Beetroot Stand Management

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Department of Primary Industries

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Final Report

HAL Project VG 06117

15 May 2012

Beetroot Stand Management

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Yanco Agricultural Institute, and

Bathurst Primary Industries Centre

New South Wales Department of Primary Industries

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Final Report for the HAL Project VG 06117

15 May 2012

Project Leader

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Purpose of the Report

This report contains results of investigations into the stand management of beetroot crops for processing in NSW. The report constitutes the final report for project VG 06117.

Project Team and Authors

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Contents

1 Media Summary

This project was carried out by the New South Wales Department of Primary Industries in response to processor and grower needs to improve the yield and quality of processing beetroot.

Size and variety are two of the main concerns for growers of processing beetroot in New South Wales. Maximum production is required of 50-75 mm diameter beetroot to fit into packaging that appears attractive to consumers on supermarket shelves. Better varieties are always needed that improve the efficiency of production and meet the specifications set by the processor.

In a series of on-farm trials, dense beetroot plant populations were found to be self-regulating. Therefore farmers can plant beetroot in rows to suit their sowing, inter-row, and harvesting machinery with little impact on processing yield. Row spacing had little impact on yield when beetroot was grown to 50-75 mm in diameter.

Farmers and processors need to monitor beetroot size late in the season and organise harvest when the optimum size range is approaching.

Orientation of the rows in an east-west direction resulted in a yield loss of 3-4 tonnes per hectare compared to the southerly-most rows in the three-row bed system used. Cropping should be in north-south orientation if this is possible, to produce more uniform yielding beetroot crops.

A key requirement of any new processing variety is that each seed produces a single plant because most beetroot seeds are actually a cluster of seeds that may produce from 1-5 seedlings. Single seedling seed helps the farmer produce the highest harvestable yield. Several of the varieties tested went close to producing 1-1.3 plants per seed. In addition, these varieties were suitably dark red/purple in colour, and they yielded as well as the industry standard. On the basis of this project, a cooperating farmer switched completely to a newer hybrid variety.

Most of the varieties were globe-shaped, but a cylindrical-shaped variety trialled yielded as well as the industry standard, and could be suitable for the industry except for the need to re-engineer the method of slicing.

2 Technical Summary

Changes in packaging materials from cans to one litre plastic containers meant that processors wanted beetroot 50-75 mm in diameter rather than the 100 mm diameter size traditionally sought. Recent batches of industry standard ‘Detroit Supreme’ variety seed had produced several seedlings per seed (seed cluster) and made it difficult for growers to determine the planting densities needed to produce the highest yield of the new smaller beetroot.

This project was carried out by the New South Wales Department of Primary Industries in response to processor (SPC Ardmona) and grower needs to improve the yield and quality of processing beetroot at Cowra in New South Wales.

Trials were established over three seasons on two grower's farms. On one farm, seed were planted on 1.5 m-wide flat beds with three rows 37 cm apart per bed on flat soil. On the other farm, seed were planted on 0.76 m-wide and 15 cm-high beds with two rows per bed and the seed 10 cm in from each edge of the beds. Densities were established using different within-row spacings (3.8-10.2 cm between seed clusters) and usually five spacings in each season were tested using 20 m beds with three replications. Seed from a range of varieties and testing material was obtained from the major companies selling beetroot seed.

In a series of on-farm trials, dense beetroot plant populations were found to be essentially self-regulating. Higher mortality found when seed were planted at higher densities meant that density had little influence on overall beetroot yield for processing. However, yields were around 30-40 t/ha on the 3-row beds, and 50 t/ha on the 2-row beds but the latter produced a higher proportion of beetroot larger than 75 mm diameter. In this research, process yield was largely determined by the harvest date chosen by the grower. This date was not fixed, but variable, because the main objective was to produce smaller beetroot that met the processors size specifications.

Orientation of the rows in an east-west direction resulted in a yield loss of 3-4 tonnes per hectare from the southerly-most rows in the 3-row bed system used on one farm. In the 2-row bed system on another farm, there were no differences in yield between rows.

