# PLANT DENSITY AND CROP ESTABLISHMENT STUDIES WITH TOMATOES FOR MECHANICAL HARVEST

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JACQUELINE CLAIRE SHELAGH GREEN

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# E R R A T A

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## ABSTRACT

Using three cultivars, chitting tomato seed and priming tomato seed with P. E. G. was found to have no effect on the early relative growth rate of the seedlings, when compared with untreated seed. However, because chitted seeds emerged earlier than primed seeds, which in turn emerged earlier than untreated seed, at any one time, the plants from chitted seed were larger than those from primed seed, and both were found to be larger than those from untreated seed.

The seed treatments along with a high quality transplant treatment were compared in a field study to determine plant weight and fruit yield at four plant densities (62,500, 160,000, 200,000 and 591,716 plants per hectare).

Castlong was found to give heavier total fruit yields than either VF 145-B7879 or Fireball. This is attributed to the higher proportion of fruit total plant weight that this variety develops. Castlong also produced a higher proportion of ripe total fruit at all harvests, this is considered to be due to this cultivar's early maturity combined with its excellent field storage characteristics.

Transplanted plants in all cases yielded heavier and matured earlier than any of the three seed treatments. The yields and maturity characteristics were not significantly different from any of the three seed treatments.

Increasing the plant density from 62,500 plants per hectare to 591,716 plants per hectare increased fruit number and yield per unit area and also tended to increase the proportion of the fruit that was ripe. The number of fruit per plant decreased as plant density increased.

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# INTRODUCTION

An essential prerequisite for the successful mechanical harvesting of tomatoes is that, at the time of harvest, a high proportion of the fruit is ripe. There are a number of ways in which the uniformity of maturity within a tomato crop can be modified -

(1) by the choice of cultivar,

(2) by the method of establishment,

(3) by the use of chemical ripening agents,

(4) by management practices such as irrigation, plant population, weed control and protection against pests and diseases.

The objective of this study was to examine the effect of seed treatment, cultivar, method of establishment and plant population on the yield of tomatoes grown for mechanical harvesting.

# LITERATURE REVIEW

## CHAPTER 1

### 1.1. Methods of Production

In New Zealand outdoor tomatoes were originally established by transplants, mainly boxed, and harvested by hand (Anon, 1975). Scoresby Dwarf was by far the most popular variety. Mechanical harvesting of the crop has now become established in two major areas, Poverty Bay and Hawke's Bay and production principles have altered radically. With three machine harvesters now operating in the Hastings region and one in Gisborne the area of outdoor tomatoes harvested mechanically has now exceeded that hand picked (Table 1).

| | Area grown (ha) | Average yield (t/ha) |
|---|---|---|
| Machine harvested | 96 | 70 |
| Hand picked | 76 | 60 |

Table 1 Production of outdoor tomatoes in New Zealand for the 1978/79 Season

(Ian Ivey, M.A.F. Advisory Officer, 1979 Pers. Comm.)

#### 1.1.1. Cultivars

The introduction from California of cultivars suitable for mechanical harvesting has been a major contributor to the increased production of tomatoes in New Zealand (Anon, 1977). There are several requirements a cultivar must have to be acceptable for machine harvesting (Sims, 1975a). The cultivar must be high yielding with a compact maturity and have good field storage. Resistance to Verticillium and Fusarium wilt is desirable. The major product of processed tomatoes in New Zealand is tomato paste, though whole canned tomatoes and tomato juice are produced on a small scale. In addition to the basic criteria, it is necessary for the

selected cultivar to have the following processing requirements for paste (Quinn and Crowther, 1976):

(a) a solids content of at least 57 as tomatoes of higher solids give a higher case yield per tonne of tomatoes. Maturity has little effect on solids content after the pink ripe stage is reached (Liu and Luh, 1977). There are several factors which can cause changes in solids content of tomatoes however, such as varietal characteristics, plant population and management practices.

(b) a high sugar content, total sugar content of paste must be over 50% on a solids basis.

(c) a low preparation loss in the form of skin, fibre and seed.

(d) the resultant paste should have a flavour as near to that of the fresh fruit as possible.

(e) the strong red colour of the fruit should be retained during processing.

(f) the paste should have a good texture and consistency (high pectin content).

Although maturity has little effect on solids content other quality factors are maturity dependant. Once the tomato fruit reaches the mature-green stage, ethylene generated by the fruit induces a sudden burst of respiration and initiates a series of developmental events that constitute maturation (Rick, 1978). As maturity is approached chlorophyll is gradually degraded and carotenoids, notably the red lycopene, are synthesised. Acidity increases briefly, then decreases although there is a steady increase in the

content of ascorbic acid (vitamin C). Starch is converted into sugars thus raising the soluble solids content. An increase in the pectin-dissolving enzyme polygalacturonase softens the fruit at the same time as essential oils and other flavour components are manufactured. If the fruit is removed from the vine before fully mature, ethylene production continues, as does pigment production but vitamin C and sugar content fall as respiration metabolises them.

Some of the recommended cultivars are listed in Table 2. The cultivars can be subdivided into time of maturity or form of fruit; soft round e.g. Fireball and VF 145 - B7879, square round e.g. UC 134 and elongated e.g. Castlong. The square round and elongated types generally have improved colour, consistency and firm, thick walls with crack resistance. These are more favourable for bulk handling and production of new cultivars is being concentrated in this area (Anon, 1977), even though the property of thick walls lowers the soluble solids content of the fruit and increases the preparation loss.

Wraight and Burgmans (1976, pers. comm.) conducted an experiment at Hastings to investigate the spread of season for process tomatoes and decided this was largely cultivar dependant. The vine storage of the two elongated cultivars, Castlong and VF 65-2A was better than that of the square round UC 134, and much better than the soft round VF 145-B7879. These workers have added however, that those cultivars with good field storage capability in New Zealand are generally low yielders. In other variety trials conducted in New Zealand Castlong has normally yielded higher over the whole season than VF 145-B7879 and frequently yields a higher

Table 2. The Major Recommended Varieties of Process Tomatoes Grown in New Zealand.

(from Crowder 1974, Sims 1975b, and Anon 1977)

| Cultivar | Early Medium Or Late Season | Fruit Shape | No. Fruit Per Kilo | Remarks Fusarium Resistant) |
|---|---|---|---|---|
| Castlong(x R220) | Early | Elongated | 14 | VF, 2-3 locules. Good vine storage and yield. Very firm. |
| 497 VFN | Early | Elongated | 17 | 2-3 locules Firm fruit |
| Hienz 1706 | Mid/Early | Elongated | 26 | VF, 2-3 locules Small fruit |
| VF 145-B7879 | Mid | Soft round | 9 | VF, 4-5 locules Good yield but poor vine storage |
| Petomech | Mid | Square-round | 12 | VF, 2-3 locules Very firm fruit. Crack resistant |
| VF 134-1-2 | Mid | Square-round | 14 | VF, 2-3 locules Very firm fruit |
| Cal. J. | Mid | Square-round | 14 | VF, 2 locules Very firm fruit |
| Dorchester | Mid | Elongated | 14 | VF, 3 locules Firm Fruit |
| UC 134 | Mid | Square-round | 13 | VF, 2-3 locules Very firm, crack resistant fruit. |
| VF 65-2A | Late | Elongated | 12 | VF, very firm fruit 2-3 locules. Good vine storage. |

percentage of process grade fruit (Bussell and Burgmans 1978 pers. comm., Wraight and Burgmans 1978, Burgmans 1979 pers. comm.).

1.1.2. Methods of Establishment

One of the major decisions the growers is faced with is whether to direct seed the crop or to use some form of transplant. Transplanted crops have been found to mature 2 to 3 weeks earlier than direct seeded crops depending on sowing date (Stevenson and Thomas 1979, pers. comm., Burgmans 1979, pers. comm.). Outside grown transplants are hardier than nursery grown transplants and under adverse conditions give higher factory grade yields (Stevenson and Thomas, 1979 pers. comm.), however this trend can be reversed under more favourable conditions. Long and Cantliffe (1976) compared direct seeding or seeding in a peat and vermiculite plugmix with several types of transplants, containerised in Jiffy-7 peat pots or speedling trays using peat and vermiculite, and bare root 7 week old transplants grown in organic soil, quartz sand or a peat and vermiculite mix. Seedling growth at the time of transplanting was greatest for peat pots; there was no difference between the growth of the bare root and transplants grown in Speedling trays. The transplants were spaced 60 cm. apart in the row, one row per bed with 1.5m. between beds. The direct seeded crop was thinned to the same density. The number of fruit set 67 days from field seeding or 44 days from setting transplants was greatest with direct seeding and containerised transplants, which also produced the highest early marketable yields and the largest fruits. Total yield and average fruit size for the entire harvest period differed

little between treatments however. These workers conclude that early yield is greatest from treatments resulting in the least amount of disturbance to the root system. It has been reported previously that severe disturbance of root systems by transplanting can reduce plant growth considerably (Thompson and Kelly, 1957).

Higher total yields from direct sown than transplanted plants have been recorded (Nezhenev, 1977) although other workers have obtained no differences (Burgmans 1979, pers. comm. Stevenson and Thomas 1979, pers. comm.). These comparisons have been made on crops grown at densities the same for the transplanted crop as the direct sown crop. Nezhenev (1977) attributed the higher total yield to the plant's high response to mineral fertilizers and greater resistance to tomato mosaic virus when direct seeded. It may be that direct seeded plants develop a tap root, thus a deeper rooting system, which is preferable to surface roots which are obtained from transplants (Gieson 1975, pers. comm.).

Sullivan and Wilcox (1971) conducted an analysis of costs of tomatoes for processing. Total production costs for direct seeding averaged $42.84 per hectare of 11% less than for traditional transplanting operations excluding potential returns from increased useable yields under direct seeding of 7.5 to 12.5 tonnes per hectare. Sullivan and Wilcox (1971) list the advantages of direct seeding other than reduced costs as increased probability of more vigorous and disease-free seedlings, elimination of scheduling problems during critical planting seasons, greater production flexibility, earlier completion of planting operations, increased yield potentials and plant populations suitable for mechanical harvest (see section 1.3.).

Direct seeding of defuzzed seed by drills such as the Stanhay is becoming more common and is undoubtedly the most economical method of establishing the high plant populations necessary for this crop. It does, however, require greater skills in land preparation, irrigation and weed control and has higher risks from adverse weather, disease and pests (Ure and Loughton, 1978).

Transplants are popular where the growing season is short. Better conditions prevail at planting and an extra 4 to 5 weeks are available for land cultivation. Bare root transplants, about 25 per cent of the cost of containerised transplants, can be raised at low cost in simple frames or beds with some provision for temporary protection, and machine transplanted (Gieson 1975, pers. comm.).

Another method of establishing tomato crops for machine harvesting which is becoming common practice in Florida is 'plug mix' planting. This involves the incorporation of seed into a blended growing medium which is precision-placed in 'plugs' in the field at rates of 25 to 50cc of loose medium per site (Hayslip, 1974a). A typical mix may be composed of shredded peat moss, vermiculite, perlite, dolomitic and calcitic lime, soluble starter fertilizer, a fungicide and water. The seed is thus surrounded by a friable medium which acts as an efficient anti-crustant (Ure and Loughton, 1978). These authors report that the substitution of pregerminated seed for dry seeds reduces days to emergence and increases percentage emergence and uniformity. Pregermination also precludes the requirement for warm soil temperatures, since growth will continue at lower temperatures than are required for germination (Price, 1978). Pregerminated seed may be stored at 9°C

for 5 days or for periods up to 14 days at temperatures near freezing with no deleterious effects (Ure and Loughton, 1978).

As there are several seeds to a plug this method of establishment results in clumps of plants. Tomatoes are not adversly affected by clump planting up to 5 plants per clump (Sims 1975a, Anon 1977).

Hayslip (1974b) lists the advantages to be gained from plug mix seeding - a uniform, optimum environment in seed and young seedling zones with an adequate, safe level of fertilizer readily available to seedlings; no compaction problem with the friable plug mix soil; fertilizer salt damage during dry periods, and leaching of nutrients during overhead irrigation and rainfall are reduced; fertilizers and seeds are conserved by placement only where needed thus reducing fertilization of competing weeds; with an automatic plug mix planter an economical and successful method of seeding through mulch covered beds is available.

Results of herbicide trials on plug mix planted tomatoes have been promising (Ure and Loughton, 1978). The rapid emergence, ahead of weed growth, facilitates cultural and chemical weed control. The plug can also provide protection to the seedlings from preplant incorporated herbicides and perfect stands of plug mix planted tomatoes have been obtained at treatment levels of metribuzin that reduced direct seeded stands by over 50% (Ure and Loughton, 1978) (see section 1.1.5.). Application of an activiated charcoal-vermiculite mixture over the plug mix seeds can give complete protection of the seedlings from metribuzin injury (Henne and Guest, 1974, Liptay and Marriage, 1978). Activated carbon has also protected some vegetable crops from injury by residual herbicides such as atrazine when incorporated in the soil (Wilson, Hines and Belotte, 1974).

Plug mix planting has increased and hastened seedling emergence, improved young plant growth, increased earliness, total yield and fruit size and resulted in better fruit quality when compared to direct seeded crops (Bryan and Hayslip 1973, Bryan et al 1973, Locascio and Myers 1974, Stour 1974).

Planting tomatoes on beds is a common practice in the more arid areas of the world such as California where furrow irrigation methods are used for maintaining soil moisture (Sims and Rubatsky, 1974). Advantages of raised beds in New Zealand have been observed for other reasons. Sims, Burgmans and Weiss (1975) obtained better bed drainage following rainfall and overhead irrigation and more uniform soil moisture obtained by raised beds. The machine harvester was more efficient with beds than on the flat, however for these advantages to occur the beds must be well made. Mediocre or poor beds can cause many problems and if there is any doubt over forming good beds it is recommended to plant on the flat (Anon, 1977)

1.1.3. Chemical Ripening

The effects of 2 chloroethyl phosphonic acid (also known under the trade names ethrel and ethephon) on tomato fruit ripening were first reported by Russo, Dostal and Leopold (1968). This growth regulator is absorbed by the plant tissue and breaks down to release ethylene. Foliar applications may be used to extend the harvest season by accelerating ripening as well as concentrating maturity thereby increasing the marketable fruit yield from a single harvest (Dostal and Wilcox, 1971). Ethephon often causes leaf yellowing however, and high rates can induce defoliation (Splittstoesser and Vandemark, 1971). This could actually be an advantage as gradual leaf drop can assist fruit hardening and facilitate

harvesting (Baquar, Edwards and Lee, 1975 pers. comm.).

### 1.1.4. Irrigation

Sims (1975a) states that cultivars grown for mechanical harvesting tend to be shallow rooting and so may suffer from a lack of moisture after a relatively short dry period. He suggests that there are three main stages in the growth of the crop when soil moisture levels must be adequate;

(1) at time of sowing,

(2) during blooming and fruit set, and

(3) over the period of fruit enlargement.

Sufficient moisture at sowing is especially important when sowing germinated seed in plug mix as the peat/perlite medium can loose moisture rapidly (Locassio and Myers, 1974). Irrigation over flowering and during the period of fruit bulking may be necessary to prevent abortion (Saito, Hatayama and Ito, 1963). Frequent irrigations aid in preventing blossom end rot, air cavities forming in the fruit and fruit cracking (Anon, 1977). The new elongated types of tomato such as Castlong are more sensitive to blossom end rot under moisture stress (Sims, 1975a).

### 1.1.5. Weed Control

Weed control is usually obtained by mechanical means supplemented with chemicals. Some initial weed control may be obtained by the 'stale seedbed technique', however drilling of the tomato seed results in more weed seedlings germinating. When direct seeding it is often necessary to thin to the desired spacing and some mechanical weed control can be obtained at the same time. The plants are thinned when small to minimize competition and damage from root pruning (Sims, 1975a).

At the present time chemicals that can be used in the tomato crop do not control nightshades and other solanaceous species and these can build up to become a major problem (Anon, 1977). Metribuzin has proved to be highly effective for broad leafed and grass weed control in transplanted tomatoes because of the tolerance of this crop to the herbicide, although foliar injury may occur (Phatak and Stevenson 1973, Fortino and Splittstoesser 1974). Pre-emergence applications are not satisfactory if the crop is to be direct seeded because of metribuzin phytotoxicity to emerging tomato seedlings (Fortino and Splittstoesser, 1974).

1.1.6. Pests and Diseases

There are a number of diseases troublesome to process tomato plants in New Zealand. These include fungal diseases such as sclerotinia, early and late blight, verticillium wilt etc., bacterial diseases such as tomato speck, tomato bacterial spot and tomato blast and the virus diseases, tomato spotted wilt and cucumber mosaic. There is a wide range of chemicals available for the control of some of these such as benomyl, dithane M.22 and copper formulations which must be applied regularly for effectiveness (Anon, 1977). Pests in the form of caterpillars, aphids and thrips can be controlled with chemical sprays such as carbaryl and metaisosytox (Anon, 1977).

## 1.2 Seed Treatments

### Introduction

The production of high quality seed should ideally render any kind of further seed treatment to enhance vigour unnecessary. Pre-sowing treatment can, however, distinctly enhance the performance of seeds already considered to be of superior quality.

### 1.2.1. Chemical treatment

#### 1.2.1.1. Nutrients

The application of nutrients to the seeds through soaking can contribute to the production of a healthy crop if they are to be sown in soils deficient in a specific nutrient. Improved growth and yield of tomatoes has been obtained by soaking seeds in solutions of minor elements (Kesheva and Kadiev, 1972). On Zn deficient soils the application of 0.035% zinc sulphate to the seeds of Lycopersicon lycopersicum (L) Karsten ex Farwell significantly increased fruit weight and, together with a subsequent foliar spray, improved the ascorbic acid content of the fruit (Mohapatra and Kibe, 1971).

#### 1.2.1.2. Pesticides and Antibiotics

Thiram, applied as a seed soak, has been found to delay the germination of tomato seed even though at the same concentration it stimulated that of capsicum (Joshua, 1973).

Arenarin, extracted from Helichrysum arenarium has counteracted attacks by the seedborne Corybebacterium michiganense when applied to tomato seeds (Kulikovskaya, 1974).

