HDC "60 DAY" ELSANTA REPORT
1992 - 1993

Collaborative Work by ADAS and HRI

Report by Mike Ryan and David Taylor

GENERAL INTRODUCTION

The UK strawberry industry is faced with increased competition from imports during July, August and September. Traditionally, UK growers have been producing everbearer varieties such as Rapella during this period, but supermarkets can now readily obtain higher quality fruit, i.e. out of season Elsanta from Holland, Belgium and France. Imports from these countries during July to September have averaged 2,840 tonnes from 1988 to 1991 and with prices averaging £1785/tonne, this represents over £5,000,000 worth of business.

UK growers are willing and able to produce Elsanta out of season to compete with overseas competitors. However, there is a shortage of suitable planting material currently, the requirement being for cold stored Elsanta plants with a high yield potential. The quality (yield potential) of cold stored plants is usually related to crown diameter, but variability in yields obtained from similar sized plants from different nursery sources suggested that other factors were also important. One such factor could be the levels of starch in the plant, both before and after the cold storage period.

Starch accumulates in strawberry roots during the autumn period and the amount stored has been correlated with productivity in the following cropping season (Long, 1935). The accumulation of starch in the autumn has also been used as a guide to the suitability of plants for cold-storage, as to when they should be lifted from the field and for how long they can be stored (Bringhurst *et al.*, 1960; Tietz and Gebhardt, 1979). More recently, work has indicated a linear relationship between the starch content of cold-stored plants at planting and the subsequent yields obtained (Ebbinghaus and Lenz, 1988).

In order to improve upon the assessment of cold stored plant quality using crown diameter alone, further research was needed to examine the variability in yields of plants from different nursery sources and of varying crown diameter, so as to determine whether other factors, such as starch levels, could be measured which might be used to provide the grower with a more accurate gauge of yield potential.

A joint HDC funded project between ADAS and HRI EM was thus set up, comprising three main parts.

Part 1 - a literature review to pull together all relevant studies on cold stored plant quality (ADAS).

Part 2 - measurement of the root starch levels found in the plants used for the field trial using two different techniques (HRI EM).

Part 3 - a commercial field trial to assess the yield potential of cold stored Elsanta of varying crown diameters and from different nursery sources (ADAS).

This report has been prepared by Mike Ryan of ADAS Maidstone and David Taylor of HRI East Malling.

Part I

Literature review of yield potential from cold stored plants and techniques for improving yield.

This review concentrates on three main areas:

1) The performance of cold stored plants in the year of planting and ways in which that performance can be predicted using correlation between - measurable plant factors and subsequent yield.

2) Techniques in which yield potential may be increased in the propagation bed or cold store and,

3) Enhancing the yield achieved by attention to relevant factors in the fruiting bed.

Measuring Yield Potential/Crown Diameter

The factor most commonly used today for predicting yield potential is crown diameter. In simple terms the larger the crown the higher the yield potential. Mason D T (1987) reported that when runners of Redgauntlet and Talisman, produced in Eastern Scotland were divided into three size grades and planted outside in spring, the initial plant size had no effect on the number of inflorescences per flowering plant.

However, in a second trial when runners of Cambridge Favourite and Redgauntlet produced in the South of England (which were larger and more complex than the Scottish runners) were grown, the number of inflorescences per plant increased with increasing runner size.

Mason D T observed that when runners (Cambridge Favourite and Cambridge Vigour) from a number of sites in south-west England were dissected axillary bud development inflorescence initiation and the number of potential cropping trusses were positively correlated with crown diameter.

In an experiment by Dijkstra (1989) runners of the cultivar Elsanta were taken from a propagation field and graded into 6 different size grades from 6-8 to 17.5-20.0 mm. crown diameter and planted out in mid July. Yields increased from 0.07 kg with the smallest plants up to 0.94 and 0.99 kg/m^2 for 15-17.5 mm and 17.5-20 mm plants respectively. Dijkstra also noted that incidence of Crown Rot increased with larger plants.

An Italian experiment (Agostini et al 1986) with cultivar Etria cold stored strawberry plants with crown diameters of 12 mm, 12-8 mm and 8 mm were planted on 23 July and 2, 13 and 23 August for cropping the following year. Interestingly with the earliest planting small plants gave the best yields and for the later plantings large plants gave the best yield. In this case it may be that starch levels were still sufficiently high in 23 August as to not be a limiting factor and with the short period from 23 August to start of flower initiation, the small plants were not able to "catch up" with large plants on terms of their rate of flower initiation.

This will be discussed further under "starch" and "influencing flower initiation in the runner bed".

Kramer and Schultze (1985) report a positive correlation between crown diameter and the number of flowers per plant and subsequent yield in Senga Sengana and Redgauntlet. A correlation was also found by Rice and Duna (1986) for the cultivars Cruz and Douglas.

Guttridge and Anderson (1973) suggested that with mature (multi crown) plants an increase in plant sizes led to a tendency for inflorescence formation to fail and therefore a smaller yield to result. However, this may only be true in certain cultivars and in mature plants. Maiden cropping plants would be expected to show a positive correlation of yield to plant size.

In a further trial by Philip Lieten 1990 using plants from 4 different nurseries in England, Belguim and France a similar correlation was found between crown diameter, flower initials and subsequent yield, ie larger plants gave a higher yield.

It was observed that although there was a general trend towards larger plants producing higher yield there was considerable variation particularly between different sources of plant material. Perhap some other factor could be measured which would give a more accurate measure of yield potential.

Starch

Starch levels at the time of planting have been looked at by a number of workers (Rudolph et al 1988, Tietz and Gebbart 1979). There was some evidence for starch levels being correlated with yield. Ebbinghaus and Lenz (1988) reported a linear relationship between the starch content of the cold stored strawberry plant (cultivar Korona) at planting time and fruit yields. More recent work has given a much clearer picture of the influence of starch on yield. Taylor (1992) showed that starch levels at the time of planting were not directly correlated with yield in the variety Elsanta.

A number of workers have looked at the effect of storage period on subsequent yield. Chercuitte et al (1991)observed that the later cold stored plants were planted the lower the yield for the varieties Kent, MicMac, Raritan, Elvira and Bogota. The average yield for 8 May planting was 84.5 g/plant; average yield for 1 August planting was 16.9 g/plant.

Okasha and Ragab (1991) observed a gradual decline in starch content of roots and crown during the storage period of Selva and Pajaro plants. The early yield obtained from plants stored for 4 months was higher than of those stored for 8 months.

The effect of reduced yields from later plantings was previously attributed to stress of transplanting and establishing when temperatures are high (Dijkstra 1989). More recent work has shown that the intrinsic plant quality has altered during cold storage.

Philip Lieten et al (1992) evaluated the flowering response of Elsanta plants stored in cold storage for increasing duration periods and subsequently grown on in controlled growth rooms where the environment was kept constant throughout the year. Graded runners (min 16 mm crown diameter) and waiting bed plants were compared in this trial.