A key requirement of any new processing variety is that each seed produces a single plant. This helps the farmer produce the highest harvestable yield. Of the varieties tested, several went close to producing 1-1.3 plants per seed. Depending on the influence of the environment of crop growth and development, these varieties solve the major problem facing the growers-choosing the correct plant spacing to give the highest yield of processing beetroot. In addition, the varieties were suitably dark red/purple in colour, and they yielded as well as the industry standard ('Detroit Supreme'). On the basis of the project, one of the cooperating farmers switched production from 'Detroit Supreme' to 'Pablo'.

Most of the varieties were globe-shaped, but a cylindrical-shaped variety ('Taunus') yielded as well as 'Detroit Supreme'. Yields in different production systems may be increased following some density trials. If yields could be increased, the 'Taunus' variety could be very suitable for the industry, but there would be a need to re-engineer the slicing method in the factory.

3 Introduction

Beetroot (*Beta vulgaris* L.), also known as red beet and table beet, is a fast growing, cool-season biennial root crop grown as an annual. Although its root can be eaten fresh, this report focuses only on processing beetroot. The processing beetroot crop is produced in south east Queensland, central west New South Wales (NSW) and north west Victoria, in areas located close to the beetroot processing factories.

The main NSW growing area is centred on the town of Cowra, as the warm, dry summers and cool, wet winters produce high quality beetroot. This particular project was undertaken in the Cowra area. Although Cowra has a local beetroot cannery, SPC Ardmona from Shepparton in Victoria was the cooperating processor.

The project was initiated following the convergence of two major events. The first event was the planned entry of a supermarket chain wishing to source high quality beetroot of a smaller size (30-75 mm diameter) than the usual 100 mm diameter size that was then popular. SPC Ardmona wished to place smaller beetroot slices in a 1 kg polyethylene ‘Fridge Pack’ to supply the supermarket chain. Secondly, there was a change in the quality of the beetroot seed supplied to Australian growers that contained multigermed seed. The convergence of these events caused problems for growers, and consultations with industry and funding bodies led to the initiation of this project. A similar project was started about the same time in south east Queensland, to deal with the likely different growing environments and varieties there. That project (VG05083) was lead by the major processor of the region and has remained confidential.

Size, shape, and soluble solids content are the major factors limiting the factory recovery of beetroot by processors. Recent changes in market requirements mean that seed planting density is crucial to the continued competitiveness of the beetroot industry. Complicating the establishment of suitable beetroot crop stands is seed containing multiple germs in fruiting bodies called seed clusters, seed balls or corks.

A further challenge affecting beetroot growth is climate change, especially increases in air temperature. This requires the further determination of correct planting dates to ensure crops will be an appropriate size and shape at harvest for processing.

4 Project Objectives

The project had the following original objectives:

1. To identify the best plant density to optimise the yield of ‘Detroit Supreme’ beetroot in the 30-75 mm diameter range,
2. To assess suitable beetroot varieties for southern Australia, including monogerm types,
3. To understand the role of seed germination as a factor controlling beetroot yield,
4. To trial herbicides for thinning plant stands at early growth stages,
5. To trial herbicides for controlling late season weeds, and
6. To investigate betacyanin pigment levels in beetroot varieties.

The project started with a particular emphasis on objectives 1 and 2. The cooperating farmers and processor wanted beetroot within the desired size range first and foremost. They also wanted a variety with a more uniform seed size than ‘Detroit Supreme’ to help meet the size objectives. Given that the root size would be smaller and so the yield per hectare lower, the growers also wanted to investigate varieties that had higher yields. Cylindrical beets were therefore included in the variety trials even though the use of such varieties may require retooling of the processor’s slicing operation.

During the project changes in the economy occurred and the processing partner opted to stop processing beetroot after the second year of the project. After the partner withdrew, and following consultation with the cooperating growers, the project continued with objectives 1 and 2, with some experimentation in objective 3.

Objectives 4-5 did not receive any further attention. These objectives were thought to be of concern during project planning as the industry was gearing up for an expansion phase, and new land was going to be brought into production. However once economic changes forced the industry to contract, the imperatives for objectives 4-6 were removed. A variety trial and two density trials were planted on one farm in 2010, but poor establishment due to rain-induced waterlogging meant the crop was not suitable for analysis. In an attempt to make up for the loss, an additional variety trial was planted on a new site in November 2010. However, this too was not suitable for harvest, as excess herbicide was applied during seeding and this reduced seedling vigour and killed several plots. To compensate for omitting the herbicide trials, during 2011 an extra set of variety and density trials were planted.