1.2.1.3. Growth Regulators

Synthetic compounds, known as growth retardants due to their inhibitory effect on gibberellin biosynthesis, when applied as a seed soak, have been found to have beneficial effects on the growth of the subsequent plants. Seed treatment with either diaminozide or chlormequat increases the amino acid, sugar, total soluble solids content and yield of tomato plants (Irulappan and Muthukrishnan, 1974).

Growth promoters have also produced similar effects which is an indication of the complexity of the processes involved. Kulkani (1978) recorded the effects of soaking tomato seeds in either IAA or $GA_3$ at 20 to 100 p.p.m. Increased fruit set leading to increased fruit yield resulted from an LAA at 100 ppm seed soak. Rumpel and Sududyga(1978) compared the effects of soaking tomato seeds in various chemicals before setting them to germinate on filter paper moistened with distilled water maintained at $8^{o}C$, $12^{o}C$ or $15^{o}C$. Polyethylene glycol (P.E.G.) 6,000 at 7.5 bars water potential plus fusicoccin $10^{5}M$ for 7 days at $20^{o}C$ was the most effective pretreatment in reducing time to 50% germination and synchronising germination at all germination temperatures (see also section 1.2.3.3.). Soaking seeds in fusicoccin with or without subsequent germination on filter paper moistened with the same solution resulted in a significant reduction in time to 50%. germination but to a much smaller extent. Permeation of seeds with fusicoccin via acetone had no effect. Pretreating with $GA_3$ at $10^{5}M$ alone or with $GA_3$ combined with kinetin and ethephon resulted in a small stimulating effect on germination at $8^{o}C$. Of the treatments investigated using growth regulators, only fusicoccin plus P.E.G. was considered to be of practical value in the establishment of drilled tomato crops under cool conditions.

1.2.1.4. Plant Extracts

The vast majority of plant extracts investigated have inhibited seed germination at high concentrations (Evanari, 1949), and of those that have been successful it is often not clear as to the nature of the active components. Under aerobic conditions and at a temperature that would have been favourable for germination, soaking tomato seeds in a medium containing a high concentration of capsicum fruit extract prevented germination (Joshua, 1973). When the seeds were rinsed in distilled water and set to germinate in an aqueous medium their subsequent germination was extremely rapid. This shows that although the extract had inhibited radicle emergence, the germination metabolism had nevertheless reached an advanced stage (Heydecker and Coolbear, 1977). The magnitude of this effect is both time and temperature dependent and can accelerate subsequent germination more than any osmotic pretreatment with P.E.G. (Coolbear, 1977) (see section 1.2.3.3.). Time to 50% germination was as little as 24 hours after soaking tomato seeds in the extract for 305 hours at 20$^{o}$C.

Abdul-Baki and Stoner (1978) obtained both a promoting and inhibiting effect on germination with tomato seed leachates from cultivars with different temperature responses. The leachate from seed of tomato cv. Pl 341984, an accession whose seeds germinate well at low temperatures, promoted the germination of the same and other cultivars. In contrast, leachate from Red Rock seed, a cultivar whose seeds germinated poorly at low temperatures, inhibited the germination of seeds of the same and other cultivars. The promotive and inhibitary effects of these leachates were highly specific and restricted to tomato

seeds. The activity was highest in fresh seeds and the responses were best exhibited at low germination temperatures.

1.2.1.5. Pelleting Seeds

Pelleting, or coating, of seeds was originally designed to round up seeds of uneven shape and size for use in direct seeding machinery (Longden, 1975). The germination rate of tomato has been accelerated using a 10% methyl cellulose slurry as a pellet to supply seeds with $GA_3$ (Gray, 1957).

1.2.2. Energy Treatments

Few results have been reported from treatment of tomato seed with various energy forms. The application of electric field treatments has proved beneficial in improving germination of tomato seed (Satulkina and Shumaeva, 1975) and increased growth of tomato plants has been obtained with low dose ionic radiation applied to the seed.

1.2.3. Pre-Sowing Imbibition Treatments

1.2.3.1. Wetting and Drying Treatments

Seeds placed in water and subsequently dried back to near their original moisture content appear to produce plants with increased drought resistance (Martʻjanova, Gabanova and Zurihin, 1961). This treatment which may be repeated a number of times, has been termed 'pre-sowing drought hardening' (May, Milthorpe and Milthorpe, 1962), or tempering (Henckel, 1968). Henckel (1968) obtained increased tomato fruit yields from tempered seeds of two tomato cultivars of 87% and 32%. On the basis of these and other findings he concludes that pretreatment initiates the formation of more high energy compounds, increased D.N.A. and especially R.N.A. in the growing points, less active

ribonuclease activity, and better preservation of ultrastructure with allied sequential changes. Bussell and Gray (1976) hardened tomato seeds of cultivar Moneymaker by soaking them in 70% of their weight in water followed by drying for varying time intervals and for different numbers of wetting and drying cycles. No improvement of germination or seedling emergence was obtained. In another experiment reported in the same paper hardening by soaking the seed in 70% by weight of water for 48 hours and repeating the cycle before germinating the seed at 12.5°C reduced spread of emergence, had no effect on speed of germination but actually reduced the percentage germination. Greater success was obtained by Rasco (1976) who carried out drought hardening on tomato by subjecting seedlings to water stress before transplanting, and/or by soaking the seeds in distilled water for 6 hours before radicle emergence and then air drying to their original moisture content. Seed hardening improved germination and all treatments increased the growth and root to shoot ratio, increased the fruit yield and reduced the transpiration rates. The leaves of hardened plants contained an increased amount of free proline confirming the drought resistance qualities conferred to the plants by the treatments. In addition, the seeds of seed-hardened plants were significantly lighter than those from non treated material and yet they had enhanced germination qualities.

### 1.2.3.2. Salt Pretreatments

Whether certain salts incorporated in pretreatment media may have specific effects other than remedying minor nutrient deficiencies is still problematical (Heydecker and Coolbear, 1977)

1.2.3.2.1. Chemical Effect

Mayer and Polyikoff-Mayber (1975) quote tomato as being calcium indifferent although Henkel (1964) found that soaking the seeds in calcium salts increased cytoplasmic viscosity, and a 24 hour soak in 0.025 M solution with 'slight' drying increases their ability to endure dehydration and over heating perhaps due to increased root growth. Puls and Lambeth (1974) improved the germination of aged tomato seeds by allowing them to germinate in a solution of $GA_3$ + kinetin + $KNO_3$ 1 showing that the $KNO_3$ caused an increase in cytochrome oxidase activity in the old seeds although $KNO_3$ alone did not increase the rate or percentage germination. A solution of 10 ppm kinetin and 0.01 M $KNO_3$ was most effective in stimulating the rate of germination and addition of $GA_3$ did not increase this although shown to increase soluble sugar levels, protein hydrolysis and ribonuclease activity.

1.2.3.2.2. Osmotic Effect

Salts have also been used as osmotic solutions in the pretreatment of seeds. Increased rate of emergence from tomato seeds soaked in 1-2% $K_3PO_4$ + 0.5-2% $KNO_3$ for 5 to 8 days before drying back (Ells 1963). A 1% solution of NaCl had the same effect as a solution of 1% $KNO_3$ + 1% $K_3PO_4$ showing the effect was due primarily to the osmotic concentration of the solutions rather than a nutrient effect. Similar treatments, of a duration in excess of the time to radicle emergence required by fully viable tomato seeds in water at the same temperature, 24°C, have also been successful (Oyer and Koehler 1966, Koehler 1967). Woodstock (1969) obtained an increased rate of germination and higher oxygen uptake by seeds treated with 2% $KNO_3$ + 2% $KH_2PO_4$ and subsequently dried back. Malnassy (1971) reports successful

pretreatment of tomato seeds using an aerated system. Wickham and Nichols (1976) found that soaking in 2% $KNO_3$ had no effect on final germination percentage of tomato seed but did hasten germination and reduce the spread at 20°C in vitro and under simulated field conditions. At 6-8°C results were similar but the seed pretreatments significantly increased final percentage emergence also. Bussell and Gray (1976) soaked tomato seeds in solutions containing 1%, 1.5% or 2% of both $KNO_3$ and $K_3PO_4$ for 5, 10 or 20 days at 10°C or 24°C before germinating them at 8°C, 10°C or 15°C. Germination rate was significantly increased by these treatments but only when germinated at 8°C or 10°C, low osmotic potentials and longer soaking periods having a greater effect. Rumpel and Sudyga (1978) were able to accelerate germination of tomato seed at 8°C, 12°C and 15°C as well as enhance germination in the field using a pretreatment of 1.5 $KNO_3$ + 1.5 $K_3PO_4$ for 5 days at 20°C.

The main function of the salt solutions is in lowering the water potential of the pretreating solution to levels (of the order of - 10 bars) which do not permit radicle emergence (Heydecker and Coolbear, 1977). Ells was even able to show that pretreatment of tomato seeds, either with water alone or with a 1% $KNO_3$ + $K_3PO_4$ solution for 6 days at 10°C produced a similar advantage to that gained by soaking seeds in water at 24°C for 48 hours.

### 1.2.3.3. 'Priming' Pretreatments Using Inert Osmotica

The uptake of water by the seed can also be controlled with the use of high molecular weight polymers (Heydecker, Higgins and Gulliver, 1974), resulting in a process which has been named 'priming'. Polyethylene glycol 6,000 has been used extensively as the molecules are large enough to remain outside

the seed but do not form a solution so viscous as to seriously interfere with oxygen uptake by the seeds. Thus in P.E.G. '6,000' oxygen solubility is 50% that of water and oxygen mobility is only 10%, depressing relative oxygen availability to the order of 5%. (Mexal, Fisher, Osteryoung and Reid, 1975). However oxygen is rarely limiting to plants if the relative solubility is above 50% (Carr 1961), and Mexal et al (1975) found that aerated P.E.G. solutions of water potentials higher than -20 bars contain a greater percentage of dissolved oxygen than 50%. However problems have arisen when using P.E.G. in large quantities as in a commercial scale treatment (Peterson, 1976).

Heydecker and Coolbear (1977) point out that few generalisations can be made about optimum pretreatment conditions with regard to duration, temperature, and osmotic potential of the P.E.G. solution, and the benefits obtained differ with the species and even the seed lot. The priming technique has been conducted on the seeds of many crops, though few have concentrated solely on tomatoes. Heydecker et al (1975) recorded the results of soaking tomato seeds in a solution of P.E.G. of -14.5 bars water potential at 15°C for 14 days. The seeds were then washed, air dried, then germinated at 20°C which resulted in an increased rate of germination although final percentage germination was unaffected. Bussell and Gray (1976) heated tomato seeds at -5 bars P.E.G. for 20 days at 15°C before germinating them at 12.5°C or 20°C. The treatment increased rate of emergence especially at the lower temperature. The final percentage emergence was significantly greater from treated seed compared to untreated at 12.5°C but at the higher temperature where the germination percentage from untreated seed was already good, no extra benefit was gained

from the treatment. In the same paper but in a different experiment Bussell and Gray (1976) observed the effects of several osmotic potentials of P.E.G. of varied duration at two temperatures. The seeds were air dried for 48 hours in an airflow at 20°C then germinated at 8°C, 10°C or 15°C. At 8°C and 10°C the pretreatments significantly reduced the time to 50% germination, low osmotic potentials and longer soaking periods having the greater effect. At 15°C all concentrations accelerated germination over the control to the same extent although there was no effect on percentage germination or on the variability in times of germination of individuals.

Rumpel and Szudyga (1978) present results of work on different pre-sowing treatments for increasing the seed germination and seedling emergence of tomato cultivar New Yorker under cool conditions. Two treatments comprised

(1) P.E.G. at -7.5 bars water potential for 7 days at 20°C

(2) P.E.G. as before with fusicoccin $10^{-5}$M at 20°C.

Dry seeds served as a control. After treatment, seeds were washed, dried in an airflow at 20°C and then germinated at 8°C, 12°C and 15°C. Both treatments reduced time to 50% germination at all temperatures and in a greenhouse trial both treatments reduced spread of germination but had no effect on final percentage germination. Seedling emergence in the field was greatly improved by both treatments also. Pretreatment (2) was found to have the greatest stimulatory effect on germination of the pretreatments mentioned here and in sections 1.2.1.3. and 1.2.3.2.2. but the use of P.E.G. 6,000 alone and 1.5% $KNO_3$ + 1.5% $H_3PO_4$ as a pretreatment are also regarded as being of practical value in obtaining early and uniform seedling emergence of drilled tomato crops under cool conditions.

Storage of primed seeds can result in a lessening of the benefits gained by the pretreatment. Graham (1977) germinated tomato seed at 15°C after a treatment of -5 bars at 20°C for one week. Both earlier and more uniform radicle protrusion was obtained. After storage for 56 days, although the seeds germinated more rapidly than the control, germination was less uniform.

The effects of priming tomato seed in P.E.G. 6,000 can be summarisedas

(1) accelerated germination

(2) more uniform germination both in the laboratory and in the field,

(3) enhanced germination at sub optimal temperatures,

(4) the seed can be stored but this may result in a reduction of the effectiveness of the treatment,

(5) drying back, compared with merely surface drying has been found, in other crops, to reduce the degree of advancement and/or synchronisation (Heydecker and Coolbear, 1977).

There are an enormous number of variations on the pre-treatment theme and whether or not they can be considered as viable commercial practices will depend on the absolute benefit obtainable, the reliability of success, the operational effectiveness and economic feasibility of treatment on a large scale, the viability of treated seeds and the maintenance of the treatment benefit during storage. In other words, in order to be viable, any treatment has to be both physiologically and economically sound (Heydecker and Coolbear, 1977).

## 1.3. Plant Population

Density studies on tomatoes for mechanical harvesting can be classified into two distinct groups,

(i) those conducted on a practical basis with the pre-requisite of 1.5m. between beds (Crowder 1970, Wilcox 1970, Zahara 1970, Bussell, Wraight and Burgmanns 1975, Adelana 1976, Teoh, Chua and Wong 1977, Wraight and Burgmanns 1978), and

(ii) those investigating a theoretical situation where the plants are spaced equidistantly (Currence 1941, Fery and Janick 1970 and 1971, Nichols, Nonnecke and Phatak 1973, Zahara and Timm 1973, Gupta and Shukla 1977).

### 1.3.1. Total Fruit Yield Per Unit Area

Many studies have found that as plant density increases total fruit yield per hectare also increases to a maximum level and remains constant (Brasher 1941, Haber 1941, Odland 1949, Cooper 1957, George and Peirce 1969, Fery and Janick 1970 and 1971, Adams and Brown 1973, Ballatore and Caruso 1975, Teoh et al 1977). This is termed an asymptotic yield-density relationship, where yield increases to a maximum as density is raised but beyond a certain density yield per unit area remains unaffected. Wilcox (1970) conducted a density trial using one or two rows per bed, varying the within row spacing between plants. With one row per bed, yield increased with density up to 23,920 plants per hectare and remained constant up to 71,700 plants per hectare. An asymptotic yield-density relationship was also obtained with the double row system where total yield per hectare remained constant over the density range of 11,960 to 143,520 plants per hectare.

Fery and Janick (1970 and 1971) using populations up to 250,000 plants per hectare and plants arranged equidistantly found that both total fruit and total top yields increased asymptotically with increasing populations whether harvested early, mid or late season. Zahara and Timm (1973), also using plants spaced equidistantly, obtained increased fruit yields with populations up to 617,500 plants per hectare but yields declined at higher populations. This is termed a parabolic yield-density relationship. The asymptotic relationship obtained by Fery and Janick (1970 and 1971) and Wilcox (1970) could be due merely to the fact that population was not increased to a high enough level for yield to decline, and if population of the same order as that reached by Zahara and Timm (1973) had been investigated total yield per unit area may well have decreased.

1.3.2. Ripe Fruit Yield Per Unit Area

Zahara and Timm (1973), using plants spaced equidistantly found that ripe fruit yield per hectare increased with density up to 617,500 plants per hectare but yield declined at higher populations. Fery and Janick (1971) obtained an asymptotic yield-density relationship for marketable fruit up to 250,000 plants per hectare from an early harvest, with plants arranged equidistantly. This relationship became parabolic with later harvests however, as a result of our maturity of the fruit at higher densities, maximum marketable yields being obtained from 42,500 and 17,500 plants per hectare for mid and late season harvests respectively.

Wilcox (1970) using one row per bed, 1.5m between beds, found that marketable yield increased asymptotically from an early harvest reaching a maximum at 35,880 plants per hectare, but parabolically from a late harvest declining at populations over

23,920 plants per hectare with double rows, ripe fruit yields were not significantly different over the density range of 11,960 to 143,520 plants per hectare from an early harvest although,when harvested later in the season,ripe fruit yields declined over 71,760 plants per hectare.

Zahara (1970) also working on 1.5 metre beds achieved various population levels by varying the number of plants per clump. With 1 or 2 plants per clump,marketable yields reached a maximum at 48,4308 and 193,750 plants per hectare respectively. Above these densities yield was unaffected. With 3 plants per clump however, a parabolic yield-density relationship for marketable fruit yield was obtained, with a maximum yield of 106 tonnes per hectare from 39,204 plants per hectare.

Bussell et al (1975) obtained marketable yield increases per unit area with densities up to 33,000 plants per hectare but above this yield increases remained non significent. The results obtained by Wilcox (1970), Zahara (1970) and Bussell et al (1975), where above a certain density yield increases remained non significant, could be an artefact resulting from the form of analysis used where each density is treated as a distinct unit instead of fitting a function to the yield density relationship. This would enable the general form of the relationship to be viewed even though differences between adjacent densities may be small.

From these findings it appears that higher densities are required to reach maximum possible fruit yields when grown at equidistant plant spacing than on 1.5 metre beds. The yield-density relationship is generally asymptotic but total and ripe fruit yield may fall at very high densities and ripe fruit yields decline when harvested late in the season due to over-

maturity of the fruit.

1.3.3. Yield Concentration

Yield concentration (% of ripe fruit) increases with plant density (Stevenson and Tolmes 1958, Crowder 1970, Fery and Janick 1970 and 1971, Postiglione 1972, Nichols et al 1973, Sims and Rubatsky 1974, Postiglione and Lanza 1978). Fery and Janick (1970) found that yield concentration increases with plant density asymptotically for early harvests but in a parabolic manner later in the season.

