruit is controlled both by competition for limited assimilates, as well as by dominance due to the production of plant growth regulators by the developing fruit.

In a study by Zhiyuang *et al*. (1982), removal of the two earliest flowers of capsicum plants increased the seed content of the remaining fruit. Although the mechanisms that brought about this phenomenon are not clear yet, this could be one of the causes for an increase in fruit size when older fruit are removed from plants.

1.3 PRUNING AND ASSIMILATE REDISTRIBUTION

Slack and Calvert (1977) considered three possible effects of truss removal from tomato plants on the ultimate fruit yield:

1. Total yield may be reduced in direct proportion to the loss of yield potential. This would occur if the level of assimilates received by the remaining trusses was unaffected by the loss of trusses, and would imply that assimilates which would otherwise have been used for fruit production were used for other purposes.

2. Total yield may be unaffected, which would imply that the available assimilates were wholly redistributed to other trusses. Since fruit are the strongest sink for assimilates in tomatoes and peppers, a change in fruit number is mainly compensated by a corresponding inverse change in mean fruit size rather than by a substantial change in fruit : shoot ratio (Cockshull & Ho, 1995).

3. There may be a less-than-proportional reduction in total yield, due to the redistribution of some, but not all of the available assimilates. Cockshull & Ho (1995) noted that removing 30% of the available fruit from the distal-end of the first three trusses increased average fruit weight of the remaining fruit and the yield of top trusses. As the dry matter content, as well as the total fresh weight of fruit produced by all trusses was not significantly affected by truss thinning, it was suggested that there was redistribution of assimilates to the remaining fruit in the trusses and between trusses. However, the redistribution to the remaining fruit did not completely compensate for the loss of fruit. Similarly, Tanaka and Fujita (1974) found that when the first truss was removed, the fruit of the second truss became larger, but the weight of fruit of the second truss under these conditions was smaller than the total weight of fruit of the first and second trusses under ordinary conditions. Furthermore, Ehret *et al.* (1993) observed higher foliage: fruit ratios when some fruit were pruned from tomato plants as compared to the non pruned ones; and an increase of about 50-60 % in the average fruit weight. Similar results were found by Heuvelink and Buiskool (1995).

1.3.1 Time of pruning

A study conducted by Bhatt and Rao (1997) indicated that removal of the fruit in the first flowering node of bell pepper plants ten days after fruit set did not increase the partitioning of dry mass to fruit on upper nodes of the plant. With the advancement of fruit growth, the first flowering node fruit acts as a major sink for photosynthates (10.2%) up to 20 days after flowering, and afterwards becomes a weaker sink (Bhatt and Rao, 1993). Ali and Kelly (1992) found that the inhibitory effect of old fruit on the increase in fresh mass, length, diameter and pericarp thickness of younger ones was significant only from flower bud inception through weeks two and four after fruit set. In line with this, Bertin *et al*. (2002) concluded that cell division is a main limiting factor for fruit growth under low assimilate supply, although cell enlargement during further fruit development is also affected.

Kirti and Nettless (1961) illustrated the importance of competition alleviation very early in the development of the fruit, that is, when buds were being formed by cell multiplication. This stage is responsible for determining the number of growth units of the fruit. In accord to this, Ali and Kelly (1992) reported that de-budding the first three nodes of pepper plants was more effective than de-flowering or de-fruiting.

1.3.2 Assimilate partitioning as affected by transport resistance (distance)

In addition to sink-strength, relative distance of sources and sinks is assumed to affect assimilate partitioning. Slack and Calvert (1977) investigated the effect of removing individual trusses on yield of glasshouse-grown tomatoes. It was found that removing a truss resulted in yield increases on some of the remaining trusses both above and below the one removed. The largest increases occurred on the trusses immediately above and below the one removed and there was a general tendency for the increases to be smaller the further away (in both directions) the truss was from the removed truss. According to Tanaka and Fujita (1974) the major portion of carbon received by each truss is derived from leaves in the immediate vicinity of the truss. Thus, in the absence of an adjacent carbon sink, the available material moves towards the remaining trusses and is absorbed by them in amounts related to their distance from the providing leaves.

In the same experiment by Slack and Calvert (1977) the greatest restitution for a missing truss occurred when middle trusses were removed. Removing earlier or later trusses resulted in diminishing total yields. It was suggested that there are separate upward and downward pathways for the photosynthate translocated from tomato leaves. Bonnemain (1965) found that carbon was translocated from every tomato leaf in two directions, upward towards the apex via internal phloem and downward towards the root via external phloem. Thus, it was hypothesized that only partial restitution could be made for the loss of an early truss because there are few, if any, fruit sinks at a lower level. However, almost full restitution may be expected when a middle truss is lost (Slack & Calvert, 1977).

Heuvelink (1995) argued that the results of Slack and Calvert (1977) could also be explained without assuming a distance effect on assimilate partitioning. Trusses closest to the excised truss show the highest yield increase as earlier initiated trusses have a shorter growth period left to profit from removing a truss, while later-initiated trusses miss a larger part of the period where removal of the truss plays a role. Trusses closest to the excised truss, however, exhibit highest sink strength (potential growth rate) in the period where excision has the largest influence on total sink strength.

1.3.3 One common assimilate pool

Despite the fact that in some cases partitioning is related to the relative distance between sinks and sources (Marcelis, 1996), distance is generally not an important factor in dry matter partitioning at the whole plant level. Schapendonk and Brouwer (1984) reported that increasing the distance between source leaves and fruit had no effect on fruit growth in cucumber. Moreover, Heuvelink (1995) showed that in tomato plants with two shoots and a shoot length of more than 2 m, dry matter partitioning between vegetative and generative parts was not affected whether the fruit were located on only one shoot or whether the same number of fruit were divided over the two shoots. It was concluded that the effect of distance (transport resistance) and the compartmentation of the plant into source-sink units could be omitted when modeling dry matter distribution and one common assimilate pool available to all sinks can be assumed. Recently, Andriolo *et al.* (2000) conducted a similar trial with tomato, and comparisons of fruit dry mass indicated that fruit position did not affect dry matter distribution, supporting the hypothesis of one common pool of assimilates circulating freely in the plant.

In contrast to this, Marcelis (1996) reasoned that some of these results could be explained by the fact that sometimes sinks were functioning close to assimilate saturation (sink limitation). The model on phloem transport proposed by Minchin *et al.* (1993) accepts that transport resistance does not affect partitioning when sinks are functioning at saturation. Hence, the role of distance on translocation is still controversial.

1.4 PRUNING AND FRUIT QUALITY

1.4.1 Fruit size

A number of studies show the influence of pruning on fruit size. Saglam *et al.* (1999) conducted a study to determine the effect of the number of fruit per truss (four, six or eight) on quality of tomatoes. Average fruit size was increased by decreasing the number of fruit per truss. Likewise, in a field trial of tomato, growth limited to six inflorescences and removal of 10% of the flowers from the trusses produced the best quality in terms of fruit size (Ramirez *et al.*, 1977). Similar results were found by Kusumo (1978) as well as Cockshull and Ho (1995).

1.4.2 Hollowness

Other quality aspects like hollowness of fruit also seem to be affected by pruning. In a study done by Oliveira *et al.* (1996) there was a decrease in the percentage of hollow fruit when fewer trusses were left on the tomato plants.

1.4.3 Earliness and harvest period

From the growers' point of view, fruit quality and earliness of production are as important as the quantity of fruit production (Schapendonk & Brouwer, 1984). In indeterminate flowering plants, an uncontrolled increase of the demand for assimilates leads to a surplus of slowly growing fruit. This is supposed to be overcome by manipulation of the number of fruit that are growing simultaneously. Bhatt and Rao (1997) found that the removal of fruit on lower nodes of bell pepper, which were major reproductive sinks for photosynthates, resulted in faster growth of fruit on upper nodes. In contrast to this, Saglam *et al*. (1999) found that earliness was not significantly influenced by the number of fruit per plant in tomato. Neither did they observe a shorter harvesting period by decreasing the number of fruit per truss.

In most cases, organ size is directly related with ontogeny, and therefore it is difficult to discriminate between effects of organ size and ontogeny. However, Marcelis and Baan Hofman-Eijer (1995) reported that restricting the number of fruit competing for assimilates strongly increased the dry weight but not ontogeny of the fruit (growing period was not affected). Streck *et al*. (1998), however, found that the yield of tomato plants pruned to three trusses was produced over a significantly shorter harvest period (four or five weeks as opposed to seven weeks of those with seven trusses).

1.5 PRUNING AND VEGETATIVE GROWTH

Dry matter partitioned into the vegetative parts is important because the pattern and amount of fruiting in indeterminate plants are influenced by the size of the vegetative organs at fruiting (Marcelis & Heuvelink, 1999).It is essential that good vegetative growth occurs before fruit set. Vegetative growth of fruit-bearing plants appears to be regulated by the developing fruit (Gautier *et al*., 2001). The pepper plant particularly has the tendency to set fruit low down on the plant, before much foliage has formed, especially when growing conditions are less than ideal. When this happens, the fruit will develop but they will be small, and the plant will be stunted as it tries to maintain fruit growth at the expense of more foliage (Morgan & Lennard, 2000).

As fruit are the major sink of the plant, a reduction in fruit load could favor the distribution of dry mass to the vegetative parts of the plant (stem, leaves and root). Heuvelink and Buiskool (1995) observed that changes in dry matter distribution under high fruit load were correlated with lower leaf areas. The data suggests that leaves and fruit compete for assimilates. For this reason, it is common practice to remove the flower buds from the first and second layers, so that fruit development does not check the plants before they build up sufficient foliage to support maximum yields, and fruit will then grow to the optimum size.

Excessive fruit loads can also stress the plant in other ways. The root system may degenerate, allowing attack by pathogens. Thus, it is recommended that growers control fruit load in young plants. This process also allows for the removal of any misshapen fruit that have formed (Morgan & Lennard, 2000). According to Hurd *et al.* (1979) leaf growth of tomato plants was markedly depressed and root growth ceased due to excessive flower production on young plants. Removing two-thirds of the flowers in some of the plants in the same experiment improved vegetative growth, and resulted in larger plants that had fewer, larger fruit and eventually a fruit yield almost as large as the control. Gautier *et al.* (2001) found an increase in mean dry mass of stems and petioles (up to 43%), and lamina (up to 22%) along with an increase in mean dry mass of fruit (up to 42%), when tomato flowers were pruned. Thus, maintaining an optimum balance between partitioning to the harvestable organs (fruit) and the other plant parts (vegetative parts) is recommended (Marcelis & Heuvelink, 1999).

1.6 PRUNING AND PHYSIOLOGICAL DISORDERS

1.6.1 Fruit cracking

Although this physiological disorder causes considerable economic losses in field-grown tomatoes (Peet, 1992), greenhouse fruit is more vulnerable to fruit cracking losses. Factors contributing to these losses are the lack of crack resistance of most greenhouse cultivars, as well as harvesting of fruit at the pink stage (when 30-60% of the surface shows pink or red color) or later (Peet & Willits, 1995).

Depending on the extent, fruit cracking (1) reduces fruit appeal (Peet & Willits, 1995), (2) reduces fruit shelf-life (Hayman, 1987), (3) increases fruit susceptibility to pathogens (Peet & Willits, 1995) and (4) reduces fruit marketability (Peet, 1992). There are several types of fruit cracking injury: fruit bursting, radial cracking (star-shaped originating from the peduncle), concentric cracking (circular cracks around the peduncle), and cuticle cracking (russeting). It is not clear why cracking sometimes takes one form, and sometimes another (Wien, 1997).

Cultivar, climatic factors and cultural practices influence the susceptibility of fruit to fruit cracking. Generally, fruit cracking is associated with the rapid movement of water and sugars towards the fruit when cuticle elasticity and resistance are weak during ripening (Dorais & Papadopoulos, 2001). High foliage : fruit ratio resulting from fruit pruning significantly increases the number of fruit affected by cracking (Ehret *et al*., 1993). Similarly, pruning of tomato plants to three trusses resulted in the highest percentage of cracked fruit as compared to plants pruned to five or seven trusses. Moreover, Oliveira *et al*. (1996) observed that while a reduction in the number of fruit per plant increased their size, it also increased the number of fruit affected by cracking (russeting and radial cracking).

1.6.2 Blossom-end rot (BER)

Blossom-end rot is the most serious physiological disorder (Kaloo, 1986). The first symptom is a small, water-soaked spot at or near the blossom scar of green tomatoes. As the spot enlarges the affected tissue dries out and becomes light brown to dark brown. Then the lesion develops in to a well-defined sunken spot with the affected tissues collapsed and leathery (Atherton & Rudich, 1986).

The immediate cause of blossom-end rot is a deficiency of calcium at the growing point (blossom-end) of locular tissue. The number of vascular bundles decreases from the proximal (stem) end to the distal end of the fruit (Belda & Ho, 1993). During the two weeks after anthesis, rapid expansion of the fruit takes place thus reducing the density of bundles dramatically. As a result, deposition of calcium in the distal pulp tissue decreases and the calcium requirements of cell walls and cell membranes may not be met. Leakage of cell contents, as a result of a loss of integrity of the cell membrane or weakened cell walls may be the direct cause of BER symptoms (Wien, 1997).

According to the findings of Masuda and Nomura (1995), uptake of nitrate, calcium and magnesium was promoted and the xylem sap concentration of these nutrients was increased by fruit removal on tomato plants. Nevertheless, De Kreij, (1992) reasoned that excessive vegetative growth and low fruit load (severe pruning) is said to favor a disequilibrium between xylem and phloem sap absorption by the fruit, in favor of the phloem sap, and lead to calcium deficiency in the fruit and increase the appearance of blossom-end rot.

1.6.3 Flower and fruit deformation

In peppers, small, deformed and parthenocarpic fruit develop after severe fruit/flower pruning (Aloni *et al.*, 1991). Such fruit develop from flowers with enlarged ovaries in which self-pollination is inefficient due to the large distance between the stigma and stamen. Aloni *et al.* (1999) suggested that assimilates which are normally transported to developing fruit may be transported, upon fruit removal, to the flower buds which subsequently swell.

According to Aloni *et al.* (1999) the sensitivity of the flower to carbon supply depends on its stage of development. Flowers that were at anthesis when the de-fruiting treatment was done were not affected by the treatment, whereas flowers that were three days pre-anthesis gave rise to a significantly increased percentage of deformed parthenocarpic fruit. The most affected were fruit developed from flowers that were at the earliest developmental stage at the time of pruning. It was suggested that once fertilization and fruit-set occur, any change in assimilate supply to the developing fruitlet determines the rate of fruit growth rather than the shape of the fruit. During earlier flower developmental stages, the ovary is still growing and any factor (like assimilate supply) that affects final ovary size at anthesis also affects the efficiency of pollination and the shape, size and seed number of the fruit.

The percentage of swollen flowers and deformed fruit was inversely related to the number of fruit in the growth phase (Aloni *et al*., 1999). The presence of at least two fruit per stem appeared to be necessary for a significant reduction in the percentage of deformed fruit. Hence, it seems important to know the optimal intensity and time of pruning for a specific crop or cultivar in order to minimize the risk of fruit deformation and enhance the fruit shape, size and regularity, which are major determinants of fruit quality in peppers and tomatoes.

1.7 PRUNING AND ASSIMILATE PRODUCTION

1.7.1 Reduced photosynthetic rate

Apart from inducing fruit disorders, intensive pruning of reproductive sinks have been found to influence the production of assimilates. Hall and Milthorpe (1978) showed that removal of rapidly growing pepper fruit caused a 30% reduction in net CO_2 uptake. Bhatt and Rao (1989) found a higher net photosynthetic rate in fruiting than de-blossomed bell pepper plants. Associated with this phenomena is the hypothesis that the concentration of assimilates in leaves alters the net photosynthetic rates of those leaves (Ho, 1976); referred to as ‘end-product- inhibition’.

The inhibition of leaf photosynthetic rate after sink removal may have several causes. Gifford and Evans (1981) explained the negative feed back control on photosynthesis by means of a hormonal mechanism influencing stomatal or mesophyl resistance. Similarly, stomatal closure resulting from a build-up of ABA in the leaf blade of peppers was found by Kriedemann *et al*. (1976). In some species, fruit removal results in an accumulation of starch grains in the leaves, which may interfere with the radiant energy reception in the chloroplasts (Schaffer *et al*., 1986). In others, accumulation of starch in the plastids may distort the membrane structure of the chloroplast enough to lower gas exchange rates (Goldschmidt & Huber, 1992).

The formation of sugar phosphates after sink removal may in some cases lead to a deficiency of inorganic phosphorus in the leaf (Plaut *et al*., 1987). Assimilate accumulation in the leaf after sink removal has lead to reduced activity of ribulose bisphosphate carboxylase, the enzyme involved in photosynthesis (in cucumber; Peet *et al*., 1986; in tomato; Yelle *et al*., 1989). According to Sonnewald and Willmitzer (1992) the basic mechanism for the 'sink regulation' of photosynthesis is the inhibition of photosynthetic gene expression by metabolic factors related to high carbohydrate content.

On the other hand, contradicting results have been found in many studies. Plaut and Mayoral (1984) found that reduced sink : source ratios, achieved by removal of flowers, fruit and buds had no effect on the CO_2 fixation of pepper. In like manner, in *Chrysanthemum morifolium*, the removal of the predominant sink for assimilates (the terminal inflorescence buds) affected the distribution of the products of photosynthesis but had no effect on the rate of photosynthesis (Cockshull, 1982).

Wien (1997) reasoned that sink removal will not invariably lead to adverse effects on photosynthesis, as most vegetable crops have alternate sinks such as branches, younger fruit, etc., that can become principal sinks after fruit removal. Many experiments showing a negative effect of reduced sink-source ratio on photosynthesis involved extreme treatments, like removal of all generative sinks (Tanaka & Fujita, 1974). In an experiment conducted by Heuvelink and Buiskool (1995) a low sink : source ratio due to fruit or truss pruning did not result in a low leaf photosynthetic rate in tomato except for the extreme case of only one fruit per truss. These results agree with observations of Nielson and Vierskov (1988) on dry matter production in sweet pepper.

In a study by Tanaka and Fujita (1974), removing one out of three trusses from a tomato plant had no influence on dry matter production. Removal of all trusses, however, reduced final dry weight by 40%. These authors also observed that pruning three out of six fruit per truss reduced dry matter production by 20%. To the contrary Bhatt and Rao (1997) found a higher net photosynthetic rate in two sweet pepper cultivars where reproductive sinks were pruned than in control plants. The result of this study indicated that the developing fruit on lower nodes are the dominant sink in bell pepper and the removal of these fruit resulted in faster growth of other fruit on upper nodes. This in turn resulted in increased assimilate demand and thus increased net photosynthetic rate (P_N) of the leaves of the plant.

1.7.2 Reduced light interception

Heuvelink and Buiskool (1995) stated that the reduction in dry matter production for plants with low sink : source ratios does not necessarily reflect a reduction in leaf photosynthetic rate. Growth reductions resulted, at least partly, from reduced light interception. Plants with only one fruit per truss showed strongly curled leaves, which pointed downwards, instead of being almost horizontal. Leaf curling at low sink : source ratio was also observed by Nederhoff *et al.* (1992). Light interception by these plants was decreased further as the plants were shorter, whereas neighboring plants (with no fruit or truss pruning) were of normal height.

1.7.3 Compensation by higher LAI

Reduced leaf photosynthetic rate may be compensated for by a higher leaf area index, as fruit pruning favors assimilate distribution towards the vegetative plant parts, including the leaves (Marcelis, 1991).

1.8 OBJECTIVES

Inconclusive published results on the effect of sink pruning on tomato yield and quality, and the absence of information on hot pepper, motivated this study.

The objectives are:

- To compare hot pepper and tomato with regard to their response to pruning.
- To determine a suitable level of pruning for best yield and fruit quality.
- To analyze the effect of time of pruning on yield compensation.
- To test different pruning methods for favorable yield and quality.

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CHAPTER 2

EFFECT OF PRUNING INTENSITY ON YIELD, YIELD COMPONENTS AND FRUIT QUALITY OF TOMATO AND HOT PEPPER

2.1 INTRODUCTION

Since fruit utilize a major portion of the photoassimilates in crops like tomatoes and peppers, variation in fruit number will influence their size (Gautier *et al*., 2001). It should be possible to maintain fruit size within a preferred size range by altering fruit number. This can be achieved by fruit pruning, thus increasing the supply of assimilates to the remaining fruit (Cockshull & Ho, 1995). If too many fruit are pruned from the plant, those remaining may be more prone to growth disorders such as cracking (Morgan & Lennard, 2000), blossom-end rot (De Kreij, 1992), as well as fruit deformation (Aloni *et al*., 1999).

Redistribution of assimilates to the remaining fruit may not completely compensate for the loss of fruit if pruning is done in excess, or too late, for instance after the fruit subjected to pruning has already accumulated a large quantity of assimilates. The degree to which plants can compensate for reduced fruit numbers by increased fruit size depends on factors like the cultivar, seed number, and fruit position. Furthermore, low sink demand brought about by fruit or flower pruning is said to have a negative feed back control on photosynthesis. To avoid yield losses the degree of thinning must be adjusted to obtain a desirable fruit size in the remaining fruit (Cockshull & Ho, 1995). The purpose of this study was to determine a suitable level and time of pruning for the best yield and fruit quality of tomato and hot pepper. A lot of research has been conducted and much information is available on the source-sink relationship of tomato, to the contrary, little information exists on hot pepper, which is a very important crop in Eritrea. Thus both crops were selected for this study in order to compare their response to fruit pruning.