Rather than specifically investigate betacyanin pigment levels in beetroot varieties (Objective 6), flesh colour was routinely monitored, as part of the variety evaluations.

5 Literature Review

5.1 The processing industry

The bulk of the Australian beetroot industry was centred in south east Queensland, where 25,000 t or 80% of total Australian production occurred in 2006. Cowra in NSW produces around 3000 t (10%) and the rest is produced at Swan Hill in Victoria. The canning industry produces processed slices and baby beets, with fresh-cut processors using leaves for salad mixes.

5.2 Beetroot classification

Beetroot are herbaceous plants in the botanical family Chenopodiaceae, harvested for thousands of years for its leafy foliage. Cultivated varieties are thought to have arisen from the sea beets (*Beta vulgaris ssp. maritima*) (Nottingham, 2004) found along the Mediterranean and coastal areas of Europe and North Africa. Over time, selection for traits such as the swollen root, deep colour, and sweetness, resulted in the development of the modern forms of this vegetable (Goldman and Navazio, 2003; McGrath et al., 2007). Modern cultivated varieties are classified as *Beta vulgaris* L. subsp. *vulgaris* (Lange et al., 1999) and include the leaf beet, garden beet, fodder beet, and sugar beet cultivar groups.

5.3 Beetroot botany and germination

Cultivated beets are propagated from seed. Botanically, a table beet seed is a fruit, termed a “seed ball” (Hayward, 1938). When the seed ball forms by the aggregation of multiple flowers, as is typical in cultivated beets, a multigermed fruit is produced from which one or more true seeds can germinate. The multigerm (also known as polygerm) property of beetroot seed has long been recognised as a significant issue in producing roots of an even size, shape, and harvest maturity. It affects factors such as germination rates and planting density, which in turn affects growth and subsequent quality characteristics of the roots. Development of monogerm beet seeds began in the early 1900’s in an attempt to overcome these problems, however it was not until the 1960’s that commercial monogerm cultivars became available (Meikle, 1981; Nottingham, 2004) with most of this work focussing on sugar beet rather than beetroot. Although some monogerm varieties are available for garden beet, Australian growers utilise polygerm seed for economic reasons. This means that the plant density issues are still relevant in the low-cost, low-input processing beetroot industry today.

Polygerm seeds can have up to five or six true seeds within the seed ball, although not all of these may germinate if planted. This results in difficulties in obtaining evenly spaced stands. Seed germination is also not uniform, occurring over several days (Khan et al., 1983; Taylor et al., 2003) and is a major factor causing non-uniformity in maturity and size of roots at harvest (Wolyn and Gabelman, 1990). Nottingham (2004) reported that beetroot seed has a relatively low germination rate and, in agreement with Taylor et al. (2003), attributes this to three reasons. The first reason is the mucilaginous layer surrounding the seed ball. The second is the presence of the ovary cap, which affects the movement of both water and oxygen into the embryo (Meikle, 1981). Thirdly, is the presence of seed inhibitors in the seed ball. Decortication (the removal of the corky surface, Peck et al., 1967) has been instrumental in providing more uniform sized seed for planting using precision seeders. This occurs by reducing the seed ball to single seed size and decreasing the mucilaginous layer and some seed inhibitors. However, decortication cannot completely eliminate poor germination due to non-viable seed or variability in seed vigour.

Tests have been devised to evaluate the physiological quality of seeds as a means of predicting field performance, with seed viability (germination capacity) and seed vigour (physiological potential i.e. emergence speed and percentage) the primary methods used. For example, TeKrony and Hardin (1969) showed that field emergence and laboratory germination of sugar beet were similar when the treatment included a 16 hour hydrogen peroxide (0.1%) soak ($P>0.05$) compared to a 12 hour water soak and germination on blotting paper ($P<0.05$). Seed sizing can determine seed viability and vigour following decortication, with larger seed size being an indicator of increased germination levels (Akeson et al., 1981; Milosevic et al., 1992; Peck et al., 1967). Longden et al. (1974) devised a size grading method which reduced polygerm, small, and non-viable seed. However, this method has limited application due to variations in seed lot caused by variety and seed production conditions. More recently, Redfearn and Osbourne (1997) reported a new seed vigour test, which was not dependent upon fruit size at all. It was based upon the relationship between laboratory germination rate and the seed RNA:DNA ratio, eliminating some of the afore-mentioned concerns. There are no reports, however, as to whether this test can be utilised to reduce the variability in seedling germination rates.