High densities have been found to accelerate ripening (Currence 1941, Reeve, Robbins, Taylor Kelly and Schmidt 1952, Reeve, Robbins, Taylor and Kelly 1962, Fery and Janick 1971, Fawusi 1977). The increased early yield is a result of the increased number of first flower clusters per unit area and not to any hastening of fruit maturity (Reeve et al, 1952). Rotten fruit increases with both increased population and time of harvest (Fery and Janick 1970 and 1971).

1.3.4. Yield Per Plant

Increasing plant population above a level where plant competition for nutrients, light or water begins, decreases the fruit yield per plant (Vittum and Tapley 1957, Austin and Dutton 1970, Gupta and Shukla 1977). Increasing plant population decreases the number of fruit set per plant (Vittum and Tapley 1953 and 1957, Moore et al 1958) and the number of marketable fruit per plant (Fery and Janick 1970, Zahara and Timm 1973). This is a result of the development of fewer clusters per plant, fewer flowers per cluster and lower per cent fruit set as population increases (Reeve et al, 1962). However Fery and Janick (1970) suggest that the reduction in flower number per plant with increased population is a result of fewer clusters

per plant rather than fewer flowers per cluster.

Increasing plant population from 316,160 to 963,000 plants per hectare decreased the number of branches, leaves, flowers and fruits set per plant (Zahara and Timm, 1973). Above 963,300 plants per hectare many plants failed to flower and bear fruits, tended to accumulate sugar in the stems and leaf area per plant, measured at final harvest, diminished. Plant height and weight decreases with increasing density but total plant weight per unit area increases (Nichols et al 1973).

1.3.5. Fruit Weight

Individual fruit weight decreases with increasing plant population (Postiglione 1972, Postiglione and Lanza 1978). Teoh et al (1977) found that increasing plant density from 20,000 to 31,700 plants per hectare decreased the mean fruit weight from 59g to 49g.

1.3.6. Vine Type

Fery and Janick (1970) observed the effect of growing five tomato vine types at five population levels ranging from 8,000 to 250,000 plants per hectare. Generally the larger the vine type the higher the total top and fruit yield of all populations below those giving maximum yield. The larger the vine the lower the density required to reach maximum potential yield per unit area, about 80 tonnes per hectare total fruit from a single harvest. However, once adequate populations were established, yield became independent of vine type and at 250,000 plants per hectare the yields of all vine types were similar.

In the same study Fery and Janick (1970) found that miniature vine types were earlier maturing than large vine

types at all population levels although there was an interaction between population and the ranking of plant type for earliness. Dwarf and miniature vine types had the greatest maturity concentration at low populations but not at high populations. Fery and Janick (1971) suggest that adequate yields can be obtained from an early destructive harvest with almost any cultivar through manipulation of population.

## 1.4. Quantitative Field-Density Relationships

Expressing the relationship between plant density and yield in a mathematical form facilitates the analysis and interpretation of data from density experiments. Yield per unit area (y) is the product of the yield per plant (w) and plant population ($\rho$):

(1) $y = w\rho$

Shinozaki and Kira (1956) derived a mathematical relationship between the weight per plant and plant density:

(2) $w^{-1} = B + A\rho$

where A and B are parameters having a constant value for sets of data where plant density was the only variable. As $\rho$ approaches zero then $\frac{1}{B} = w$ which is the yield per plant in a non competitive situation and may be considered as a measure of the genetic potential. As $\rho$ approaches $\infty$ then $\frac{1}{A} = w\rho$ which gives the maximum yield per unit area and may be considered as a measure of the yield potential of the environment. Holliday (1960) independently proposed the same equation as adequately describing the yield-density relationship in which, with increasing density, yield rises to a maximum and remains constant at higher densities. This relationship is termed 'asymptotic' and Holliday (1960) suggested that this was characteristic of vegetative yield. However many forms of yield have been shown to decrease above a certain density and Bleasdale and Nelder (1960) proposed a modification to (2) to describe 'parabolic' relationships.

(3) $w^{-\theta} = B + A\rho^{\phi}$

where $\theta$ and $\phi$ are parameters having constant values for any one set of data, in practice, data is rarely accurate enough to enable specific values of $\theta$ and $\phi$ to be determined and Bleasdale and Thompson (1966) suggested that it is the ratio

rather than the absolute values of these two parameters that is important and that, for practical purposes, it is adequate to take $\phi$ as unity. Equation (3) then becomes:

$$(4) \quad W^{\theta} = B + A\rho$$

Kira, Ogawa, Hozumi, Koyama and Yoda (1956) had earlier proposed an allometric equation to define the effect of competition on the proportion of the total production allocated to the economically important plant part. They showed that there exists a linear relationship between $\log_{10}$ total plant weight (w) and $\log_{10}$ weight of a plant part ($w_1$). Thus:

$$(5) \quad \log w = \log k + \theta_1 \log w_1$$

where $\theta_1$ and k are constants.

Bleasdale (1967) developed this relationship further and showed the relationship between $\theta$ in equation (4) and $\theta_1$ in equation (5). The exponential form of equation (5) is:

$$(6) \quad w = k\, w_1^{\theta_1}$$

Substituting in equation (2):

$$(7) \quad w_1^{-\theta_1} = k\,B + k\,A\rho$$

As k is a constant this can be rewritten as:

$$(8) \quad w_1^{-\theta_1} = B_1 = A_1\rho$$

which is identical to equation (4).

Using equation (5), a value for $\theta$ can be obtained which can be inserted into equation (4) to give values for A and B provided that total yield per unit area is asymptotically related to plant density (i.e. $\theta = 1$ in equation (3)). Thus knowledge of both the total plant weight and the weight of any biologically significant plant part at two distinct plant densities theoretically enables the determination of the whole of the relationship between yield of the plant part and density. A more accurate determination could be obtained from three or four distinct densities however.

## 1.5. Growth Analysis

Over the last 60 years quantitative techniques have been developed which allow the experimenter to derive important information about the growth of whole plants under natural, semi-natural or artificial conditions. These techniques require only the simplest of basic data and have collectively become known by the informal title of 'plant growth analysis' (Hunt, 1978). Growth analysis can provide an insight into the mode of plant growth and the physiological development of the components of yield. Efforts can then be concentrated on maximising those factors which will result in more efficient production and higher yields.

The growth analysis paramaters are:-

Relative Growth Rate (R.G.R.)

This is the rate of production of new material per unit weight (w) per unit time (t).

$$R.G.R. = \frac{1}{w} \cdot \frac{dw}{dt}$$

Net Assimilation Rate or Unit Leaf Rate (N.A.R.).

This expresses the rate of increase of dry weight per unit time per unit area of leaf (A).

$$N.A.R. = \frac{1}{A} \cdot \frac{dw}{dt}$$

Leaf Area Ratio (L.A.R.).

This is the ratio of leaf area to weight of plant (usually excluding roots (Hunt 1978)).

$$L.A.R. = \frac{A}{w}$$

$$(1)\ \frac{1}{w} \cdot \frac{dw}{dt} = \frac{1}{A} \cdot \frac{dw}{dt} \cdot \frac{A}{w}$$

$$R.G.R. = N.A.R. \times L.A.R.$$

L.A.R. can be considered as being made up of two components (Evans and Hughes, 1961)+

Specific Leaf Area (S.L.A.)

This is the mean area of leaf displayed per unit of leaf weight $L_w$ .

$$S.L.A. = \frac{A}{L_w}$$

Leaf Weight Ratio (L.W.R.)

This gives an indication of the leafiness of the plant on a weight basis

$$L.W.R. = \frac{L_w}{w}$$

Thus : $L.A.R. = S.L.A. \times L.W.R.$

or

$$\frac{A}{w} = \frac{A}{L_w} \times \frac{L_w}{w}$$

This concept enables differences in leaf area ratio to be attributed either to the differential distribution of photosynthetic products between leaf growth and other plant growth or the differences in leaf density or relative thickness. These subdivisions of L.A.R. may be inserted into equation (I) to give:-

$$\frac{1}{w} \cdot \frac{dw}{dt} = \frac{1}{A} \cdot \frac{dw}{dt} \cdot \frac{A}{L_w} \cdot \frac{L_w}{w}$$

or

$$R.G.R. = N.A.R. \times S.L.A. \times L.W.R.$$

The classical approach to growth analysis has traditionally involved the use of these parameters in the form of the mean values calculated over regular time intervals using the formulae:-

$$R.G.R. = \frac{(\log_e w_2 - \log_e w_1)}{(t_2 - t_1)}$$

$$N.A.R. = \frac{(w_2 - w_1)}{(t_2 - t_1)} \times \frac{(\log_e A_2 - \log_e A_1)}{(A_2 - A_1)}$$

$$\overline{L.A.R.} = \frac{(A_2 - A_1)}{(w_2 - w_1)} \times \frac{(\log_e w_2 - \log_e w_1)}{(\log_e A_2 - \log_e A_1)}$$

$$\overline{S.L.A.} = \frac{(L_2 - L_1)}{(L_{w_2} - L_{w_1})} \times \frac{(\log_e L_{w_2} - \log_e L_{w_1})}{(\log_e L_2 - \log_e L_1)}$$

$$\overline{L.W.R.} = \frac{(L_{w_2} - L_{w_1})}{(w_2 - w_1)} \times \frac{(\log_e w_2 - \log_e w_1)}{(\log_e L_{w_2} - \log_e L_{w_1})}$$

(Subscripts 1 and 2 denote first and second harvests).
assuming that the weight and leaf area vary exponentially with time.

An alternative approach to growth analysis has been termed the dynamic approach by Radford (1967). This involves fitting mathematical functions by regression technique to experimental data to describe the relationship between plant growth and time (Hunt, 1978). From these functions (growth curves) fitted values of data are obtained and then used to describe the various growth analysis quantities which may subsequently be plotted as fitted instantaneous values.

There are several advantages in using the dynamic approach in favour of the classical one. More frequent harvests of fewer plants are used to provide information about the growth of the plants on a more or less continuous basis (Hughes and Freeman, 1967). This means that less information is at risk from accidental loss at any one harvest and the work load is more evenly spread throughout the period of measurements. There is no need for arbitrary pairing of sample plants across harvests as in the classical methods. The regression technique utilizes information from all available harvests in determining values at any point in time, whereas the traditional methods only use data

from two consecutive harvests. Small deviations from the overall trend of the original experimental data against time are 'smoothed' often making the final results less erratic (Hunt, 1973). This effect can, however, result in actual fluctuations from the overall trend being overlooked. The only assumption required for the effective use of the dynamic approach is that the fitted growth curves adequately describe the relationship between the parameters under investigation and time, over the period in question.

# EXPERIMENT 1

## CHAPTER 2

### 2.1. Introduction

This experiment was designed to study the effect of temperature and seed treatment on emergence and early growth of three cultivars of tomatoes for processing.

### 2.2. Materials and Methods

#### 2.2.1. Cultivars

Three cultivars of determinate growth habit were compared, two early maturing, Castlong and Fireball, and one mid season, VF 145-B7879. Fireball, although not a mechanically harvested cultivar was included in the study to investigate the different results obtained by Fery and Janick (1971) using transplants, and Nichols et al (1973) with a direct seeded crop.

#### 2.2.2. Treatments

Two seed treatments, priming and chitting, were compared with untreated seed at two temperatures, 12°C and 20°C.

Primed Seed

The osmoticum used was polyethylene glycol (P.E.G.) '6,000'. A solution was made up of 19.3g P.E.G. in 100 mls of water. At 20°C this has an osmotic potential of -5 bars (Michel and Kaufmann, 1973). Two layers of Bondina capillary matting were placed in the base of three airtight plastic containers. The lids were lined with blotting paper to prevent condensation dripping onto the seeds. P.E.G. solution was poured onto the capillary matting until thoroughly moistened and 1 gm. of seeds (approximately 350 seeds) was sprinkled over the surface, one cultivar in each box. The seeds were only partially covered in P.E.G. solution to ensure that oxygen availability was not

too restricted. The containers were sealed and placed in polythene bags to prevent excessive evaporation. They were then placed in an incubator at 20°C and the capillary matting was remoistened with P.E.G. solution when necessary. After seven days the seeds were rinsed in distilled water, surface dried and dusted with Captan fungicide ready for sowing.

Chitted Seed

The seed was chitted using a modified version of the apparatus designed by Darby and Salter (1976) (Figure VI). The equipment was set up in a room at 18°C. It consisted of three glass cylinders, sealed at the base, except for an outlet pipe leading to a mixing vessel. Water was introduced into the base of the mixing vessel from a tap, at a rate of approximately 1 litre every 24 hours. The water was aerated by an electrical pump, pumping air into the mixing vessel through the central inlet tube. The amount of air and water reaching the three columns was equalised by means of screw clips placed on the connecting hoses. The level of water in the columns was maintained by means of overflow pipes leading to a sink. Seeds were prevented from entering the overflow by plastic gauze placed over the aperture. One gm. of seed of each cultivar was introduced, one cultivar per column. Seeds were maintained above the water - air inlet by a circular disc of stainless steel gauze, held in position with a rubber 'O' ring, to ensure the seeds were kept circulating.

The treatment was carried out for three days at the end of which the seeds from each column were transferred into sieves. Seeds with radicles between 2mm and 4 mm long were selected for sowing and dusted with Captan fungicide.

2.2.3. Experimental Design

This was a factorial experiment consisting of three cultivars, three treatments and two replicates. Two 'Temperzone' controlled climate cabinets were used, maintained at 12°C and 20°C. For each cabinet ninety 10 x 10 cm. pots were filled with sand. In each of these, ten seeds of one treatment were sown 10mm deep, thirty pots of each cultivar. This gave ten pots of each treatment, of each cultivar to allow for five harvests to be taken. The sand was kept moist with a nutrient solution (Cooper, 1975) applied with a watering can. After applying the nutrient solution, a little water was sprayed over the soil to prevent the accumulation of mineral salts at the surface.

Seedling emergence was recorded daily, emergence being taken as the time when the plumule became visible. Final percentage emergence was recorded and quartile deviations were calculated. The seedlings were then thinned to five plants per pot.

2.2.4. Harvest

Eight days after sowing, the first harvest was taken from plants grown from treated seed at 20°C. Four days after this the first harvest of plants from untreated seed at 20°C was taken. Two pots of each cultivar of each treatment were selected. The plants were carefully separated from the sand by immersing the pots in a sink of water and gently rinsing the roots. Leaf area and dry weight of leaves, stems and roots of the five plant sample from each pot were recorded. Two more harvests were taken at weekly intervals and growth analyses performed on the data as outlined by Watson (1952). An analysis of variance was carried out on the growth analysis parameters.

Emergence at 12°C was slow and seedling growth was very poor. Emergence was recorded daily but growth analysis was abandoned after the first harvest.

## 2.3. Results

### 2.3.1. Final Percentage Emergence

Final percentage emergence and treatment and cultivar means are shown in Appendix 1. The results of the analysis of variance conducted on the arc since transformation are shown in Table 3 . At both temperatures the final percentage emergence was greatest for chitted, then primed, then untreated seed. These differences were greater at 12°C than at 20°C but at 12°C the cultivar means were in the order of Castlong, VF 145-B7879, and Fireball. The low final percentage emergence of Fireball was due mainly to poor emergence of untreated seed.

### 2.3.2. Time to 50% Emergence

At both temperatures seedling emergence was most rapid from chitted seed but primed seed also reached 50% emergence faster than untreated seed (Table 4). Chitting the seed was expecially effective in improving the time to 50% emergence at 12°C. No cultivar differences were obtained at 12°C but at 20°C Fireball was most rapid, followed by Castlong then VF 145-B7879 although chitting the seed removed these differences. The times to 50% emergence were much longer at 12°C than at 20°C although chitting, and to some extent priming, the seed helped to reduce these differences.

### 2.3.3. Quartile deviation

Treatment differences were present at 12°C only, where chitted seed was much more uniform in emergence than primed or untreated seed (Table 5). Spread of emergence was greater at 12°C than 20°C although chitting the seed helped to reduce the difference. No clear overall pattern emerged however, as the

| Seed Treatment | Primed | | Chitted | | Untreated | | Cultivar Means | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C |
| VF 145-B7879 | 58.1 | 76.1 | 71.6 | 84.2 | 55.6 | 62.1 | 61.8 | 74.1 |
| Castlong | 67.8 | 76.1 | 73.6 | 90.0 | 62.0 | 71.6 | 67.8 | 79.2 |
| Fireball | 60.7 | 71.1 | 69.8 | 76.0 | 46.2 | 76.1 | 58.9 | 74.4 |
| Treatment Means | 62.2 | 74.4 | 71.7 | 83.4 | 54.6 | 69.9 | | |

S.E. Treatment at 12°C = 3.2 S.E. of interaction 12°C = 3.2
and cultivar means at 20°C = 1.9 20°C = 3.6
for 18 d.f.

Table 3 Final Percentage Emergence
(Arc sine transformation, degrees)

| Seed Treatment | Primed | | Chitted | | Untreated | | Cultivar Means | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C |
| VF 145-B7879 | 457 | 95 | 226 | 72 | 570 | 165 | 418 | 111 |
| Castlong | 417 | 90 | 243 | 74 | 580 | 130 | 413 | 98 |
| Fireball | 392 | 77 | 226 | 72 | 574 | 120 | 397 | 90 |
| Treatment Means | 422 | 87 | 232 | 73 | 375 | 138 | | |

S.E. of treatment and cultivar means for 18 d.f. at 12°C = 15.5 at 20°C = 2.7 S.E. of interaction at 12°C = 26.9

Table 4 Time to 50% (of final percentage) Emergence (hrs)

| Seed Treatment | Primed | | Chitted | | Untreated | | Cultivar Means | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C | 12°C | 20°C |
| VF 145-B7879 | 77.1 | 11.2 | 19.1 | 16.4 | 51.5 | 22.3 | 49.2 | 16.6 |
| Castlong | 54.2 | 12.3 | 37.2 | 14.4 | 42.0 | 11.9 | 44.5 | 12.9 |
| Fireball | 58.4 | 8.3 | 34.2 | 13.1 | 87.2 | 11.5 | 59.9 | 11.0 |
| Treatment Means | 63.2 | 10.6 | 30.2 | 14.6 | 60.2 | 15.2 | | |

S.E. of treatment and cultivar means for 18 d.f. at 12°C = 8.4
at 20°C = 2.2

Table 5 Quartile Deviation (hrs)

treatments produced different effect on each cultivar at each temperature. This was due to the fact that emergence levels were recorded every 24 hours and a more accurate determination of quartile deviation could have been obtained from more frequent observations.