2.2 MATERIALS AND METHODS

Experimental set-up

Experiments were conducted during the year 2002-2003 in a 5m x 4m x 4m glasshouse compartment, at the Phytotron of the Department of Plant Production and Soil Science, University of Pretoria.

Seeds of hot pepper cultivar ‘Challenger’ and tomato cultivar ‘Graziela’ were planted in polystyrene seedling trays filled with sand and coconut coir (50%-50% by volume). Seedlings were thinned to one plant per cell. After six to eight weeks, uniform seedlings were transplanted into cylindrical PVC pots filled with the same sand and coir mixture used for seedling production. Pots were arranged in a completely randomized design with four replicates.

Temperature conditions in the greenhouse ranged from a minimum of 22/12 ^{0}C (day/night) to a maximum temperature of 33/18 ^{0}C during the trial. Plants were watered and fertigated with a commercial nutrient solution (HYDRO-GRO and HORTICAL, products of Hortichem division of Ocean Agriculture). Ammonium chloride and Didecyl dimethyl (trade name Spore-kill) was added (100 ppm) to the nutrient solution to prevent disease. The composition of the fertilizer products and the nutrient solution is set out in Table 2.1.

Table 2.1 Composition of the fertilizer products and concentration of the nutrient solution used in fertigating tomato and hot pepper plants

Composition of fertilizer product			**Concentration in nutrient solution**
Product	**Nutrient**	**g/kg**	**mg/l**
HORTICAL	Ca	195	124.8
	N	155	99.2
HYDRO-GRO	N	65	65
	P	45	45
	K	240	240
	Mg	30	30
	S	60	60
	Fe	1.68	1.68
	Mn	0.4	0.4
	B	0.5	0.5
	Zn	0.2	0.2
	Cu	0.03	0.03
	Mo	0.05	0.05

Source: Hortichem, Ocean Agriculture, P O Box 741, Muldersdrift, South Africa.

Plants

Tomato plants were trained according to the high-wire system with all axillary shoots removed, and the apical meristem was topped two leaves above the sixth truss. This method was based on the work done by Walker and Ho (1977).

As peppers show dichotomic branching (Marcelis & Baan Hofman-Eijer, 1995), one first order branch was retained and subsequently the larger of each two dichotomic branches was retained, while the smallest one was pruned just above its first leaf. In this way, plants with apparently one main branch were formed. The apical meristem of the hot pepper plants was topped after producing the sixth fruit.

Treatments

In the tomato trial, plants were allowed to produce six trusses before the removal of the apical meristem, and pruning intensity included four treatments:

i. the first truss pruned
ii. the first two trusses pruned
iii. the first three trusses pruned
iv. no truss pruned (control).

Time of pruning included two treatments:

i. at anthesis of the first flower
ii. at fruit-set (when the first fruit was 2 mm in diameter).

In the hot pepper trial, plants were allowed to produce six fruit before the apical meristem was topped and pruning intensity included four treatments:

i. the first fruit pruned
ii. the first two fruit pruned
iii. the first three fruit pruned
iv. no fruit pruned (control).

Time of pruning included two treatments:

i. at anthesis
ii. at fruit-set (fruit 2 mm in diameter)

Data collected

Yield and fruit quality

Fruit were harvested at the mature-red stage. The numbers of fruit harvested per truss and per plant were recorded. Fruit diameter and pericarp thickness were measured using a caliper; tomato fruit ≥ 6 cm in diameter were considered as class-one fruit. Assuming hot pepper fruit shape as conical, fruit volume was estimated from the length and diameter of the fruit, using the formula $\pi d^2 h/12$ (where d and h represent diameter and length respectively). Fresh mass of individual fruit was determined by weighing the fruit without peduncle, and dry mass was taken after splitting and drying fruit for at least two days at 75 ^{0}C. Total solids of individual fruit were calculated from the dry mass : fresh mass ratio (Garvey & Hewitt, 1991). The fresh mass and dry mass of individual tomato fruit in a truss and on a plant were added to get the fresh and dry mass of fruit per truss and per plant respectively.

Seed number per fruit was recorded for samples of three to six fruit per plant. Seed was first squeezed out of the fruit into a petri-dish, dried in an oven at 50 ^{0}C for two days, separated by hand into individual seeds and counted with a 'Numigral' seed counter. The dry weight of the seeds was added to that of the rest of the fruit to get the total dry weight of the fruit.

Tomato fruit harvested in the first eight weeks out of the total 16 week harvest period was considered as early yield. Similarly, hot pepper fruit harvested in the first five weeks out of the total ten week harvest period was considered as early yield. The number and weight of fruit affected by fruit disorders (mainly blossom-end rot and cracking) was recorded. Defected fruit and undersized fruit ($\leq$ 3 cm in diameter for tomato and $\leq$1cm^3 in volume of hot pepper) were deducted from the total yield to estimate the marketable yield.

Vegetative and total plant dry mass

The aboveground parts of the tomato plants were harvested 22 weeks after transplanting, and those of hot pepper plants were harvested 16 weeks after transplanting. These were oven-dried at 75 ^{0}C for 48 hours and weighed to get the vegetative dry mass. The vegetative dry mass was added to the dry mass of the fruit to get the total dry mass of the plants.

Statistical analysis

Data were analyzed by analysis of variance using the SAS (SAS Institute Inc., Cary, NC, USA. Copyright © 1999-2001). Differences at the $P \leq 0.05$ level of significance are reported and means are separated using Duncan's Multiple Range test.

2.3 RESULTS AND DISCUSSION

The time of pruning (at anthesis or at fruit-set) had no significant effect on yield, yield components and fruit quality of both tomato and hot pepper (Tables 6.1.1-6.1.19 in Appendix). This could be due to the fact that flowers are weak sinks of assimilates (Ho, 1988) and thus, the amount of assimilates they drain before fruit-set may be insignificant. The time x degree of pruning interaction effect was also not significant on yield, yield components and fruit quality. The main effect intensity of pruning was, however, significant on yield, yield components and quality of both tomato and hot pepper.

2.3.1 Tomato trial

Fruit number

There was a steady and significant increase in the number of fruit per truss with increased pruning level (Figure 2.1). A significant increase in fruit number per truss was found in the two-trusses-pruned and three-trusses-pruned treatments. The one-truss-pruned treatment was not significantly higher than the control. Due to the increase in the number of fruit per truss, the total number of fruit per plant was not significantly affected by any of the pruning treatments.

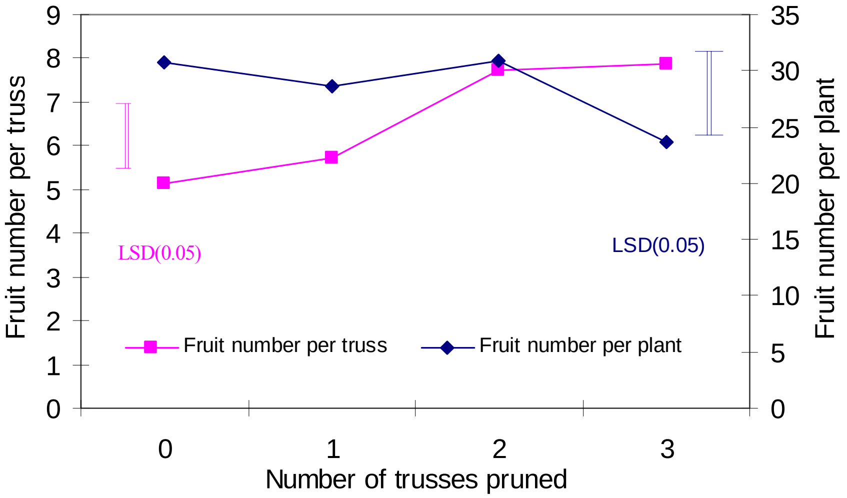


Figure 2.1 Fruit number per truss and per plant of tomato at various pruning intensities

The three-trusses-pruned treatment tended towards a lower fruit number per plant in spite of the fact that it had a slightly higher fruit number per truss than the two-trusses-pruned treatment (Figure 2.1). This indicates that pruning the third truss did not increase the number of fruit per truss enough to compensate for the number of fruit lost by pruning.

The number of fruit per truss mainly depends on flower formation and fruit-set. Murneek (1926) noted that the presence of fruit on a plant could lead to a decrease in inflorescence size and abortion of the flower buds. According to Cockshull and Ho (1995), removal of fruit or restriction of vegetative growth results in increases in the size of the inflorescences and reduction in incidence of flower abortion. These effects can be explained by the dependence of flower formation, development, and subsequent fruit-set on photoassimilate availability.

The above explanation contradicts the results of Slack and Calvert (1977) where the increased source: sink ratio brought about by pruning one truss at different positions on the plant promoted fruit size but had no effect on fruit number. However, there is a similarity between the results of Slack and Calvert (1977) and the observed result on fruit number per truss (Figure 2.1) in that, pruning of a single truss did not affect fruit number per truss. It can be hypothesized that pruning only one truss was not enough to increase the source : sink ratio to the level that formation of more fruit is stimulated.

Fruit size

All the truss pruning treatments in tomato increased the diameter of the fruit. It resulted in more class-one fruit per truss as compared to the control (Table 2.2). When the comparison was made on a per plant basis, however, only the one-truss-pruned treatment had a higher number of class-one fruit than the control. Thus, in the treatments with two and three trusses pruned, the increase in class-one fruit in the remaining trusses could not fully compensate for the loss of potential class-one fruit due to pruning.

Increasing fruit size of tomato by pruning has been found in numerous studies (Tanaka & Fujita, 1974; Ramirez *et al*., 1977; Cockshull & Ho, 1995; Saglam *et al.*, 1999). This has been explained by the increased allocation of available assimilates to the remaining fruit due to the increased source : sink ratio created by reduction of sink load.

The above result contradicts that of Bertin *et al*. (2001) who investigated the influence of source-sink balance on the quality of tomato by fruit and leaf pruning. Where the source : sink ratio was high, fruit size was not bigger than where the source : sink ratio was low. Fruit can grow to their potential size under non-limited assimilate supply and no further growth takes place if the supply of assimilates is increased further (Ho, 1988). Thus, Bertin *et al*. (2001) reasoned that the plants in all the treatments were not source-limited, as all the trusses were thinned to a maximum of six fruit and all the side-shoots were pruned.

Table 2.2 Effect of truss pruning intensity on the number of class-one fruit, seed content, average pericarp thickness and total solids content of tomato fruit

Treatments (T)	Number of class-1 fruit/truss	Number of class-1 fruit/plant	Seed content of fruit	Average pericarp thickness (mm)	Total solids content (%)
Control	1.83b	11.0b	96.37a	8.52b	4.89c
1-truss-pruned	2.88a	14.29a	105.95a	9.46a	5.28bc
2-trusses-pruned	2.46ab	8.50b	86.75a	8.95b	6.29a
3-trusses-pruned	3.12a	9.37b	88.17a	9.66a	6.1ab
LSD(T) P≤0.05	2* = 0.785 3* = 0.824 4* = 0.849	2* = 3.059 3* = 3.212 4* =3.309	2* = 18.10 3* = 19.00 4* = 19.57	2* =0.474 3* =0.498 4* =0.513	2* = 0.95 3* =0.98 4* =0.99
CV(%)	27.83	25.68	17.09	4.70	14.56

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test (P ≤ 0.05).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

Seed content of fruit

Pruning of tomato trusses at various intensities did not significantly affect the seed content of the fruit (Table 2.2). Nor was there any trend of increase or decrease in seed content with pruning intensity. This contradicts the result of Aya *et al*. (1981) where a higher seed number per fruit was found in pruned tomato plants.

Pollination and fertilization which are determinants of seed production are reported to be affected by assimilate supply (Howlett, 1936; Ho & Hewitt, 1986). However, the treatments they applied included extremely low source sink: ratios (high sink load accompanied by low irradiation). These conditions do not seem to be comparable to the conditions of all the treatments in Table 2.2, where sink load was reduced by removing side shoots and clipping the growth tip two leaves above the sixth truss.

According to Aya *et al.* (1981), seed content of fruit was higher in the lowest trusses as compared to the higher ones. Thus, subjection of these lower trusses (with high potential seed number) to pruning might have masked the positive effect of increased assimilate availability due to truss pruning on seed formation.

Pericarp thickness

Pericarp thickness of tomato fruit increased where one or three trusses were pruned, but in the case of the two-trusses-pruned treatment the pericarp thickness was similar to that in the control (Table 2.2). Ali and Kelly (1992) observed similar results in sweet pepper where older fruit inhibited the increase in pericarp thickness of young fruit, and removal of the older fruit significantly increased the pericarp thickness of the young fruit.

The pericarp thickness of fruit was positively correlated (r=0.82) with fruit size. This is similar to the observation of Stevens *et al*. (1977) where large fruit had thicker pericarp than small fruit. According to Stevens *et al.* (1977) and De Bruyn *et al.* (1971) the pericarp of tomato contained more reducing sugars and total soluble solids than the locular tissue. As sugars are the major components of a tomato fruit and of the phtoassimilates, a correlative increase in pericarp thickness and fruit size can be expected with increasing source :sink ratio.

Fresh fruit mass

The fresh mass of individual tomato fruit increased by truss pruning (Figure 2.2), with the exception of the two-trusses-pruned treatment. The fresh mass of fruit per truss also increased with increased degree of pruning as illustrated in Figure 2.3. Statistically, the three-trusses-pruned treatment had a significantly higher fresh mass of fruit per truss than the control. The one-truss-pruned and two-trusses-pruned treatments, however, were not significantly higher than the control. The increase in fresh mass yield of fruit per truss was brought about by the increase of both yield components: fruit number per truss (Figure 2.1) and mass of individual fruit (Figure 2.2).

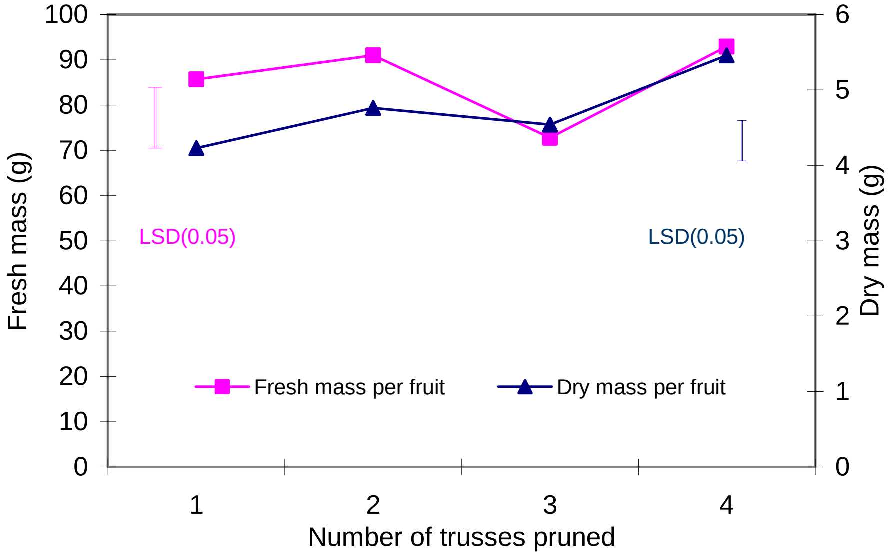


Figure 2.2 Fresh mass and dry mass of individual tomato fruit at various pruning intensities

Both fruit size and fruit number were increased with increasing level of pruning, probably due to the redistribution of assimilates to the remaining trusses. Several authors like Slack and Calvert (1977), and Ho (1995), have reported a similar increase in fruit yield per truss as the result of truss or fruit pruning primarily through increased mean fruit size, while the number of set fruit on the remaining trusses was not influenced. In a study by Adams *et al*. (2001) on truss pruning, yield per truss increased due to a slight increase in the number of fruit and mean fruit size on the remaining trusses.

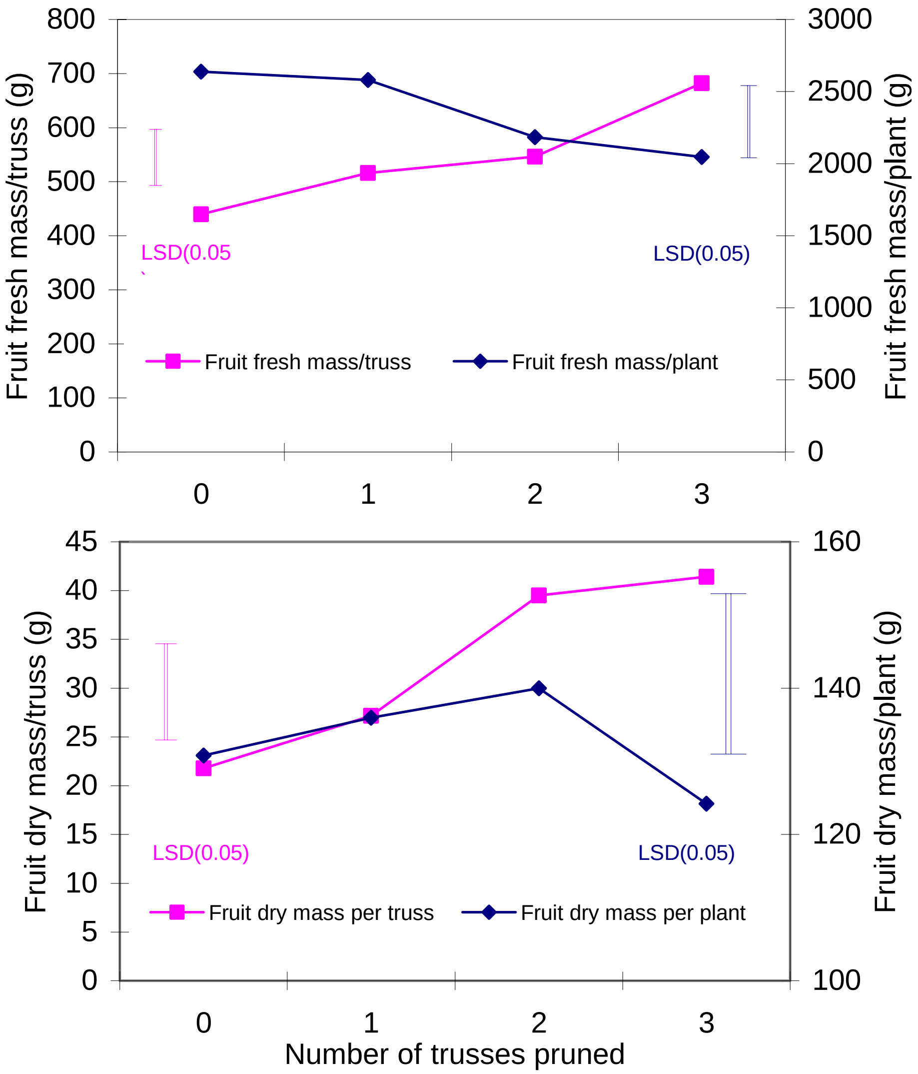


Figure 2.3 Fruit fresh mass and dry mass per truss and per plant at various pruning intensities in tomato

While the effect of pruning on the pattern of total fruit fresh mass per plant was small (Figure 2.3), the loss in yield (although not statistically significant) was in agreement with that expected from the literature. It is generally agreed that the distribution of assimilates among sinks is primarily regulated by the sink strength (Marcelis, 1996); and generative sink strength is assumed to be proportional to the number of fruit, as has been proven by (Heuvelink, 1997). Thus, the reduction in total fruit yield per plant can be explained by a decreased partitioning of photoassimilates to the fruits due to the reduced generative sink strength as the result of truss pruning. The reduction in total yield was insignificant because the yield from the remaining trusses increased and almost completely compensated for the loss of potential yield due to pruning. Similar results were found by Cockshull and Ho (1995) where 30 % of the fruit from the distal-end of the first three trusses were removed. The average weight of the remaining fruit significantly increased and the yield of small fruit was greatly reduced. They indicated that the total yield of fruit from the three trusses was reduced by 16 %, but the yield from higher trusses was increased significantly enough to fully compensate the loss of yield.

Despite a lower fraction of biomass allocated to the fruit, Heuvelink (1997) stated that fruit pruning may increase dry matter production to such an extent that total fruit yield does not change, or even increases. This has been observed for eggplant by Lenz (1970), and predicted for tomato by De Koning (1994). This was often associated with increased allocation of biomass for vegetative growth, including leaf growth, and hence increased light interception. Slack and Calvert (1977) however, attributed the increased yield of the remaining trusses only to the redistribution of assimilate unused by the pruned trusses. Thus, either or both events could have brought about the result in the present study.

The dry mass of tomato trusses was also increased by pruning (Figure 2.3). The increase in dry mass of fruit per truss could be due to an increase in individual fruit dry mass or number of fruit per truss. According to the statistical analysis, the three-trusses-pruned and one-truss-pruned treatments had significantly higher individual fruit dry mass than the control and the two-trusses-pruned treatment (Figure 2.2) but were not significantly different from each other.