The plants were held in cold storage for 49, 89, 168, 217 or 259 days before planting in the growth chambers. In both the graded runners and the waiting bed plants, longer cold storage periods resulted in lower numbers of inflorescences and flowers developing per plant. Waiting bed plants appeared to lose their flower potential more rapidly than the graded runners.

Starch levels were measured in the crowns for each storage period. Starch levels dropped as the storage period increased. There was a good correlation between the decrease in starch level and the decrease in flowers developing per plant.

No work has been found during this review to show what happens to the flowers which are "lost" over time in cold storage. Possibly these flowers abort as starch levels decrease, alternatively they may be re absorbed by the plant seeking further energy reserves for respiration.

Further research papers cite similar results for other varieties such as Elvira, Tenira, Korona and Bogota, which all gave lower yields from longer cold storage periods Schmitz and Lenz (1989).

Flower Counts

Ahmed Temmali and Philippe Boxus (1992) described their microscopic dissection of dormant Gorella plants to count the flower initials of the main truss. They found that the number of flower initials is highly correlated with the number of flowers emerging in the spring. They suggested that the number of flowers developing later on the secondary trusses depends on their size when dissections are made. Generally it is very difficult to count the flower initials on secondary or tertiary trusses due to their small size.

Other workers have also found correlation between the number of flower initials counted in the first truss in the autumn and those that emerge in the spring (Guttridge and Mason (1966), Mason and Rath (1980)). Initiation of the terminal inflorescence usually occurs before initiation of inflorescences elsewhere in the plant (Guttridge (1955)). Other inflorescences include those that occur on crown extension axes originating from the uppermost axillary bud and those forming on axillary buds further down the crown (Hunt 1991). The lower buds may grow out into secondary branch crowns and initiate inflorescences in late autumn.

Sometimes these buds do not grow out but contain a small number of flowers on a single inflorescence. In spring these may die out or emerge soon after the main inflorescences. (Robertson and Wood 1954). The trial described elsewhere in this report on performance of graded runners and waiting bed plants showed a strong correlation between flower number and subsequent yield. The yield of fruit produced by a strawberry plant is a function of the number of crowns, the number of inflorescences per crown, number of berries per inflorescence and mean berry weight (Webb et al 1974 as sited by Hunt 1991).

It is difficult to use autumn counting of flower initiates as a means of predicting yield due to the problems of accurately counting flower initiates other than on the terminal inflorescence. This may be overcome by growing on a sample of plants in a growth chamber and counting flowers as they emerge. However, a simpler method is possible due to a strong correlation being found between the number of flowers in the first truss and the total flowers per plant when taking crown diameter in to account. For full details of the methodology see part 3 of this report.

Techniques in which yield potential may be increased in the propagation bed or cold store.

There are many different variables which could have an influence on yield potential of runners in the runner bed. These include, other plant health and vigour, hygiene and husbandry in the propagation cycle, soil quality (texture, structure freedom from soil borne pathogens and pests) time of planting, plant density, temperature, light levels, humidity, irrigation, nutrition, growth regulators, time of lifting, length of growing season etc.

This report cannot deal with all of these areas but concentrates on those factors which have direct effect on the major yield components already identified earlier in this report, namely crown diameter, number of flower initials and starch reserves.

The crown diameter has been shown to be a major factor determining yield potential in cold stored plants. There is some evidence that above 18 mm-19 mm crown diameter in a single crown plant yield starts to plateau or even decline (Philip Lieten 1991). A possible explanation for this is that the plant may be switching over to branch crowns development with a temporary cessation of flower initiation.

In typical commercial practice very few runners would reach this size. The main problem is to get sufficient large runners (15 mm) to meet the demand without producing large numbers of smaller runners for which demand is limited.

Typically the commercial yield of runners with a crown diameter of 15 mm + would be 15-25%. However, runner producers have reported that it may be possible to produce 50% or more in the 15 mm + grade by increasing the mother plant density to 20,000 - 25,000 per hectare and planting early with floating film covers to get the autumn initiated flowers out of the crowns and removed as early as possible. This enables stolon production to start early under long days so that by the time flower initiation starts in September the runners are well rooted with substantial crown development.

Irrigation is very important to ensure that rooting starts early and the plants quickly become anchored.

The higher density of mother plants means that more primary runners (first runner per stolon) are formed per unit area. Each mother will typically produce about 8-10 stolons, so for a mother plant density of 12,000 per hectare 120,000 primary runners might develop. However, with 25,000 mother plants per hectare 250,000 primary runners might be achievable.

The primary runners (ie the earliest to be produced) are more likely to be 15 mm + plants by the end of the season than secondary or tertiary runners.

To prevent excessive interplant competition it may be necessary to limit the number of runners that are allowed to develop. Commercially growers have attempted to do this mechanically using discs to cut stolons after the secondary runners have rooted. An alternative mechanical method has been to use an onion topping machine to suck up and remove unwanted runners before they root. This does however, cause damage to the foliage of the runners which remain. Chemical methods have been tried experimentally using paclobutrazol which will inhibit further runnering and promote crown development in the remaining runners, however there is no clearance for this chemical on strawberry plants.

The optimum number of runners per unit area has not been reported in the literature. The optimum will vary depending upon the light levels from one location to another and of course from one season to another. The optimum will also depend on the exact specification of plant required. It is unlikely however, that tertiary runners will be required at the higher mother plant densities. Control of unwanted runners can therefore commence when a majority of secondary runners have rooted.

Nutrition

Adequate nutrition must be provided to encourage vigorous healthy growth in the mother plants and subsequent runners. The interactions of nutrients with each other and with other growth factors, such as water, light, temperature, humidity and inter plant competition, make it difficult to identify precise requirements. Albregts and Howard (1985) found that lowering the soil fertility in the nursery prior to plant harvest increased Dover fruit yield in one of two seasons and of Florida Belle in both seasons. They commented that total fruit yields of both cultivars as related to nursery fertility were inconsistent. Suzuki et al (1983) reported that extra fertiliser after flower initiation improved yield the following year.

Ootake et al (1981) reported on the increase in commercial plantings of strawberry plants for autumn harvesting following long term cold storage. Plant weight at the time of cold storage was found to be greatest with the use of additional N after flower initiation, however, the highest yield was obtained with the use of additional N before flower initiation and the planting out of small and medium runners. This and other work has shown that it is not only runner size which is important in yield potential of strawberry plants.

Flower Initiates

The yield potential from cold stored plants depends upon the number of flower initiates laid down in the autumn before lifting and the ability of the plant to express these initiates after a period of cold storage.

In order to consider ways in which we can increase the number of flowers per plant the basic physiology of flower initiation needs to be considered.

Flower initiation is a complex process and for convenience is often broken into three stages. The first, induction, is where the meristem moves from a vegetative to a reproductive state. This occurs when the leaves stop producing or produce less of a substance probably a gibberellin which normally travels from mature leaves to the buds and inhibits initiation.