## 2.4. Discussion

In these experiments seedling emergence is a process quite distinct from seed germination. Germination can be considered as a two stage process which is initiated by the uptake of water and completed by the protrusion of the radicle, although many biochemical and physical processes occur between the two stages. Seedling emergence was recorded when the cotyledons became visible above the surface of the soil. Chitted seed is seed that has germinated before sowing and hence time to seedling emergence above the soil is reduced. Priming the seed initiates the germination process by allowing uptake of water by the seed, which results in the breakdown of food reserves and the synthesis of materials required for germination to occur but prevents cell elongation and, in consequence, radicle emergence (Heydecker et al, 1975). Thus primed seed, although more rapid in emergence above the soil than untreated seed, was not as rapid as chitted seed.

Imbibition of water by seeds is a passive process and, as such, could be expected to occur at a rate independant of temperature. However temperature does have an affect on the rate of imbibition by altering factors such as membrane permeability. Enzyme activity and cell elongation are both temperature dependant and occur at a more rapid rate at 20°C than 12°C. Hence seedling emergence was more rapid at 20°C than 12°C. The notable improvement in time to 50% emergence from chitted seed

at 12°C was probably due to the fact that the temperature dependant steps of cell elongation and radicle protrusion had occurred before sowing. The primed seed reached 50% emergence after a longer time than chitted seed due to a reduced rate in cell elongation and radicle protrusion. Untreated seed was slower in emergence than primed seed due to a reduced rate in imbibition in addition to slower cell elongation and radicle protrusion at 12°C.

Final percentage emergence above the soil was greatest from chitted seed then primed seed at both temperatures. This was probably because only seed that had already germinated was sown as chitted seed and initiation of germination of the primed seed had occurred under ideal conditions before the seed was sown.

It can be seen from the values obtained for seedling emergence from chitted seed (which were less than 100%) that death can occur in between seed germination and seedling emergence and the mortality rate is higher at 12°C than 20°C. The emerged radicle is very vulnerable and damage to it during the sorting process or during sowing in the coarse, sandy medium would effectively prevent seedling emergence. Incorporation of the chitted seed into a carrier gel such as sodium alginate used by Currah, Gray and Thomas (1974) could help overcome this problem.

Uniformity was introduced into the chitted seed by selecting for radicles between 2mm and 4 mm long before sowing. This could explain the reduced quartile deviation obtained from chitted seed at 12°C. As previously stated however, for the quartile deviations to have been more accurate it would have been necessary to record seedling emergence counts more frequently.

Final percentage emergence only differed between cultivars at 12°C where Castlong reached a higher level than VF 145-B7879,

and Fireball had the lowest level of emergence. The low level of emergence of Fireball at 12°C from untreated seed was particularly apparent but both priming and chitting the seed helped to overcome this.

No cultivar differences were present at 12°C in time to 50% emergence but at 20°C Fireball was more rapid than Castlong or VF 145-B7879. Fireball had a greater quartile deviation than the other two cultivars at 12°C but at 20°C VF 145-B7879 had the greatest spread of emergence of the three cultivars. Thus it appears that Fireball which has good germination characteristics at 20°C but which is slow, uneven and unreliable in emergence at 12°C benefits to a greater extent by the seed treatments of chitting and priming than Castlong or VF 145 -B7879.

### 2.3.5. An Interpretation of the Results in Terms of Growth Analysis

Values of Relative Growth Rate (R.G.R.) over the early seedling growing period at 20°C are shown in Table 6. Initial R.G.R. of the plants was independant of cultivar and seed treatment.

Differences in Leaf Area Ratio (L.A.R.) between treatments and cultivars were due mainly to differences in Specific Leaf Area (S.L.A.) rather than Leaf Weight Ratio (L.W.R.) (L.A.R. = S.L.A. x L.W.R.) (Table 7) Castlong had a slightly greater L.A.R. than Fireball and VF 145-B7879. The Net Assimilation Rate (N.A.R.) of Castlong however, was lower than the other two cultivars and hence the R.G.R., the product of L.A.R. and N.A.R., did not differ between cultivars (Table 7). Similarly chitted seed had a lower L.A.R. than primed or untreated seed but the high N.A.R. of chitted seed resulted in no differences in the R.G.R. between treatments (Tables 6 and 7).

| Seed Treatment | Primed | Chitted | Untreated | Cultivar means |
|---|---|---|---|---|
| Cultivar | | | | |
| VF 145 -B7879 | 2.41 | 2.43 | 2.43 | 2.42 |
| Castlong | 2.51 | 2.50 | 2.42 | 2.48 |
| Fireball | 2.33 | 2.75 | 2.57 | 2.55 |
| Treatment Means | | | | |

S.E. of treatment and cultivar means for 18 d.f. = 0.08

Table 6 Relative Growth Rate at 20°C (g/g/week)

| CULTIVAR | S.L.A. ($cm^2/_g$) | L.W.R. (g/g) | L.A.R. ($cm^2/_g$) | N.A.R. ($(g/cm^2/week) \times 10^{-3}$) |
|---|---|---|---|---|
| VF 145-B7879 | 299 | .684 | 205 | 11.92 |
| Castlong | 346 | .694 | 240 | 10.44 |
| Fireball | 334 | .674 | 225 | 11.44 |
| TREATMENT | | | | |
| Primed | 349 | .674 | 235 | 10.29 |
| Chitted | 301 | .689 | 207 | 12.42 |
| Untreated | 329 | .691 | 227 | 11.08 |
| S.E. for 18 d.f. | 10 | .007 | 6 | .42 |

Table 7 Cultivar and Treatments Means of S.L.A., L.W.R., L.A.R. and N.A.R. at 20°C

2.3.6. Comparison of Plant Dry Weights at Final Harvest

The final harvest was taken at a time when the plants from the three seed treatments appeared to be at the same stage of growth, chitted and primed on the same day and untreated four days later. An analysis of variance of the total plant dry weight was conducted on values adjusted for plants grown from untreated seed. This was effected by taking the R.G.R. obtained between harvest 2 and 3, calculating the weight increase over 3 days and adding this to the weight obtained at harvest 2. This gives a value for the expected weight if the plants from untreated seed had been harvested on the same day as the plants from primed and chitted seed. The dry weight of Fireball was greater than that of the other two cultivars, which did not differ from each other (Table 8). This could be due to Fireball having a larger embryo in the seed than the other two cultivars or to the more rapid germination of Fireball (Section 2.3.2.). Total plant dry weight was greatest for plants from chitted, then primed, then untreated seeds. This was also the order in which they germinated.

2.4. Summary.

Chitted seed emerged more quickly, over a shorter time interval and resulted in a greater level of seedling emergence at 12°C and 20°C than primed or untreated seed. Priming the seed accelerated emergence and improved final percentage emergence at both temperatures but had no affect on the spread of emergence. Reducing the temperature from 20°C to 12°C delayed emergence, increased the spread and reduced the final level of emergence of all seed treatments. Seedling growth at 12°C was extremely slow and the plants eventually died.

Castlong had a higher level of seedling emergence at 12°C than VF 145-B7879 or Fireball. Fireball reached 50% emergence

| Seed Treatment | Primed | Chitted | Untreated | Cultivar Means |
|---|---|---|---|---|
| Cultivar | | | | |
| VF 145-B7879 | 1.36 | 1.84 | 0.79 | 1.33 |
| Castlong | 1.40 | 1.64 | 0.76 | 1.27 |
| Fireball | 1.50 | 1.92 | 1.09 | 1.50 |
| Treatment means | 1.42 | 1.80 | 0.88 | |

S.E. of treatment and cultivar means for 8 d.f. = .06

Table 8 Total Plant Dry Weight 22 Days after Sowing (g x 10)

(values for untreated seed have been extrapolated from Harvest 3 using the Relative Growth Rates)

faster than Castlong or VF 145-B7879 at 20°C but had a greater quartile deviation at 12°C. VF 145-B7879 had a greater quartile deviation than either Fireball or Castlong at 20°C.

Differences between cultivars and treatments in Net Assimilation Rate, Leaf Area Ratio, Specific Leaf Area and Leaf Weight Ratio, in effect, cancelled each other out so that the Relative Growth Rates over the early growth period of the plants was independant of cultivar and seed treatment. Thus although the seed treatments had a beneficial affect on the emergence characteristics of the seedlings, seedling growth was unaffected.

## 2.5. Yield-Density Relationships

### 2.5.1. Results and Discussion

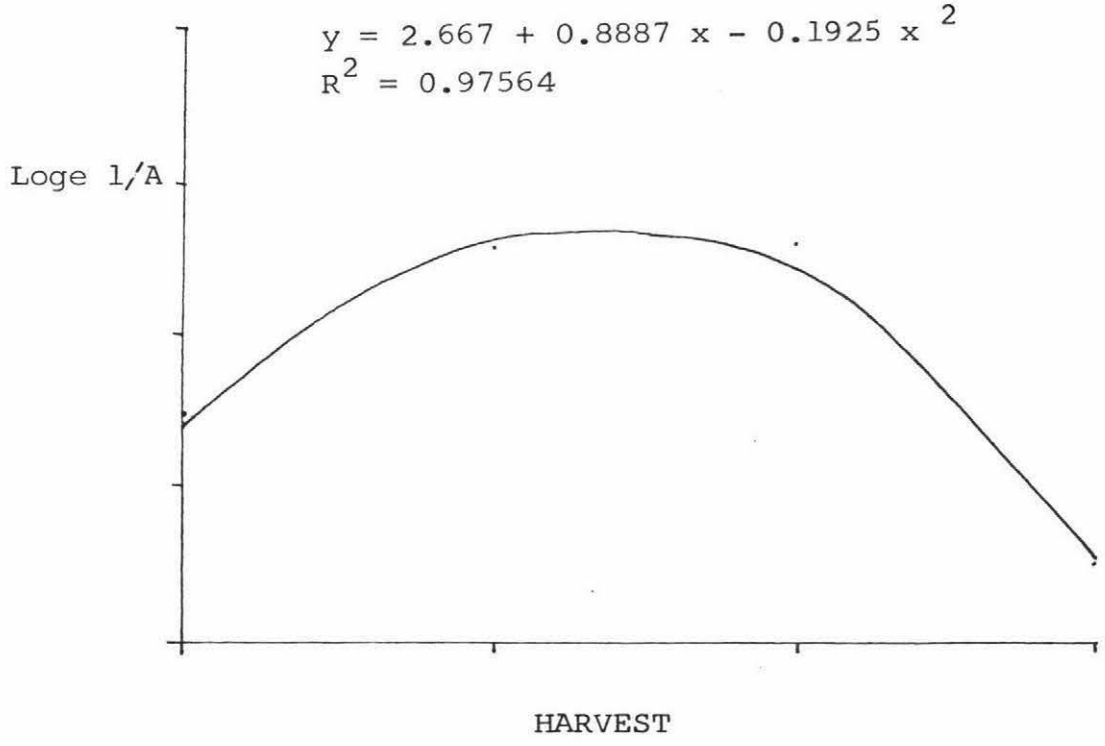
The total plant weight for each density, method of establishment and harvest was fitted to the yield-density equation, equation (4)

$$w^{-\theta} = B + A\rho$$

where A and B are constants and w is the total plant weight at density $\rho$. For the whole plant, $\theta$ was assumed to equal unity as the total plant weight usually exhibits an asymptotic relationship with density (Bleasdale and Thompson 1966, Fery and Janick 1971). The total plant weights were fitted to equation (4) using the weighted least squares method of Mead (1970).

An analysis of variance on the A parameters showed there was a significant difference between harvest ($P < .001$) (Figure I). A quadratic function was fitted to the log of the data. $\frac{1}{A}$ (which can be considered as a measure of the yield potential of the environment) reached a peak at harvests 2 and 3 and then declined. The initial increase in $\frac{1}{A}$ was due to increased plant weight in the form of both vegetative matter and fruit weight. The decline of

Figure I




$\text{Log}_{e}\frac{1}{A}$ from reciprocal yield-density model for total plant as influenced by time of harvest.

$\frac{1}{A}$ at harvest 4 was probably due to total plant weight decreasing as leaves sinesced and fruit rotted, decreasing total fruit weight (Table19 ). There were no differences obtained in A between cultivars which agrees with the findings of Fery and Janick (1971) working with transplanted tomatoes although Nichols et al (1973), with a direct seeded crop did obtain cultivar differences.

An analysis of variance on the B parameters showed that there were no differences between cultivars or harvests (which supports the findings of Nichols et al (1973)) but the B paramater was affected by the method of plant establishment ($P<.05$) (Table 9 ). $\frac{1}{B}$ may be considered as a measure of the genetic potential of the plant and the fact that this appears to be influenced by the method of plant establishment could be a result of the different physiological ages of the seed at sowing. It is obvious that the plants were at different physiological ages at each harvest from the varying percentages of ripe fruit obtained from the different methods of establishment at each harvest (Table 9 ).

The total fruit weight was also fitted to equation (4). The yield of a plant part usually follows a parabolic relationship with time and, hence, a value of $\theta$ less than unity is appropriate. A value of $\theta_1$ for total fruit was estimated using equation (5)

$$\log w = \log k + \theta_1 \log w_1$$

where w is the total plant weight, $w_1$ is the total fruit weight and k and $\theta_1$ are constants. As there was found to be no differences in the values of $\theta_1$ and K between establishment methods mean values for these two parameters were obtained by bulking the establishment methods. $\theta_1$ was found to be independant of cultivar and harvest and a mean value of $\theta_1 = 0.966$ was obtained.

Table 9 $\frac{1}{B}$ from Reciprocal Yield-Density Model for Total Plant Weight as Influenced by Method of Plant Establishment

| | $\frac{1}{B}$ |
|---|---|
| Primed | 15.658 |
| Untreated | 7.869 |
| Chitted | 5.766 |
| Transplanted | 5.181 |
| | S.E. for 11 d.f. = 3.048 |

These findings relate very closely to those of Nichols et al (1973) who also found $\theta_1$ to be unaffected by harvest or cultivar and obtained a mean value of $\theta_1 = 0.96$. Fery and Janick (1971) obtained a mean value of $\theta_1 = 0.98$ which was also independant of harvest and cultivar. $\theta_1$ is a measure of the effect of density on the proportion of total fruit to total plant yield and a $\theta_1 < 1$ indicates that the total fruit/total plant yield decreases with increasing density.

An analysis of variance of the K parameter showed that this was influenced by both cultivar and harvest ($P =< .001$) (Table 10 a &b). The lower value of k for Castlong suggests that this cultivar has a greater proportion of total fruit to total plant weight than Fireball or VF 145 -B7879 (Table 10 ). k was found to fall with time of harvest indicating that as the season progresses fruit yield makes up an increasing proportion of the total plant weight (Table 10b).

The mean value of $\theta_1 = 0.966$ was then fitted into equation (4) to obtain values of A and B for total fruit yield, again using the weighted least squares method of Mead (1970). An analysis of variance on the A parameters showed that this was influenced by time of harvest ($P < .01$) but independant of cultivar (FigureII). A quadratic function was fitted to the data. (This finding conflicts with that of Nichols et al (1973) who found that the A parameter for total fruit was influenced by cultivar but not harvest). The increase in $\frac{1}{A}$ obtained with time to harvests 2 and 3 is due to increased fruit weight as can be seen from Table 12. The decline in $\frac{1}{A}$ at harvest 4 is due to a drop in total fruit weight as the proportion of rotten fruit to total fruit increased (Table 19 ).

An analysis of variance on the B parameter for total fruit weight showed that this was independant of cultivar and method

Table10 k Parameters for Total Fruit as Influenced by (a) Cultivar and (b) Time of Harvest

| (a) | CULTIVAR | k |
|---|---|---|
| | Fireball | 0.159 |
| | VF 145-B7879 | 0.153 |
| | Castlong | 0.090 |

S.E. for 11 d.f. = 0.008

| (b) | HARVEST | k |
|---|---|---|
| | 1 | 0.181 |
| | 2 | 0.136 |
| | 3 | 0.124 |
| | 4 | 0.096 |

S.E. for 11 d.f. = 0.010

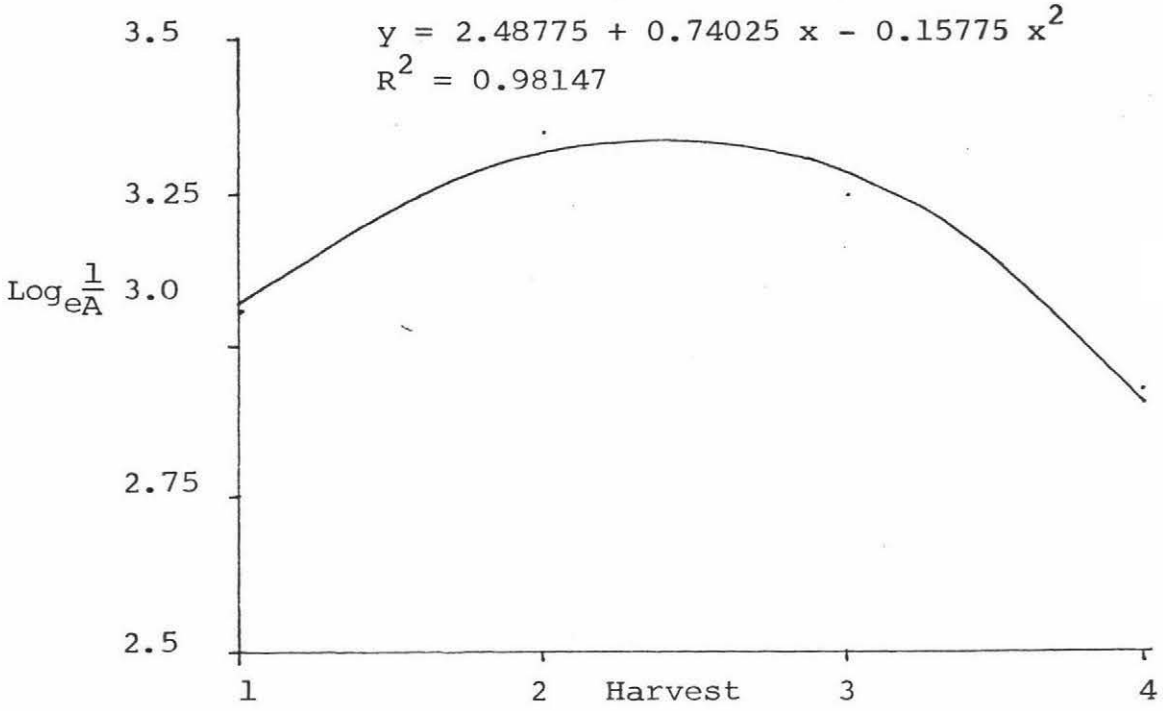



Figure II

Graph to show the influence of time of harvest on $\text{Log}_e\frac{1}{A}$ from reciprocal yield-density model for total fruit weight.