Apparently, there was source-saturation in the one-truss-pruned treatment and the three-trusses-pruned treatment because individual fruit mass was similar in both treatments (Figure 2.2). This is in accordance with Heuvelink (1997) who found insignificant increase in dry mass of individual fruit when 50% of fruit were removed from a tomato plant as compared to a control where all trusses were pruned to five fruit per truss. Fruit were already growing close to their potential rate in the control treatment because of pruning all trusses to only five fruit.

Inexplicably, the dry matter per fruit was lower in the two-trusses-pruned treatment than the one-truss-pruned treatment. The number of fruit per plant tended to be the highest in this treatment (Figure 2.1) which might have resulted in source limitation which eventually led to a reduction in dry matter content of individual fruit.

It can be concluded that in the one-truss-pruned and three-trusses-pruned treatments, the increase in fruit mass per truss was due to increase of both fruit number and fruit mass, where as in the two-trusses-pruned treatment mainly increase in fruit number contributed to the increase in fruit mass per truss.

The total dry matter yield of fruit per plant was not significantly affected by truss pruning. Unlike the fruit fresh mass per plant, the fruit dry mass per plant tended to increase from the control to the treatment with two trusses pruned (Figure 2.3). This could be due to a considerable increase of fruit dry matter in the remaining trusses. In the three-trusses-pruned treatment, however, the total fruit dry mass declined slightly. This was because the increase of dry matter per truss in this treatment was not high enough to fully compensate the loss of three trusses.

Total solids content of fruit (%)

Increasing total solids content of fruit was observed with increasing intensity of truss pruning (Table 2.2). This result is supported by the finding of Bertin *et al.* (2000) where the proportion of water to dry matter of tomato fruit was lowered by reducing fruit load. This implies that, as the result of truss pruning the proportion of dry matter accumulation in fruit surpassed the accumulation of water. This explains the contrasting trends of fruit fresh mass and fruit dry mass per plant presented in Figure 2.3.

It is important to note that 77 to 85 % of water is imported by tomato fruit via the phloem (Ho *et al.*, 1987, Guichard *et al.*, 1999), together with assimilates. Thus, fruit dry matter content (total solids content) can change only if (1) the proportion of xylem and phloem water changes, (2) the loss by transpiration varies, or (3) the concentration of phloem sap fluctuates (Bertin *et al.*, 2000).

An increase in phloem sap concentration can be suggested as a possible reason for increased total solids content of fruit (Table 2.2) since a similar truss pruning treatment done by Bertin *et al.* (2001) promoted the concentration of dry matter components, including acids and sugars in tomato fruit. In line with this, Bertin *et al.* (2001) reasoned that low assimilate supply in winter and spring production of tomato in absence of water stress, leads to the production of fruit with low dry matter and sugar content due to the dilution of phloem sap. Besides, a change in the balance of phloem and xylem sap translocation to the fruit due to fruit pruning can be suggested as a possible cause of the increase in total solids of fruit (Table 2.2). According to (De Kreij, 1992), low fruit load is said to favor disequilibrium between xylem and phloem sap absorption by the fruit, in favor of the phloem sap.

Total plant dry mass

Total plant dry mass of tomato was not significantly affected by truss pruning (Figure 2.4). Hence there was no indication of reduction in dry matter production in the three-trusses-pruned treatment or in the other truss-pruning treatments. To the contrary, however, a slightly higher total plant dry mass was observed in the three-trusses-pruned and one-truss-pruned treatments as compared to the control. This contradicts the observations by Nederhoff *et al.* (1992), Guinn and Mauney (1980), and Gifford and Evans (1981) where profound increase in source : sink ratio due to intensive pruning inhibited dry matter production (source activity).

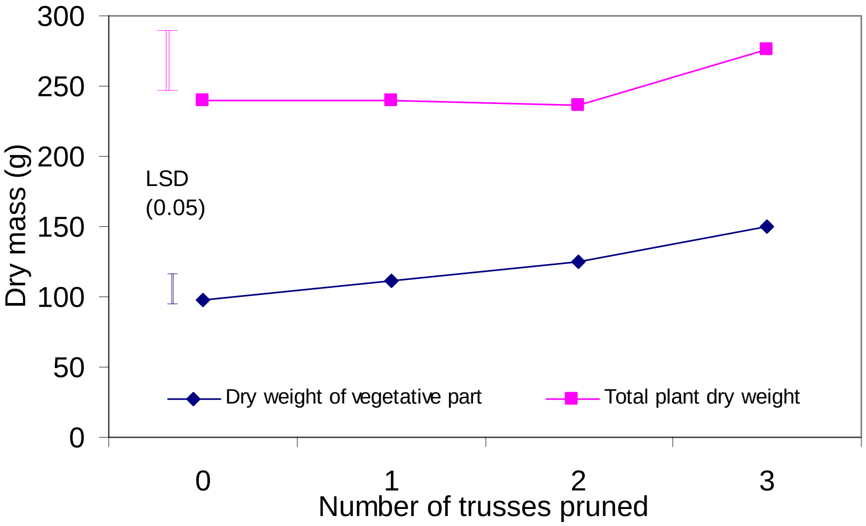


Figure 2.4 Total dry mass of plants and dry mass of vegetative plant part at various pruning intensities of tomato

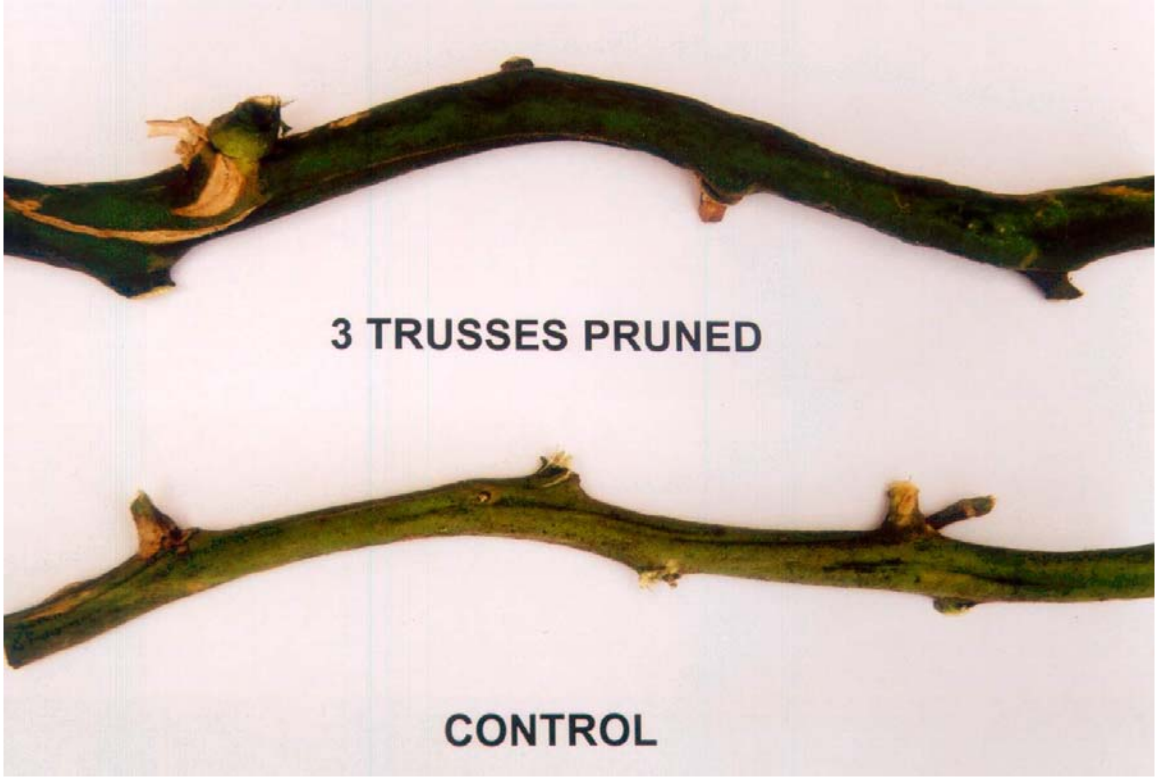


Figure 2.5 Stem diameter of three-trusses-pruned tomato plants as compared to the control

The truss pruning treatments resulted in considerable increase in dry mass of vegetative plant parts of tomato (Figure 2.4), in addition to the increase in fruit dry mass discussed above. Wien (1997) stated that sink removal will not invariably lead to adverse effects on photosynthesis, as most vegetable crops have alternate sinks that can become principal sinks after fruit removal. In a study conducted by Heuvelink and Buiskool (1995), fruit and truss pruning led to higher average fruit weight, heavier stems and leaves, and thicker leaves. As shown in Figure 2.5, an obvious increase in stem diameter also occurred as the result of truss pruning. Hocking and Steer (1994) reported that the stem is a major sink for assimilates in tomato; and according to Khan and Sagar (1969), assimilates translocated to the stem are used for secondary thickening, besides for storage purposes.

Reducing the number of trusses by one-half had no effect on dry matter production (Figure 2.4). In contradiction to this, reducing the number of fruit in a truss by one-half reduced dry matter production by 20% in an experiment by Tanaka and Fujita (1974). The amount of sinks removed in both cases is seemingly comparative. However, truss pruning has the ability to compensate the removed sinks (fruit) by forming more fruit in the remaining trusses (as shown in Figure 2.1) this can increase the sink demand and reduce the inhibition of dry matter production caused by excess availability of assimilates.

Early yield

In tomato, a significant reduction in percentage early yield per plant was observed in the treatments where two and three trusses were pruned (Table 2.3). This could be because the tomato trusses that were pruned were the first formed ones, which are usually the first to mature. However, when comparison was made on ‘corresponding-trusses basis’ (the remaining trusses of the pruned plants compared with the corresponding trusses of the control), an increase of 35.3 to 73.1 % in early yield was obtained in the various pruning treatments as compared to the control (Table 2.4).

Table 2.3 Effect of pruning intensity on the early fruit yield of tomato

Treatments (T)	**Early yield (%)**
Control	71.73a
1-truss-pruned	64.22ab
2-trusses-pruned	54.76bc
3-trusses-pruned	51.09c
LSD (T) P≤0.05	2* = 11.11 3* = 11.66 4* = 12.01
CV (%)	40.79

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test (P ≤ 0.05).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

Table 2.4 Early yield of tomato at various pruning intensities as compared to the corresponding trusses of the control

Control		**Pruning treatment**		**% Increase from control**
Trusses	**Early yield (g)**	**Trusses**	**Early yield (g)**	
Trusses 2-6	1282.99	1-truss-pruned	1736.2	35.3 %
Trusses 3-6	777.34	2-trusses-pruned	1190.05	54.2 %
Trusses 4-6	577.44	3-trusses-pruned	999.38	73.1%

A similar trend of earliness was obtained on fruit of husk tomato (Saray & Miranda, 1986) when some of the fruit were removed. In principle, the growth rates of sink organs increases when the assimilate supply increases (Papadopoulos & Pararajasingham, 1997). Likewise, thirteen early maturing characteristics were combined by factor analysis in to seven principal factors; speed of flower and fruit development was among the most important in determining early maturity, followed by density of fruit. Thus the reduction of fruit density and increase in growth rate of fruit due to increased assimilate supply in pruned plants justifies the increase in early yield mentioned above.

Fruit disorders

Fruit cracking

The fruit disorders that occurred in the tomato were mainly fruit cracking and blossom-end rot (Figure 2.6). The incidence of fruit cracking was the highest and significant in the three-trusses-pruned treatment, followed by the two-trusses-pruned treatment which was not, however, significantly higher than the control (Figure 2.7). In the one-truss-pruned treatment, the incidence was very little, and it was further lowered to zero in the control.

Straver (1995) observed that while a reduction in the number of fruit per tomato plant increased their size, it also increased the number of fruit affected by cracking. This is possibly due to rapid movement of sugars and water towards the remaining fruit when cuticle elasticity and resistance are weak towards the later developmental stage of the fruit (Dorais & Papadopoulos, 2001). On the other hand, an increase in fruit size which exerts more physical stress against the epidermis is suggested to lead to an increasing susceptibility to fruit cracking in pruned plants (Considine & Brown, 1981).

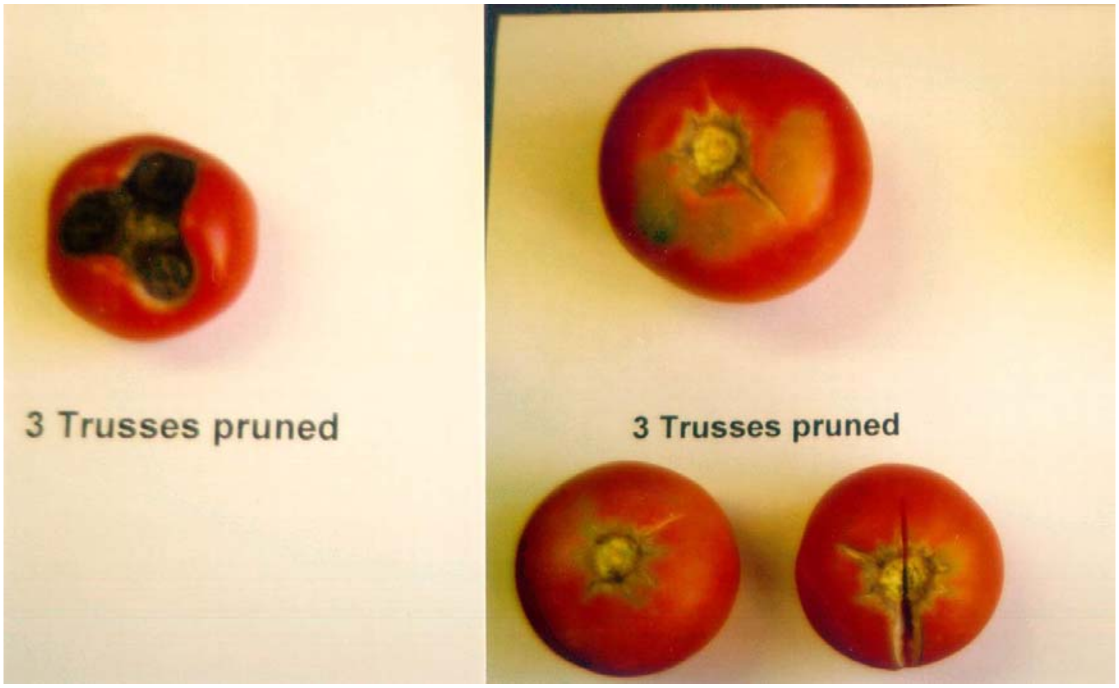


Figure 2.6 Incidence of blossom-end rot (left) and fruit cracking (right) in the three-trusses-pruned treatment of tomato

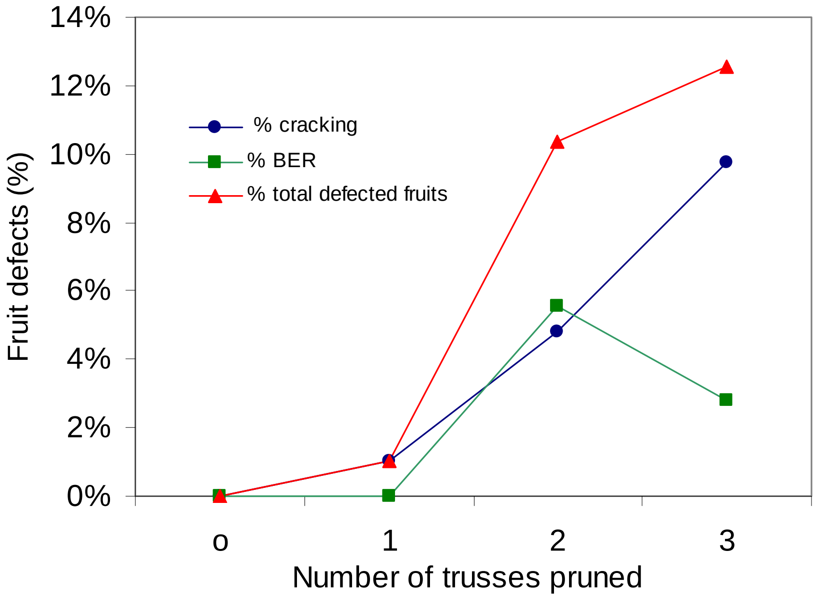


Figure 2.7 Fruit (%) affected by cracking and BER at various pruning intensities of tomato

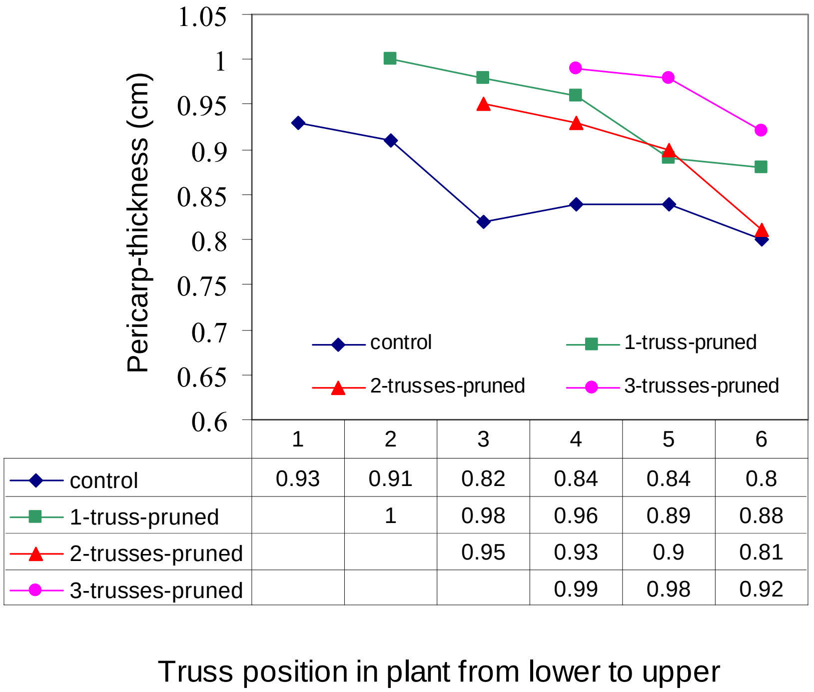
Accoring to Dorais and Papadopoulos (2001), fruit : leaf ratio is an indicator of the occurrence of fruit cracking. A ratio of 1.24 : 1 to 1.28:1 is generally optimal , but lower ratios resulting from fruit pruning cause fruit cracking. Partly, the results shown in Table 2.5 support this hypothesis in that the control treatment where no fruit cracking was observed (Figure 2.7), had an average fruit : leaf ratio of 1.31 : 1 (above the optimal level), whereas in the two-trusses-pruned and three-trusses-pruned treatments, where high incidence of fruit cracking occurred, the ratio was 1.21 : 1 and 1 : 1 respectively (below the optimal level). Nevertheless, in the one-truss-pruned treatment, the incidence of cracking was very low (much lower than the two and three trusses-pruned treatments) while the fruit : leaf ratio was lower than the two-trusses-pruned treatment. Although speculative, a truss: leaf ratio seems more relevant to fruit cracking than the fruit: leaf ratio.

Table 2.7 Fruit to leaf ratio of tomato plants at various intensities of truss pruning

Treatments	**Number of fruit/ plant**	**Number of leaves/ plant**	**Fruit : leaf ratio**
Control	30.75	23.5	1.31:1
1-truss-pruned	28.6	23.5	1.21:1
2-trusses-pruned	29.1	23.5	1.23:1
3-trusses-pruned	23.6	23.5	1:1

According to Slack and Calvert (1977), more assimilate is transported to the trusses closer to the one removed than those further away. As trusses were pruned from the lowest part of the plants in the various treatments, fruit cracking incidence may be expected to be higher in the remaining lower trusses due to high influx of assimilates. To the contrary, however, the results indicated more cracking in higher trusses as compared to the lower ones. This is in agreement to Peet and Willits (1995) who found a significant increase in cracking incidence of fruit on upper trusses, with the percentage of fruit affected by cracking increasing from 2% in the first truss to 38%, 41% and 45% for trusses 5, 6, and 7, respectively. Many factors can explain the greater susceptibility of fruit of upper clusters to cracking, such as a higher irradiance and higher fruit temperature, especially once plants are topped. These factors favor pulp expansion and, consequently, a weakening of the cuticle (Peet & Willits, 1995). An additional component of cracking in upper clusters may be the reduced fruit load as fruit is progressively harvested up the main stem.

Among others, thin pericarp is one of the anatomical characteristics most frequently associated with fruit cracking (Peet, 1992). Therefore, the pericarp thickness of fruit in all the trusses of the various treatments was assessed, in order to check whether the variability of fruit cracking incidence among trusses of a plant was associated with the innate differences in their pericarp thickness. Surprisingly, in all the treatments, an obvious decrease of pericarp thickness was found from lower to higher trusses (Figure 2.12).



	1	2	3	4	5	6
◆ control	0.93	0.91	0.82	0.84	0.84	0.8
■ 1-truss-pruned		1	0.98	0.96	0.89	0.88
▲ 2-trusses-pruned			0.95	0.93	0.9	0.81
● 3-trusses-pruned				0.99	0.98	0.92

Figure 2.8 Pericarp thickness of tomato fruit at different truss positions of the various truss pruning treatments

Correlation coefficients indicated a strong negative correlation between pericarp thickness and truss position in the plant from lower to higher (correlation coefficients of -0.97, -0.96, -0.96, and -0.92 were found for the 0, 1, 2, and 3-trusses pruned treatments, respectively). Thus, it is tempting to hypothesize that, the increased incidence of fruit cracking observed in higher trusses in this experiment and in other studies might have been attributed partly or fully to the innate behavior of reduced pericarp thickness of fruit at higher trusses.