The second phase is initiation proper where the meristem is transformed to the floral state. Thirdly, differentiation involves the formation of the distinct floral parts.

The environmental factors favouring each stage may be different. For example, stressing the plant may promote induction but inhibit differentiation.

The runner plants in the nursery bed will be able to initiate flowers when they reach a critical size as can be measured by leaf number or crown diameter (crown is made up from swollen leaf bases).

Flower initiation will then take place when day length drops below a critical level for the variety. Temperature plays an important part. The lower the temperature the longer the critical day length at which flower initiation starts.

For Elsanta flower initiation typically takes place around 13 hour daylength at the beginning of September but in hot conditions may not start until later in the month. When regrowth begins in the spring the critical day length has already passed and no further flower initiation takes place. However, under protection it is possible that growth would commence under short days and further flower initiation could take place. This is observed in heated glasshouse crops of Elsanta in Northern Europe and occasionally in outdoor crops of Elsanta in the South of France.

The most common approach to improving the number of flower initiates in the nursery bed has been threefold.

1. To make certain that as many runners as possible have passed the critical growth stage by the time the correct environmental conditions occur to allow flower initiation to start as early as possible.

2. To ensure the plants don't receive any detrimental stresses during flower initiation such as excess or lack of nutrients, drought etc.

3. To extend the flower initiation period by placing floating film covers over the crop in the autumn to keep the temperature above 7°C the temperature at which strawberry plants start to become dormant.

If runners have passed the critical growth stage well in advance of the critical day length being reached there may be a case for covering the plants with opaque plastic to induce artificial short days. No reference have been found on this subject but the Author is presently experimenting with this technique. The opaque material could either be a black polythene with minisprinklers to provide a light misting (evaporating water from the surface to cool the plants) or a white on black polythene with white uppermost to reflect light and prevent a heat build up. Covers could be placed on the crop in early evening (6 - 7 pm) and removed in early morning (7 - 8 am).

Starch Levels

The level of starch does not appear to correlate consistently with yield but there is some evidence that as starch levels drop below critical levels (Philip Lieten 1992) yield diminishes. Starch levels depend primarily on light intensity during propagation. Plants grown in more southerly latitudes may have higher starch levels (Taylor 1992) and hence a longer storage life. Few references were found as to ways in which starch levels could be raised within any particular nursery bed. Colin Salmond (1992) proposed a system of improving establishment of fresh runners in the autumn by triggering earlier runner maturity using a hormone bioregulator to move the plant into a storage phase earlier. With the use of Cycocell he was able to achieve a carbohydrate increase of 15% in one week. No attempt was made to test the storage life. There is, however, the possibility that flower initiation or flower quality could be adversely affected by the use of this hormone bioregulator.

An alternative approach to achieving higher starch levels at the time of planting would be to shorten the period of time in cold store. The planting date in the fruiting bed is determined by economic factors thus to shorten the storage period the plants would have to go into the cold store later. This could be achieved by production in the Southern Hemisphere so that the plants would not go into cold store until May (instead of December - January as with Northern Hemisphere plants). This is presently being attempted on a commercial basis.

Lifting Date for Cold Storage

Many attempts have been made to clarify the optimum lifting dates for cold storage and factors which could be measured in the plants to show that plants were ready for lifting.

Van Gostel 1987 carried out a trial using Elsanta and Elvira plants. These were lifted from the waiting bed at intervals between 4 November and 11 March and between 4 November and 18 December respectively, and cold stored until 13 June when they were all planted outdoors.

For Elsanta yields were highest from plants lifted on 4 December and for Elvira from those lifted on 29 November. The first and last lifting dates for both cultivars gave poor results as did 18 December with Elsanta. Other workers have also looked at the effect of lifting date (Bester & Truter 1982; Tasi 1981; Anderson & Guttridge 1975). Plants lifted while actively growing in September and October died in storage. Survival and subsequent growth of plants lifted in November varied from year to year but was generally not so good as for plants lifted in December and January after the plants had had a period of time below 7°C and were considered dormant.

The level of starch in the crown as a measure of physiological maturity of the plants has been looked at very carefully (Tiets & Gebhart 1979). They reported on a technique using Iodine staining solution to determine starch concentration with a measurement greater than 75% being required for long term storage.

Waiting Bed Plants

The waiting bed technique involves planting runners into the "waiting bed" in summer (June-July) to bulk up the size of the plant for lifting when dormant in December - January. This larger plant is carrying more flowers than a typical cold stored runner and may have one, two, three or more crowns per plant.

The system was originally developed in Holland with fresh runners planted into waiting beds at a density of 90,000 to 120,000 per hectare. These plants are subsequently lifted and cold stored when dormant and planted out the following spring and summer for annual cropping.

The system used in England is very similar except that small cold stored runners are planted into the waiting bed and the waiting bed plants are typically planted at a lower density (35,000/ha) than in Holland and cropped for at least one full crop after the "60 day" crop. A few fruit growers are also producing their own waiting bed plants from module raised plants. Tips are rooted into small 5 cm modules (80 mls medium grade peat per module) and planted into the waiting bed in mid July.

The experimental evidence shows that waiting bed plants do produce more fruit per plant than cold stored runners lifted direct from a nursery bed (Wijsmuller & Dijkstra 1990).

This is backed up by considerable commercial experience. The average crown diameter of the waiting bed is larger than the average crown diameter of a cold stored runner. When comparing a waiting bed plant with cold stored runners of the same size the evidence is less clearcut (Dijkstra 1990) (Ryan 1993 - see part 3 of this report). Philip Lieten (1993 - to be published) demonstrated that waiting bed plants tend to lose their starch reserves more quickly than graded runners (A+) and their ability to express flowers diminishes at the same rate that starch is lost.

Tray Plants

This system involves propagating tips in modules (6 - 7 cm root trainers) or potting small cold stored plants in modules in late July - early August and growing on through the autumn. These plants are then cold stored and used mainly for planting into bags in greenhouses the following July August. The plants store well because the root system is not disturbed. The technique is relatively new and the quality of plants available is variable.

Obtaining the Best Yields in the Fruiting Bed

Cold stored runners are used to produce fruit in the year of planting both outdoors and under protection. Outdoor cropping takes place in July-August after mainseason and protected cropping takes place in September - November. The protected cropping side is outside the remit of the paper. The outdoor fruiting bed is dealt with here. There are few experimental reports in the literature on systems in the fruiting bed that are of direct relevance to growers in the UK except these already mentioned elsewhere in the report on crown size planting density etc. Much of this section is based therefore on recent commercial experience in the UK.

Growing System

The actual system used will depend on many factors such as soil type, the number of crops to be taken, grower preferences and so on. However at the present time where more than one crop is to be taken raised beds with a polythene mulch, subirrigation and 2 rows of plants per bed is the most favoured option. Bed spacing is 1.50 - 1.75 m with a plant density of 35,000 to 45,000 per hectare depending on plant type, soil type (vigour) and number of crops to be taken.