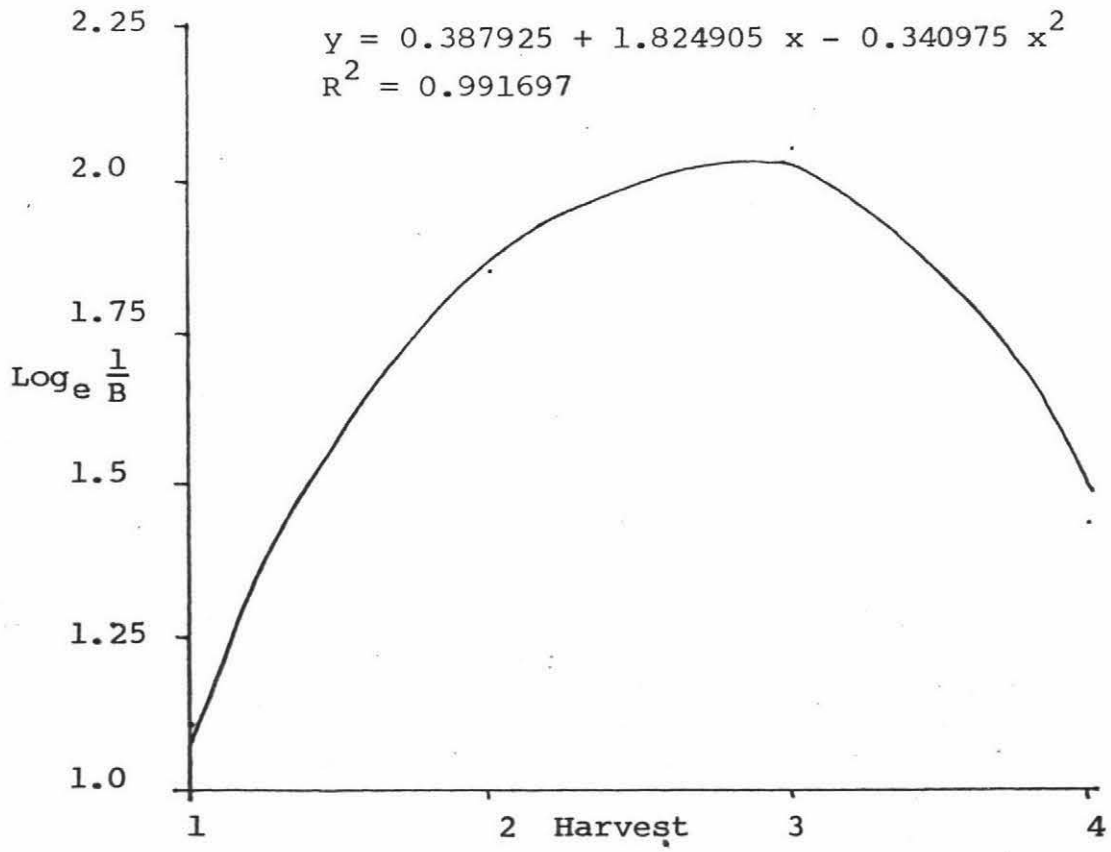



Figure III

Graph to show the influence of time of harvest on $\text{Log}_e\frac{1}{B}$ from reciprocal yield-density model for total fruit weight.

of plant establishment but was influenced by harvest ($P < .05$) (FigureIII). The initial increase in $\frac{1}{B}$ with time to harvests 2 and 3 was again due to an increase in weight of total fruit on the plant and the decline at harvest 4 was due to fruit rotting.

# EXPERIMENT 2

## CHAPTER 3

### 3.1. Introduction

In this experiment the yield of the three cultivars was compared in the field when established by different methods and grown at different densities.

### 3.2. Materials and Methods

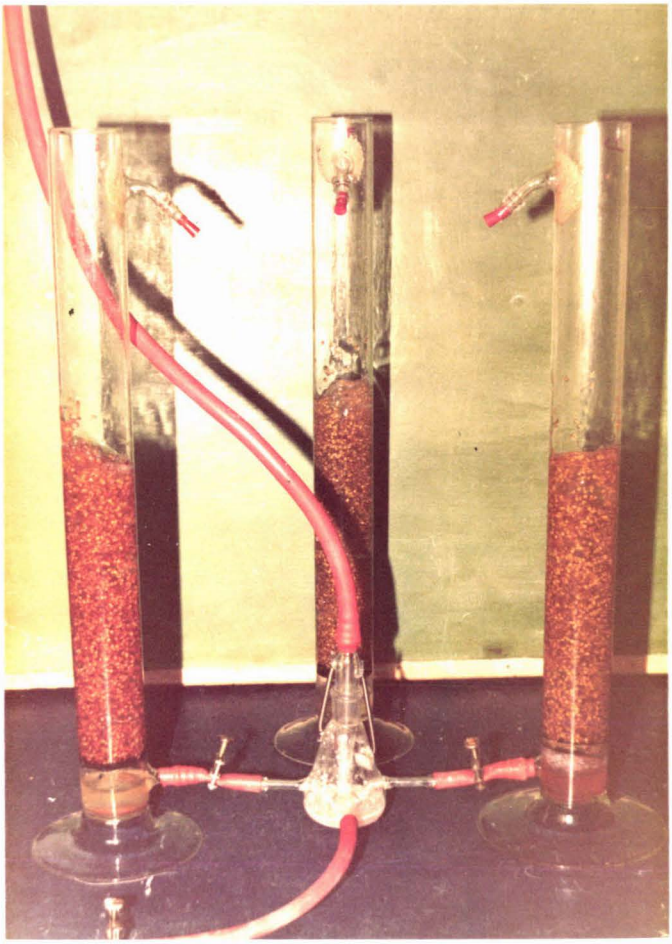
#### 3.2.1. Treatments

Primed Seed

The apparatus used for priming the seed was a modified version of that used for chitting in the previous experiment. It consisted of three narrower and shorter glass cylinders sealed at the base above which was a short side arm (Figure IV). The side arms were connected via rubber tubing to a four way junction into which air was introduced by means of an electric pump. Seeds were prevented from falling below this side arm by a stainless steel gauze held in position with a rubber 'O' ring.

A solution of 193g P.E.G. in 1 litre of water was made up. This had an osmotic potential of -5 bars at 20°C. To this was added 3 drops of Sigma antifoam C emulsion (Beryl Gibbins, pers. comm.). The equipment was set up in a constant environment of 20°C. Screw clips on the rubber tubing controlled the amount of air entering each column and, when closed, prevented flowback of P.E.G. into the four way junction. The screw clips were closed and the columns partially filled with equal amounts of P.E.G. solution. The clips were then opened and at the same time the pump was switched on until the solution was fully aerated. 23 gm. (approximately 8,000 seeds) of each variety were introduced into the columns, one variety per column and when thoroughly incorporated the clips were shut and the pump

Figure IV Equipment used for Priming the Seed



Priming 3 cultivars simultaneously involved the use of 3 glass columns slightly smaller than those used for chitting the seed.

The seeds were supported on wire gauze held in place with a rubber 'O' ring. Air was bubbled through the base of the columns and could be regulated by means of 3 pinch clips. Water lost by evaporation and absorbed through imbition was replaced each day by running distilled water down the inner surface of the column, returning any stranded seeds to the solution.

turned off. The mixture was then allowed to settle for one minute to release the air pocket beneath the gauze and the three levels were marked on the outside of the columns. The pump was restarted and the clips opened.

Water was lost from the P.E.G. solution in two ways, through imbibition by the seeds and through evaporation. P.E.G. was lost from solution by deposition on the inside of the columns as a result of bubbles bursting as they reached the surface. To ensure the osmotic potential of the solution remained constant it was adjusted every twelve hours as follows. The pump was turned off, the clips closed and the mixture allowed to settle for one minute. Solidifying P.E.G. was washed back into solution by running distilled water down the inside of the columns until the level reached that marked previously on the outside of the column. The pump was then switched on and the clips opened for another twelve hours. This was repeated twelve times over the seven day treatment period. At the end of this the seeds were poured into sieves, rinsed thoroughly with distilled water and surface dried. The seeds were then dusted with Captan fungicide and stored at $2^{o}C$ in glass jars until required for sowing (FigureV ).

Chitted Seed

The seed was chitted as in Experiment 1, only this time 23g of each variety was treated. The large volume of seed involved required an improved separation technique. The three sieves containing the chitted seeds were placed in a trough of 20% sucrose solution and gently agitated. Seeds with radicles greater than four millimetres long floated to the surface and were removed. The remaining seeds were drained and transferred to a trough of 30% sucrose solution, one sieve at a time. Unchitted seed remained in the sieve. The chitted seeds floated

Figure V Primed Seed.

After priming, the seed was washed, surface dried and dusted with Captan. It can be stored for a few days at low temperature in this condition with no deleterious effects.

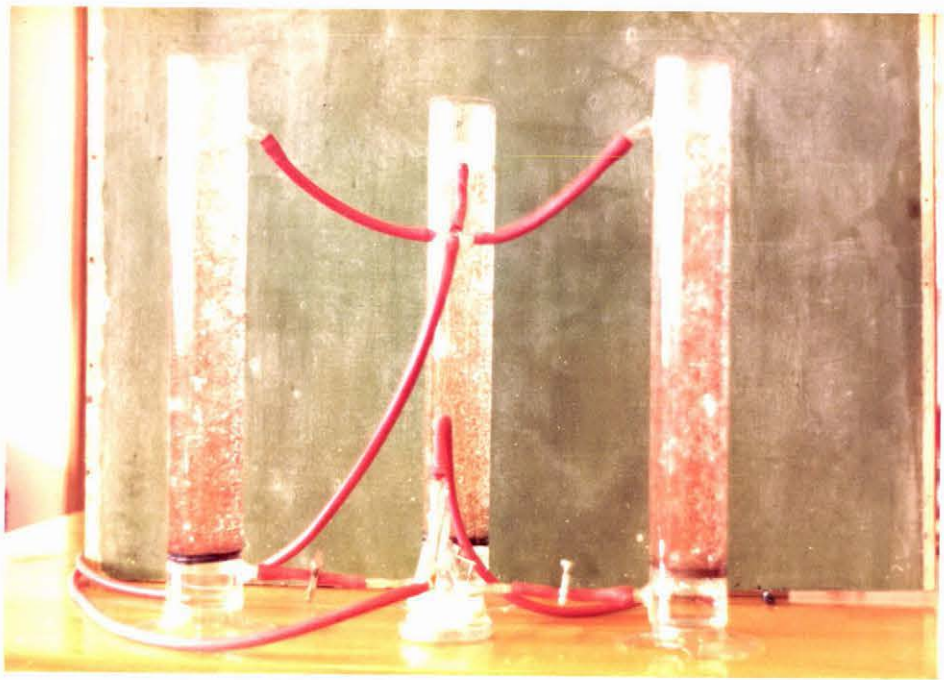


Figure VI Equipment Used for Chitting the Seed

The three cultivars were chitted simultaneously with the use of 3 glass columns. Water was introduced into the base of the mixing vessel from a tap at the rate of $\hat{=}$ 1 litre/24 hours. Overflow pipes connected by tubing to a sink were covered with a fine mesh gauze to prevent seeds from entering them. The water was aerated by an electrical pump pumping air into the mixing vessel through the central inlet tube. Seeds were kept above the ater-air inlet by a circular disc of stainless steel gauze, held in position with a rubber 'O' ring to ensure the seeds were kept circulating.

to the surface, were removed and rinsed thoroughly in water. These seeds were then incorporated into a 'plug mix'.

Three twenty litre batches of plug mix were made up to embody the three varieties. Each batch consisted of

| | |
|---|---|
| 10 litres | Peat |
| 10 litres | Perlite |
| 30g | Superphosphate |
| 60g | Dolomite lime |
| 30g | Osmocote, 3-4 month release (15-5-10) |
| 2.5g | Fritted trace elements |
| 4.0g | Terrazole (fungicide) |

This was thoroughly mixed with the chitted seed and 20 litres of water using a cement mixer in order to reduce damage to the radicles. This gave a density of approximately six seeds per 20cc of mix. The plug mix was then ready for planting (Figure VII).

Transplants

Seeds for transplants were sown in polystyrene 'speedling type' trays (Figure VIII)Each tray held 98 plants, one plant per cell, which could be removed easily by inserting a finger through the hole in the base of each cell. A University of California type peat/sand mix was used for the potting medium.

| | | |
|---|---|---|
| 40 litres | Peat | 30 litres Peat |
| 40 litres | Sand | 30 litres Sand |
| 1.132 litres | Hoof and horn | 60 g Osmocote |
| 2.925 litres | Dolomite lime | 120 g Dolomite Lime |
| 1.425 litres | Ground limestone | 60 g Ground Limestone |
| 145cc | Potassium nitrate | 60 g Superphosphate |
| 112cc | Potassium sulphate | 7 g Fritted Trace Elements |
| 1.57 litres | Superphosphate | |

Figure VII Plug Mix Incorporating the Chitted Seed

Three bins of plug mix, one for each cultivar, were prepared. Water was incorporated to prevent the chitted seed drying out. The seeds themselves are just visible as rust brown specks.

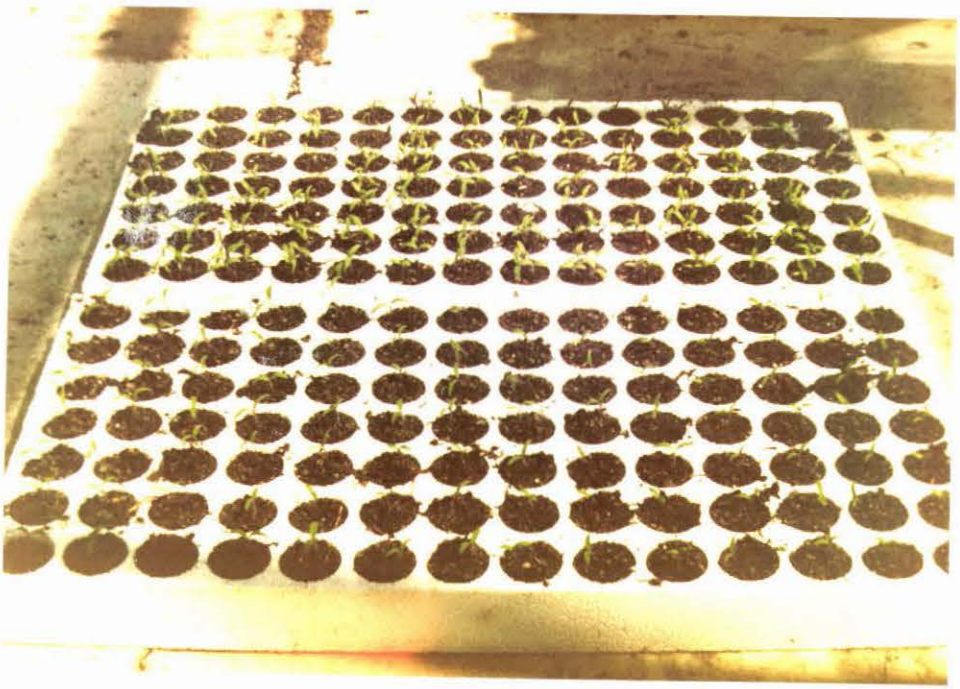


Figure VIII Transplants before and after Thinning

Seed for the transplants were sown on the same day as the other treatments, in U C compost in 'Seedling' type trays. After one week the seedlings were thinned to one seedling per cell.

3.2.2. Field Preparation

The experimental area of 0.09ha (45m x 20m) (Figure IX) was ploughed in May, and disced on the 4 October.

A soil test was conducted to determine the pH, potassium and phosphorus levels present. The results of the test and the predicted response to fertilizer are shown in Appendix 2 . However the soil, a Karapoti brown sandy loam, was formed relatively recently rendering the Olsen Test for potassium and phosphorus an inaccurate measure of the availability of these two elements to plants. Liming was considered unnecessary, but 300 kg of a compound fertilizer (133 kg/ha N, 223kg/ha P, 166kg/ha K) was incorporated by two discings.

3.2.3. Experimental Design

The experiment was factorial and consisted of three cultivars, four methods of establishment, four plant densities and four harvest dates. There were two replicates.

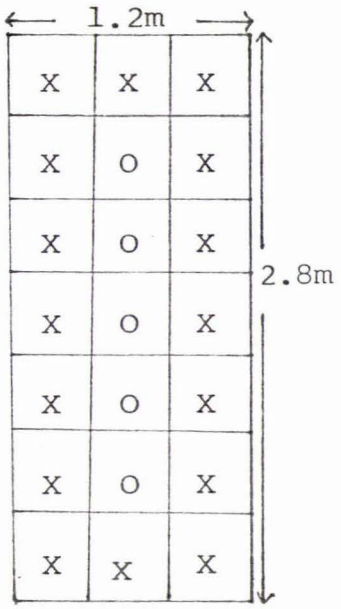
3.3.3. Sowing

Rigid but light frames were constructed of bamboo and string to mark the different densities, 62,500 plants/ha, 160,000 plants/ha, 200,000 plants/ha and 591,716 p/ha (Figure X). Sowing was done on the 17 October. Raw and primed seed were sown 2cm deep, five seeds per site (Figure XI) The chitted seed was sown by placing a tablespoon of plug mix into a 3 cm deep scoop in the soil. This contained about 6 chitted seeds. After sowing 20mm of water was applied through an overhead irrigation system. Seeds for transplants were sown on the same day, with additional ones to serve as replacement plants later. Six seeds per cell were sown and the trays placed on capillary bed matting in a glasshouse maintained between 25$^{o}$C and 36$^{o}$C. One week later

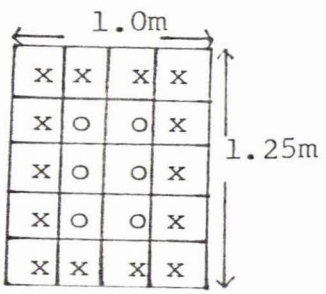
Figure IX The Experimental Area on the Day of Sowing

The experimental area of .09 ha (45m x 20m) on the day of sowing, 17th October. Bamboo canes supporting a plastic label denoting the cultivar, treatment, density, harvest and replicate were placed in each plot.