Blossom-end rot (BER)

Like fruit cracking, blossom-end rot occurred mainly in the two-trusses-pruned and three-trusses-pruned treatments of tomato, while fruit in the control and one-truss-pruned treatments were unaffected. The highest blossom-end rot incidence was found in the two-trusses-pruned treatment (Figure 2.7), but was not significantly higher than the three-trusses-pruned treatment. This result is similar to that of De Cock *et al.* (1982) where the incidence of blossom-end rot increased significantly with fruit thinning. This increase in occurrence is said to be due to the lack of coordination between accelerated cell enlargement caused by high import of assimilates in pruned plants and inadequate supply of calcium due to poor development of xylem at the growing point (blossom-end) of tomato fruit (Kinet & Peet, 1997). Others have associated this to the excessive supply of hormones from the roots to the developing fruit of pruned plants (Dorais & Papadopoulos, 2001).

The BER-affected fruit were generally small in size, as can be seen in Figure 2.6. This is in agreement to the observation of De Cock *et al.* (1979) who concluded that BER inhibits fruit enlargement. Thus, the high occurrence of this disorder in the two-trusses-pruned treatment might also have contributed to the reduction of class-one fruit in the same treatment which was mentioned earlier.

Unlike cracking, BER occurrence tended to be higher in the lower trusses than in the upper trusses (Figure 2.9). This is in accord to the finding of El-Gizawy and Adams (1986), and Adams and Ho (1993), but contradicts with Nukaya *et al.* (1995) who observed an increasing BER incidence for successive trusses. Within a truss, the fruit from the basal part were affected most severely with BER, which is in agreement with Banuelos *et al.* (1985).

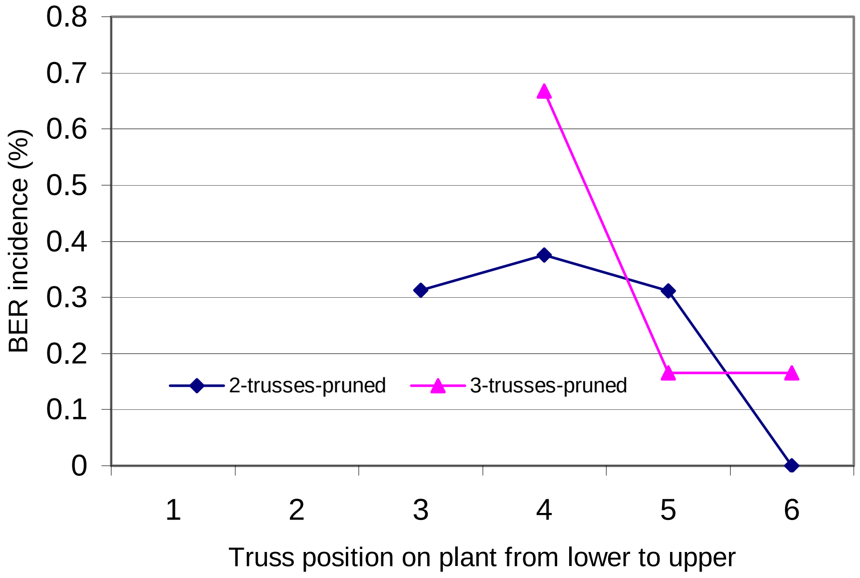


Figure 2.9 BER incidences at various truss positions in the two-trusses-pruned and three-trusses-pruned treatments of tomato

Westerhout (1962) stated that vigorous plant growth before anthesis of the first flower was responsible for the incidence of BER. Moreover, he suggested that the prevalence and severity of BER depended on the growth rate of tomato fruit being closely related to the vigor of the plants. This can explain why the lower trusses were more affected by BER than the upper trusses (Figure 2.9). In the treatments where BER occurred (two and three-trusses-pruned), the removal of the first two or three trusses might have caused vigorous plant growth and high assimilate supply at the time of anthesis of the flowers in the next few trusses, resulting in luxuriant growth but high susceptibility to BER. As more and more trusses are formed, the competition for assimilates from the earlier formed trusses reduces the plant vigor and assimilate availability at the time of anthesis of the later trusses, rendering them less susceptible to BER.

Marketable fruit yield

Marketable yield per plant (total yield minus defected and undersized fruit) was the highest in the one-truss-pruned treatment and the control (Figure 2.10). Even though the difference was not significant, the one-truss-pruned treatment tended to have a higher marketable yield than the control, and the control was not significantly different from the two-trusses-pruned treatment. The three-trusses-pruned treatment gave the lowest marketable yield. The increase of fruit size due to increased source : sink ratio and less occurrence of fruit disorders enabled the one-truss-pruned treatment to give the best marketable yield.

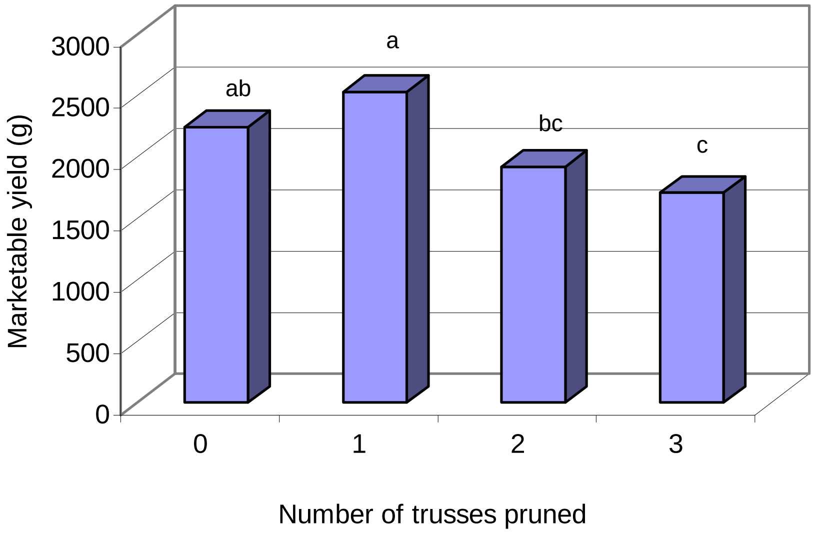


Figure 2.10 Marketable fruit yield per plant of tomato at various truss-pruning intensities

2.3.2 Hot pepper trial

Fruit size

In hot pepper, fruit volume was increased by fruit pruning. While all the pruning treatments tended towards higher fruit volumes than the control, a significant increase was found in the two-fruits-pruned treatment only, and there was no significant difference among the treatments with fruit(s) pruned (Table 2.6).

In a pepper plant, the fruit, new shoots and leaves of the plant compete for assimilates. As the number of fruit per plant increases, the fruit size tends to decrease. Reducing the number of fruit allows the plant to distribute assimilates to a lesser number of fruit which will attain a bigger size. Besides, Ali and Kelly (1992) reported that, even if assimilate availability is not limited, the presence of older fruit can suppress the growth of the younger fruit by producing growth inhibiting substances. Removal of the older fruit in their experiment increased the size of the remaining young fruit.

Seed content

Seed content of pepper fruit tended to increase with the intensity of pruning. The two-fruit-pruned treatment produced more seed per fruit (41) than the control (31), but the one and three fruit pruned treatments were not significantly higher than the control (Table 2.6). A high correlation (r=0.85) was found between fruit size of hot peppers and their seed content. Similarly, Morgan and Lennard (2000) reported a direct relationship between the number of seeds per fruit and final fruit size.

Pericarp thickness

The pericarp of hot pepper fruit is thin (1.5 mm) and was not significantly affected by fruit pruning intensities (Table 2.6). No consistent trend of increase or decrease in pericarp thickness was observed with pruning intensity. This result contradicts to that of Ali and Kelly (1992) where pericarp thickness of sweet pepper fruit increased as the result of pruning older fruit.

Table 2.6 Effect of fruit pruning intensity on size, seed content, total solids content and average pericarp thickness of hot pepper

Treatments (T)	**Volume of fruit (cm3)**	**Seed content of fruit**	**Total solids content of fruit (%)**	**Average pericarp thickness (mm)**
Control	1.68b	30.90b	23.96a	1.52a
1-fruit-pruned	1.90ab	34.67ab	24.18a	1.60a
2-fruit-pruned	2.05a	41.52a	25.36a	1.51a
3-fruit-pruned	1.84ab	38.27ab	26.34a	1.54a
LSD(T) P≤0.05	2* = 0.308 3* = 0.323 4* = 0.333	2* = 7.654 3* = 8.036 4* = 8.279	2* = 2.638 3* = 2.770 4* = 2.853	2* = 0.168 3* = 0.176 4* = 0.182
CV(%)	14.97	19.12	9.60	9.91

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

Fruit mass

Fresh mass of individual fruit increased with increasing intensity of pruning (Figure 2.11). The increase was significant in the three-fruit-pruned and two-fruit-pruned treatments. The one-fruit-pruned treatment was only slightly higher than the control. Ali and Kelly (1992) found a similar increase in the size of sweet pepper fruit, as the result of removal of flower buds, flowers and set fruit on the first three flowering nodes. This was assumed to be due to the alleviation of inter-fruit competition. Archibold *et al.* (1982) explained this as the alleviation of dominance exerted by older fruit on younger ones through production of hormones. Marcelis and Baan Hofman-Eijer (1997) suggested a combination of both explanations.

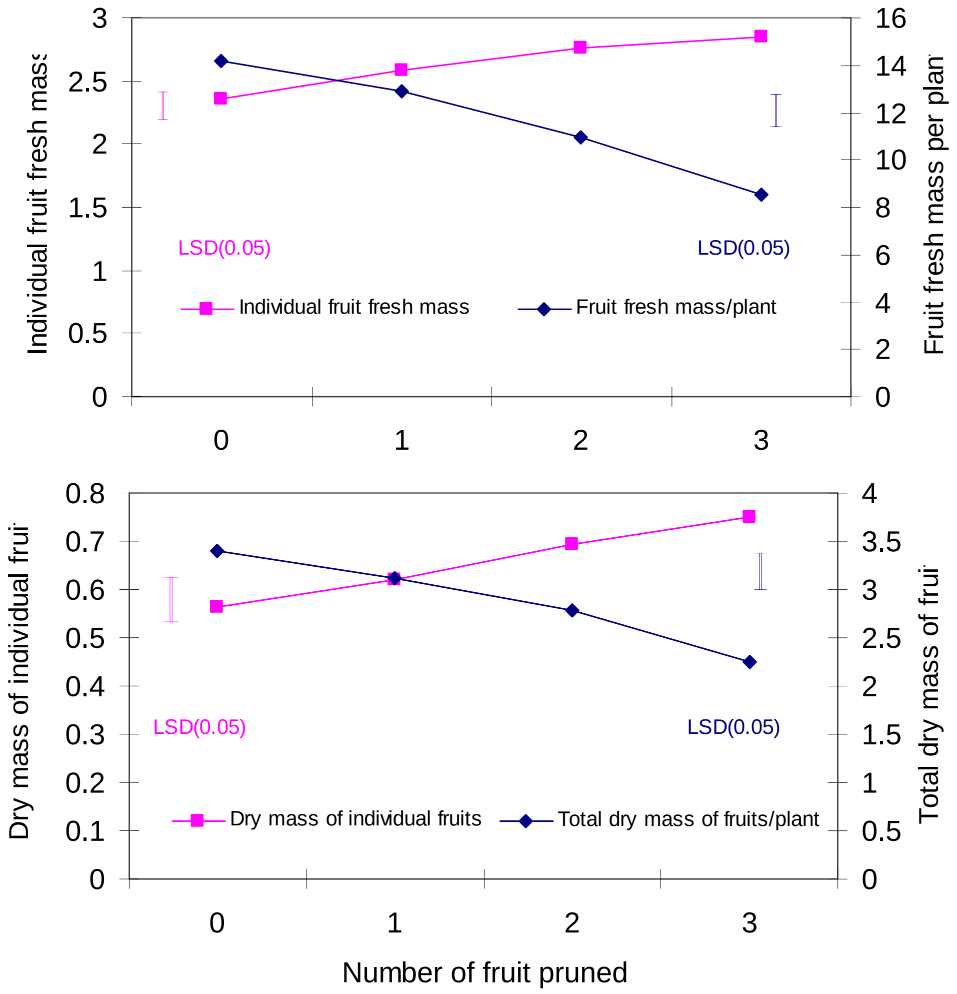


Figure 2.11 Fresh mass and dry mass of individual fruit and total fruit per plant in hot pepper

Like the fresh mass, dry mass of individual fruit in hot pepper was increased by pruning (Figure 2.11). The two-fruit-pruned and three-fruit-pruned treatments had higher individual fruit dry mass than the control, but the one fruit pruned treatment was not significantly different from the control. Total dry mass of fruit per plant, however, declined as the intensity of pruning increased (Figure 2.11). Even though the one-fruit-pruned and two-fruit-pruned treatments were not significantly affected as compared to the control, the total fruit dry mass of hot pepper fruit from which three fruit were pruned was lowered significantly.

The main factor for the difference in total fruit mass between tomato and hot pepper was that in tomato a truss, consisting of many flowers is formed and an increase in the number of flowers/fruit per truss could be achieved by increasing assimilate supply, in addition to an increase in fruit size. This enabled the tomato plants under all pruning intensities to compensate the yield loss due to pruning to a higher degree than hot pepper.

There are two possible explanations for the above mentioned yield loss at higher source-sink ratios. According to Cockshull and Ho (1995), dry matter accumulation can be sink-limited when the increased availability of assimilates by pruning exceeds the sink strength of the fruit in the remaining trusses. In this case, the excess assimilates accumulate in the assimilate pool (Ho, 1979) or may be diverted to vegetative growth (Gautier *et al*., 2001). Secondly, profound increase in source : sink ratio due to intensive pruning might have inhibited dry matter production (source activity) as has been claimed by Nederhoff *et al.* (1992), Guinn and Mauney (1980), and Gifford and Evans (1981).

Total soluble solids

Total solids content of hot pepper fruit was around 25%. There was a tendency of increasing total solids of the fruit with intensity of pruning (Table 2.6). The increase was, however, not significant. Bertin *et al.* (2001) concluded that increased assimilate availability increases the dry matter accumulation of fruit but does not change the proportion of dry matter (total solids) and water content in fruit, as sugar import is accompanied by a similar increase in phloem water uptake by the fruit.

Table 2.7 Effect of fruit pruning intensities on dry mass of the aboveground plant parts of hot pepper

Treatments (T)	Dry mass of Stem (g)	Dry mass of leaves (g)	Dry mass of vegetative plant part (g)	Total dry mass of plant (g)
Control	11.825a	7.43a	19.255a	33.422a
one-fruit-pruned	10.506a	7.946a	18.452a	31.743a
two-fruit-pruned	10.302a	6.418a	16.721a	27.752b
three-fruit-pruned	12.349a	7.153a	19.503a	27.385b
LSD(T) P≤0.05	2* = 2.267 3* = 2.381 4* = 2.454	2* = 1.751 3* =1.839 4* = 1.896	2* = 3.246 3* = 3.410 4* = 3.515	2* = 3.861 3* = 4.054 4* = 4.176
CV(%)	19.53	23.45	17.02	11.68

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time

Total plant dry mass

Total plant dry mass was significantly reduced in the two-fruit-pruned and three-fruit-pruned treatments (Table 2.7) but was not affected in the one fruit pruned treatment. This is in accordance to the hypothesis of Nederhoff *et al*. (1992), Guinn and Mauney (1980), and Gifford and Evans (1981) where dry matter production was inhibited by a profound increase in source-sink ratio. Similarly, Hall and Brady (1977) showed that defloration of pepper plants slowed the photosynthetic rate.

Early yield

The amount (%) of early yield was not significantly increased by fruit pruning in hot pepper (Table 2.8). pruning of the oldest fruit might have affected the effect of increased source : sink ratio on earliness, or in hot pepper earliness could be unaffected by assimilate supply. Similarly, De Koning (1994) reported that fruit growth period (time from anthesis until harvest-ripe) was hardly affected by fruit load.

Table 2.8 Effect of pruning intensity on the early fruit yield of hot pepper

Treatments (T)	**Early yield (%)**
Control	66.50a
1-fruit-pruned	60.00a
2-fruit-pruned	59.37a
3-fruit-pruned	66.71a
LSD (T) P≤0.05	2* = 29.37 3* = 30.83 4* = 31.76
CV (%)	42.21

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test (P ≤ 0.05).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

Fruit disorders

Fruit cracking

Fruit cracking also occurred in hot pepper. Unlike tomatoes, however, the affected fruit were undersized (Figure 2.12), deformed and contained few seeds. The cracking incidence was significant in the two-fruit-pruned and three-fruit-pruned treatments (Figure 2.13) but was not considerable in the other treatments.

Aloni *et al*. (1999) observed a similar disorder in bell pepper plants that had remained temporarily fruitless. Those cracked fruit were formed from flowers with swollen ovaries, and contained few seeds. Likewise, the cracked hot pepper fruit shown in Figure 2.12 contained few numbers of seed. An average of 10-15 seeds was found in the cracked fruit in the three-fruit-pruned treatment, while 55-60 was counted in the normal fruit of the same treatment.

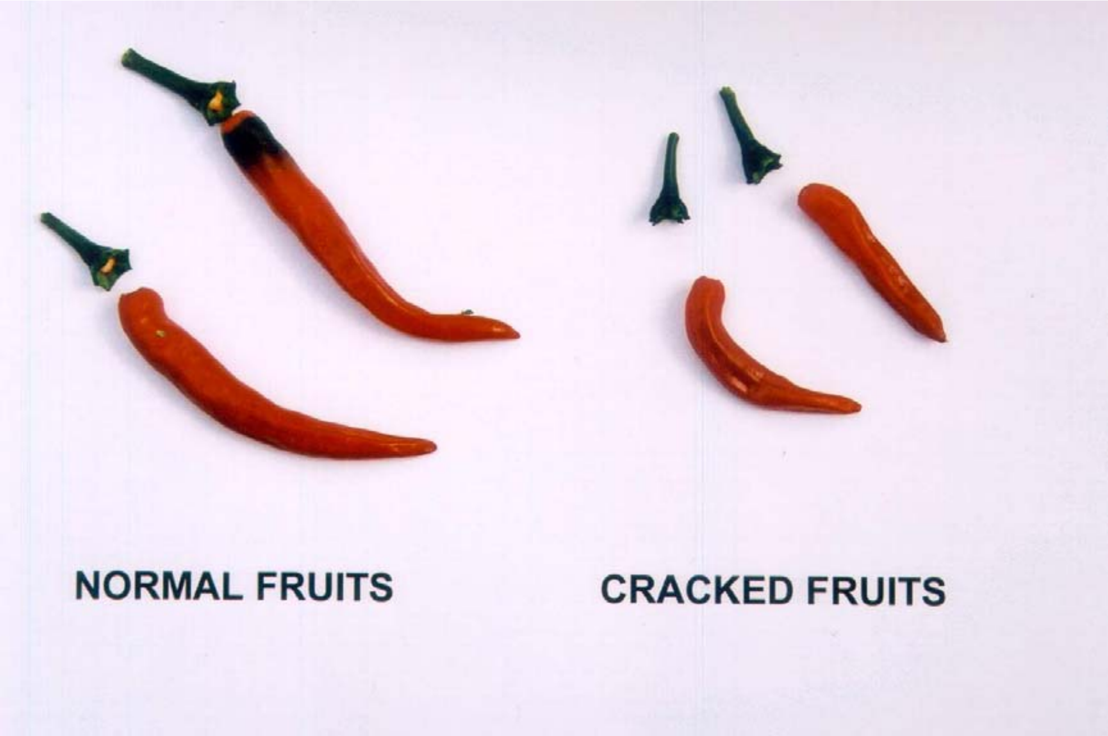


Figure 2.12 Cracked and deformed hot pepper fruit found in intensive pruning treatments (right) as compared to the normal fruit (left)

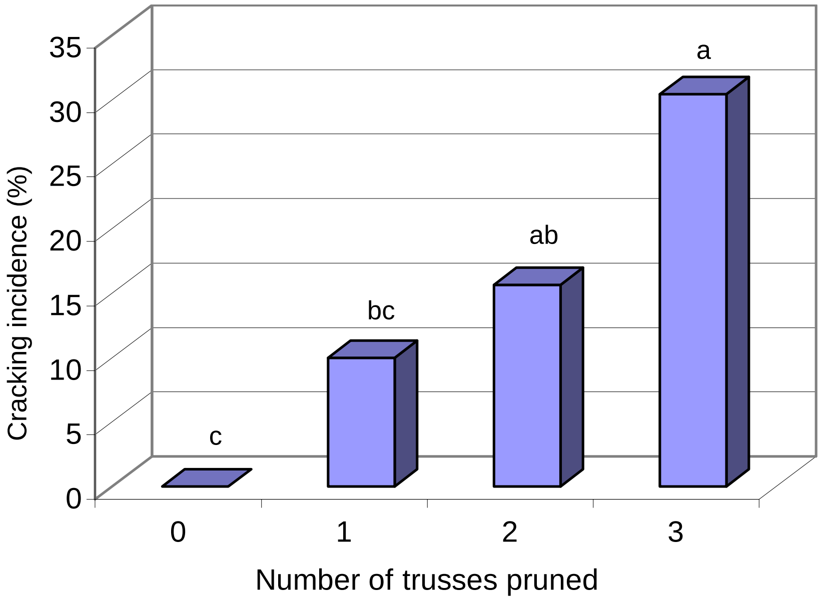


Figure 2.13 Fruit cracking incidence at various fruit pruning intensities of hot pepper

Therefore, Aloni *et al*. (1999) suggested that assimilate partitioning may be an important process in determining flower morphology and pollination and subsequent fruit shape. Flower ovaries grow excessively due to high assimilate supply. In such flowers, self-pollination is not efficient because of the large distance between the stigma and stamens. Therefore, the mechanism by which intensive pruning induces fruit cracking disorder in peppers seems to be indirect by affecting seed setting.