Three colours of polythene are being used black, blue or white on black. One trial (Lieten & Baets 1991) showed that under plastic tunnels the highest yields per plant and per metre squared were obtained with white plastic in warm summers. A further trial in the open (Lieten and Baets 1991) showed the highest yield was obtained with blue plastic and the mid harvest date was advanced by up to 4 days.

In commercial practice the Author has observed occasions where white on black or black polythene has caused problems. Black polythene gets very hot and can scorch the fruit but it does give the earliest fruit the following spring. White on black polythene works well on light soils, particularly in hot summers but can lead to very slow growth on heavier soils which reduces yields. Blue polythene is intermediate in its effect and gives a useful buffer over a wide range of temperatures. The polythene surface does not get hot so fruit is not scorched. In cold conditions the plant growth rate is only marginally behind black polythene.

Soil

Light soils with a good tilth usually produce the best "60 day" crops because the root system is able to develop rapidly. However other soils may be perfectly adequate (except heavy clay or poorly drained soils), as long as there is a well developed structure which is worked to a good tilth. The condition of the soil at the time of cultivating is very important. Raising beds is often achieved in the autumn and polythene covering immediately applied. Holes should not be made until shortly before planting to avoid localised compaction from rain.

Planting

Planting often takes place under hot conditions so it is very important that plants do not dry out before planting. Plants should not go into dry soil and irrigation may be required preplanting.

Cold stored plants, particularly waiting bed plants have a long root system. It is very difficult to get the roots straight down in the soil profile when planting if using a trowel or dibber. An alternative tool for planting is a modification of the section of water pipe used in Holland and Belgium for planting into peat. This tool has two major advantages.

1. The entire root system can be planted without bunching.

2. Crown depth can be very accurately determined.

For the "60 day" crop a small error in the depth of planting can be made without seriously reducing yield. However the detrimental effect on next years crop can be enormous. If the crown is planted too shallow subsequent crowns (axillary) develop too shallow. When the scaffold roots develop in the autumn they may struggle to anchor themselves in the soil adequately enough to form a strong root system. Growers should be aware that if beds are raised shortly before planting some slumping of the soil may occur. Shallow planting is a much more common error than deep planting with cold stored plants planted during the summer.

If a planting tool is being used which does not enable the entire root system to be planted straight down then it is better to remove the excess root than to allow bunching or folding of the roots.

Establishment

The cold stored plant is required to develop an adequate root system and leaf canopy to support the crop in a very short period of time. Attention to watering is therefore very important to maximise plant growth and avoid checks.

Soil should be adequately wet preplanting but not so wet as to cause smearing from the planting tool.

Immediately after planting watering in helps to obtain an intimate contact between root system and soil and bring moisture levels in the soil up to the optimum for plant growth.

If a solid set mini sprinkler system is used during the establishment phase this can apply little and often watering to keep the leaves cool and wet. Stress is minimised and growth maximised in this way. An electronic leaf can be used to ensure that the leaves are rewetted as they dry. Once the plants are established they can be weaned from the mist. Further irrigation is put on through the subirrigation system (T-Tape).

Planting date/type of plant material

The comparison of yield performance or different types of cold stored plant is fully documented in Part 3. The planting date typically varies between early May and early July depending when the crop is required. Due to the evidence that waiting bed plants do not store as long as graded runners these are probably best planted first.

Subsequent cropping

Typically growers are taking one further crop from waiting bed plants and 2 from graded runners. The market demand is increasingly for higher quality berries and this is best achieved from younger plantations. There is also the difficulty of getting sufficient late Elsanta to meet the demand without producing too much crop for early and mainseason.

High Density Plantings

To overcome the problem of being able to achieve high yields of Elsanta in the late season (post mainseason) without overdoing the early and mainseason production the following year growers are trying various methods of high density planting.

i. TRADITIONAL WAITING BED

Planting of waiting bed plants for a single 60 day crop and grubbing them after harvest. English growers have found the yields are not high enough to justify the high costs of plants and establishment.

ii. Planting into peat bags or similar container at high density then cold storing the bags until the following year. This enables all of the fruit to be picked out of season. However storage and handling costs are high. Successful storage of plants in bags can be difficult. A few growers are persevering with this system.

iii. High density planting into bare soil say 70,000 to 100,000 plants per hectare of field graded (10 mm+) of 12 mm+ graded runners. In this system a high yield of fruit is taken 60 days after planting then a further crop in the spring by limiting the number of runner which are allowed to root into the soil. (Bain 1993).

iv. High density plantings into a similar configuration as for waiting bed production. Graded 12mm + runners or field graded (10 mm+) runners are planted into a fruiting bed, but typically with up to 4 rows of plants per bed (60,000 - 90,000 plants per hectare). After taking the 60 day crop the plants are allowed to grow on as if in a waiting bed then lifted when dormant to be used as cold stored waiting bed plants for a late crop the following year.

Part 2.

Measurement Of Root Starch Content Using Two Different Techniques

Introduction

Various methods have been employed previously to assess/measure the starch content of strawberry roots and these fall into two main categories. Firstly, those which rely on the property of starch to give a blue/black colour with iodine solution, with determination of the colour visually or with the aid of measuring devices (Bringhurst *et al.*, 1960; Rudolph *et al.*, 1988). Secondly, methods which rely on the enzymatic conversion of starch to glucose and measurement of this using colorimetric techniques (Gagnon *et al.*, 1990; Ebbinghaus, 1990).

The aim of this part of the project was to evaluate two different methods for measuring the root starch content of the cold stored Elsanta plants from different nursery sources and of varying crown diameters used in the field trial (Part I).

Materials And Methods

Representative samples of plants from each treatment (see Part I for details) were taken at the time of planting of the field trial, placed in polythene bags and stored at -2°C until required for starch assessment. Five plants of each treatment were selected at random and the roots washed to remove any soil, the roots being then separated from the crown using a razor blade. The diameter of the crown of each plant was recorded; five of the largest sound roots from each plant were then selected and a 15 mm length segment was removed from the basal end (nearest the crown), these being placed in small plastic bags and stored in a refrigerator until they were prepared further (Technique I).

The remainder of the root system from each plant was weighed, placed in a pre-weighed paper bag and freeze-dried to constant weight, which was recorded (root dry weight). The dried root material was ground to a fine powder and stored in a freezer at -18°C until required for further analysis (Technique II).

Starch Assessment - Technique I

This technique involved the use of Iodine-Potassium Iodide (I-KI) to stain the starch grains on the surface of a cross-section of root and examination under a microscope (Bringhurst *et al.*, 1960; Maas, 1986). The root segments were mounted in elder pith and thin transverse sections were cut freehand with a razor blade from the basal end. Four or five sections were cut from each segment and stained with several drops of I-KI on a microscope slide. The sections were examined under a stereomicroscope (Wild M32) at 250-400 x magnification for the presence of black-staining starch grains.

Root starch content was assessed by estimating the percentage of the cross-sectional area of the sections that contained the black-stained starch grains. The figures obtained for the five roots/plant were then averaged.