Seed priming methods, such as a pre-plant soaking in water, osmotic, salts, or sand at various water contents (Nirmala and Umarani, 2008), can assist greatly in increasing the germination rate of beetroot through the controlled hydration of the seed. However, more recent research gives a strong indication that oxygen availability is also important. Nottingham (2004) describes the process whereby water and oxygen play an interactive part in seed germination, through the seed ovary cap and mucilaginous layer. Taylor et al. (2003) demonstrated that upon removal of the seed cap, germination rates increased significantly – particularly in those with a mucilaginous layer. The priming methods have each been tested with beetroot seed, and have produced improvements in germination rates (Braun et al., 2010; Khan et al., 1983; Lee et al., 2004; Nirmala and Umarani, 2008). However, whilst Taylor et al. (2003) and Nottingham (2004) both discuss the three seed factors influencing germination, neither they nor successive researchers draw linkages between seed priming methods and their effect on these factors. To date there is no scientific agreement on which priming options(s) provide the best outcome for beetroot producers; only that their use speeds the germination process through phase I and II of imbibition, so that the seed enters phase III immediately upon hydration after sowing.

The physiological potential of seed is sometimes determined by percentage germination following accelerated aging. This aging can be undertaken by suspending seed above a moisture source for various times. Silva et al. (2006) investigated the effect of accelerated ageing of beetroot seed on the germination rate and reported a noticeable reduction of germination percentage after 72 hours of ageing. These results show an impact on the storage potential of seeds, and ageing may well have contributed to the differing germination and field emergence rates observed by Bralewski and Holubowicz (2008) when comparing seed lots from various companies.

5.4 Agronomic factors affecting production variability

Soil nutrient levels, irrigation, and environmental conditions can affect both the development of seed on the mother plant and the germination rate and seedling vigour upon planting. Catusse et al. (2008) claimed that the preparation of the seed for germination (in sugar beet) is mainly achieved during it's maturation on the mother plant. Therefore production in the seed-bearing phase requires as careful management as does the root production phase. Although beetroot show a tolerance to a wide range of soil conditions, nutrients such as nitrogen, sodium, potassium, and phosphorus are needed to be kept at optimum levels. Availability of nitrogen is the most important factor in terms of nutrients (Nottingham, 2004), as this element has a substantial but variable uptake by beetroot. While nitrogen fertilisation can significantly increase yield (Feller and Fink, 2004; Lee et al., 1971), it can also be financially and environmentally costly. Feller and Fink (2002) devised a model to predict total nitrogen uptake based on the expected yield for table beet, thus assisting in developing a balance between fertiliser costs and benefits.

Irrigation is required to maximise crop yield, by providing an even growth rate throughout the season. Moisture is required for seed germination, as discussed previously, however excess water can restrict gas exchange within the seed during germination. Once the plant has emerged, prolonged dry conditions can limit plant growth and yields (Hoffmann, 2010). Overwatering can result in excessive leaf growth at the expense of root growth, leach nutrients away from the roots, and facilitate disease development (Nottingham, 2004).

Temperature is another parameter which can affect size or shape of beetroots. The majority of varieties grow best in a cooler climate with average daily temperatures between 15 and 19 °C. In their study on sugar beet in Germany, Kenter et al. (2006) reported that for taproot growth, the optimum mean daily air temperature was approximately 18 °C, corresponding to maximum daily temperatures between 22 and 26 °C. This was significant because it was the first study done under field conditions rather than under controlled conditions. Temperatures below 10 °C can cause the plant to shift from vegetative to reproductive growth, resulting in the root shrinking, while temperatures above 25 °C cause smaller roots due to the reduced storage of nutrients. The texture and flavour of the roots may also be impaired at these higher temperatures. The availability of varieties such as 'Crimson Globe' and 'Detroit,' which are tolerant to warmer climates, overcomes these issues and allows production to occur almost all year round in the varied climates throughout Australia. Most plantings in NSW occur in the later part of summer, when higher temperatures predominate during early plant growth and root development.