Marketable yield

Marketable fruit yield per plant was highest in the treatments where one fruit was pruned and the control (Figure 2.14). Whereas in the treatments where two and three fruit were pruned, marketable yield was considerably reduced. The two-fruit-pruned treatment had a lower marketable yield than the control but was not significantly lower than the one-fruit-pruned treatment. In addition to the loss of potential yield due to pruning, the high incidence of fruit disorders (cracking and BER) that occurred in these two treatments contributed much to this effect.

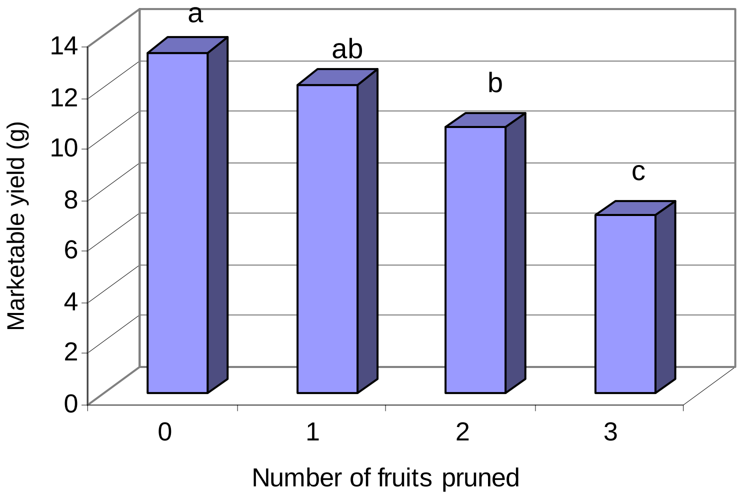


Figure 2.14 Marketable yield of hot pepper per plant at various fruit pruning intensities

2.4 CONCLUSION

Time of pruning (at anthesis or at fruit-set) did not affect yield and fruit quality of tomato and hot pepper.

With increasing pruning intensity, yield per truss of tomato and yield per fruit of hot pepper increased. The total yield per plant, however, reduced with increasing pruning intensity. The possible reason for this is that the extent to which a truss or a fruit can grow and compensate for a yield loss due to pruning is limited. Thus the level of yield compensation is expected to decline with increasing intensity of pruning. The treatments where one truss of tomato and one fruit of hot pepper were pruned resulted in increased fruit size, pericarp thickness and freedom from fruit defects, without loss of total and marketable yield.

With increasing pruning intensity, tomato fruit seem to attain more dry mass than fresh mass. This was shown by the significant increase in total solids content (proportion of dry mass over fresh mass) with pruning intensity. The response of tomato and hot pepper to pruning intensity was different. An increase of both fruit number per truss and fruit size was observed in tomato which resulted in greater yield compensation than in hot peppers where only increase in fruit size was possible due to its flowering and fruiting habit.

Total plant dry mass was not affected by truss pruning in tomato plants, but it was significantly reduced in hot pepper plants following intensive pruning (two-fruit-pruned and three-fruit-pruned). This could be an indication of inhibition of dry matter production due to negative feedback control of photosynthesis.

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CHAPTER 3

EFFECT OF FRUIT PRUNING AT VARIOUS POSITIONS ON THE PLANT ON YIELD OF TOMATO AND HOT PEPPER

3.1 INTRODUCTION

Assimilate partitioning to different sinks affects crop yield. Slack and Calvert (1977) observed that when one of the first ten trusses were removed from a tomato plant at different positions on the plant, the largest increase in yield occurred in trusses immediately above and below the one removed, with less effect on trusses further away. They suggested that separate upward and downward pathways exist for the photosynthate translocation from tomato leaves, upward via internal phloem and downward via the external phloem. Whether there is equal division of photosynthates into upward and downward pathways is questionable.

According to Ho (1988) the distribution of assimilates among sinks is primarily regulated by sink strength, whereas the distance from source to sink (transport resistance) is of minor importance. This implies equal access to an apparent common assimilate pool for all sinks, as was shown by Heuvelink (1995) with double-shoot tomato plants. The sink strength of a tomato fruit depends on its position within a truss and the position of the truss on the plant (Bertin, 1995). Assimilate availability in the plant at the time of macroscopic appearance of the fruit or truss has been suggested to account for the difference in sink strength of fruit (Kinet, 1977). Therefore, in order to maximize the total biomass partitioning to fruit (harvest index), fruit and truss pruning should be done in such a way that fruit or trusses with lower sink strength (potential size) are removed, and those with higher sink strength are retained. Moreover, the time of active growth of the remaining trusses should coincide with the time of increased assimilate supply when the truss is pruned.

Therefore, this experiment was intended:

- to identify the effect of distance between source and sink on photoassimilate allocation to the remaining trusses or fruit
- to investigate which tomato trusses or hot pepper fruit should be pruned in order to get the highest yield compensation (harvest index), and
- to determine whether there is equal division of photosynthates upward and downward to the remaining trusses or fruit.

3.2 MATERIALS AND METHODS

Seedlings of tomato cultivar 'Graziela' and hot pepper cultivar 'Challenger' were raised in the same way as described in chapter 2. After transplanting to PVC pots, plants in both the tomato trial and hot pepper trial were arranged in complete randomized designs replicated four times, and were fertigated and trained in the same way as for the experiments in chapter 2. Training methods used for tomato and hot pepper are illustrated in Figure 3.1a and b. In the tomato trial, plants were allowed to produce six trusses before the apical meristem was removed. The first, third or sixth truss was removed at anthesis or at fruit-set of the first fruit. All the six trusses were retained in the case of the control treatment. In the hot pepper trial, plants were allowed to produce six fruit before the apical meristem was removed. The first, third or sixth fruit was removed at anthesis or at fruit-set. All the six fruit were retained in case of the control treatment.

At harvest, the number of fruit, and the fresh and dry mass of fruit per truss and per plant were determined for tomato, and fresh mass and dry mass of individual fruit and total fruit per plant were determined for hot pepper. Data was analyzed using the SAS/STAT program (SAS Institute Inc. Cary. NC, USA Copy right ©1999-2001). Differences at the $P \leq 0.05$ level of significance are reported and means were separated using Duncan's Multiple Range test.

a.

B.

Figure 3.1 Training methods used for tomato (a) and hot pepper (b) plants

(a) side-shoot being removed from leaf axils of tomato, (b) one of the two sympodial branches being removed from a hot pepper plant

3.3 RESULTS AND DISCUSSION

Pruning of fruit at various positions of the plant (top, middle and bottom) affected yield and fruit quality of tomato and hot pepper. The time of pruning at anthesis and at fruit-set, however, had no effect on yield, yield components and fruit quality of both tomato and hot pepper plants. (Tables 6.2.1 - 6.2.6 may be referred in the appendix). The interaction between time of pruning and position of pruning was also not significant on both crops.

3.3.1 Tomato trial

The treatments where individual trusses of tomato were pruned at various positions on the plants and the control were compared for yield and yield components. Considerable increase in fruit number per truss, fresh mass per truss and dry mass per truss was observed when a truss was removed from the middle part of the tomato plants (third truss) (Table 3.1). Regarding fruit number per plant, fruit fresh mass per plant and fruit dry mass per plant, no significant difference was found among all the treatments, although pruning of the middle truss appeared to have yielded the best.

Generally, pruning of a single truss of tomato at various positions on the plants did not reduce the total dry mass and fresh mass yield of fruit significantly, as has been found in the previous experiment on pruning intensity, and in the findings by Slack and Calvert (1977). This indicates that, assimilates from those leaves normally supplying the missing truss were readily diverted to the remaining trusses, and as the result, the enhanced growth of the remaining trusses compensated more or less fully for the missing truss.

Although the same number of truss was pruned in all three pruning treatments, the position of the pruned truss in the plant seemed to have a considerable effect on the allocation of assimilates to the remaining trusses. Pruning of the middle truss was the most effective in yield compensation as followed by pruning of the upper truss. In agreement to this, Slack and Calvert (1977) found the greatest compensation for a missing truss when the middle truss (fifth truss) was removed out of the 10 trusses in glasshouse-grown tomato plants. They associated this to the bi-directional transportation of carbon from tomato leaves. Thus, if the lowest trusses are pruned, there are no trusses to benefit from the downward movement, and pruning of the upper trusses will result in no truss to benefit from the upward movement of assimilates from the supplying leaves. By pruning the middle truss however, the trusses above and below it can benefit.

Apart from the transport pathway, the differential sink strength of the various tomato trusses and hot pepper fruit might have contributed to the difference in yield observed by pruning a truss or fruit at different positions of the plants. Being the first to be induced, the lowest trusses have the highest sink strength, owing to a larger number of cells at anthesis, which is a basis for the later growth by cell expansion. This was referred to as ‘primegenic dominance’ (Bangerth & Ho, 1984). Thus, potentially, they can grow bigger if a later truss or fruit is pruned causing higher yield. Considering this hypothesis of Bangerth and Ho (1984), pruning of the last tomato truss (sixth truss) could be expected to result in the highest yield compensation. However, pruning the middle truss performed better than pruning the last truss, in spite of the fact that the middle truss has higher potential growth (sink strength) than the last truss according to the ‘primegenic dominance’ principle of Bangerth and Ho (1984).

Although the potential size of a tomato fruit is dependent on its position (on the truss and on the plant), the size actually achieved is dependent on the amount of assimilate produced by the foliage and the number of fruit competing for the assimilates (Ho, 1980). The amount of assimilate produced by the foliage is regulated by photosynthesis, which in turn is dependent on the quantity of solar radiation incident on the crop. According to Heuvelink (1996), upper trusses achieve better growth because of more light interception at the higher position on the tomato plant. For lower trusses, however, maximal potential growth is reached only under very high irradiance. This may explain why pruning of the last truss did not give higher yields than pruning the middle truss.

Table 3.1 Yield and yield components of tomato as affected by pruning of a truss at various positions on the plant

Treatment (T)	**Fruit number /truss**	**Fruit fresh mass /truss (g)**	**Fruit dry mass /truss (g)**	**Fruit number /plant**	**Fruit fresh mass /plant (g)**	**Fruit dry mass /plant (g)**
Control	5.12b	439.66b	21.79c	30.75a	2638.01a	130.77a
First-truss-pruned	5.54b	502.54b	26.57bc	27.67a	2512.74a	132.84a
Third-truss-pruned	7.00a	624.89a	33.19a	35.00a	3124.5a	165.99a
Sixth-truss-pruned	6.00ab	516.27b	28.54ab	30.00a	2581.38a	142.69a
LSD (T) P≤0.05	2* = 1.363 3* = 1.430 4* = 1.472	2* = 101.2 3* = 106.1 4* = 109.3	2* = 6.248 3* = 6.554 4* =6.746	2* = 7.381 3* = 7.742 4* = 7.969	2* = 569.2 3* = 597.1 4* = 614.6	2* = 34.39 3* = 36.08 4* = 37.13
CV (%)	19.39	16.39	19.23	19.87	17.47	20.13

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

The lower trusses of tomato seem to have the highest potential size, but the upper trusses often achieve the greatest actual size due to better light interception. Thus, pruning should be targeted to the middle trusses to achieve maximal yield.

Comparison of yield increase in the various trusses of tomato

In all the treatments where a single truss of tomato was pruned from various positions of the plants, yield increase occurred in most of the remaining trusses. The relative yield for the individual trusses (Tables 3.3) show that, about 80% of the tomato trusses of the treated plants out-yielded the corresponding ones on the control plants.

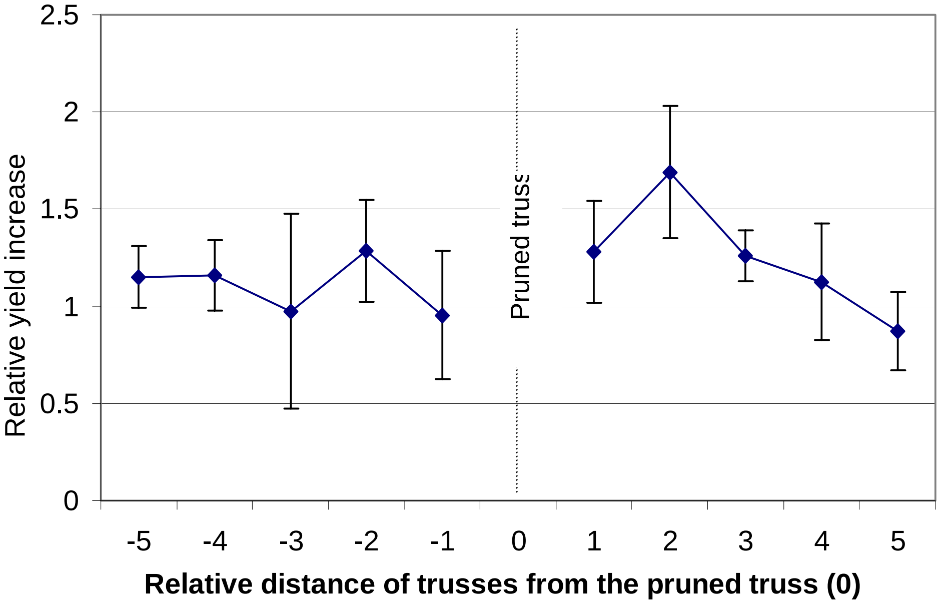

Figure 3.2 Relative yield of the remaining trusses above (positive numbers) and below (negative numbers) the pruned truss (0) in tomato

The increase in yield tended to decrease the farther away (upwards and downwards) the truss was from the one removed, especially in the trusses above the pruned truss (Figure 3.2). This is similar to the result obtained by Slack and Calvert (1977) who reasoned that the remaining trusses would absorb larger amounts of assimilates unused by the pruned truss the closer they are from the providing leaves. Heuvelink (1996) also observed a similar trend in his simulations while distance to the providing leaves was not taken in to account in the model. He re-interpreted Slack and Calverts' (1977) 'distance effect hypothesis' and proposed that the trusses closest to the pruned one get the highest yield increase, as the lowest trusses have a shorter growth period left to profit from the removal of a truss, and the highest trusses miss a larger part of the period when assimilate availability is increased by removal of the truss. It was further noted that trusses closer to the pruned truss exhibit greatest sink strength in the period where the greatest sink strength of the pruned truss would have occurred.

Thus, Heuvelink (1996) supported the assumption of a 'common assimilate pool' equally accessible to all sinks on a tomato plant, which was further supported by double-shoot and truss removal treatments (Heuvelink, 1995), and rejected the idea that sinks are supplied by the nearest sources due to a significant resistance to movement in the phloem. This hydraulic resistance of the phloem is expected to be negligible in most cases, as several authors concluded that fully differentiated phloem networks have considerable spare transport capacity (Wardlaw, 1990).

In spite of the generally decreasing tendency of yield increases with increasing distance of trusses from the pruned truss, the second trusses above and below the pruned truss had higher yield increase than the first trusses above and below the pruned truss (Figure 3.2). This deviating result may also disprove the 'distance effect' hypothesis of Slack and Calvert (1977) on assimilate partitioning, but is intriguing and invites speculation as to the mechanisms involved. Perhaps, the trusses directly above and below the one pruned experienced the critical stage of cell division at low resource availability, before the truss was removed. Cell division or early cell elongation of the second trusses above and below the pruned truss might have coincided with the peak assimilate supply at the time of pruning of the truss, thus promoting their growth.

Table 3.2 Yield and relative yield of trusses in single-truss-pruning treatments of tomato at various positions of the plant

Truss no.	**Yield of control (g)**	**Yield of ‘T1’ (g)**	***Relative yield of ‘T1’**	**Yield of ‘T3’ (g)**	***Relative yield of ‘T3’**	**Yield of ‘T6’ (g)**	***Relative yield of ‘T6’**
1	566.77			763.16	1.346	652.46	1.15
2	580.65	681.29	1.173	530.10	0.913	672.12	1.16
3	294.92	570.45	1.934			288.18	0.98
4	439.18	554.04	1.261	606.52	1.381	540.03	1.23
5	448.43	505.95	1.128	626.26	1.396	446.96	1.00
6	308.06	269.25	0.873	397.77	1.291		

‘T1’ stands for first-truss-pruned treatment

‘T3’ stands for third-truss-pruned treatment

‘T6’ stands for sixth-truss-pruned treatment

***Relative yields were calculated by dividing yield of trusses in the treatments by the corresponding trusses of the control treatment thus values >1 indicate yield increases.**

Comparison of yield increases in tomato trusses above and below the pruned truss

It has been shown earlier that, the tomato trusses both above and below the pruned truss had yield increases. The question remains whether the yield increase in trusses above and below the pruned truss are equal. Comparison of the mean relative yield (Table 3.3) indicated a higher yield increase in the trusses above the pruned trusses (1.25) as compared to those below the pruned trusses (1.11), which is similar to the result found by Slack and Calvert (1977).

Table 3.3 Relative yield over controls for trusses above and below a pruned truss in tomato plants

	Truss position relative to the pruned truss									
	Below					**Above**				
	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5
Relative yield	1.15	1.16	1.00	1.29	0.95	1.28	1.69	1.26	1.13	0.87
Mean	1.11					1.25				

N.B. positive numbers represent relative distance of trusses above the pruned truss.
Negative numbers represent relative distance of trusses below the pruned truss.

Referring to the bi-directional flow pattern of phloem, Slack and Calvert (1977) suggested a greater export of assimilates in the upward direction than in the downward direction as a possible explanation for the greater relative yield in the trusses above the pruned one. Apart from this, it may be attributed to the change in the pattern of export from leaves with the continuing development of the plant (Kahn & Sagar, 1966), which was considered to be affected by the aging of the lower leaves and changing sink strengths of trusses with the age of the plant.

3.3.2 Hot pepper trial

Dry mass of individual fruit was significantly increased by pruning the top fruit (sixth fruit) and it tended to decrease with position of the pruned fruit in the plant from top to bottom (Table 3.4). Similar to the tomatoes, the total dry mass and fresh mass of hot pepper fruit per plant were not significantly affected by the pruning treatments. This implies that the mass of the pruned fruit was fully compensated for by the increase in the mass of individual fruit.

The position of the pruned fruit on the plant affected the allocation of assimilates to the remaining fruit of hot pepper, pruning the upper most (sixth) fruit being the most effective This .is in agreement to the findings of Bangerth and Ho (1984) who hypothesized that older fruit have a higher sink strength than younger fruit. Thus lower fruit (older fruit) can achieve better growth if the higher fruit are pruned than upper fruit could have achieved if lower fruit were pruned.

The observation by Heuvelink (1996) on tomato plants and the result of the tomato trial (Table 3.2) indicate that upper trusses achieve better growth due to better light interception at the top part on the plant. This is not relevant to the results obtained on hot pepper (Table 3.4). The possible reason could be that light interception may not affect the actual size of hot pepper fruit due to the size and phylotaxy of the leaves

Table 3.4 Yield and yield components, as affected by pruning of individual fruit at different positions of the hot pepper plant

Treatment (T)	**Fruit fresh mass/fruit (g)**	**Fruit dry mass/fruit (g)**	**Fruit fresh mass/plant (g)**	**Fruit dry mass/plant (g)**
Control	2.36a	0.56b	14.17a	3.39a
First-fruit-pruned	2.58a	0.62ab	12.91a	3.11a
Third-fruit-pruned	2.75a	0.67ab	13.78a	3.36a
Sixth-fruit-pruned	2.91a	0.73a	14.54a	3.66a
LSD (T) P≤0.05	2* = 0.5214 3* = 0.5473 4* = 0.5638	2* = 0.1248 3* = 0.1310 4* = 0.1350	2* = 2.674 3* = 2.807 4* = 2.891	2* = 0.6574 3* = 0.6900 4* = 0.7108
CV (%)	17.48	17.05	17.09	17.14

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test (P ≤ 0.05).

2*, 3* and 4* denote the number of adjacent ranked means compared at a time.

Comparison of yield increase in the various fruit of hot pepper

As the result of pruning a single fruit at various positions of the plant, 87% of the remaining fruit from the pruned plants out yielded the corresponding fruit in the control plants. The pattern of relative yield increase of hot pepper was not consistent in the remaining fruit at various distances from the pruned fruit (Figure 3.3).