Starch Assessment - Technique II

The starch content of the freeze-dried root samples was determined using the procedure described by Oakley (1983), with some modifications. An accurately weighed 0.5 g sub-sample was placed into a 33 x 100 mm cellulose Soxhlet extraction thimble and plugged with a wad of quartz wool. This was then subjected to a Soxhlet extraction with 80% aqueous ethanol (v/v) for 18 h to remove any soluble sugars from the tissues. The insoluble starch-containing residue was dried under vacuum in a desiccator and in an oven at 110°C (1 h) to remove any remaining traces of ethanol. After being dried, the residue together with the thimble and quartz wool was placed in a 500 ml round-bottomed flask, to which was added 70 ml of 0.1 M sodium acetate-acetic acid buffer (pH 4.5), together with a few drops of silicone antifoaming agent (BDH) to control frothing. The sample was boiled under reflux for 1-2 h to 'solubilize' the starch and then filtered while the solution was still hot. After the solution had cooled to room temperature, it was transferred to a 100 ml volumetric flask and made up to the mark with more of the sodium acetate buffer.

The starch content of the solution was measured using an enzymatic bioanalysis kit [Boehringer Mannheim UK (Diagnostics and Biochemicals) Ltd., Bell Lane, Lewes, East Sussex, BN7 1LG], the method involving the hydrolysis of the starch and subsequent colorimetric measurement of a reaction product (Boehringer Mannheim, 1989). Briefly, a 0.1-0.5 ml sub-sample was incubated at 60°C for 15 min in a water-bath with an enzyme, amyloglucosidase, which converts the starch to D-glucose. After two further steps, a reaction product, nicotinamide-adenine dinucleotide phosphate (NADPH), is formed which can be quantitatively related to the amount of D-glucose and thus the starch in the original sample. NADPH was determined by measuring its absorbance at 340 mm in a spectrophotometer (Kontron UVIKON 860) and the quantity of starch in the sample was then calculated. This figure was then used to calculate the concentration of starch in the roots and the total amount of starch in the plant root system as a whole.

Crown diameter, dry weight of the roots, starch concentration, total starch content per plant and the visually estimated starch concentration from Technique I, were then subjected to analysis of variance, the starch concentration and total starch content data being log-transformed prior to analysis for statistical reasons.

Results

The root dry weight and crown diameter measurements are given in Table 1. Plants from the nursery source C generally had greater root dry weights and crown diameters compared to sources A and B, there being little difference between these two sources except for the large size category, where source A plants were significantly larger for both parameters compared to source B. It was notable, however, that the medium sized plants from source A gave lower values compared to the small sized plants from the same source, this being inconsistent with the other results. Waiting bed plants had significantly larger crowns compared to the other sources at all plant sizes and the same was largely true in respect of root dry weight.

Table 1

Root dry weight (g) and measured crown diameter (mm)

Nursery source	Root dry wt			Measured crown diameter		
	Plant size category			Plant size category		
	small	medium	large	small	medium	large
A	1.4	1.0	3.2	10.3	9.0	16.1
B	1.4	1.8	2.2	10.8	11.7	13.5
C	2.5	2.6	5.1	12.7	13.4	14.8
WB	2.5	3.3	3.8	16.6	17.8	19.9
SED		0.38			1.01	

SED = standard error of different (48 d.f.)

The visually estimated starch content of the roots obtained by Technique I, showed that plants from source C gave the highest values for all the different size categories, followed by the waiting bed plants (Table 2). There was no significant difference between plants from sources A and B. Averaged over the different sources, large size plants had higher starch levels compared to small sized plants, while medium sized category tended to produce slightly lower values than the latter. However, there was considerable variability in the results and differences between the different size categories within individual sources often failed to reach statistical significance.

Table 2

Visually estimated starch concentration (%)

Nursery source	Plant size category		
	small	medium	large
A	20	14	24
B	18	12	26
C	34	34	49
WB	31	27	31
SED		7.0	

SED = Standard error of difference (48 d.f.)

Results obtained for measured starch concentration from Technique II are given in Table 3 and show that the concentration in plants from source C was significantly higher compared to the

other sources and waiting bed plants, which did not differ significantly. It was notable that, except for the waiting bed material, medium sized plants tended to have a lower starch concentration compared to both the small and large sized categories, this being particularly apparent with source A. There were no other significant differences between the size categories irrespective of plant source/type.

Table 3

Measured starch concentration (mg/g dry wt. of root)

	Plant size category		
Nursery source	small	medium	large
A	12.0 (2.45)	4.1 (1.29)	11.4 (2.36)
B	7.8 (1.91)	5.9 (1.75)	11.0 (2.35)
C	30.0 (3.38)	24.4 (3.11)	33.4 (3.48)
WB	11.5 (2.40)	12.6 (2.46)	11.1 (2.39)
SED		(0.257)	

( ) = log - transformed data. SED = Standard error of difference (48 d.f.)

Calculation for the total amount of starch, taking into account the dry weight of the roots, show that large sized plants had significantly more starch compared to small and medium sized plants for all three sources, but there was no difference between the small and medium size categories (Table 4). One exception, however, was the medium sized plants from source A which had a very low amount of starch compared to the small plants. There were no significant differences between different sized waiting bed plants. As with the starch concentration data, the total amount of starch in plant roots from source C was higher compared to the other sources, followed by the waiting bed plants.

Table 4

Total measured starch/plant (mg)

Nursery source	Plant size category		
	small	medium	large
A	16.6 (2.78)	4.4 (1.18)	35.9 (3.52)
B	11.1 (2.26)	10.5 (2.33)	24.5 (3.12)
C	79.9 (4.25)	63.5 (4.03)	175.9 (5.08)
WB	28.8 (3.30)	43.3 (3.65)	41.9 (3.72)
SED		(0.322)	

( ) = log - transformed data. SED = Standard error of difference (48 d.f.)

When the results of starch concentration obtained by the two different methods were compared, there was a significant correlation ($r = 0.50$; $P<0.001$) between the visual estimation and the measured values (Figure 1). However, to a large extent this correlation simply reflects the fact that both methods produced results in the same order in respect of plant source/type. Within sources, it was found that the relationship between the two variables was not consistent, with any correlations being less significant or not significant at all (data not shown).

Discussion

There were obvious clear differences in plant quality from the different nursery sources, as defined by root growth, crown diameter and root starch content. Plants from nursery source C had larger root systems, crown diameters and a higher root starch content compared to plants from the nurseries A and B, with plants from the latter two sources being very similar to each other in most respects. There was no clear trend in starch content (concentration) of roots in relation to crown diameter of the plants, although the total amount of starch was higher for large sized plants from the three sources, reflecting the larger amount of roots associated with these larger plants.