5.5 Planting density

Spacing between plants, or the density of seed plantings, is likely to be the most significant factor for controlling root size of beetroot. Indeed the previously discussed factors all ultimately impact on the density of the plant stand. As only a certain root size group is considered desirable or marketable (depending on intended function or use), the challenge is to maximise the production/yield of the desired root size group. Through knowledge and manipulation of the effects of germination and plant density on production and yield of beetroot, the root size of 30-75 mm diameter (down from about 100 mm) desired by Australian growers, producers and retailers can be achieved.

Non-uniformity of germination results in initial variability of the plant number, plant density, and to a lesser extent root sizes during the earlier stages of crop development i.e., under 85 days (Khan et al., 1983; Taylor et al., 2003). This may still be true despite employing the techniques discussed above to improve seed viability and vigour. As the crop develops to commercial maturity, the range in root size becomes more pronounced, with small, relatively undeveloped/unthickened roots, as well as medium sized and large roots. While plant density has been identified as a major contributor to this size-range phenomenon (Liere, 1984; Mack, 1979), other factors such as nutrients and environmental conditions also play a role.

It is unclear as to why some roots develop fully whereas growth is arrested in others. Plant hormone signalling between the roots is one possible explanation. By the 1950's it was well recognised that for many crops, close spacing reduced the size of individual plants (Warne, 1951). However, details on the stage(s) where the plant-interactions become significant were not investigated.

Warne (1951) found that for the variety 'Crimson Globe', 2 inches (5.08 cm) was the optimal thinning distance (at approximately 8 weeks post-sowing) to achieve the largest number of roots of an acceptable size, which at that time was 1½ to 2½ inches (3.8 to 6.4 cm) in diameter. From this experiment it was noted that at the first harvest, the yield of roots per plot was almost directly proportional to the number of plants present. However as the season progressed, this became less so, and the mean root weight became increasingly related to the space available per plant. Warne (1951) concluded that close spacing within the rows gave a better yield of desirably-sized beetroot.

Mack (1979) looked at the effects of row spacing, fertiliser, and harvest dates on table beets, and identified the different effects of between-row spacing from within-row (plant density) spacings. Mack established that harvest dates and row spacings were most important - as row spacing was reduced, yields of small roots (<25 mm, and 25-51 mm) increased, while yields of large roots (76-102 mm and >102 mm) decreased. With a slight delay in the harvest date of beets from narrow-spaced rows, similar root size distributions can be obtained to those from wider rows, with increases in total yield as well. Thus it was economically viable to decrease within-row spacing, and utilise an increase in growing time to harvest to offset the otherwise resulting smaller total yield.

Benjamin et al. (1985) further examined the effects of within-row spacing and sowing rate, and found that when plant spacing was less than 5 cm, self-thinning was more marked. The authors postulated that distance to the nearest plant (density) was more important than between-row spacing. Maximum yield of small beet per unit area was achieved with high plant densities, while maximum yields of large beet were achieved at low plant densities. Interestingly, the researchers also found little evidence that plant density affected beet shape, although they found some examples, as did Peck and Wilczynski (1967, cited in Benjamin et al. 1985), that suggested mutual distortion was due to the close presence of neighbouring beets. This may be a characteristic of European cultivars (Goldman and Navazio, 2003).

Benjamin et al. (1985) also noted that variation in plant weight increased with plant density. The researcher showed in a following experiment (Benjamin, 1987) that this variation was due to a hierarchy of plant sizes caused by competitive interactions between plants, but noted that the variation in plant weight did not increase consistently with duration of growth. Competitive interactions between neighbouring plants must not be underestimated with closely planted stands such as beetroot. It is highly possible that those plants emerging earlier than others, as well as those with a comparatively increased vigour, are able to establish a well-developed root system supplying the storage root, and thus depleting the nutrients available to surrounding plants. Width and depth of roots, and plant-plant signalling are areas which, once investigated further, may bring to light important information regarding interactions amongst dense beetroot stands.