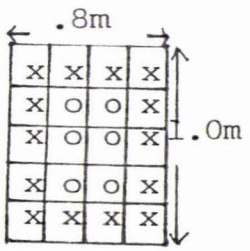
Frame 1
Spacing - 40 x 40 cm
Density - 62,500 plants/ha



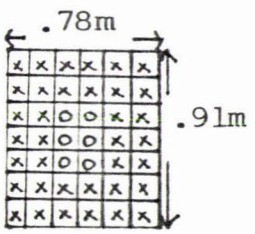

Frame 2
Spacing - 25 x 25 cm
Density - 160,000 plants/ha




Frame 3
Spacing - 20 x 20 cm
Density - 200,000 plants/ha




Frame 4
Spacing - 13 x 13 cm
Density - 591,716 plants/ha




Key x - guard plant
0 - harvest plant

Figure X Frame Dimensions, Plant Spacing and Resulting Densities Used in Experiment 2

Figure XI Sowing the Seeds

Each pair of helpers did the sowing for one density only, using a rigid but light frame of bamboo and string. A shallow scoop was made in the soil with a tablespoon, $\triangleq$ 5 seeds dropped in and the hde recovered. At the front right can be seen a plot sown with the plug mix.

the seedlings were thinned to one per cell and transferred to another glasshouse maintained between 10°C and 20°C (Figure VII). Ten days later the trays for transplants were moved outside the glasshouse to harden off. On 1 November the transplants were watered with 25% solution of calcium nitrate.

On the 2nd, 3rd and 4th November small glass jars were placed over the emerged primed, chitted and raw seeded plants. The experimental area was sprayed with paraquat at a rate of 1kg a.i. per hectare and the seedlings were thinned to one per site.

On 5 November the transplants were planted into the plots using the frames as before. 20mm of water was applied and during the rest of the season irrigation was applied as required.

The primed, chitted and raw seedlings were again thinned to one plant per site on the 20 November. Where a seedling had failed to emerge a replacement plant of the appropriate variety was transplanted. Where this occurred with plants designated for harvest a bamboo cane was placed beside it. Plots with less than four harvest plants were abandoned.

Control of weeks, pests and diseases was achieved by means of a spray programme (Table11). The crop was handweeded as required after 12 December.

### 3.3.4. Harvest

Four harvests were taken at fortnightly intervals beginning on 15 February. The central five plants from each plot were cut at soil level and bulked together. Total plant weight and the number and weight of green, ripe and overmature fruit were recorded.

| Date of Application | Chemical | Use | Rate |
|---|---|---|---|
| Nov 5th<br>Dec 15th<br>Jan 12th | Metaldehyde | Molluscide | 700g a.i./ha |
| Nov 2, 3, 4th<br>Nov 22nd<br>Dec 12th | Paraquat *<br>Glyphosate*<br>Metribuzin | Herbicide<br>Herbicide<br>Herbicide | 1kg a.i./ha<br>180g a.i./ha<br>350g a.i./600l/ha |
| Nov 24th<br>Dec 8th, 22nd<br>Jan 5, 12,26th | Mataisosystox | Aphicide | 1.1l/ha |
| Dec 15th, 22nd<br>Jan 5,12,19,26th<br>Feb 2nd, 9th | Carbaryl | Insecticide | 1.5kg a.i./ha |
| Nov 24th<br>Dec 8th, 22nd<br>Jan 5th, 19th<br>Feb 2,16 & 23rd<br>Mar 2nd | Benomyl | Fungicide to control Sclerotinia and Botrytis | 1k g.a.i./700l/ha |
| Dec 22nd<br>Jan 12th & 26th<br>Feb 9th, 23rd<br>Mar 2nd | Dithane M22 | Fungicide to control late blight | 2kg.a.i./ha |
| Dec 1st, 15th<br>Jan 5th, 19th<br>Feb 2nd, 16th<br>Mar 2nd | Copper oxychloride | Fungicide and Bacteriocide to control Tomato speck, early and late blight | 3kg.a.i./ha |

* Plants covered with jars when applied

Table 11 Chemical Spray Programme for Control of Weeds, Pests and Diseases.

These results were converted to a per plant basis for analysis. Five plants from each plot were cut at soil level and bulbed together. Total plant weight and the number and weight of green, ripe and overmature fruit were recorded. These results were converted to a per plant basis for analysis. An analysis of variance was conducted on the data using a Teddybear programme. Data frompplots which had suffered heavy plant loss and had not been harvested were automatically calculated and adjusted for by the programme.

## 3.3. Results

### 3.3.1. Total Fruit

a. Yield (t/ha)

The total fruit yield increased with time to reach a maximum at harvests 2 and 3 but declined at harvest 4 (Table 12a) This decline later in the season was due to loss of fruit and fruit weight as the fruit rotted. At the first two harvests the total fruit produced on Castlong plants was much greater than on the other two cultivars. At harvest 3 VF 145-B7879 had a significantly lower weight of fruit than Fireball and Castlong but by harvest 4 there were no differences between the cultivars.

The general trend was for fruit yield per unit area to increase as plant density increased from 62,500 plants per hectare (density 1) to 591,716 plants per hectare (density 4) Table 12b ). The yield obtained from 160,000 plants per hectare (density 2) was, however, greater than that obtained from 200,000 plants per hectare (density 3). Method of establishment had no effect on total fruit yield.

The total yield can be looked at in more detail either as the distribution of fruit number or weight per unit area,or fruit number or weight per plant.

a)

| Cultivar→ Harvest | Fireball | VF 145-B7879 | Castlong | Harvest Means (SE=8.7) |
|---|---|---|---|---|
| 1 | 138.9 | 137.8 | 201.8 | 159.5 |
| 2 | 213.3 | 210.8 | 261.1 | 228.4 |
| 3 | 227.5 | 183.0 | 246.6 | 219.0 |

Error d.f.=191 (SE HXC=15.1)

b)

| Density | Yield (t/ha) |
|---|---|
| 1 | 147.8 |
| 2 | 209.3 |
| 3 | 176.3 |
| 4 | 226.5 |

Error d.f.=191 (SE = 8.7)

Table 12 Total Fruit Yield (t/ha) as influenced by

a) harvest and cultivar and

b) density

b) Fruit number per $m^2$

Total fruit number per $m^2$ was constant over the first three harvests but fell at harvest 4 due to losses through overmature fruit (Table 13a). Castlong had more fruit per $m^2$ than the other two cultivars which did not differ from each other (Table 13b). The general trend was for fruit number per $m^2$ to increase with plant density although the number of fruit from densities 2 and 3 were similar (Table 13c). The method of plant establishment had no effect on the number of fruit per $m^2$.

c) Fruit number per plant

The number of fruit per plant fell at the final harvest for all cultivars which was a result of over ripe fruit falling off the vine (Table 14 ). Castlong had more fruit per plant at each harvest than the other two cultivars which did not differ from each other.

As plant density increased the number of fruit per plant decreased irrespective of method of establishment (Table 15 ). At densities 2, 3 and 4 the number of fruit per plant was independent of method of establishment. At the lowest density of 62,500 plants per hectare and summing over alldensities, the number of fruit per plant was lower for transplants than for the other methods of plant establishment which were similar to each other.

By subdividing total fruit yield into green,ripe and rotten fruit, a more clear picture can be obtained.

| a) Harvest | Fruit number per $m^2$ | |
|---|---|---|
| 1 | 456.2 | |
| 2 | 490.7 | |
| 3 | 450.1 | (SE = 19.7) |
| 4 | 322.3 | Error d.f. = 191 |

| b) Cultivar | | |
|---|---|---|
| Fireball | 350.2 | |
| VF 145-B7879 | 342.2 | (SE = 17.0) |
| Castlong | 598.0 | Error d.f. = 191 |

| c) Density | | |
|---|---|---|
| 1 | 311.4 | |
| 2 | 430.8 | |
| 3 | 410.3 | |
| 4 | 566.7 | Error d.f. = 191 |

Table 13 Total Fruit Number per $m^2$ as influenced by a) Harvest b) Cultivar and c) Density.

| | Cultivar→ | | | |
|---|---|---|---|---|
| Harvest | Fireball | VF 145-B7879 | Castlong | Harvest means(SE=1.0 |
| 1 | 20.0 | 22.6 | 40.0 | 27.5 |
| 2 | 27.3 | 26.2 | 41.5 | 31.7 |
| 3 | 32.3 | 22.2 | 37.2 | 27.5 |
| 4 | 13.9 | 13.7 | 32.0 | 19.8 |
| Cultivar means (SE = 0.9) | 21.1 | 21.1 | 37.7 | (SE HXC = 1.7) Error d.f. = 191 |

Table 14 Total fruit number per plant as influenced by time of harvest and cultivar.

| Density → / Establishment | 1 | 2 | 3 | 4 | Establishment means (SE = 1.0) |
|---|---|---|---|---|---|
| Untreated | 54.7 | 26.3 | 19.1 | 11.0 | 27.8 |
| Primed | 51.6 | 24.1 | 22.2 | 8.5 | 26.6 |
| Chitted | 50.9 | 30.7 | 21.1 | 9.2 | 28.0 |
| Transplants | 41.1 | 26.4 | 19.6 | 9.6 | 24.2 |
| Density means (SE = 1.0) | 49.6 | 26.9 | 20.5 | 9.6 | (SE DXE = 2.1) Error d.f. = 191 |

Table 15 Total Fruit Number per Plant as influenced by Method of Establishment and Plant Density

a)

| Density → / Harvest | 1 | 2 | 3 | 4 | Harvest means (SE = 3.6) |
|---|---|---|---|---|---|
| 1 | 3.3 | 5.7 | 3.7 | 12.7 | 6.8 |
| 2 | 17.3 | 30.9 | 30.4 | 50.5 | 32.3 |
| 3 | 85.2 | 126.1 | 97.9 | 145.9 | 113.8 |
| 4 | 38.5 | 56.4 | 41.8 | 46.9 | 44.4 |
| Density means (SE = 3.6) | 36.1 | 53.3 | 43.9 | 64.0 | (SE DXH = 7.3) Error d.f. = 191 |

b)

| Cultivar / Harvest | Fireball | VF 145-B7879 | Castlong |
|---|---|---|---|
| 1 | 3.7 | 4.9 | 12.0 |
| 2 | 24.5 | 17.6 | 54.8 |
| 3 | 102.1 | 77.2 | 162.0 |
| 4 | 23.7 | 27.5 | 82.0 |

(SE CXH = 6.3)
Error d.f. = 191

Table 16 Ripe fruit yield as influenced by times of harvest and and a) Density and b) Cultivar.

3.3.2. Components of total fruit

a. Yield (t/ha)

Ripe fruit yield increased to a maximum at harvest 3 and then declined (Table 16a). The general trend was for ripe fruit to increase with plant density for the first three harvests but these differences were no longer significant by harvest 4. Castlong was the highest yielding cultivar of ripe fruit at each harvest (Table16b ). There were no differences in ripe fruit yield between VF 145-B7879 and Fireball except at harvest 3 where VF 145-B7879 had a higher yield than Fireball. For the first three harvests the transplanted plants yielded more ripe fruit than plants established by any other method (Table 17). At the final harvest there were no longer any differences in ripe fruit yield between the methods of plant establishment. Maximum ripe fruit yields were thus obtained by Castlong at a density of 591,716 plants per hectare, established by transplanting.

Green fruit yield increased to a maximum at harvest 2 as each fruit gained in weight and then rapidly declined as the fruit ripened (Table 18a). Looking at each method of plant establishment however, it can be seen that this general pattern was not followed by transplants. Transplants had the maximum yield of green fruit at the first and second harvests. At harvest 2, 3 and 4, transplants had a lower yield of green fruit than plants established by all the other methods due to the fruit ripening earlier (Table 17)

There were no differences in yield of green fruit between cultivars at all plant densities (Table 18b). There was no clear pattern of green fruit yield changing with density, yield being greatest at densities 2 and 4 and lowest at the lowest plant density, density 1.

c)

| Establishment → Harvest | Untreated | Primed | Chitted | Transplanted |
|---|---|---|---|---|
| 1 | 1.6 | 2.6 | 3.8 | 19.4 |
| 2 | 12.6 | 20.9 | 23.9 | 71.8 |
| 3 | 105.9 | 113.0 | 94.2 | 142.0 |
| 4 | 51.7 | 44.7 | 41.3 | 39.8 |

(SE EXH = 7.3)
Error d.f. = 191)

Table 17 Ripe fruit yield (t/ha) as influenced by time of harvest and method of establishment.

a)

| Establishment → Harvest | Untreated | Primed | Chitted | Trans-planted | Harvest means (SE = 7.1) |
|---|---|---|---|---|---|
| 1 | 148.6 | 155.7 | 164.4 | 142.5 | 152.8 |
| 2 | 211.1 | 214.7 | 225.3 | 133.9 | 196.3 |
| 3 | 83.8 | 86.8 | 89.3 | 58.4 | 79.6 |
| 4 | 35.8 | 31.6 | 26.2 | 17.9 | 29.4 |
| Establishment means (SE = 7.1) | 119.8 | 122.2 | 126.3 | 88.2 | (SE HXE=14.2 Error d.f. = 191 |

b)

| Density → Cultivar | 1 | 2 | 3 | 4 | Cultivar means (SE = 6.1) |
|---|---|---|---|---|---|
| Fireball | 93.6 | 128.0 | 108.5 | 106.3 | 109.1 |
| VF 145-B7879 | 88.0 | 126.4 | 103.4 | 132.1 | 112.5 |
| Castlong | 92.0 | 135.9 | 113.5 | 141.6 | 120.8 |
| Density means (SE = 7.1) | 91.2 | 130.1 | 108.5 | 126.7 | (SE DXC = 12.3) Error d.f. = 191 |

Table 18 Green fruit yield (t/ha) as influenced by a) time of harvest and method of plant establishment and b) Cultivar and plant density

There were no rotten fruit until harvest 3 whereupon yield of rotten fruit increased with time (Table 19a). At harvest 3 density had no effect on yield of rotten fruit but at harvest 4 the general trend was for rotten fruit to increase with density.

The yield of rotten fruit was greatest from Fireball, then VF 145-B7879 then Castlong (Table 19b ). This was so at all densities, for all methods of plant establishment, at both harvest 3 and 4. The method of plant establishment had no effect on yield of rotten fruit.

b) Fruit Number per $m^2$

The number of ripe fruit per $m^2$ increased with time until the final harvest when numbers declined due to overmaturity (Table 20 ). Transplants had more ripe fruit per $m^2$ at the first three harvests but did not differ from the other methods of plant establishment at harvest 4. At all plant densities, Castlong had a higher number of ripe fruit per $m^2$ than the other two cultivars which did not differ from each other (Table 21a ). The highest plant density of 591,716 plants per hectare yielded the highest number of ripe fruit per $m^2$ independent of cultivar. Generally, as density increased, the number of ripe fruit per $m^2$ also increased. At harvests 1 and 4 there were no differences in ripe fruit number per $m^2$ between densities (Table 21b). At harvest 2 as density increased, the trend was for the number of ripe fruit per $m^2$ to increase but no clear pattern emerged at harvest 3.

a)

| Density → / Harvest | 1 | 2 | 3 | 4 | Harvest means |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 (SE = 3.9) |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 17.0 | 26.6 | 25.9 | 33.1 | 25.6 |
| 4 | 64.8 | 77.1 | 70.0 | 110.3 | 80.5 |
| Density means (SE = 5.5) | 20.5 | 25.9 | 24.0 | 35.9 | (SE DXH = 7.8) Error d.f. = 95 |

b)

| Cultivar | Yield (t/ha) | |
|---|---|---|
| Fireball | 65.5 | |
| VF 145-B7879 | 52.2 | (SE = 4.8) |
| Castlong | 41.5 | Error d.f. = 95 |

Table 19 Rotten Fruit Yield (t/ha) as Influenced by a) Density and Time of Harvest and b) Cultivar

| Establishment → / Harvest | Untreated | Primed | Chitted | Trans-planted | Harvest means (SE = 6.6) |
|---|---|---|---|---|---|
| 1 | 3.1 | 3.3 | 4.8 | 40.7 | 13.0 |
| 2 | 23.7 | 38.2 | 36.4 | 129.2 | 56.9 |
| 3 | 193.4 | 176.0 | 168.0 | 278.3 | 204.1 |
| 4 | 107.2 | 79.2 | 88.8 | 76.2 | 87.8 |
| Establishment means (SE = 6.6) | 81.8 | 74.4 | 74.5 | 131.1 | (SE HXE = 13.1) Error d.f.=191 |

Table 20 Ripe fruit number per $m^2$ as influenced by time of harvest and method of plant establishment.

a)

| Density → / Cultivar | 1 | 2 | 3 | 4 | Cultivar means (SE = 5.7) |
|---|---|---|---|---|---|
| Fireball | 30.3 | 60.5 | 41.5 | 74.7 | 51.8 |
| VF 145-B7879 | 22.6 | 48.0 | 54.5 | 54.6 | 44.9 |
| Castlong | 126.1 | 175.1 | 171.8 | 225.6 | 174.6 |
| Density means (SE = 6.6) | 59.7 | 94.6 | 89.2 | 118.3 | (SE CXD = 11.4) Error d.f. = 191 |

b)

| Density → / Harvest | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 5.3 | 11.3 | 15.2 | 20.1 |
| 2 | 26.8 | 51.5 | 58.0 | 91.2 |
| 3 | 143.7 | 212.3 | 197.0 | 263.4 |
| 4 | 63.0 | 103.0 | 86.8 | 98.4 |

(SE DSH = 13.1)
Error d.f. = 191

Table 21 Ripe Fruit Number per $m^2$ as influenced by

a) Cultivar and Plant Density and

b) Time of Harvest and Plant Density

| Cultivar → / Harvest | Fireball | VF 145-B7879 | Castlong |
|---|---|---|---|
| 1 | 4.3 | 5.1 | 29.6 |
| 2 | 26.6 | 24.0 | 120.1 |
| 3 | 145.5 | 118.9 | 347.9 |
| 4 | 30.8 | 31.7 | 200.9 |

(SE = 11.4)
Error d.f. = 191

Table 22, Ripe fruit number per $m^2$ as influenced by time of harvest and cultivar

At each harvest Castlong had more ripe fruit per $m^2$ than the other two cultivars which did not differ from each other (Table 22 ). The number of ripe fruit per $m^2$ for Fireball and VF 145-B7879 reached a maximum at harvest 3. Ripe fruit number per $m^2$ from Castlong increased with time till harvest 3 then declined. By harvest 4 the proportion of ripe fruit which must have turned rotten was much greater for Fireball and VF 145-B7879 than Castlong. The maximum number of ripe fruit per $m^2$ was then obtained from transplanted Castlong at the third harvest from the highest plant density of 591,716 plants per hectare.