In regard to the two methods used to assess the root starch content of the plants, the work shows that both techniques give broadly similar results in relation to the general pattern of starch levels found in the roots of plants from the different nursery sources. For example, both methods indicate that the plants from nursery source C have significantly higher levels of root starch compared to the other sources. However, analysis of the results from the different size categories of plants within a source show that the results obtained from the two methods do not correspond well, as shown by the wide scatter of points when the individual results plotted out in Figure 1. Thus, if we assume that Technique II will give the more precise measurement of root starch content, then it seems that Technique I can only give a general idea of rootstarch levels and indicate any large differences there may be between samples.

Acknowledgements

The author gratefully thanks Malcolm Wickenden and Carol Crisp for their excellent technical assistance, and Martin Ridout for the statistical analysis of the data.

Part 3

Evaluating the cropping potential of cold stored strawberry plants and identifying parameters which could be used to form a predictive model.

Introduction

Grower experience with cold stored plant material of the variety Elsanta suggested that the larger the diameter of the crown the higher would be the number of flower initiates and hence yield. However, there was some evidence (Philip Lieten 1991) that there was a large variation in flower number and yield potential between plants from different sources when comparing identical crown diameters.

The aim of this part of the project was to evaluate the cropping potential of cold stored graded runners from three different sources.

Waiting bed plants were also included in the trial. These were cold stored plants which had been planted out in a propagation bed to develop large crowns before lifting when dormant and cold storing for a second time.

Various parameters were measured before and during the trial to see if they could be used in developing a predictive model.

Materials and Methods

Samples of cold stored Elsanta plants were obtained from 3 sources and graded into the following size bands:

Crown diameter
10 - 12 mm
12 - 14 mm
14 - 16 mm

Waiting bed plants were obtained from one source and graded into 3 size bands

Average crown diameter	
small	16 mm
medium	18 mm
large	24 mm

Representative sub-samples were taken of each treatment and placed in polythene bags and stored at -2°C until required for analysis.

A replicated trial was then planted on a growers holding using his standard system of growing; raised beds with blue polythene mulch and T-tape sub irrigation. The site which had previously been cropped with strawberries was fumigated with methyl

bromide in the previous autumn when the beds were raised and covered with polythene.

The trial layout was a replicated randomised block design with 3 replicates of each of ten treatments. Each raised bed represented a block. All plants were removed from cold store, and planted on the same day (26 May 1992). Twenty plants per replicate were planted in double rows 40 cms apart across the bed and 30 cms down the bed.

Immediately after planting solid set overhead watering was used to water in the plants. The solid set system was then used as required over the following 3 weeks to establish the plants. Thereafter T-tape sub irrigation alone was used for irrigation. Soluble feed was applied through the trials lines (1 KgN:0.5 kg$P_2 0_5$: 2Kg K_2O: 0.25 Kg Mg, per ha/week + trace elements).

Counts were made of number of flower trusses, number of flowers per truss and total number of flowers per plant. Flowers on all plants were counted and a mean per plant calculated for each replicate.

During the harvest period three picks per week were made and fruit graded into supermarket 35mm + fruit, supermarket 25-35 mm fruit. Wholesale 18mm+ plus and waste consisting of rots, misshapes and smalls. The fruits were weighed and counted.

Leaf area, measurements were made one week after picking commenced. The leaves on every third plant were counted according to the number of small, medium and large leaves. A sample of each leaf size was accurately measured for leaf area and a leaf area per plant calculated for each replicate.

The representative sub-samples taken before planting were tested for nutrient and carbohydrate levels. The starch testing is described in Part 11 of this report.

The remaining plants of each sub-sample were cut into crown and root samples and thoroughly washed before the following measurements and analyses were carried out.

Nutrient determinations of N, P, K, Mg and Ca using standard ADAS laboratory techniques.

Fresh wt, dry wt and percentage dry weight measurements.

Cellulose levels by acid detergent determination.
Lignin levels by acid detergent determination.
Fibre levels by acid detergent determination.
Fibre levels by Amylase neutral detergent determination.
Cutin by acid detergent determination.
Hemicellulose was also measured.

Cellulose Lignin Fibre, Cutin and hemicellulose are all carbohydrate fractions. They were analysed in case the differences between treatments correlated with subsequent yields from the plants.

Results

Yields:

Non marketable fruit was below 5% by weight in all of the treatments. The main reason for these fruits being non-marketable was their small size.

Table 1 Yields

Source	Size	Supermarket gms/plant	Wholesale gms/plant	Total gms/plant	Tons/acre at 1500 plants/acre
A	10-12 mm	119	52	171	2.6
	12-14 mm	121	57	172	2.6
	14-16 mm	152	38	190	2.9
B	10-12 mm	102	38	140	2.1
	12-14 mm	145	62	207	3.1
	14-16 mm	206	83	289	4.3
C	10-12 mm	113	39	152	2.3
	12-14 mm	156	50	206	3.1
	14-16 mm	196	56	252	3.8
W/bed	small (16mm)	163	58	221	3.4
	medium (18mm)	253	84	337	5.0
	large (24 mm)	254	96	350	5.3
	Average	223	80	303	4.6

The larger plants did tend to produce higher yields and this was analysed statistically. The 14-16 mm plants produced significantly higher yields than the 12-14 mm plants at the 0.1% level of significance and the 12-14 mm plants produced significantly higher yields than the 10-12 mm plants at the 0.1% level of significance.

However, there were also some significant differences between sources of plants of the same crown diameter as follows:

10-12 mm plants. Source A higher yield than B or C at 5% level.
12-14 mm plants. Sources B and C higher yield than A at 0.1% level.
14-16 mm plants. Sources B and C higher yield than A at 0.1% level.
14-16 mm plants. Source B higher yield than C at 1.0% level.

These results suggest that crown diameter alone is not a completely accurate guide to yield potential and some other factor must be involved.

Starch

Part 11 of this report discusses the two different techniques of measuring the starch content of strawberry roots. The first method involved staining with iodine solution and determining the percentage of staining in cross section (Bringhurst et al 1960; Rudolph et al, 1988). The second method involved the enzymatic conversion of starch

to glucose and measurement of this using calorimetric techniques (Gagnon et al, 1990; Ebbinghous 1990). The conclusion was that the enzymatic method gave the most accurate results and these have been compared with the yield results in Table 2.

Table 2

Comparison between starch concentration in the roots at the time of planting and subsequent yield.

Source	Size (mms)	Starch Conc. (mg/g dry wt of root)	Yield (g/plant)
A	10-12	12.0	171
A	12-14	4.1	172
B	14-16	11.4	190
B	10-12	7.8	140
B	12-14	5.9	207
B	14-16	11.0	289
C	10-12	30.0	152
C	12-14	24.4	206
C	14-16	33.4	252
WBed	16	11.5	221
WBed	18	12.6	337
WBed	24	11.1	350

There was no correlation between starch concentration in the roots and subsequent yield from these plants. Starch levels were very high from Source C (24-33 mg/g) and much lower from Source B (5.9-11 mg/g) but there was no significant difference in yield between the two sources for plants with 10-12 mm or 12-14 mm crown diameter. For plants with 14-16 mm crown diameter source B with 11 mg/g starch had a significantly higher yield (at 5% level) than Source C with 33.4 mg/g starch.