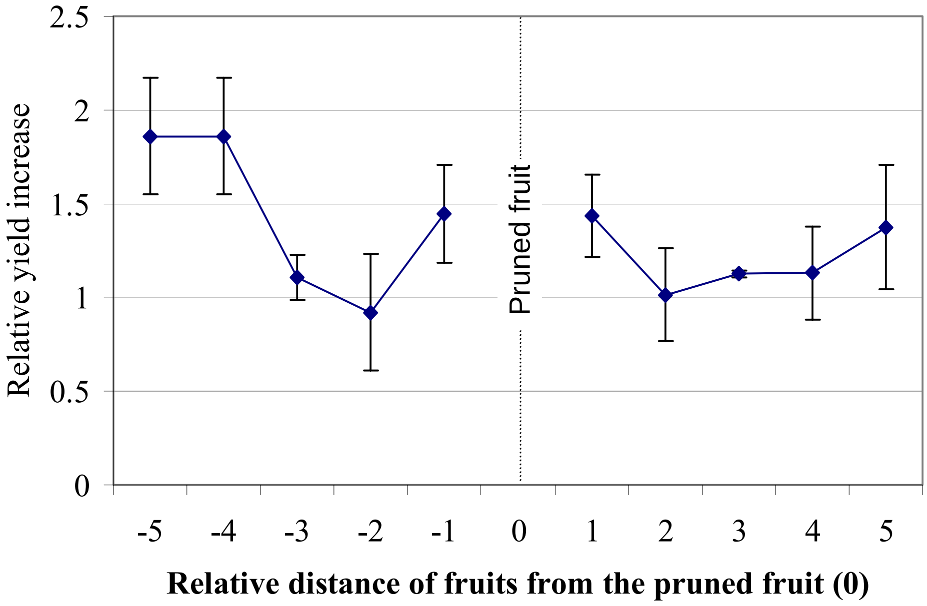

Figure 3.3 Relative yield of the remaining fruit above (positive numbers) and below (negative numbers) the pruned fruit (0) in hot pepper

According to the results shown in Figure 3.3, distance does not appear to affect the allocation of assimilates to the remaining fruit, or it may have been influenced by the dominating effect of some of the fruit on the growth of others. Heuvelink and Korner (2001) stated that the presence of developing fruit inhibits subsequent growth of new fruit both by competition for limited assimilates as well as by dominance due to the production of plant growth regulators. Only when the early-formed fruit are almost fully-grown and their sink-strength (competitive ability to attract assimilates) is lower, can the new fruit grow. This may also explain the alternating high and low yield of fruit from node to node in the un-pruned (control) pepper plants (Table 3.5).

Table 3.5 Yield and relative yield of fruit in single-fruit-pruning treatments of hot pepper at various positions of the plant

Fruit no.	Yield of control (g)	Yield of 'F1' (g)	*Relative yield of 'F1'	Yield of 'F3' (g)	*Relative yield of 'F3'	Yield of 'F6' (g)	*Relative yield of 'F6'
1	2.70			1.89	0.7	2.84	1.05
2	1.56	2.37	1.52	2.55	1.63	2.91	1.86
3	2.75	2.30	0.84			3.03	1.10
4	2.64	2.92	1.10	3.39	1.28	3.01	1.14
5	2.38	2.69	1.13	3.48	1.46	3.00	1.26
6	2.13	2.92	1.37	2.24	1.05		

'F1' stands for first-fruit-pruned treatment

'F3' stands for third-fruit-pruned treatment

'F6' stands for sixth-fruit-pruned treatment

***Relative yields were calculated by dividing mass of fruit in the treatments by the mass of the corresponding fruit of the control treatment thus values >1 indicate yield increase.**

Comparison of yield increases in fruit above and below the pruned fruit

The means of the relative yield increase in the fruit above and below the pruned fruit were more or less equal (Table 3.6). This differs from the result obtained on tomato where trusses above the pruned truss had a higher mean relative yield than trusses below the pruned truss (Table 3.3). Possibly, the bi-directional flow of assimilates reported for tomatoes could be absent in hot pepper. Besides, hot pepper leaves remain functional for a longer time than tomato leaves (Hall & Brady, 1977), hence, the pattern of assimilate export to the fruit of different age may not vary.

Table 3.6 Relative yield over controls for fruit above and below a pruned fruit in hot pepper plants

	Fruit position relative to the pruned fruit									
	Below					**Above**				
	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5
Relative yield	1.05	1.86	1.10	0.92	1.44	1.40	1.15	1.07	1.13	1.37
Mean	1.27					1.22				

N.B. Positive numbers represent relative distance of fruit above the pruned fruit.
Negative numbers represent relative distance of fruit below the pruned fruit.

3.4 CONCLUSION

The highest yield compensation was achieved by pruning the middle truss in tomato, and the topmost fruit in hot pepper plants. Yield increases occurred in almost all the remaining trusses or fruit of the pruned plants. In tomatoes the yield increase (especially in trusses above the pruned truss) generally tended to be lower the farther the trusses were from the pruned truss, while in hot pepper no consistent trend of yield increase was observed with relative distance of the remaining fruit from the pruned fruit. In tomato the trusses above the pruned truss gave a higher yield increase than those below the pruned truss, whereas in hot pepper the yield increase was equal towards the fruit above and below the pruned fruit.

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CHAPTER 4

COMPARISON OF PRUNING ALTERNATE AND CONSECUTIVE TOMATO TRUSSES AND HOT PEPPER FRUIT FOR YIELD AND FRUIT QUALITY

4.1 INTRODUCTION

In the first set of experiments (Chapter 2) it has been indicated that intensive pruning may cause excessive assimilate availability which may exceed the sink potential of the remaining fruit. As a result assimilates may divert to vegetative growth, and low harvest indices may result. The situation seems to be worse if consecutive trusses or fruit are pruned, as in the case of the first experiments, as a large quantity of assimilates will be mobilized over a short period of time. The question remains whether the excess assimilates remain in the storage pool and be available for the subsequent fruit to be formed.

Ho (1979) showed that under low light conditions intake of carbon by fruit was greater than the leaves could have provided from photosynthesis, indicating that some carbon might have come from storage pools in the stem. Hall and Milthorpe (1978) also claimed the use of stored carbohydrate for fruit production when capsicum plants were defoliated.

As the tomato stem grows it undergoes extensive secondary thickening and also functions as a storage organ. Many studies indicate that there is a pool of available carbohydrates stored in the stem, but there is little evidence to indicate its utilization during fruit production. Although tomato and hot pepper are commonly regarded as annual plants, they are capable of functioning as perennials (Khan & Sagar, 1967). Consequently, the carbon stored in the stem for a long period may be utilized in vegetative plant growth and may never be remobilized for current fruit production.

Pruning may result the mobilization of too much assimilates in a short period of time which can lead to diversion of assimilates to vegetative growth and thus reduction in harvest index. Hence, appropriate pruning techniques are required to ameliorate this effect.

Objective

The objective of this experiment was to test the effectiveness of pruning alternating tomato trusses and hot pepper fruit over pruning of consecutive trusses or fruit in preventing the diversion of assimilates to vegetative growth.

4.2 MATERIALS AND METHODS

The experiments were conducted in a greenhouse at the Hatfield Experimental Farm of the University of Pretoria. The tomato cultivar ‘Graziela’, and hot pepper cultivar ‘Challenger’, were used for the trials. Details of the facilities, statistical procedure, greenhouse climate, and crop husbandry practices are described in Chapter 2.

Two pruning method treatments were applied. In the first treatment for tomato the first (lowest) three consecutive trusses were pruned out of the total of six trusses that were allowed to be formed. In the second treatment, three alternate trusses were pruned (first, third and fifth). For hot pepper, the treatments included pruning of the first three consecutive fruit out of the six fruit, and pruning of the three alternating fruit.

Data on yield and yield components - such as fruit number, total fruit mass (fresh and dry) per fruit, per truss and per plant, fruit diameter, pericarp thickness, early yield, and number of defected fruit were taken. After the fruit were harvested, the leaf area of hot pepper plants was determined using a ‘Li-COR Model 3100’ area-meter, and the stem diameter was measured with a ‘Vernier’ caliper. Leaf area could not be measured for tomato plants, as the lower leaves were already senesced. In hot peppers, however, the leaves remain functional for a long time, even up to the late phases of fruit growth, as was also observed by Hall and Brady (1977).

Data was analyzed by analysis of variance using the SAS/STAT program (SAS Institute Inc. Cary. NC, USA Copy right ©1999-2001). Differences at the $P \leq 0.05$ level of significance are reported and means were separated using Duncan’s Multiple Range test.

4.3 RESULTS AND DISCUSSION

As in the first and second experiments (Chapters 2 and 3), the effect of time of pruning (at flowering or at fruit-set) was not significant on yield and yield components of tomato and hot pepper, and no significant interaction effect was found between the time and method of pruning (Tables 6.3.1 - 6.3.9 in appendix). The two pruning method treatments had little effect on yield and yield components but affected the early yield and some quality aspects of the fruit.

4.3.1 Tomato trial

Yield and yield components

Fruit number (per truss and per plant), total fresh mass and dry mass of fruit, number of class-one fruit and pericarp thickness of tomato were similar between the two methods of pruning : pruning of the three lowest consecutive trusses vs. pruning of three alternate trusses (Table 4.1).

Obviously, pruning of the first consecutive tomato trusses causes an enormous increase of assimilate in the assimilate pool when most of the fruit in the next three trusses were not even formed. By implication, the assimilates unused by the pruned trusses had to be stored long enough until the last truss or fruit was formed. According to the hypothesis of Hocking and Steer (1994), the longer assimilates are stored in the assimilate pool, the more they are converted to structural material (vegetative growth), and thus become unavailable for fruit production. If every other truss is pruned, however, some assimilates are assumed to be available for each of the remaining subsequent truss, and assimilates will not be required to store long. The results shown in Table 4.1, however, did not give differences in yield and yield components of tomato for the two pruning methods significant enough to support the above hypothesis.

Assimilates stored when the lowest three trusses or fruit were pruned might have been remobilized during the fruit production period of the subsequent three trusses as was also suggested by (Ho, 1979). Even if some of the stored assimilates are converted to structural materials that can not be remobilized, fruit can still grow to their potential as long as the remaining assimilates are enough to meet the potential sink demand of the remaining trusses (Heuvelink, 1997). In other words, the similar yield obtained in the plants treated with two different pruning methods (Table 4.1) could be an indication that the plants under both pruning methods were sink limited (source saturated).

Table 4.1 Yield and yield-components of tomato using two different truss-pruning methods

Treatments (pruning method)	**Fruit number /plant**	**Fruit number / truss**	**Number of class-1 fruit**	**Pericarp-thickness (cm)**	**Fruit fresh mass/ plant (g)**	**Fruit dry mass/ plant (g)**	**Early yield (g)**
Consecutive-trusses-pruned	23.62a	7.86a	9.37a	9.6a	2046.66a	124.23a	1013.38a
Alternate-trusses-pruned	22.85a	7.82a	10.33a	9.8a	2106.81a	124.21a	1383.66b
LSD ($P \leq 0.05$)	7.503	2.492	3.284	0.639	488.8	29.27	306.2
CV (100)	28.3	28.26	29.8	5.75	20.82	20.84	21.72

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

Early yield

Unlike the total yield, early yield of tomato plants was significantly affected by the pruning methods (Table 4.1). A higher mean early yield (1383.66g) was found in plants with alternate trusses pruned than those with consecutive trusses pruned (1013.39g).

The variation in early yield may not be due to variation in growth rate, because assimilate availability, which is a determinant of growth rate (Papadopoulos & Pararajasingham, 1997), was not apparently limiting in both treatments. It may, however, be due to the ontogeny of the pruned and retained trusses. Obviously, the lowest trusses are formed first, and are usually earlier to mature. Thus the amount of early yield can be lowered by pruning the lowest consecutive trusses than by pruning alternating trusses where some of the older trusses are left. Thus, it can be hypothesized that, higher early yield would have been obtained if consecutive upper or middle trusses were pruned, as compared to the alternate trusses or fruit pruning method. Hence, if one is interested in early yield, pruning of the first formed consecutive trusses should be avoided.

Fruit disorders

Occurrence of BER and fruit cracking in tomato tended to increase in the consecutive-trusses-pruning method as compared to the alternate-trusses-pruning method (Table 4.2). This was, however, not found to be significant. Both fruit disorders are generally associated with the rapid movement of water and sugars (Dorais & Papadopoulos, 2001). Thus, pruning of consecutive trusses might have resulted in more rapid flow of assimilates to the fruit as compared to pruning of alternate trusses. The trusses formed immediately after the three consecutive pruned trusses are supplied by a large assimilate pool, thus becoming susceptible to fruit disorders (cracking and BER).

Table 4.2 Effect of the two truss pruning methods on the incidence of fruit disorders in tomato

Treatments	**Fruit Cracking incidence (%)**	**BER (%)**	**Total defected fruit (%)**
Consecutive-trusses pruned	9.7%a	2.9%a	12.4%
Alternate-trusses-pruned	1.6%a	1.0%a	2.6%
LSD $P \leq 0.05$	10.13	4.83	-

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

4.3.2 Hot pepper trial

Like in the tomato trial (Table 4.1), hot pepper plants treated with the two different pruning methods (Table 4.2) did not differ significantly regarding fruit yield (fresh and dry mass) and fruit quality (fruit volume and pericarp thickness). Fresh and dry mass yield of fruit and fruit size tended to be higher in the treatment where three consecutive fruit were pruned.

The utilization of stored assimilates for fruit growth in the consecutive fruit pruned treatment can be a factor as has been discussed earlier .Source-saturation due to intensive pruning in both treatments might also have caused the fruit to grow to their potential and thus resulting in similar yield.

Table 4.3 Yield and fruit quality of hot pepper using two different fruit pruning methods

Treatments (Pruning method)	**Fruit volume (cm^2)**	**Pericarp thickness (cm)**	**Fruit fresh mass/ plant (g)**	**Fruit dry mass/ plant (g)**	**Early yield (g)**
Consecutive-fruit-pruned	1.948a	0.15a	7.391a	2.027a	4.27a
Alternate-fruit-pruned	1.57a	0.15a	6.787a	1.785a	5.147a
LSD ($P \leq 0.05$)	0.296	0.0293	1.733	0.580	4.01
CV (%)	16.243	13.844	17.068	21.09	62.24

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

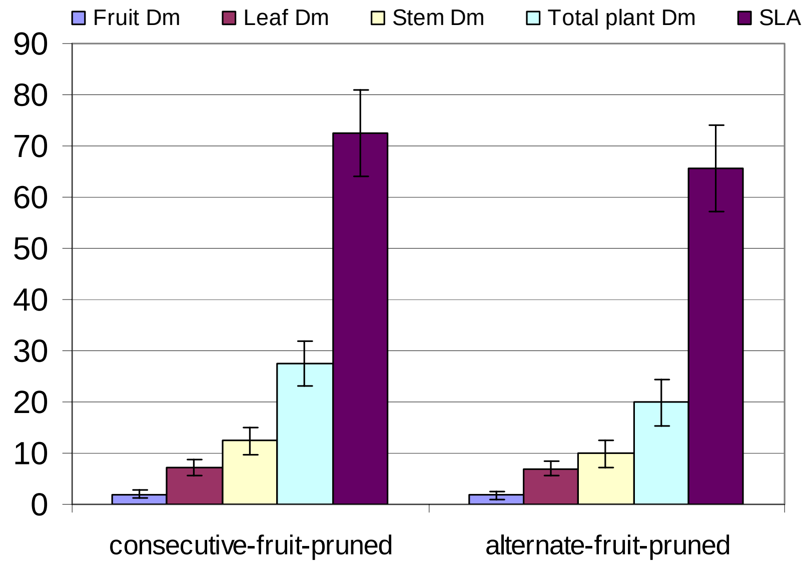

Figure 4.1 Specific leaf area (SLA) and plant dry matter of hot pepper plants treated using two different pruning methods

In the other hand, the diversion of more assimilates in to vegetative growth in the consecutive fruit pruning method might have indirectly contributed to the increased assimilate availability. According to Marcelis and Heuvelink (1999), reducing fruit load results in partitioning of dry matter in to the leaves, roots and the stem. The growth of these organs in turn increases dry matter production and availability, and thus increases fruit yield. The significantly higher total plant dry mass along with the slightly higher specific leaf area, leaf dry mass and stem dry mass found in hot peppers (Figure 4.1) where three consecutive trusses were pruned, may justify this assumption.

Early yield

The early yield of hot pepper was not affected by the two pruning methods (Table 4.3). How ever there was a tendency of higher early yield in the alternate fruit pruning method (5.1g) than in the consecutive fruit pruning method (4.3g). Perhaps, fruit growth rate which is a major determinant of earliness (Papadopoulos & Pararajasingham, 1997) did not differ in the two pruning methods due to high assimilate availability.

Fruit disorder

The occurrence of cracked and deformed fruit in hot pepper tended to be higher in the consecutive-fruit-pruning method than the alternate-fruit-pruning method (Table 4.4). A similar disorder has been observed by (Aloni *et al*., 1999) in bell peppers treated with intensive fruit pruning and cold temperature. High assimilate supply particularly during the early flower development (pre-anthesis) was assumed to be the possible reason for the disorder. Thus, where the first three consecutive fruit are pruned, the remaining fruit are formed at the peak period of assimilate supply and have higher tendency of being affected by fruit cracking and deformation. In the alternate-fruit-pruned plants, however, some fruit might have escaped the peak of assimilate supply.

Table 4.4 Fruit cracking and deformation incidence in hot pepper plants pruned using two different pruning methods

Treatments (Pruning methods)	**Fruit cracking and deformation incidence (%)**
Consecutive-fruit pruned	29.0%a
Alternate-fruit- pruned	16.5%a
LSD (T) $P \leq 0.05$	27.55

Footnote: Means within the columns followed by the same letter are not significantly different according to Duncan's Multiple Range test ($P \leq 0.05$).

4.4 CONCLUSION

Yield, yield components and fruit quality of tomatoes and hot peppers were not significantly affected by the two pruning methods. This may be due to sink-limitation in both treatments, because the degree of pruning in both methods was intensive. Thus, studying similar methods under less intensive pruning may give better indication of their effect on yield and quality of tomato and pepper.

The incidence of fruit disorders tended to increase in consecutive truss or fruit pruning method in tomato and hot pepper.

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CHAPTER 5

GENERAL DISCUSSION

Indeterminate crops, like tomatoes and peppers, continuously produce flowers and fruit, resulting in competition for assimilates, and consequently small fruit size. The reduction of fruit number by pruning trusses of tomato and fruit of hot pepper at various intensities increased the size of the remaining fruit. Similar results have been found by Cockshull and Ho (1995), Saglam *et al.* (1999) and others, and was explained by the redistribution of assimilates unused by the pruned fruit to the remaining fruit. The increase in fruit size in hot pepper was accompanied by a correlative increase in seed content of fruit, and a parallel increase in pericarp thickness and total solids content was found in tomato with increased fruit size by pruning trusses at various intensities.

In addition to fruit size, fruit number per truss also increased with increasing intensity of pruning in tomato. This contrasts with the finding of Slack and Calvert (1977), where truss pruning had no effect on fruit number per truss. The increase in source:sink ratio in this experiment might have enhanced flower formation or reduced abortion rate (Cockshull & Ho, 1995) leading to the observed increase in fruit number.

Due to the increase of both yield components (fruit size and fruit number per truss) in tomato, fruit yield was not significantly reduced by any of the truss pruning intensities. In hot pepper, however, total yield was fully compensated only in the one-fruit-pruned treatment, whereas significant reduction in total yield occurred in the treatments where two and three fruit were pruned. Obviously the increased assimilate supply brought about by pruning can only increase fruit size but not fruit number, because hot pepper produces a single flower per node, and growth was terminated after the sixth flowering node. Thus, yield loss occurred by pruning due to the reduction of generative sink strength, which is assumed to be proportional to fruit number. Furthermore, total plant dry mass was significantly reduced by intensive pruning in hot pepper, which is an indication of inhibited dry matter production due to negative feedback control (Nederhoff *et al*., 1992) caused by high assimilate supply.

The amount of early yield per truss in tomato, compared per corresponding truss basis with the control, was considerably increased with intensity of pruning. This could be due to an increased growth rate of fruit by increased assimilate supply (Papadopoulos & Pararajasingham, 1997). Nevertheless, early yield per plant did not indicate significant increase in hot pepper and was even reduced in tomato treatments where two and three trusses were pruned. This was because the pruned trusses or fruit were the first formed ones, which are usually earlier to mature.

The incidence of fruit disorders (blossom-end rot and fruit cracking) was increased by intensive pruning (two and three trusses pruned) in tomato. According to Dorais and Papadopoulos (2001), fruit cracking occurred due to the rapid movement of sugar and water towards the remaining fruit. Kinet and Peet (1997) explained BER incidence by the lack of coordination between accelerated cell enlargement, caused by high import of assimilates in pruned plants, and inadequate supply of calcium, due to poor development of xylem at the growing point (blossom-end) of tomato fruit.

Within the same plant, fruit cracking increased from lower to upper trusses. This was correlated with pericarp thickness of fruit, which markedly decreased from lower to upper trusses. To the contrary, BER tended to be higher in lower trusses and basal fruit. Westerhout (1962) suggested that prevalence and severity of BER depend on the growth rate of tomato fruit, which is closely related to the vigor of the plants. Since lower trusses are formed when assimilate availability is higher due to the pruning of the lowest trusses, they are expected to have higher growth rate and thus be more prone to BER.