Most recently, Kikkert et al. (2010) investigated the effects of row width, population density, and harvest date on the marketable yield of table beet. They tested only the row widths that were achievable using currently (US) available field equipment: an important consideration for any scientific research is the practicality and feasibility of applying the research results. However, this meant that they did not investigate row widths less than 18 inches (45 cm), which was the focus for many other researchers.

From the information gained throughout decades of research, it can be concluded that there is a range of beetroot planting densities whereby a high yield of marketable root weights and sizes are produced. Densities less than and greater than this range reduce production efficiency. There are variations between globe and cylindrical varieties, as well as within these varieties, and the likely best course of action to determine the optimal density for production of 50-75 mm diameter roots is to test the locally grown varieties in fields representative of the various Australian production farming systems and areas.

5.6 Beetroot varieties

Variety is usually an important factor in beetroot production, with most of the varieties processed in the United States (US) and Australia are now probably related to the ‘Detroit’ line. The ‘Detroit’ line was first produced in the US in 1892, with ‘Detroit Dark Red’ listed as an heirloom variety, and 'Perfected Detroit' winning the 1934 All-America Selections (an American group promoting and regulating variety development) Board prize. ‘Detroit Supreme’ was released in the 1980’s with better disease resistance (Nottingham, 2004). Obviously there was room for improvement with the introduction of more modern varieties for Australian growing systems, especially with the increase in newer hybrid varieties. Goldman and Navazio (2003) describes the founding table beet populations in the US and descriptions of other available varieties have been produced by Goldman (2010), Nottingham (2004), and Oregon State University (2004). The varieties available within Australia, however, are much more limited, as selections are usually imported from Europe or the US.

Apart from pest and disease resistance and yield, the key varietal characteristics for processing beetroot are regular globe shape (Barański et al., 2001), uniform dark red colour without any white rings or flecking (Watson and Goldman, 1997), and high soluble solids contents (mainly to reduce the requirement to add sugar (and add to costs) prior to canning).

Most of the varieties available in Australia are globe-shaped. These are readily sliced using the commercial slicing machine in the SPC processing factory. Varieties used for processing include ‘Detroit Dark Red’, ‘Detroit Supreme’, ‘Eagle’, ‘Pablo’, and ‘Lion’.

However, cylindrical beets are also of interest as the requirement for smaller beetroot means that yields and returns to the farmers will be lowered. Cylindrical beets offer the opportunity to produce a suitable diameter of beet, but with a longer root so the yield of processed root can be increased to compensate for the lower yield of globe-shaped beets. Goldman (1995), in a study on the effect of population density on shape and size of cylindrical beet genotypes, found that population density has a differential and significant effect on the shape and size of cylindrical beet genotypes. In general, however, greater harvest weights, a higher percentage of harvestable beets, and greater shape measurements (length, middle width, and length x width) were achieved at low plant densities. Goldman determined that additional investigation was required to determine the optimal population densities for maximum production of small size grade cylindrical beets. Varieties of cylindrical beet include ‘Taunus’, ‘Cylindra’, and ‘Forono’.

While there are also varieties with a range of colours (Gasztonyi et al., 2001; Wolyn and Gabelman, 1990), dark red/purple is the desired colour for processing. Although there is genetic variation, and pigmentation is higher on the outer zones of the root (Gaertner and Goldman, 2005), environment also has an influence on colour intensity. Cooler growing conditions are more conducive to darker pigmentation (Sistrunk and Bradley, 1970; Takacs-Hajos, 2009), and to soluble solids accumulation (Sistrunk and Bradley, 1970).

5.7 Healthy beetroot

The characteristic deep red colour of the root is due to water-soluble nitrogen-containing pigments called betalains, which are comprised of red-violet betacyanins and yellow betaxanthins. These pigments can provide, at times, alarming colours in urine (Watts et al., 1993) and faeces (Cserni and Kocsis, 2008; Handysides and Handysides, 2005). These betalains may provide antioxidant and anti-inflammatory effects of broad, significant medical value (De Azeredo et al., 2009; Kujala et al., 2000; Lee et al., 2005; Nottingham, 2004; Song et al., 2010; Stintzing and Carle, 2007; Wettasinghe et al., 2002).