Other Carbohydrate Fractions

As mentioned in Materials and Methods various carbohydrate fractions were looked at to see if they correlated with yield.

Table 3

Comparison of various carbohydrate fractions in the crowns with subsequent yield.

Source & Size (mms)	Hemicellulose % dry wt	Cutin % dry wt	Cellulose % dry wt	Lignin % dry wt	Fibre (Acid) % dry wt	Fibre (Amylase) % Dry wt	Yield gms/plant
A 10-12	29.2	3.7	12.9	9.8	8.9	38.1	171
A 12-14	28.4	3.7	14.0	9.0	9.2	37.6	172
A 14-16	32.4	3.5	13.2	10.4	8.6	41.0	190

B 10-12	26.6	4.2	13.2	8.2	10.6	37.2	140
B 12-14	27.0	3.8	13.0	9.0	12.6	39.6	207
B 14-16	30.5	5.1	13.7	10.2	11.8	42.5	289
C 10-12	25.6	3.2	13.5	7.4	10.2	35.8	152
C 12-14	28.2	3.3	13.0	8.8	9.8	38.0	206
C 14-16	33.6	8.5	13.2	8.9	10.5	44.1	252
Wbed 16	34.7	6.9	11.8	9.6	9.6	44.2	221
Wbed 18	36.2	10.7	11.2	9.0	9.5	45.7	337
Wbed 24	32.8	5.7	12.7	10.4	9.0	41.8	350

Table 4

Comparison of various carbohydrate fractions in the roots with subsequent yield.

Source & Size (mms)	Hermicellulose % dry wt	Cutin % dry wt	Cellulose % dry wt	Lignin % dry wt	Fibre (Acid) % dry wt	Fibre (Amylase) % Dry wt	Yield gms/plant
A 10-12	21.3	1.6	15.4	6.9	10.4	31.7	171
A 12-14	26.2	1.7	15.8	8.8	9.7	35.8	172
A 14-16	27.9	2.4	15.4	9.0	10.1	38.0	190
B 10-12	25.1	0.6	16.8	7.3	10.9	36.0	140
B 12-14	27.7	1.6	17.1	8.0	10.0	37.7	207
B 14-16	27.4	0.9	16.8	8.7	11.1	38.5	289
C 10-12	23.4	1.5	14.1	6.5	10.7	34.1	152
C 12-14	25.5	3.2	13.4	7.5	11.1	36.6	206
C 14-16	26.1	6.3	12.4	5.6	10.7	36.8	252
Wbed 16	34.1	4.7	15.7	10.6	10.2	44.3	221
Wbed 18	30.9	3.9	16.7	9.9	11.3	42.1	337
Wbed 24	29.5	1.9	15.9	10.4	10.8	40.3	350

There were no correlation's between the various carbohydrate fractions and subsequent yield. Nor were there any correlation's between the carbohydrate fractions and starch concentration as measured by the enzymatic method.

Nutrient Levels

Levels of major nutrients were analysed in crown and root samples and compared with subsequent yield.

Table 5

Comparison between levels of major nutrients (in crown tissue) and subsequent yield.

Source size (mms)	Total N %	Total P %	Total K %	Total Mg %	Total Ca %	Yield gms/plant
A 10-12	3.14	0.41	1.4	0.34	1.28	171
A 12-14	3.03	0.49	1.65	0.36	1.05	172
A 14-16	2.61	0.33	1.38	0.34	1.17	190
B 10-12	3.24	0.46	1.5	0.38	1.61	140
B 12-14	3.21	0.52	1.78	0.38	0.94	207
B 14-16	2.95	0.52	1.6	0.4	1.0	289
C 10-12	2.47	0.43	1.7	0.4	1.14	152
C 12-14	2.66	0.39	1.43	0.4	0.6	206
C 14-16	2.72	0.38	1.32	0.43	0.66	252
Wbed 16	2.68	0.25	1.27	0.28	1.11	221
Wbed 18	2.68	0.35	2.24	0.26	1.15	337
Wbed 24	2.58	0.30	1.87	0.25	1.29	350

Table 6

Comparison between levels of major nutrients (in root tissue) and subsequent yield.

Source size (mms)	Total N %	Total P %	Total K %	Total Mg %	Total Ca %	Yield gms/plant
A 10-12	3.44	0.35	0.97	0.33	1.15	171
A 12-14	3.18	0.48	1.39	0.4	0.74	172
A 14-16	2.27	0.3	1.31	0.34	1.61	190
B 10-12	3.42	0.43	1.43	0.47	0.68	140
B 12-14	3.71	0.48	1.33	0.47	0.94	207
B 14-16	2.84	0.4	1.09	0.39	1.06	289
C 10-12	2.04	0.28	1.37	0.37	0.5	152
C 12-14	2.02	0.26	1.36	0.39	0.5	206
C 14-16	1.98	0.26	1.25	0.44	0.54	252
Wbed 16	2.52	0.25	0.61	0.21	1.51	221
Wbed 18	2.75	0.27	1.26	0.23	1.45	337
Wbed 24	2.7	0.27	1.39	0.24	1.44	350

There were no definite correlation's between the major nutrients and subsequent yield.

Leaf area

Leaf area measurements were made on the 20 July 1992 one week after harvesting had commenced. This date was chosen to represent the average leaf area per plant during the harvesting period.

Table 7 Average leaf area per plant for each treatment.

Source	Size (mms)	Leaf area cms^2
A	10-12	1504
A	12-14	1505
A	14-16	1460
B	10-12	1000
B	12-14	1290
B	14-16	1333
C	10-12	1413
C	12-14	1360
C	14-16	1724
Wbed	16	1235
Wbed	18	1625
Wbed	24	2296

Source effect

Plants from Source B had a significantly (1% level) smaller leaf area than plants from Source A or C.

Size effect

14-16 mm plants had a significantly (5% level) larger leaf area than 12-14 or 10-12 mm plants.

The leaf area did not always correlate with yield as can be seen in Table 8.

Table 8

Correlation between leaf area and yield. Source leaf area cms^2 (yield gms/plant).

Crown Diameter (mms)	A	B	C
10-12	1504 (171)	1000 (140)	1413 (152)
12-14	1505 (172)	1290 (207)	1360 (206)
14-16	1460 (190)	1333 (289)	1724 (252)

Plants from Source B had the smallest leaf area for each size category of crown diameter but overall had the highest yield. Conversely the 10-12 mm plants from Source A had the largest leaf area for that size category and the highest yield.

The waiting bed plants were more consistent with yield increasing with increasing crown diameter and increasing leaf area (see Table 7).

PICKING DATE

During harvesting it was noticed that although all plants were planted on the same day some treatments had ripe fruit before other treatments. This was analysed statistically to see if these differences were significant.

Table 9

Effect of plant source on picking date. (% Total fruit picked per week).