Fruit cracking in hot pepper was high in the three-fruit-pruned treatment. Fruit were small, deformed and contained few seeds. Aloni *et al.* (1999) found similar disorders in bell pepper after severe fruit removal and observed that such fruit were being produced from swollen flower ovaries, probably due to assimilate over-supply at early stages of flower growth. The large distance created between the stigma and stamen due to swelling of the ovary may make self-pollination less efficient, resulting in small and deformed fruit.

Marketable yield per plant was highest in the treatments where one truss of tomato and one fruit of hot pepper were pruned as well as in the control treatments. In the treatments where two and three trusses or fruit were pruned, high incidence of fruit disorders and loss of potential yield occurred resulting in lower marketable yield.

In the second experiment, a single truss of tomato and fruit of hot pepper was pruned from various positions of the plants. Pruning of the middle (third) truss gave the highest yield compensation as compared to pruning of the topmost (sixth) truss and lowest (first) truss. Slack and Calvert (1977) associated this with the bidirectional transportation of carbon from tomato leaves. That is, the trusses above and below the pruned truss can benefit from the upward and downward phloem transport from the leaves normally supplying the pruned truss. Lower trusses may also have higher potential sink strengths owing to a larger number of cells at anthesis (Bangerth & Ho, 1984), and upper trusses achieve better growth owing to better light interception at the top of the plant (Heuvelink, 1996). Thus, pruning of the middle truss, which has a lower potential yield, may result in better yield compensation.

In hot pepper, pruning of the top (sixth) fruit gave the highest yield compensation, and compensation tended to decrease with the position of the pruned fruit in the plant from top to bottom. This seems to be due to the reduction in potential sink strength of fruit from bottom to top of the plant (Bangerth & Ho, 1984) , while light interception does not seem to limit growth of fruit at various positions of the plant.

Comparison of yield increases in the various trusses of tomato indicated a higher relative yield in trusses closer to the pruned truss, especially in trusses above the pruned ones, and tended to lower in the trusses further away. Slack and Calvert (1977) explained this phenomenon by the effect of distance on assimilate partitioning. Heuvelink (1996), however, argued that this is due to the ontogeny of the retained and the pruned trusses. That is, trusses closer to the pruned truss exhibit greatest sink strength in the period where the greatest sink strength of the pruned truss would have occurred. In hot pepper, no such trend of yield increase was seen in the fruit at various positions on the plant.

Comparison of yield increase between the trusses above and below the pruned truss in tomato indicated a higher mean relative yield on the trusses above the pruned truss. In hot pepper, however, the mean relative yield was more or less equal. Even though Slack and Calvert (1977) suggested a greater export of assimilates in an upward direction, it may also be attributed to the change in the pattern of export from leaves with development of the plant (Khan & Sagar, 1967), which is considered to be affected by aging of the lower leaves and changing sink strength of trusses with the age of the plant.

As pruning of the first three trusses of tomato and fruit of hot pepper in the first set of experiments (chapter 2) was found to cause yield loss and fruit disorders, a different pruning method was tried, where every other truss or fruit was pruned in contrast to pruning of three consecutive trusses or fruit. Yield and yield components were similar between the two methods of pruning. Incidence of fruit disorders (cracking and BER) was however markedly reduced by pruning alternate tomato trusses and hot pepper fruit. A more rapid influx of assimilates to fruit in consecutive trusses or fruit pruned plants could be a possible reason for the increased incidence of fruit disorders (Dorais & Papadopoulos, 2001; Aloni *et al.*, 1999).

- As there was an indication that dry matter production was inhibited in hot peppers under intensive pruning treatments, measurement of photosynthetic rate and evaluation of leaf growth and senescence by destructive harvesting at various growth stages would have been interesting.
- The two methods of pruning in this experiment (alternate and consecutive trusses/fruit pruned) were done at high intensity of pruning, where yield was apparently sink-limited. Before practical recommendations can be made additional research with less intensive pruning levels need to be investigated.

- Pruning was done at anthesis and at fruit-set. The time lag between the two was too short to result in an effect on yield. The option of removing flower buds at an earlier stage should be investigated.

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SUMMARY

The study on source-sink relationship was done in a greenhouse at the experimental farm of the University of Pretoria using tomato (cultivar 'Graziela') and hot pepper (cultivar. 'Challenger') plants trained to one stem and six trusses (fruit incase of hot pepper). The main objective was to determine the optimal intensity, time and method of pruning for best yield and fruit quality of tomatoes and hot pepper. The major findings of the study can be summarized as follows:

1. Pruning of one truss in tomato and one fruit in hot pepper gave the best fruit quality in terms of fruit size, pericarp thickness and freedom from fruit disorders, without loss of total and marketable yield
2. The response of tomato and hot pepper to pruning intensity was similar in that, fruit size and occurrence of fruit disorders increased with increasing intensity of pruning, but differed in that, total yield was not affected in tomato due to the increase of fruit number per truss with pruning intensity, but significant yield reduction occurred in hot pepper where two and three fruit were pruned.
3. Within individual plants, the incidence of fruit cracking increased from lower to higher trusses, and it was correlated with decreasing pericarp thickness of fruit from lower to higher trusses. Conversely, the incidence of BER decreased from the lower to higher trusses.
4. Total dry matter per plant, which is an indicator of dry matter production, was significantly reduced in hot pepper plants with two and three fruit pruned, but was not affected in tomatoes.
5. Where a single truss of tomato and a single fruit of hot pepper was removed from the various positions of the plant (top, bottom and middle), the highest yield compensation was found by pruning a middle truss of tomato and the topmost fruit of hot pepper.
6. Within individual plants, the yield restitution to the remaining trusses of tomato tended to decrease with increasing distance of the trusses from the pruned truss, whereas no consistent trend was found in hot peppers.

7. Pruning of every other truss appeared to be helpful in minimizing the incidence of fruit disorders (cracking and blossom-end rot in tomato, and fruit cracking and deformation in hot pepper) as compared to pruning of consecutive trusses, even though it had little effect on yield and yield components.

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APPENDIX

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Table 6.2.3b ANOVA of fresh mass per fruit as affected by pruning of an individual fruit at various positions of the hot pepper plant.

Table 6.2.4a ANOVA of fruit fresh mass per plant as affected by pruning of an individual truss at various positions of tomato the plant.

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Table 6.2.5a ANOVA of fruit dry mass per truss as affected by pruning of an individual truss at various positions of the tomato plant.

Table 6.2.5b ANOVA of dry mass per fruit as affected by pruning of an individual fruit at various positions of the hot pepper plant.

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Table 6.3.9b ANOVA of fruit cracking incidence in tomato using two different fruit pruning methods.

Table 6.3.9c ANOVA of blossom-end rot incidence in tomato using two different fruit pruning methods.

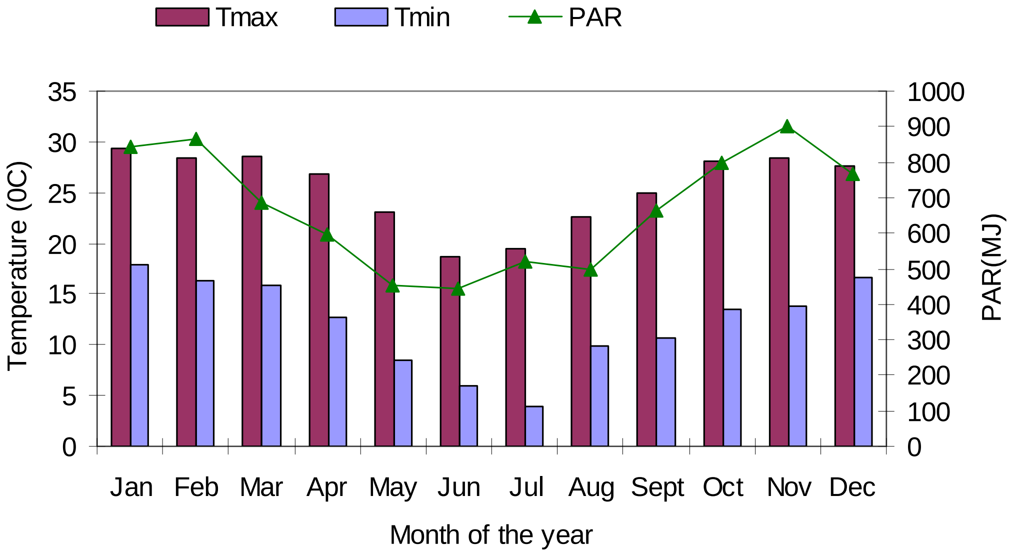

Figure 6.1 Monthly meteorological data for Hatfield Experimental Farm showing PAR, and minimum and maximum temperatures, 2002

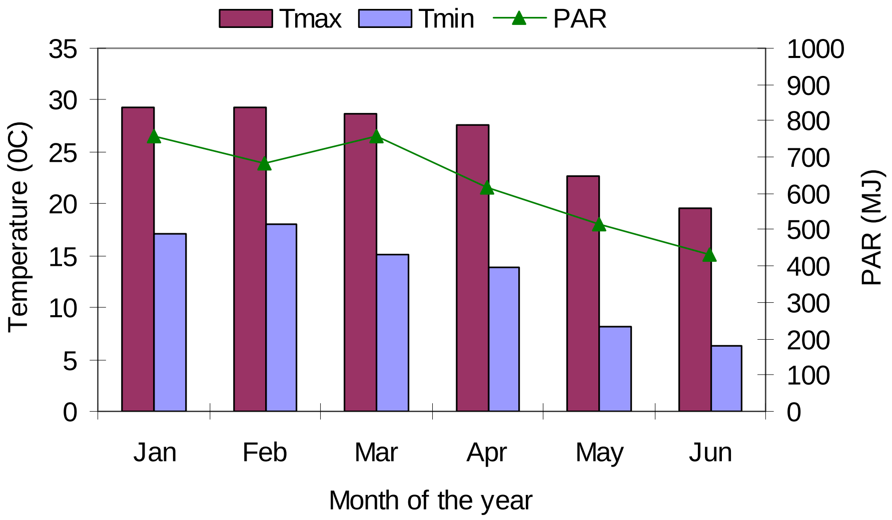

Figure 6.2 Monthly meteorological data for Hatfield Experimental Farm showing, PAR, and minimum and maximum temperatures, 2003

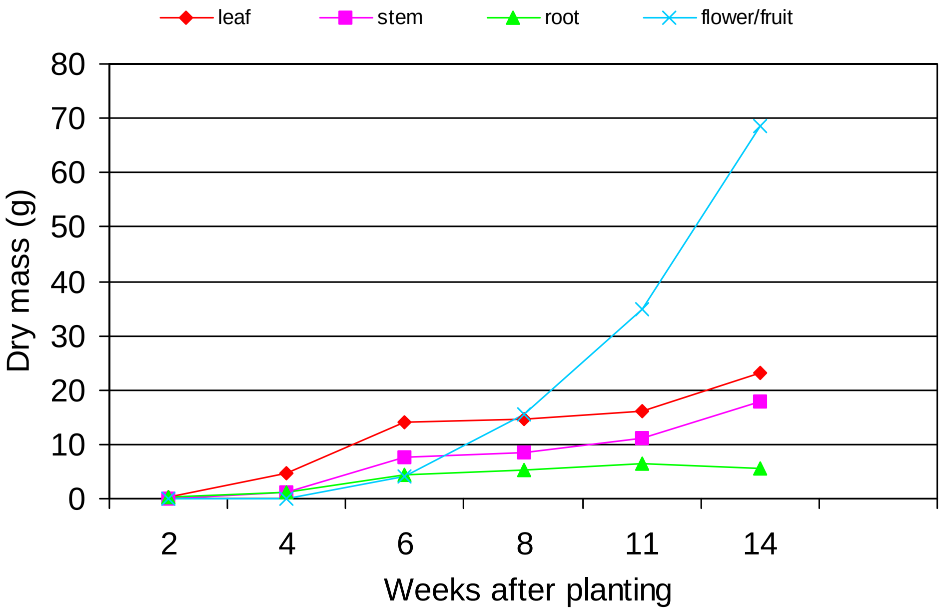

Figure 6.3 Growth patterns of tomato plant parts over time

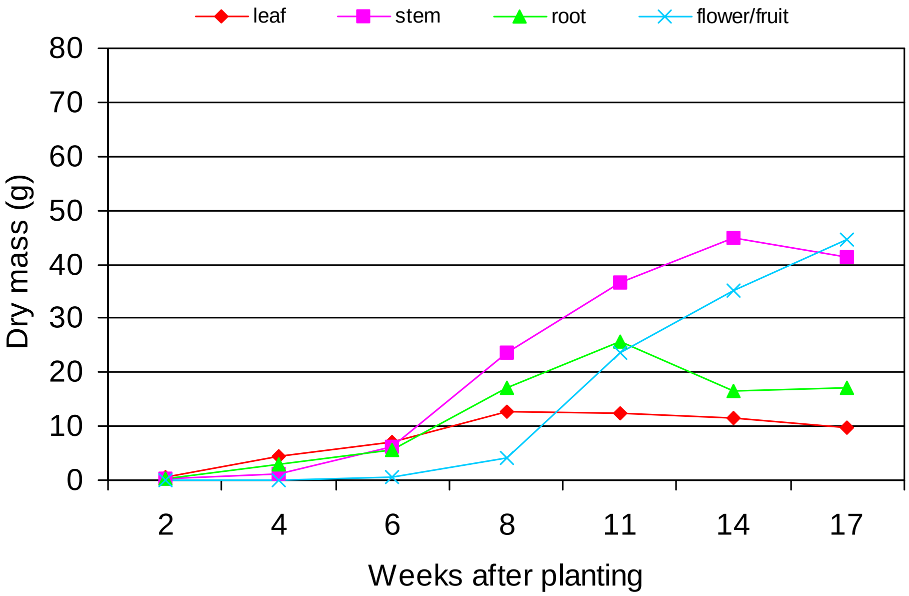

Figure 6.4 Growth patterns of hot pepper plant parts over time

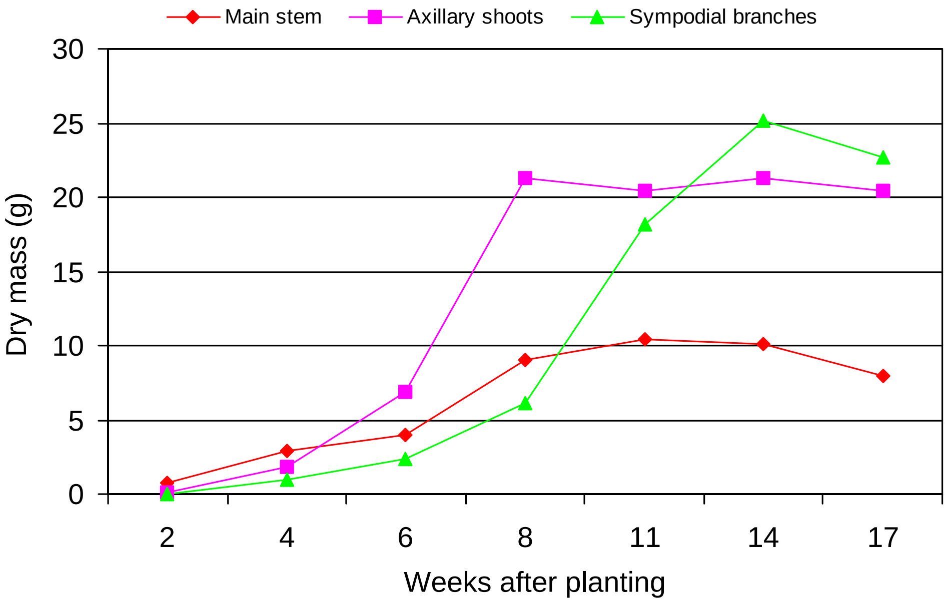

Figure 6.5 Growth patterns of the main stem, axillary shoots and sympodial branches of hot pepper over time

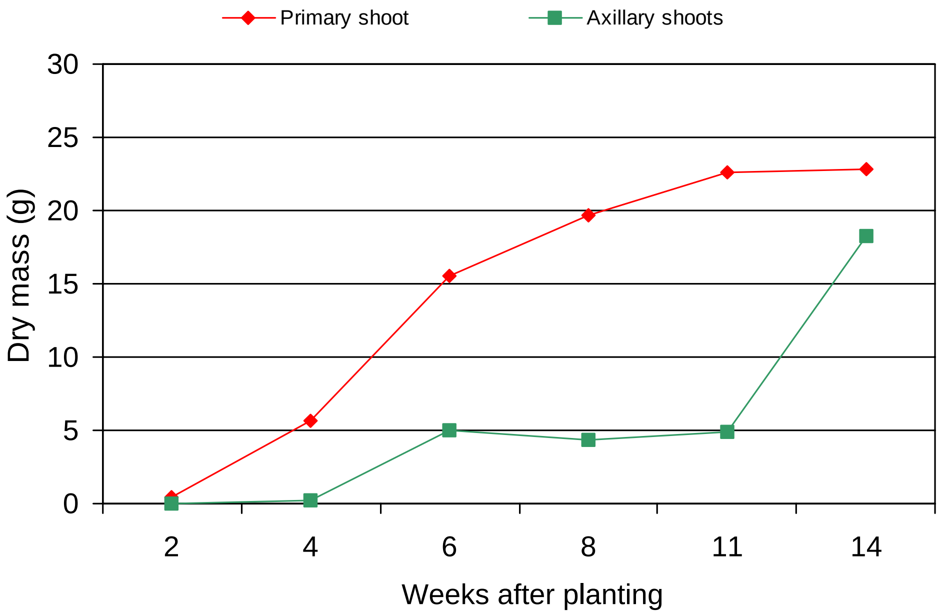

Figure 6.6 Growth patterns of the primary and axillary shoots of tomato over time

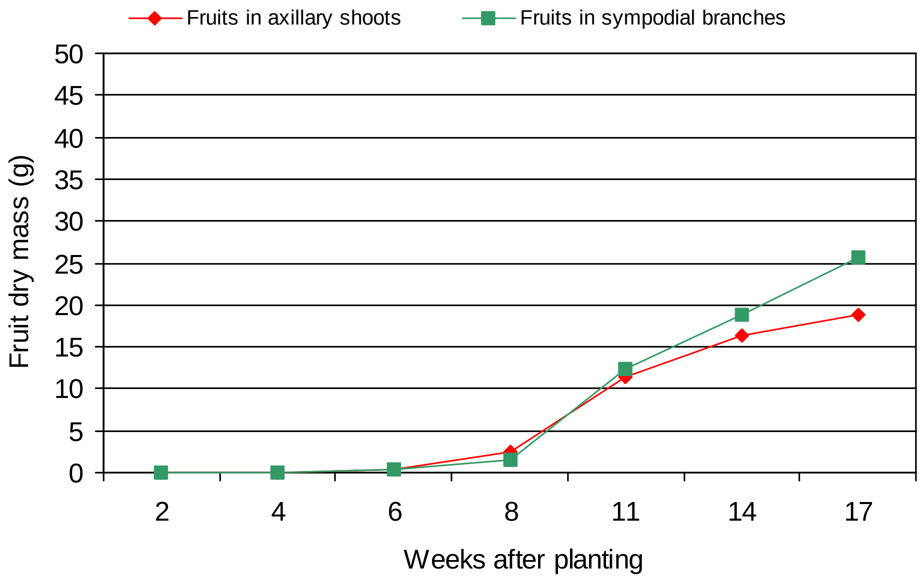

Figure 6.7 Growth patterns of fruit in the axillary and sympodial branches of hot peppers over time

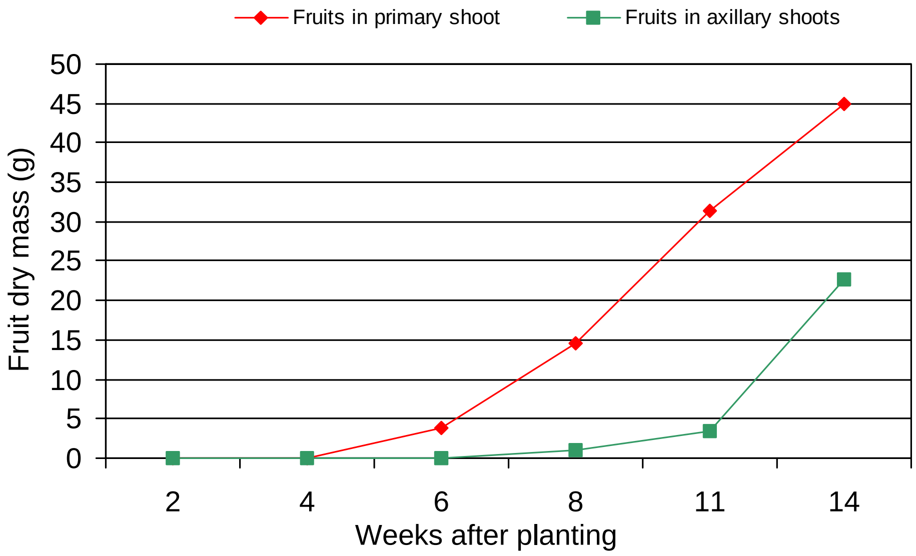

Figure 6.8 Growth patterns of tomato fruit in the primary shoot and axillary shoots over