The number of green fruit per $m^2$ was highest at harvests 1 and 2 and then declined as the fruit ripened (Table 23 ). This trend was followed for all methods of plant establishment except transplants which had fewer green fruit per $m^2$ at harvest 2 than at harvest 1. At the first two harvests, transplants had fewer green fruit per $m^2$ than the other methods of plant establishment but this difference was not present at harvests 3 and 4. These two findings, along with the results in Table 20 illustrate the advanced maturity of transplants. Castlong had more green fruit per $m^2$ at every harvest than the other two cultivars which did not differ from each other (Table 24a ). Although there were no differences in the number of green fruit per $m^2$ between densities 2 and 3, the general trend was for the number of green fruit per $m^2$ to increase as plant density increased (Table 24b).

| Establishment→ Harvest | Untreated | Primed | Chitted | Trans-planted | Harvest means (SE = 16.8) |
|---|---|---|---|---|---|
| 1 | 461.2 | 441.8 | 487.5 | 383.5 | 443.5 |
| 2 | 468.4 | 458.1 | 525.4 | 284.9 | 434.2 |
| 3 | 198.5 | 189.6 | 209.5 | 186.9 | 196.1 |
| 4 | 136.7 | 85.2 | 54.6 | 41.1 | 79.4 |
| Establishment means (SE = 16.8) | 316.2 | 293.7 | 319.2 | 224.1 | (SE HXE = 33.8) Error d.f. = 191 |

Table 23 Green Fruit Number per $m^2$ as influenced by the Time of Harvest and Method of Establishment

a)

| Cultivar→ Harvest | Fireball | VF 145-B7879 | Castlong |
|---|---|---|---|
| 1 | 355.2 | 373.7 | 601.7 |
| 2 | 385.8 | 386.0 | 530.7 |
| 3 | 175.9 | 194.3 | 218.2 |
| 4 | 53.3 | 55.9 | 129.1 |

(SE HXC = 29.1)
Error d.f. = 191

b)

| Density | Fruit Number | |
|---|---|---|
| 1 | 215.9 | |
| 2 | 289.7 | |
| 3 | 274.3 | |
| 4 | 373.3 | (SE = 16.8) Error d.f. = 191 |

Table 24 Green fruit number as influenced by a) time of Harvest and Cultivar and b) density.

The number of rotten fruit per $m^2$ increased as the season progressed (Table 25 ). Rotten fruit number per $m^2$ was unaffected by plant density at harvest 3 but at the final harvest there were more rotten fruit per $m^2$ at density 4 than the lower plant densities which did not differ from each other. Method of plant establishment and cultivar had no affect on the number of rotten fruit per $m^2$.

c) Fruit Number per Plant

The number of ripe fruit per plant increased with time until harvest 3 and then declined (Table 26a ). This general trend was followed independent of method of establishment. Transplants had more ripe fruit per plant at the first three harvests than the other methods of plant establishment which did not differ from each other. At harvest 4 all methods of establishments gave an equal number of ripe fruit per plant. At harvest 1, there were no differences between cultivars in the number of ripe fruit per plant but at later harvests Castlong had more ripe fruit per plant than Fireball and VF 145-B7879,which did not differ from each other (Table 26b). At harvest 1, there were no differences in the number of ripe fruit per plant between densities but at the later harvests the number decreased as density increased (Table 27a). At all densities the number of ripe fruit per plant increased with time from harvest 1 to 3 but declined at harvest 4 as the fruit over matured. The differences between harvests were more apparent the lower the plant density. Ripe fruit number per plant decreased as density increased for all cultivars (Table 27b)

| Density → Harvest | 1 | 2 | 3 | 4 | Harvest means (SE = 7.7) |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 39.0 | 47.6 | 51.5 | 61.1 | 49.8 |
| 4 | 104.6 | 138.6 | 136.2 | 239.9 | 154.8 |
| Density means (SE = 10.9) | 35.9 | 46.6 | 46.9 | 75.25 | (SE DXH = 15.4) |

Table 25 Number of Rotten Fruit per $m^2$ as Influenced by Time of Harvest and Plant Density

a)

| Establishment→ Harvest | Untreated | Primed | Chitted | Trans-planted | Harvest means (SE = 0.4) |
|---|---|---|---|---|---|
| 1 | 0.2 | 0.1 | 0.2 | 2.0 | 0.7 |
| 2 | 1.3 | 1.7 | 2.0 | 6.9 | 3.0 |
| 3 | 12.0 | 10.4 | 10.5 | 17.6 | 12.6 |
| 4 | 7.0 | 5.4 | 5.3 | 4.8 | 5.6 |
| Establishment means (SE = 0.4) | 5.1 | 4.4 | 4.5 | 7.9 | (SE EXH = 0.8) Error d.f.=191 |

b)

| Cultivar → Harvest | Fireball | VF 145-B7879 | Castlong | |
|---|---|---|---|---|
| 1 | 0.2 | 0.2 | 1.6 | |
| 2 | 1.6 | 1.4 | 6.2 | |
| 3 | 8.0 | 6.9 | 23.0 | |
| 4 | 2.1 | 2.2 | 12.6 | (SE CXH = 0.7) Error d.f. = 191 |

Table 26 Number of Ripe fruit per plant as influenced by Time of Harvest and a) Method of Establishment and b) Cultivar

a)

| Harvest \ Density → | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| 1 | 0.8 | 0.7 | 0.8 | 0.3 | |
| 2 | 4.3 | 3.2 | 2.9 | 1.5 | |
| 3 | 23.0 | 13.3 | 10.0 | 4.4 | |
| 4 | 10.1 | 6.4 | 4.3 | 1.7 | (SE DXH = 0.8) Error d.f. = 191 |

b)

| Cultivar \ Density → | 1 | 2 | 3 | 4 | Cultivar means (SE = 0.3) |
|---|---|---|---|---|---|
| Fireball | 4.8 | 3.8 | 2.1 | 1.2 | 3.0 |
| VF 145-B7879 | 3.6 | 3.0 | 2.7 | 0.9 | 2.6 |
| Castlong | 20.1 | 10.9 | 8.6 | 3.8 | 10.9 |
| Density means (SE = 0.4) | 9.5 | 5.9 | 4.5 | 2.0 | (SE CXD = 0.7) Error d.f. = 191 |

Table 27 Number of ripe fruit per plant as influenced by
a) Time of arvest and density.
b) Density and cultivar.

a)

| Harvest \ Establishment → | Untreated | Primed | Chitted | Trans-planted | Harvest means (SE = 0.9) |
|---|---|---|---|---|---|
| 1 | 28.5 | 26.8 | 29.1 | 23.1 | 26.9 |
| 2 | 27.8 | 32.3 | 35.4 | 19.4 | 28.7 |
| 3 | 12.8 | 13.5 | 12.4 | 8.1 | 11.7 |
| 4 | 8.9 | 5.2 | 4.3 | 2.0 | 5.1 |
| Establishment means (SE = 0.9) | 19.5 | 19.5 | 20.3 | 13.1 | (SE HXE = 1.8) Error d.f.=191 |

Table 28 Number of green fruit per plant as influenced by time of harvest and method of establishment

This was most apparent with Castlong and this cultivar had more ripe fruit per plant than the other two cultivars, which did not differ from each other, irrespective of density.

The number of green fruit per plant was greatest at harvests 1 and 2 and declined with time after this (Table 28). Primed and chitted plants, however, had more green fruit per plant at harvest 2 than at harvest 1, although the number decreased after harvest 2. At harvests 1, 2 and 4, Castlong had more green fruit per plant than the other two which did not differ from each other (Table 29a). At harvest 3 the number of green fruit per plant was unaffected by cultivar. The number of green fruit per plant was a maximum at harvest 2 for VF 145-B7879 and Fireball but at a maximum at harvest 1 for Castlong illustrating the advanced maturity characteristics of this cultivar. As plant density increased the number of green fruit per plant decreased (Table 29b) at each harvest. At densities 1 and 2 the number of green fruit per plant increased from harvest 1 to 2 and then steadily declined as the fruit ripened. At the lower densities 3 and 4, the number of green fruit per plant was at a maximum at harvest 1 and decreased as the season advanced.

The number of rotten fruit per plant increased with harvest at all plant densities (Table 30a). The number of rotten fruit per plant decreased with plant density at both the third and fourth harvests.

a)

| Harvest \ Cultivar → | Fireball | VF 145-B7879 | Castlong |
|---|---|---|---|
| 1 | 99.3 | 112.1 | 191.7 |
| 2 | 128.8 | 125.1 | 176.6 |
| 3 | 55.9 | 65.0 | 54.4 |
| 4 | 15.8 | 16.7 | 44.2 |

(SE HXV=1.6)
Error d.f.=191

b)

| Harvest \ Density → | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 258.0 | 117.3 | 107.5 | 54.6 |
| 2 | 279.1 | 155.7 | 97.0 | 42.2 |
| 3 | 95.8 | 64.5 | 52.6 | 20.9 |
| 4 | 52.2 | 24.3 | 17.2 | 8.5 |

(SE HXD = 1.8)
Error d.f. = 191

Table 29 The Number of Green Fruit per Plant as Influenced by Time of Harvest and a) Cultivar and b) Plant Density

a)

| Harvest \ Density → | 1 | 2 | 3 | 4 | Harvest means (SE = 0.5) |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 6.3 | 3.0 | 2.6 | 1.0 | 3.2 |
| 4 | 16.8 | 8.6 | 6.8 | 4.1 | 9.1 |
| Density means (SE = 0.7) | 5.8 | 2.9 | 2.4 | 1.3 | (SE DXH = 0.9) Error d.f. = 95 |

b)

| Cultivar | Number per plant |
|---|---|
| Fireball | 6.3 |
| VF 145-B7879 | 5.3 |
| Castlong | 6.9 |

(SE = 0.6)
Error d.f. = 95

Table 30 Number of Rotten Fruit per Plant as Influenced by a) Time of Harvest and Plant Density and b) Cultivar.

Castlong had more rotten fruit per plant than Fireball which had more than VF 145-B7879 (Table 30b ). The method of plant establishment did not affect the number of rotten fruit per plant.

### 3.3.3. Yield of Green, Ripe and Rotten Fruit as a Percentage of the Total

By plotting the yield of green, ripe and rotten fruit as a percentage of the total against time, a more clear picture can be obtained of the maturity characteristics of the difference in cultivars, plant densities and methods of establishment.

a) Establishment Methods

There were no significant differences in the percentages of green, ripe and rotten fruit from untreated, primed and chitted plants except at the final harvest where the percentage of rotten fruit on chitted plants was highest ( Figure XV a,b,c, and d.) The earlier ripening characteristics of transplants can easily be seen in Figure XV d. The higher percentage of red fruit at harvests 1 and 2 and of rotten fruit at harvest 3 over chitted, primed and untreated plants clearly illustrate this. The maximum percentage of ripe fruit was obtained from transplanted plants at the third harvest.

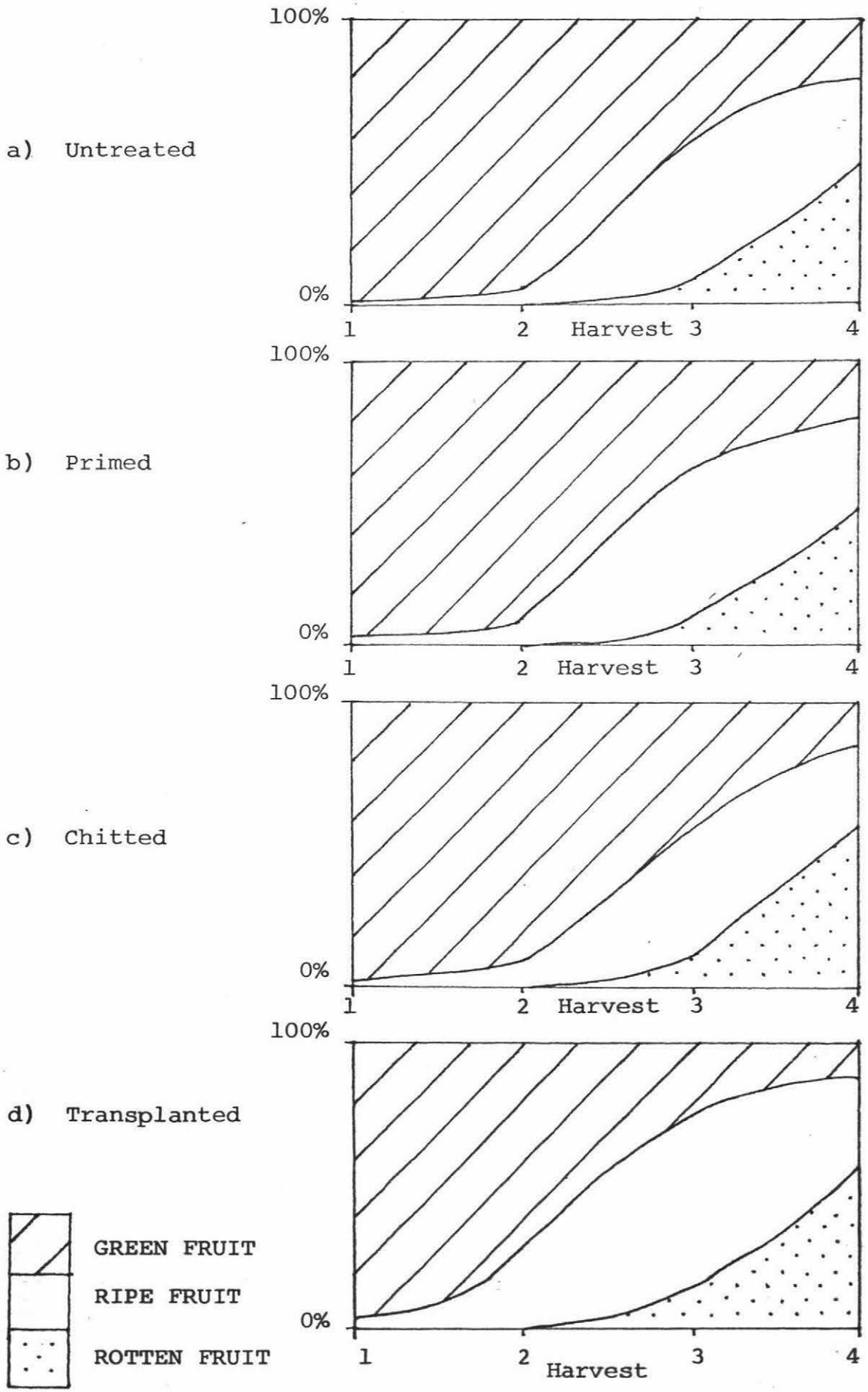



Figure 12

Percentage by weight of ripe, green and rotten fruit as affected by harvest and method of establishment.

b) Cultivar

Castlong matures a little earlier in the season than the other two cultivars with a greater percentage of the fruit being ripe at harvest 1 and 2. (Figure XVI).By Harvest 3 the green fruit was still ripening but the ripe fruit was beginning to overmature. Castlong had the highest percentage of ripe fruit at the third harvest. The percentage of rotten fruit from Fireball was similar to that from Castlong at harvest 3 but Fireball also had a much higher percentage of green fruit at that stage. VF 145-B7879 had the lowest percentage of rotten fruit at harvest 3 but by harvest 4 there were no differences between this cultivar and Fireball in the percentage of rotten fruit. Castlong, however, had a much lower percentage of rotten fruit at the final harvest than the other two cultivars, illustrating the ability of Castlong to hold ripe fruit for long periods before the fruit begins to rot.

c) Plant Density

Plant density had little effect on the ripening of fruit at harvests 1 and 2 except at the highest plant density of 591,716 plants per hectare, density 4 ( Figure XVII ). At this very high plant population, maturity was advanced and at the first two harvests, the percentage of ripe fruit was greater than at any of the other densities. At the third harvest density 1, 62,500 plants per hectare,had the lowest percentage of ripe fruit.