Date (week beginning)	Source		
	A	B	C
13 July	22.0	15.5	28.5
20 July	37.5	34.0	32.0
27 July	19.5	22.5	19.0
3 Aug.	11.0	16.0	12.0
10 Aug.	8.0	10.0	7.0
17 Aug.	2.0	2.0	1.5
	100	100	100

Picking started significantly earlier on plants from Source C than plants from the other 2 sources (at 0.1% level). In fact as you can see in Table 9 almost twice as much fruit was picked from Source C than Source B in the first week of picking. These differences could still be seen at the 50% pick date, see Table 10. Final pick dates were the same for all sources.

Table 10 50% pick dates.

Source	50% pick date	50% pick (days after planting)
A	25 July	60
B	27 July	62
C	24 July	59

Table 11

Effect of plant size on picking date (% total fruit picked per week).

Date (week beginning)	Size		
	10-12 mm	12-14 mm	14-16 mm
13 July	28.5	21.0	17.0
20 July	35.5	34.0	34.5
27 July	18.0	21.0	23.0
3 Aug.	10.0	14.0	15.5
10 Aug	7.0	9.0	9.5
17 Aug	1.0	1.0	0.5
	100	100	100

Picking started significantly earlier on plants with the smallest crown diameter (10-12 mm) compared with the two larger sizes (0-1% level).

Picking started significantly earlier on plants with 12-14 mm crown diameter than the larger 14-16 mm crown diameter plants (on 5% level).

Block effects

The trial was planted in the middle of a commercial planting of strawberries planted at the same time as the trial. Three raised beds next to one another were used as the 3 blocks in the trial layout. As the whole field had been treated in exactly the same way with all blocks being planted at the same time no block effects were anticipated. However, a block effect was discovered when comparing yields.

Average weight of fruit picked per plant (gms).

Block 1	-	181
Block 2	-	224
Block 3	-	217

Significantly less fruit was picked from Block 1 than from either of the other 2 blocks at the 1% level. This difference amounted to nearly 20% higher yields in Blocks 2 and 3 compared with Block 1. The reason for this difference has not been discovered with any degree of certainty. There was no significant difference in leaf area between the three blocks. It is possible that slightly less water was received in block one leading to some flower abortion.

Flower Numbers

Flower numbers were recorded on all plants in the trial. Truss number, flower number on each truss and total flowers per plant were all recorded.

Table 12

Comparison of flower and truss numbers between treatments.

Source	Size (mms)	Flowers in first truss	Flowers/per plant	Trusses/plant
A	10-12 mm	12.95	18.40	1.65
A	12-14 mm	12.03	15.86	1.45
A	14-16 mm	12.26	17.45	1.65
B	10-12 mm	11.05	13.63	1.37
B	12-14 mm	13.61	16.35	2.24
B	14-16 mm	17.78	22.45	3.00
C	10-12 mm	10.91	14.83	1.46
C	12-14 mm	12.20	23.93	2.36
C	14-16 mm	13.95	28.84	2.70
W.bed	16	16.50	26.90	2.25
W.bed	18	20.05	35.35	2.80
W.bed	24	18.52	43.94	3.58

There were considerable differences between different sizes of plant and different sources of plant for the 3 characteristics; flowers in first truss, flowers per plant and trusses per plant. Many of these were statistically significant as shown below.

Size effects

Crown diameter	Av. flowers/first truss	Av. flowers/plant	Av. Trusses/plant
10-12 mm	11.64	15.62	1.50
12-14 mm	12.62	20.92	2.03
14-16 mm	14.67	26.77	2.45

The difference in Av. flower number per plant between the 3 size bands are all significant at the 0.1% level.

The difference in Av. flowers/first truss are significant between the 12-14 mm plants and the 14-16 mm plants at the 0.5% level.

Source effects

Source	Av. flower/first truss	Av. flower/plant	Av. truss/plant
A	12.42	17.24	1.59
B	14.15	23.53	2.21
C	12.36	22.54	2.18

Plants from Source B had significantly more flowers on the first truss than the other 2 sources at the 5% level. Plants from Source A had significantly less flowers per plant than the other 2 sources at the 1% level.

Flower numbers were then compared with yields.

Source	Size (mms)	Flowers per plant	Flowers first truss	Yield/g plant
A	10-12 mms	18.40	12.05	171
A	12-14 mms	15.86	12.03	172
A	14-16	17.45	12.26	190
B	10-12	13.63	11.05	140
B	12-14	16.35	13.61	207
B	14-16	22.45	17.78	289
C	10-12	14.83	10.91	152
C	12-14	23.93	12.20	206
C	14-16	28.84	13.95	252
W.bed	16	26.90	16.50	221
W.bed	18	35.35	20.05	337
W.bed	24	43.94	18.52	350

As flower number increased in the first truss there was an increase in flower number in the whole plant and an increase in yield however, there was considerable variation. The larger the crown size the more able was the plant to express extra flowers as higher yield.

DISCUSSION

Of all the factors looked at including nutrition, starch, other carbohydrate fractions, % dry wt., crown diameter, flowers on first truss, total flowers per plant and truss number only 2 were found to be reliable indications of yield potential. These were crown diameter and flower number in the first truss. Both of these factors can be measured pre-planting. It was found that a formula involving both crown diameter and flowers in the first truss gave the best correlation with yield.

Predictive model

$$y = [\{f[\{c-7)\ 0.075 + 1]\ M \times P)/1250$$

where y = Av. yield (tonnes/hectare)
f = Av. number of flowers on first truss.
c = Av. crown diameter (mms)
m = Av. wt of one fruit (13 gms)
p = Plant density (000's/hectare)

The accuracy of the model was between 95% and 98% for all of the treatments

The formula was developed slightly further to encompass waiting bed plants and variation in growing conditions to produce a commercial formula.

Formula

$$y = [\{f[\{c-7)\ 0.075 + 1]\ M \times P\}/1500] \times Fp \times Ff$$

where y = Av. yield (tonnes/hectare)
f = Av. number of flowers on first truss
c = Av. crown diameter (mms)
m = Av. wt of one fruit [gms (normal range 11-15 gms)]
p = plant density (000's/hectare)
Fp = plant type factor
Ff = Field factor

Plant Type Factor

The formula was originally designed for graded runners. The plant type factor enables a prediction to be made for other types of plant material.

Plant type		Factor
Cold stored graded runner	-	1.0
Waiting bed (double cold stored) max 2 crowns	-	0.85

Field Factor

To allow for variable weather and grower expertise.

Growing Conditions	Factor
Excellent	1.35
Very good	1.2
Average	1.0
Below average	0.6
Poor	0.4
Very poor	0

N.B. This formula has only been tested for plant densities of 0-20,000/acre (i.e. where inter plant competition is absent).

ACKNOWLEDGEMENTS

The Author gratefully thanks Messrs Brooks for hosting the trial at Gt Hollanden Farm, Underriver, Mr Hugh Lowe for his help in getting this project off the ground in the first place, and Anne Sackree, Scott Raffle and David Caverley for their help with the experimental work.

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