Beetroot are also rich sources of nitrate (Santamaria, 2006) that may have adverse or beneficial effects. Beneficial effects are through lowering of blood pressure (Webb et al., 2008), and increased efficiency of mitochondrial energy production that can reduce oxygen consumption during exercise (Bailey et al., 2009; Larsen et al., 2011).

The red colouration and health benefits of beetroot are positive attributes for the food industry into the future, when what is currently seen as an “old” vegetable, could be re-evaluated by the younger generations. The “earthy” flavour, due to geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol), could be genotype and/or environment related (Acree et al., 1976; Lu et al., 2003a; Lu et al., 2003b), and its removal through breeding may also improve the consumption of beetroot.

6 Materials and Methods

6.1 General Methods

6.1.1 Experimental sites and management

The experimental field trials were conducted on commercial beetroot farms near Cowra in New South Wales. On farm 1 (DEL), the trials were planted on a silty loam, floodplain soil. On farm 2 (PAC), the trials were sown on a clay loam, alluvial soil.

The trials were planted in the centre of commercial crops on both farms using the same commercial planting equipment, contractor, and sowing time as the farmer co-operators. The trials were grown under normal commercial management practices (with no hand thinning done), and herbicides, fertilisers, and irrigation were managed by the farmer co-operators. Water was applied with solid-set (farm 1) or linear move (farm 2) overhead sprinklers.

Fertiliser applications were typically 160 kg/ha of Rustica Plus (Campbells Fertiliser Australasia, Laverton North, Victoria) containing 12% nitrogen, 5.2% phosphorus, 14% potassium, 8.3% sulphur, 4.5% calcium, 1.2% magnesium, 0.1% zinc and 0.02% boron (according to label). Pre-emergent weeds were controlled with label recommendations of ethofumesate (500g/L) as Tramat® 500SC (Bayer CropScience, Hawthorn, Victoria) or Matrix® 500 (Farmoz, St Leonards, NSW). Post-emergent grasses were controlled with herbicides, and broadleaf weeds with tillage.

6.1.2 Plant material

For the plant density trials, 'Detroit Supreme' seed, a selection of 'Detroit Dark Red', was obtained from Terranova Seeds. For the variety trials, seed were obtained from a number of seed companies and planted as supplied. The seed was supplied pre-treated with fungicides, usually Thiram, Iprodione, Metalaxyl, or combinations thereof.

6.1.3 Seeding

Seed were planted at 10-12 mm depth at different within-row spacings and planting dates using a Gaspardo (Morsano al Tagliamento, Italy) V12 series precision planter (Fig. 6.1).

Figure 6.1 Gaspardo precision vacuum planter.

On farm 1, seed were planted on 1.5 m-wide beds with three rows 37 cm apart per bed on flat soil (Figure 6.2). On farm 2, seed were planted on 0.76 m-wide and 15 cm-high beds with two rows per bed and the seed 10 cm in from each edge of the beds.

As the seed were sown in randomised blocks, seed were removed from the hoppers after each plot was sown in the variety trials. The gearing needed to be adjusted after each plot to allow for the range of within-row spacings in the density trials. Replicate plots were approximately 20 m-long for the density trials and 8 m-long for the variety trials.

6.1.4 Harvest and handling

In one variety experiment, 10 plants were harvested per plot throughout the season to determine the pattern of fresh and dry weight growth. Plants were randomly selected, placed in plastic bags, and then placed in a cooler with ice until returned to the laboratory for weighing and drying.

At commercial harvest, all plants were hand-pulled from 1 m length of the variety trials. For the density trials, 2 m lengths of each plot were hand-harvested, and plants from each of the three rows were placed into separate nylon bags (Fig. 6.3). Bags were loaded onto a trailer and transported back to the laboratory at Yanco (4 hours drive). Bags containing beets were washed under a stream of running tap water to remove adhering soil, and held at ambient temperature (12-18 °C) during the processing period (14 days) in 2008, and at 5 °C in 2009-2011. Beets were warmed to 20 °C overnight prior to any quality measurements.