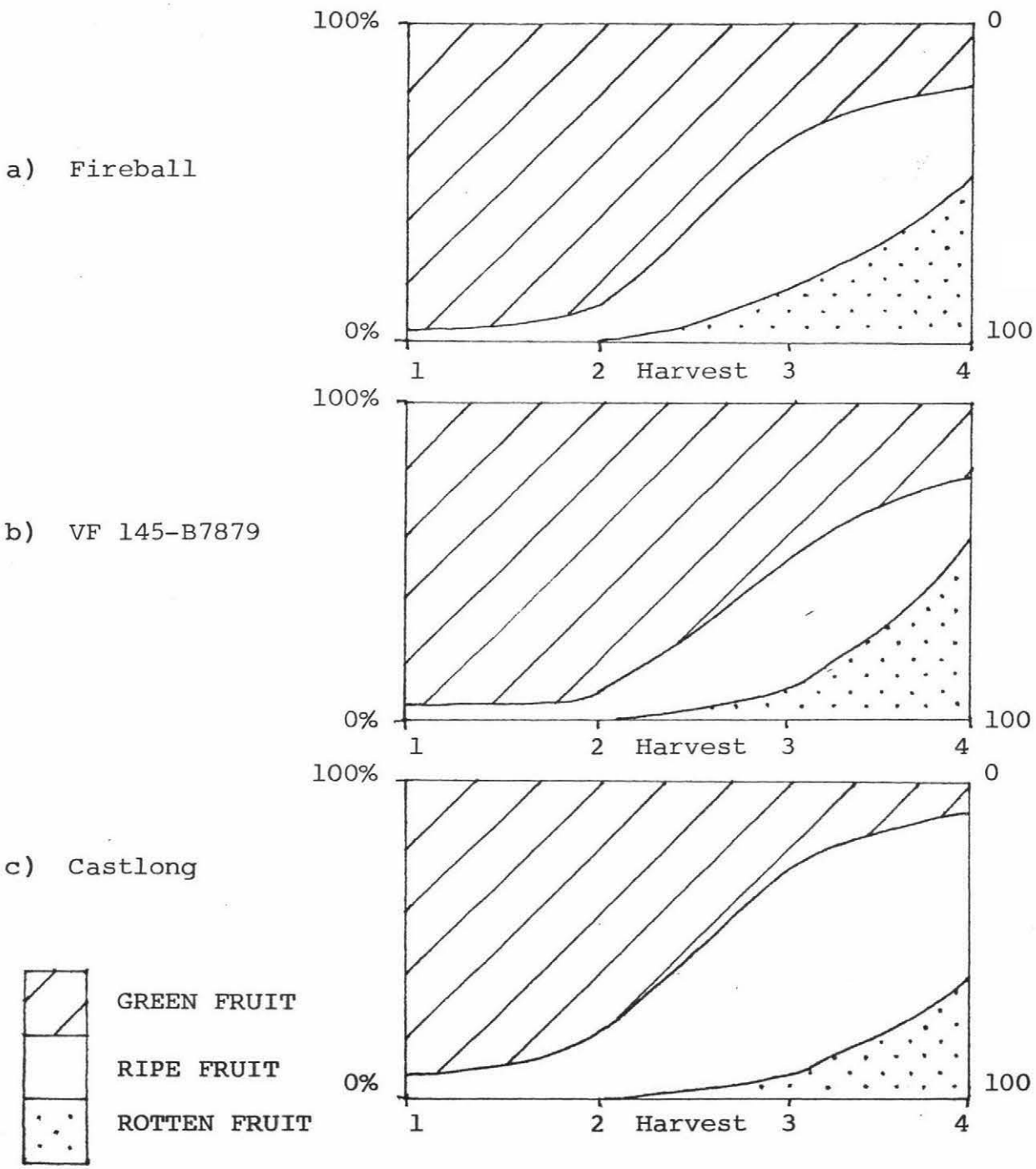



Figure 13

Percentage by weight of ripe, green and rotten fruit as affected by harvest and cultivar.

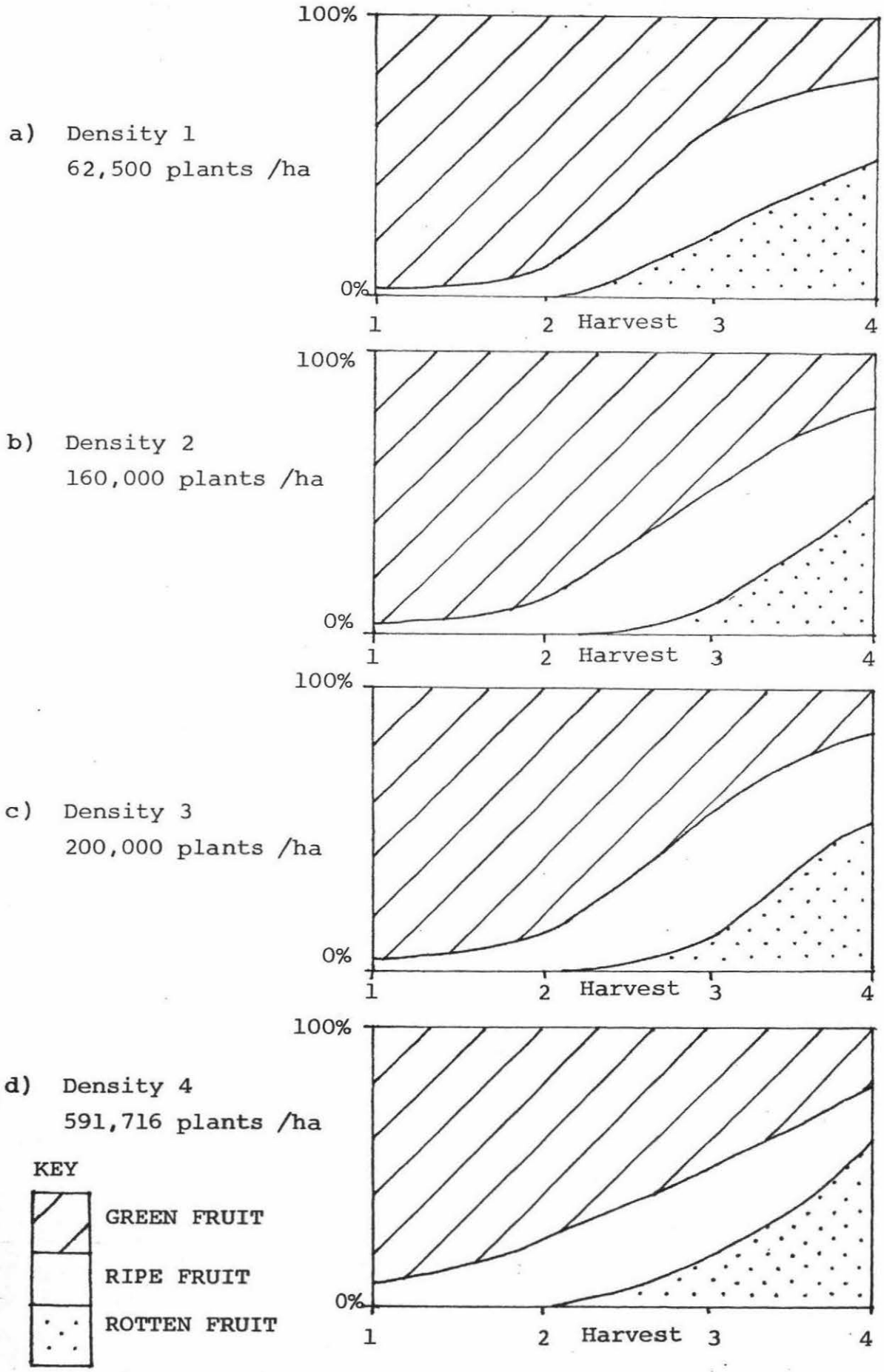



Figure 14

Percentage by weight of ripe, green and rotten fruit as affected by harvest and plant density.

Generally as density increased, the percentage of ripe fruit also increased to reach a maximum at density 4. From Figure XVI it can also be seen that at the final harvest, the process of rotting was accentuated by increasing the plant density.

## 3.4. Discussion

### 3.4.1. Yield Components

a). A Number of Fruit per Plant

The number of fruit per plant was constant over the first three harvests but fell at harvest 4 due to fruit rotting. The proportions of green, ripe and rotten fruit altered, however. The number of ripe fruit per plant increased until harvest 3 and then declined due to overmaturity and hence the number of rotten fruit increased. The number of green fruit was at a maximum at harvests1 and 2 and then declined as the fruit ripened.

As the plant population increased, the number of fruit per plant decreased, whether green, ripe or rotten. Transplants had fewer fruit per plant than the other methods of plant establishment at the lowest density of 62,500 plants per hectare, but at the higher densities there were no differences in the number of fruit per plant between the methods of establishment.

The number of ripe fruit per plant at the first three harvests was greatest from transplants but at harvest 4 there were no differences between the methods of establishment. The number of green fruit per plant was lowest from transplants at all harvests, the other methods of establishment being similar in the number of green fruit per plant. The number of rotten fruit per plant was independent of method of establishment.

At all harvests, Castlong had more fruit per plant than the other two cultivars which did not differ from each other. This was mainly due to more ripe and green fruit per plant on Castlong than the other two cultivars.

Thus the number of fruit per plant was generally independent of method of establishment but greatest at the lowest density of 62,000 plants per hectare from Castlong. The number of ripe fruit per plant was maximum at harvest 3 on transplants of Castlong at the lowest density of 62,500 plants per hectare.

b) Number of Fruit per Unit Area

The number of fruit per unit area was constant over the first three harvests but fell at harvest 4 due to fruit rotting. The number of green fruit per unit area was at a maximum at the first harvest but declined as fruit ripened. Ripe fruit number per unit area reached a maximum at harvest 3 and then declined due to overmaturity.

The general trend was for fruit number per unit area to increase with increasing plant density although there were no differences in the number of fruit per unit area from plants at density 2 to those at density 3 (160,000 and 200,000 plants per hectare). The increase in fruit number with density was due to an increase in both green and ripe fruit at all harvests. The number of rotten fruit per unit area was generally independent of plant density except at the final harvest where plants grown at the highest density yielded more rotten fruit per unit area than the lower densities.

At each harvest, Castlong had more fruit per unit area than the other two cultivars both as green and ripe fruit. There were no cultivar differences in the number of rotten fruit per unit area, however.

The method of plant establishment had no effect on the total or rotten fruit number per unit area but it did influence the number of green and ripe fruit. Transplants had more ripe and less green fruit over the early harvests indicating an earlier maturity. The other methods of plant establishment were similar to each other. There were no differences in the number of rotten fruit per unit area between methods of plant establishment.

Thus the number of fruit per unit area was independent of method of establishment but greatest at the highest density of 591,716 plants per hectare on cultivar Castlong. The number of ripe fruit per unit area was greatest on transplants of Castlong at harvest 3 when grown at a density of 591,716 plants per hectare.

### 3.4.2. Fruit Yield (tonnes per hectare)

Maximum fruit yield was obtained at harvests 2 and 3. At harvest 2 this was composed mainly of green fruit but by harvest 3 the bulk of this had ripened. As the number of fruit per unit area remained constant between harvests 1 to 3 the increase in yield must have been due to an increase in weight of fruit already on the plants. The decline in fruit yield at harvest 4 was a result of fruit rotting from overmaturity.

The general trend was for fruit yield per hectare to increase with plant density. Even though the numbers of ripe, green and rotten fruit per plant decreased as plant density increased, the greater number of fruit per unit area from the higher plant densities resulted in maximum ripe, green and rotten fruit yields being obtained at the highest density of 591,716 plants per hectare. Similarly, the lowest density of 62,500 plants per hectare gave the lowest green, ripe and rotten fruit yields.

The total fruit yield did not differ between methods of plant establishment but the component parts of green, ripe and rotten fruit did. Transplants had a higher yield of ripe fruit at harvests 1, 2 and 3 than the other methods of plant establishment. The increased ripe fruit yield from transplants was due to a greater number of ripe fruit per plant. At the first harvests, transplants did not differ from the other methods of plant establishment in green fruit yield but yields of green fruit were less at harvests 2, 3 and 4 from transplants than from the other methods of plant establishment which did not differ from each other. The fact that transplants had fewer green fruit per plant at harvest 1 but similar yields of green fruit per unit area to the other methods of plant establishment indicates that generally the green fruit on the transplants at harvest 1 were heavier than those on the other methods of plant establishment. Rotten fruit yield was independent of method of establishment.

Total and ripe fruit yields were greater at each harvest from cultivar Castlong than from Fireball and VF 145-B7879 which generally did not differ from each other. This was due to the greater number of fruit set on the cultivar Castlong, and their earlier matirity as there were no differences between cultivars in the number of green fruit per plant. Yield of rotten fruit from Castlong was less than from VF 145-B7879. Fireball had the highest yield of rotten fruit at each harvest and yet had fewer rotten fruit per plant than Castlong which indicates that the rotten fruit of Castlong were, on average, lighter than those of Fireball.

Maximum fruit yields were thus obtained at harvests 2 and 3 from Castlong grown at 591,716 plants per hectare regardless of method of establishment. Ripe fruit yields were greatest at harvest 3 from transplants of Castlong at 591,716 plants per hectare.

3.4.3. Earliness (Percentage of total fruit that is ripe at harvest 1.)

Earliness of maturity is desirable in enabling the producer to supply the processor with ripe fruit at a time when production is generally low. The higher percentage (by weight) of ripe fruit from transplants at harvest 1 indicate the advanced psychological age of the transplants over the other methods of plant establishment which did not differ from each other.

The early maturity of transplants suggests that the early growing environment of the glasshouse enabled the plants to advance to a stage so far ahead of the other methods of plant establishment that the 'shock' received at transplanting was not so excessive as to nullify this gain.

Earliness appeared to be independent of plant density.

Castlong was much earlier in maturing than the other two cultivars which did not differ in the percentage of ripe fruit at harvest 1.

Thus the highest early yields of ripe fruit as a percentage of total fruit were obtained from transplants of cultivar Castlong and were independent of plant density.

### 3.4.4. Yield Concentration (Percentage of total fruit marketable at a single harvest)

A high yield concentration is desirable to maximise the ripe fruit yield, and hence revenue, from a single destructive harvest. Yield concentration was independent of plant density at all harvests except harvest 2 where the general trend was for yield concentration to increase with plant density.

For the first three harvests, transplants had a higher yield concentration than the other methods of plant establishment which did not differ from each other. At the final harvest yield concentration of chitted plants was lower than the other methods of plant establishment though why this was so is not clear.

The yield concentration of Castlong was greater than the other two cultivars and was independent of density for this cultivar. Yield concentration of VF 145-B7879 was also independent of density but Fireball had a higher yield concentration at the highest plant density of 591,716 plants per hectare.

Thus, yield concentration at harvests 1 and 3 were highest from transplants of cultivar Castlong and independent of density. At harvest, 2 transplants of Castlong at the highest density of 591,716 plants per hectare had the greatest yield concentration. At harvest 4, Castlong again had the highest yield concentration but this was independent of method of plant establishment and plant density.

# GENERAL DISCUSSION

## CHAPTER 4

Seed treatment differences in germination characteristics though present in the controlled climate rooms, were not apparent under field conditions. Thus, although priming or chitting the seed speeded up germination over untreated seed in the controlled climate rooms, these differences were not detected under field conditions. Similarly, any advantage in reduced spread of emergence from chitted seed over untreated seed was not apparent as an increase in the yield concentration from chitted plants in the field. This inconsistency could be a result of several factors. When the seeds were sown, soil and air temperatures were low and differences in time to emergence of several days were easy to measure. As the season progressed and temperature rose, however, these differences became smaller and hence more difficult to detect by the methods used in this investigation. Another factor which could have led to undesirable variability in the field was the thinning of untreated, chitted and primed seedlings to one seedling per spot. This process may have adversely affected the remaining seedling by, for example, disturbing the soil and exposing the roots. The seedling may also have been more spindly having been shaded by other seedlings before thinning, than if it had emerged and grown as single entity. Conditions are also more variable between plots in the field than between plants in the controlled climate rooms and the analysis of variance of the field experiment would thus have been reduced in sensitivity.

Castlong although no more rapid in germinating in the controlled climate rooms, was much earlier in maturing than the other two cultivars in the field. Similarly, the quartile deviation was no lower for Castlong than for Fireball or VF 145-B7879 yet the yield concentration of Castlong was greater than for the other two cultivars. Castlong also differed from the other two cultivars in the value of k obtained which indicated that Castlong has a greater proportion of total fruit to total plant weight than Fireball or VF 145-B7879.

Transplants were superior to the other methods of plant establishment for total and ripe fruit yields, earliness and yield concentration. When establishing a crop for mechanical harvesting, however, the returns must be weighed against the cost of establishment. A transplanted crop does cost more to establish than a direct seeded one but it allows a greater time for field preparation, easier weed control and eliminates the need for thinning etc. as discussed in Section 1.1.2. Whether these benefits, plus the increased revenue which can be obtained from the transplanted crop, can outweigh the additional expenditure necessary, will depend, to a certain extent, on the season (early maturity will facilitate harvesting in a wet autumn) but also on the machinery and facilities already available to the producer.

The highest plant density of 591,716 plants per hectare gave the highest ripe fruit yields but density did not affect yield concentration. This density could not be accomplished in practice using the same spacing of 13 centimetres between plants as allowances must be made for tractor wheels and a certain minimum distance between rows is necessary to facilitate harvesting.

From these experiments, however, it does appear that, within the range of densities investigated, returns can be maximised by increasing the plant density. The choice of method of establishment will be greatly influenced by this desire for high plant densities as it is much easier and more economical to establish these high densities by direct seeding than by transplants. There appears to be no advantage in priming or chitting the seed as far as increased revenue from the harvested crop is concerned but these treatments may reduce establishment costs not investigated in these experiments, such as thinning. Both these seed treatments increased the final percentage emergence of the seedlings in the controlled climate room and it could be that either method could be used to obtain a certain plant density using less seed than if untreated seed were sown, an important consideration when the expense of hybrid seed is a major cost of the establishment of the crop.

a)

| $12^{o}C$ | Primed C | Chitted) | Untreated | Cultivar means |
|---|---|---|---|---|
| VF 145-B7879 | 58.1 | 71.7 | 55.6 | 61.8 |
| Castlong | 67.9 | 73.6 | 62.1 | 67.8 |
| Fireball | 60.8 | 69.8 | 46.2 | 58.9 |
| Treatment means | 62.2 | 71.7 | 54.6 | |

b)

| $20^{o}C$ | Primed | Chitted | Untreated | Cultivar means |
|---|---|---|---|---|
| VF 145-B7879 | 76.1 | 84.3 | 62.1 | 74.1 |
| Castlong | 76.1 | 90.0 | 71.7 | 79.2 |
| Fireball | 71.2 | 76.1 | 76.1 | 74.6 |

Appendix 1. Final percentage emergence and treatment and cultivar means at a) $12^{o}C$ and B) $20^{o}C$

| | | | | |
|---|---|---|---|---|
| | | pH | 6.5 | |
| Olsen Test | ( | K + | 6.5 | response possible |
| | ( | P | 38 | high response unlikely |

## Appendix 2 Results of Soil Analysis for Experiment 2

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