Table 6.1.1 ANOVA of the effect of truss pruning intensity and time of pruning on number of class-1 tomato fruit per truss

Source	df	SS	MS	F-Value
Total	28	18.760		
Time (T)	1	0.217	0.217	0.43ns
Intensity (I)	3	7.570	2.524	4.95**
T X I	3	0.339	0.113	0.22ns
Error	21	10.700	0.509	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.2 ANOVA of the effect of truss pruning intensity and pruning time on the total number of class-1 tomato fruit per plant

Source	df	SS	MS	F-Value
Total	28	318.138		
Time (T)	1	0.003	0.003	0.00ns
Intensity (I)	3	137.948	45.983	5.95**
T X I	3	22.206	7.402	0.96ns
Error	21	162.417	7.734	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.3 ANOVA of the effect of fruit pruning intensity and pruning time on the volume of hot pepper fruit

Source	df	SS	MS	F-Value
Total	28	2.899		
Time (T)	1	0.0642	0.064	0.82ns
Intensity (I)	3	0.601	0.200	2.56*
T X I	3	0.617	0.205	2.63ns
Error	21	1.642	0.078	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.4 ANOVA of the effect of truss pruning intensity and pruning time on the percentage of class-1 tomato fruit per plant

Source	df	SS	MS	F-Value
Total	28	6194.134		
Time (T)	1	21.007	21.007	0.11ns
Intensity (I)	3	1671.165	557.055	2.81*
T X I	3	399.955	132.985	0.67ns
Error	21	4169.431	198.544	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.5a ANOVA of the effect of truss pruning intensity and pruning time on the seed content of tomato fruit

Source	df	SS	MS	F-Value
Total	28	8383.975		
Time (T)	1	1294.953	1294.953	5.01*
Intensity (I)	3	2079.855	693.285	2.68ns
T X I	3	702.433	234.144	0.91ns
Error	21	5165.015	258.251	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.5b ANOVA of the effect of fruit pruning intensity and pruning time on the seed content of hot pepper fruit

Source	df	SS	MS	F-Value
Total	28	2403.918		
Time (T)	1	187.690	187.690	3.88ns
Intensity (I)	3	465.999	155.333	3.21*
T X I	3	712.817	237.606	4.91**
Error	21	1016.843	48.421	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.6a ANOVA of the effect of truss pruning intensity and pruning time on the average pericarp thickness of tomato fruit

Source	df	SS	MS	F-Value
Total	28	0.103		
Time (T)	1	0.000	0.000	0.01ns
Intensity (I)	3	0.061	0.021	11.05**
T X I	3	0.003	0.001	0.47ns
Error	21	0.039	0.002	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.6b ANOVA of the effect of fruit pruning intensity and pruning time on the average pericarp thickness of hot pepper fruit

Source	df	SS	MS	F-Value
Total	28	0.0053		
Time (T)	1	0.0000	0.0000	0.05ns
Intensity (I)	3	0.0003	0.0001	0.42ns
T X I	3	0.0001	0.0000	0.14ns
Error	21	0.0053	0.0002	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.7 ANOVA of the effect of truss pruning intensity and time of pruning on number of tomato fruit per plant

Source	df	SS	MS	F-Value
Total	28	1364.207		
Time (T)	1	4.938	4.938	0.09ns
Intensity (I)	3	262.241	87.364	1.68ns
T X I	3	3.739	1.246	0.02ns
Error	21	1092.667	52.032	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.8 ANOVA of the effect of truss pruning intensity and time of pruning on number of fruit per truss of tomato

Source	df	SS	MS	F-Value
Total	28	112.887		
Time (T)	1	0.360	0.225	0.07ns
Intensity (I)	3	42.874	14.312	4.33*
T X I	3	0.366	0.122	0.04ns
Error	21	69.358	3.302	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.9 ANOVA of the effect of truss pruning intensity and time of pruning on individual fruit fresh mass of tomato

Source	df	SS	MS	F-Value
Total	28	4386.094		
Time (T)	1	27.531	27.531	0.20ns
Intensity (I)	3	1554.381	518.127	3.79*
T X I	3	37.484	12.495	0.09ns
Error	21	2731.139	136.557	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.10a ANOVA of the effect of truss pruning intensity and time of pruning on fruit fresh mass per truss of tomato

Source	df	SS	MS	F-Value
Total	28	487430.835		
Time (T)	1	2420.476	2420.476	0.21ns
Intensity (I)	3	245117.647	81705.882	7.23**
T X I	3	4462.448	1487.483	0.13ns
Error	21	237344.199	11302.105	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.10b ANOVA of the effect of fruit pruning intensity and time of pruning on individual fruit fresh mass of hot pepper

Source	df	SS	MS	F-Value
Total	28	3.092		
Time (T)	1	0.014	0.014	0.17ns
Intensity (I)	3	1.047	0.349	4.02*
T X I	3	0.223	0.074	0.86ns
Error	21	1.822	0.087	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.11a ANOVA of the effect of truss pruning intensity and time of pruning on fruit fresh mass per plant of tomato

Source	df	SS	MS	F-Value
Total	28	6956731.594		
Time (T)	1	56530.610	56530.610	0.25ns
Intensity (I)	3	1919044.275	639681.425	2.78ns
T X I	3	94446.482	31482.161	0.14ns
Error	21	4834801.798	230228.657	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.11b ANOVA of the effect of fruit pruning intensity and time of pruning on fruit fresh mass per plant of hot pepper

Source	df	SS	MS	F-Value
Total	28	177.604		
Time (T)	1	0.361	0.361	0.18ns
Intensity (I)	3	129.491	43.164	22.08**
T X I	3	4.936	1.645	0.84ns
Error	21	41.054	1.955	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.12a ANOVA of the effect of truss pruning intensity and time of pruning on fruit dry mass per truss in tomato

Source	df	SS	MS	F-Value
Total	28	3033.503		
Time (T)	1	8.980	8.980	0.15ns
Intensity (I)	3	1738.514	579.504	9.48**
T X I	3	10.754	3.584	0.06ns
Error	21	1284.383	61.161	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.12b ANOVA of the effect of fruit pruning intensity and time of pruning on individual fruit dry mass of hot pepper

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	0.1561		
Time (T)	1	0.0006	0.0006	0.07ns
Intensity (I)	3	0.1443	0.0481	6.00**
T X I	3	0.0093	0.0031	0.39ns
Error	21	0.1683	0.0080	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.13a ANOVA of the effect of truss pruning intensity and time of pruning on fruit dry mass per plant of tomato

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	23873.219		
Time (T)	1	187.572	187.572	0.18ns
Intensity (I)	3	1027.664	342.555	0.32ns
T X I	3	253.817	84.606	0.08ns
Error	21	22404.165	1066.865	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.13b ANOVA of the effect of fruit pruning intensity and time of pruning on fruit dry mass per plant of hot pepper

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	9.064		
Time (T)	1	0.027	0.027	0.16ns
Intensity (I)	3	5.253	1.751	10.35**
T X I	3	0.209	0.069	0.41ns
Error	21	3.552	0.169	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.14 ANOVA of the effect of truss pruning intensity and time of pruning on individual fruit dry mass of tomato

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	10.539		
Time (T)	1	0.059	0.059	0.27ns
Intensity (I)	3	5.852	1.950	8.75**
T X I	3	0.115	0.038	0.17ns
Error	21	4.458	0.229	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.15a ANOVA of the effect of truss pruning intensity and time of pruning on total solids content of tomato fruit

Source	df	SS	MS	F-Value
Total	28	9.289		
Time (T)	1	0.589	0.589	2.85ns
Intensity (I)	3	5.944	1.981	9.59*
T X I	3	2.157	0.719	3.48ns
Error	21	1.033	0.207	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.15b ANOVA of the effect of fruit pruning intensity and time of pruning on total solids content of hot pepper fruit

Source	df	SS	MS	F-Value
Total	28	151.509		
Time (T)	1	0.043	0.043	0.01ns
Intensity (I)	3	24.571	8.190	1.42ns
T X I	3	4.468	1.489	0.26ns
Error	21	120.793	5.752	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16a ANOVA of the effect of truss pruning intensity on dry matter of vegetative plant part of tomato

Source	df	SS	MS	F-Value
Total	10	5844.803		
Intensity (I)	3	4455.407	1485.136	7.48*
Error	7	1389.395	198.485	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16b ANOVA of the effect of truss pruning intensity on total plant dry matter of tomato

Source	df	SS	MS	F-Value
Total	10	6921.742		
Intensity (I)	3	3087.340	1029.113	1.88ns
Error	7	3834.402	547.772	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16c ANOVA of the effect of truss pruning intensity and time of pruning on dry matter of vegetative plant part of hot pepper

Source	df	SS	MS	F-Value
Total	28	432.240		
Time (T)	1	46.996	46.996	4.75*
Intensity (I)	3	37.910	12.637	1.28ns
T X I	3	109.815	36.605	3.70*
Error	21	237.518	9.895	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16d ANOVA of the effect of fruit pruning intensity and time of pruning on stem dry matter of hot pepper

Source	df	SS	MS	F-Value
Total	28	241.097		
Time (T)	1	29.204	29.204	6.05*
Intensity (I)	3	23.932	7.977	1.65ns
T X I	3	72.143	24.048	4.98**
Error	21	115.818	4.826	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16e ANOVA of the effect of fruit pruning intensity and time of pruning on leaf dry matter of hot pepper

Source	df	SS	MS	F-Value
Total	28	92.467		
Time (T)	1	2.117	2.117	0.74ns
Intensity (I)	3	9.734	3.245	1.13ns
T X I	3	11.512	3.837	1.33ns
Error	21	69.104	2.879	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.16f ANOVA of the effect of fruit pruning intensity and time of pruning on total plant dry matter of hot pepper

Source	df	SS	MS	F-Value
Total	28	586.806		
Time (T)	1	38.730	38.730	4.23ns
Intensity (I)	3	198.630	66.210	5.26**
T X I	3	81.560	27.187	2.21ns
Error	21	258.779	12.323	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.17a ANOVA of the effect of fruit pruning intensity and time of pruning on the % of cracked tomato fruit

Source	df	SS	MS	F-Value
Total	28	153.250		
Time (T)	1	6.348	6.348	1.30ns
Intensity (I)	3	39.999	13.333	2.74*
T X I	3	8.609	2.870	0.59ns
Error	21	97.417	4.871	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.17b ANOVA of the effect of fruit pruning intensity and time of pruning on the % of fruit affected by blossom-end rot in tomato

Source	df	SS	MS	F-Value
Total	28	42.300		
Time (T)	1	0.628	0.628	0.70ns
Intensity (I)	3	17.479	5.826	6.52**
T X I	3	3.896	1.299	1.45ns
Error	21	19.669	19.667	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.17c ANOVA of the effect of fruit pruning intensity and time of pruning on the % of cracked hot pepper fruit

Source	df	SS	MS	F-Value
Total	28	8085.31		
Time (T)	1	738.028	738.028	4.44*
Intensity (I)	3	3529.40	1176.468	7.09**
T X I	3	789.466	263.155	1.58ns
Error	21	3486.75	166.036	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.18a ANOVA of the effect of fruit pruning intensity and time of pruning on the % early yield of hot pepper

Source	df	SS	MS	F-Value
Total	28	16291.310		
Time (T)	1	13.444	13.444	0.02ns
Intensity (I)	3	349.990	116.663	0.16ns
T X I	3	926.657	308.886	0.43ns
Error	21	14969.500	712.833	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.18b ANOVA of the effect of fruit pruning intensity and time of pruning on the % early yield of tomato

Source	df	SS	MS	F-Value
Total	28	4778.159		
Time (T)	1	1.141	1.141	0.01ns
Intensity (I)	3	2051.433	683.811	6.96**
T X I	3	894.579	298.193	3.03ns
Error	21	1965.306	98.265	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.19a ANOVA of the effect of truss pruning intensity and time of pruning on marketable yield per plant of tomato

Source	df	SS	MS	F-Value
Total	28	7713895.13		
Time (T)	1	34280.934	34280.934	0.16ns
Intensity (I)	3	2845075.69	948358.566	4.48*
T X I	3	282323.208	94107.736	0.44ns
Error	21	4444094.29	211623.538	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.1.19b ANOVA of the effect of truss pruning intensity and time of pruning on marketable yield per plant of hot pepper

Source	df	SS	MS	F-Value
Total	28	278.779		
Time (T)	1	0.071	0.071	0.01ns
Intensity (I)	3	164.228	54.743	10.43**
T X I	3	7.212	2.404	0.46ns
Error	21	110.259	110.259	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.1 ANOVA of fruit number per truss as affected by pruning of an individual truss at various positions of the tomato plant

Source	df	SS	MS	F-Value
Total	28	36.491		
Time (T)	1	1.984	1.984	1.56ns
Truss position (P)	3	13.069	4.356	3.43*
P X I	3	1.942	0.647	0.51ns
Error	21	21.560	1.268	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.2 ANOVA of fruit number per plant as affected by pruning of an individual truss at various positions of the tomato plant

Source	df	SS	MS	F-Value
Total	28	867.440		
Time (T)	1	49.594	49.594	1.33ns
Truss position (P)	3	180.376	60.125	1.62ns
P X I	3	48.543	16.181	0.44ns
Error	21	632.000	37.176	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.3a ANOVA of fruit fresh mass per truss as affected by pruning of an individual truss at various positions of the tomato plant

Source	df	SS	MS	F-Value
Total	28	130474.53		
Time (T)	1	9698.853	9698.853	1.39ns
Truss position (P)	3	113277.81	37759.271	5.40**
P X I	3	16837.175	5612.392	0.80ns
Error	21	118809.21	6988.777	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.3b ANOVA of fresh mass per fruit as affected by pruning of an individual fruit at various positions of the hot pepper plant

Source	df	SS	MS	F-Value
Total	28	6.864		
Time (T)	1	0.191	0.191	0.89ns
Truss position (P)	3	1.292	0.431	2.01ns
P X I	3	1.195	0.398	1.86ns
Error	21	4.284	0.214	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.4a ANOVA of fruit fresh mass per plant as affected by pruning of an individual truss at various positions of the tomato plant

Source	df	SS	MS	F-Value
Total	28	5592339.81		
Time (T)	1	242493.443	242493.443	1.10ns
Truss position (P)	3	1373255.03	457751.678	2.07ns
P X I	3	420939.233	140313.078	0.63ns
Error	21	3759411.02	221141.825	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.4b ANOVA of fruit fresh mass per plant as affected by pruning of an individual fruit at various positions of the hot pepper plant

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	154.039		
Time (T)	1	4.559	4.559	0.81ns
Truss position (P)	3	9.756	3.252	0.58ns
P X I	3	29.419	9.806	1.74ns
Error	21	112.681	5.634	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.5a ANOVA of fruit dry mass per truss as affected by pruning of an individual truss at various positions of the tomato plant

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	940.978		
Time (T)	1	22.533	22.533	0.85ns
Truss position (P)	3	451.119	150.373	5.64**
P X I	3	48.695	16.232	0.61ns
Error	21	452.986	26.646	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.5b ANOVA of dry mass per fruit as affected by pruning of an individual fruit at various positions of the hot pepper plant

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	0.411		
Time (T)	1	0.003	0.003	0.28ns
Truss position (P)	3	0.117	0.039	3.17*
P X I	3	0.047	0.016	1.29ns
Error	21	0.246	0.012	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.6a ANOVA of fruit dry mass per plant as affected by pruning of an individual truss at various positions of the tomato plant

Source	**df**	**SS**	**MS**	**F-Value**
Total	28	19712.688		
Time (T)	1	563.619	563.619	0.70ns
Truss position (P)	3	4957.084	1652.361	2.05ns
P X I	3	1216.422	405.474	0.50ns
Error	21	13724.137	807.302	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.2.6b ANOVA of fruit dry mass per plant as affected by pruning of an individual fruit at various positions of the hot pepper plant

Source	df	SS	MS	F-Value
Total	28	9.007		
Time (T)	1	0.084	0.084	0.25ns
Truss position (P)	3	1.035	0.345	1.01ns
P X I	3	1.136	0.379	1.11ns
Error	21	6.810	0.340	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.1 ANOVA of total fruit number per plant of tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	642.933		
Time (T)	1	118.564	118.564	2.73ns
Pruning method (m)	1	0.026	0.026	0.00ns
M X I	1	56.641	56.641	1.31ns
Error	11	477.167	43.379	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.2a ANOVA of fruit fresh mass per plant of tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	2333669.348		
Time (T)	1	140052.215	140052.216	0.76ns
Pruning method (m)	1	13359.222	13359.222	0.07ns
M X I	1	188047.686	188047.686	1.02ns
Error	11	2025345.148	184122.286	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.2b ANOVA of fruit fresh mass per plant of hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	23.845		
Time (T)	1	7.923	7.923	5.26ns
Pruning method (m)	1	0.972	0.972	0.65ns
M X I	1	0.445	0.445	0.30ns
Error	11	12.049	1.506	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.3a ANOVA of fruit dry mass per plant of tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	8687.540		
Time (T)	1	1001.173	1001.173	1.52ns
Pruning method (m)	1	0.001	0.001	0.00ns
M X I	1	507.963	507.963	0.77ns
Error	11	7264.405	660.400	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.3b ANOVA of fruit dry mass per plant of hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	1.978		
Time (T)	1	0.232	0.232	1.38ns
Pruning method (m)	1	0.157	0.157	0.93ns
M X I	1	0.091	0.091	0.54ns
Error	11	1.349	0.169	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.4a ANOVA of number of class-1 fruit per plant of tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	133.333		
Time (T)	1	10.776	10.776	1.30ns
Pruning method (m)	1	3.391	3.391	0.41ns
M X I	1	32.314	32.314	3.81ns
Error	11	91.417	8.311	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.4b ANOVA of average fruit volume of hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	1.369		
Time (T)	1	0.254	0.254	2.90ns
Pruning method (m)	1	0.382	0.382	4.37ns
M X I	1	0.000	0.000	0.00ns
Error	11	0.701	0.088	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.5a ANOVA of average pericarp thickness of fruit in tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	0.390		
Time (T)	1	0.028	0.029	0.91ns
Pruning method (m)	1	0.010	0.011	0.34ns
M X I	1	0.001	0.001	0.03ns
Error	11	0.346	0.031	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.5b ANOVA of average pericarp thickness of fruit in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	0.0036		
Time (T)	1	0.00001	0.00001	0.04ns
Pruning method (m)	1	0.00000	0.00000	0.00ns
M X I	1	0.00015	0.00015	0.35ns
Error	11	0.00345	0.00043	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.6a ANOVA of early fruit yield per plant in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	95.444		
Time (T)	1	28.733	28.733	3.56ns
Pruning method (m)	1	2.503	2.053	0.25ns
M X I	1	4.594	4.594	0.57ns
Error	11	64.515	8.064	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.6b ANOVA of early fruit yield per plant in tomato using two different truss pruning methods

Source	df	SS	MS	F-Value
Total	14	1279125.387		
Time (T)	1	156915.210	156915.210	2.42ns
Pruning method (m)	1	465008.216	465008.216	7.18*
M X I	1	1707.352	1707.352	0.03ns
Error	11	647415.989	64741.599	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.7 ANOVA of specific leaf area per plant in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	52240.401		
Time (T)	1	5582.215	5582.215	1.03ns
Pruning method (m)	1	5637.373	5637.373	1.04ns
M X I	1	5318.603	5318.603	0.98ns
Error	11	37910.293	5415.756	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.8a ANOVA of leaf dry mass per plant in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	29.513		
Time (T)	1	6.689	5.838	2.05ns
Pruning method (m)	1	0.051	0.051	0.02ns
M X I	1	0.855	0.855	0.30ns
Error	11	22.769	2.846	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.8b ANOVA of stem dry mass per plant in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	95.909		
Time (T)	1	24.200	24.200	2.35ns
Pruning method (m)	1	16.138	16.137	0.02ns
M X I	1	0.191	0.190	0.30ns
Error	11	53.943	4.90	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.8c ANOVA of total plant dry mass in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	270.802		
Time (T)	1	9.784	9.784	0.59ns
Pruning method (m)	1	143.070	143.070	8.61*
M X I	1	4.896	4.896	0.29ns
Error	11	116.361	10.57	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.9a ANOVA of fruit cracking and deformation incidence in hot pepper using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	17.428		
Time (T)	1	4.024	4.024	3.45ns
Pruning method (m)	1	0.595	0.595	0.51ns
M X I	1	0.595	0.595	0.51ns
Error	11	11.667	1.1667	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.9b ANOVA of fruit cracking incidence in tomato using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	119.714		
Time (T)	1	8.149	8.149	0.96ns
Pruning method (m)	1	19.339	19.339	2.27ns
M X I	1	5.006	5.006	0.59ns
Error	11	85.083	8.508	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant

Table 6.3.9c ANOVA of blossom-end rot incidence in tomato using two different fruit pruning methods

Source	df	SS	MS	F-Value
Total	14	4711.667		
Time (T)	1	416.667	416.667	0.32ns
Pruning method (m)	1	416.667	416.667	0.32ns
M X I	1	416.667	416.667	0.32ns
Error	11	3045.000	276.818	

*, **, = significantly different at P≤0.05, P≤0.01 respectively
Ns = not significant