Figure 6.2 Seeding beetroot plots.

Figure 6.3 Beetroot hand-harvested from plots into nylon bags.

6.1.5 Measurements

6.1.5.1 Plant populations

Two weeks after sowing, the numbers of seedlings in a 1.5 m length of a uniform row of each plot were counted. The numbers of seedlings emerging from the same seed cluster (as judged by close proximity of the seedlings) were also counted and recorded.

The singularity ratio (SR) was calculated as:

SR = number of plants/ number of seed clusters.

6.1.5.2 Root weights

After harvest, bags with beets were weighed, then tops were removed from the roots and the roots weighed again to enable calculation of tops and roots weights.

6.1.5.3 Root dimensions

For density trials, the length of the longest diameter on a root, the length of the shortest diameter, and the length of the root (from the crown to the base of the root where the root emerges) were determined using digital callipers (Model 64-012-10 Series 264 PC data input device, Mitutoyo Corp., Kawasaki, Japan).

A circularity index (CI) was calculated as:

CI = 100*(width of wide diameter – width of narrow diameter)/(width of wide diameter).

The larger the difference between the diameters, the higher the index, and the more oval-shaped the root. If CI = 0, the diameters were the same, and the beet was round.

The numbers of roots with diameters greater than 30 mm were determined. For the variety trials, additional measurements were the length of the longest petiole and attached leaf blade, determined using a ruler placed on the laboratory bench and against the leaf.

6.1.5.4 Colour and soluble solids (variety trials)

After these measurements, 10-20 beets per replicate with narrow diameter greater than 30 mm and less than 100 mm, were randomly selected from each plot and sliced. A chroma meter (CR-400, Konica Minolta Sensing, Osaka, Japan) reading was taken at three random positions 15 mm from the edge of each slice, and average values recorded using the CIE L*, a*, and b* colour space, CIE illuminant source C, 2° observer angle.

Immediately after colour measurements on each plot, slices were juiced for 10 seconds with an industrial blender (800JE, Breville, Sydney). The juice was filtered through Whatman No 1 filter paper, and a few drops of juice were taken for triplicate readings of total soluble solids concentration (°Brix) using a digital refractometer (PAL-1, Atago, Tokyo, Japan).

6.1.6 Planting density trials

Within-row spacings were set on the seeder (Table 6.1) and no thinning was undertaken. This pragmatic approach was done to ensure the results reflected commercial practice. Due to poor establishment, 'Detroit Supreme' data for 2010 and 2011 are not presented.

Table 6.1. Within-row spacings used for 'Detroit Supreme' (DS) and 'Pablo'.

Year	Variety	Farm	Planting Number.	Within-row Seed Spacing (cm)				
2008	DS	DEL	1	3.8	4.4	4.8	5.4	6.1
2008	DS	DEL	2	3.8	4.4	4.8	5.4	6.1
2009	DS	DEL	1	4.1	5.1	6.1	7.1	8.1
2009	DS	PAC	1	4.1	5.1	6.1	7.1	8.1
2011	Pablo	DEL	1		7.6	8.2	9.2	10.2

6.1.6.1 Planting dates

Details of planting dates are shown in Table 6.2. 'Detroit Supreme' was planted in 2010 and 2011 but due to poor establishment, these are not included in the table.

Table 6.2. Planting and harvest dates for plant density trials using 'Detroit Supreme' (DS) and 'Pablo'.

Year	Variety	Farm	Planting Date	Harvest Date	Growing Days
2008	DS	DEL	12 Feb	27 May	105
2008	DS	DEL	26 Feb	17 July	140
2009	DS	DEL	10 Feb	19 June	129
2009	DS	PAC	27 Feb	19June	112
2011	Pablo	DEL	3 March	14 July	133

6.1.6.2 Experimental design and data analyses

The spacing experiment used a randomised complete block (RCB) design with three replications. Each block was a separate row though there were no known spacial variations in the site. Planting date and spacing data were analysed as a factorial RCB design with three replicate blocks. Where two planting dates were undertaken, the planting area was about 200 m apart. Where one planting occurred on one date, an RCB design was used. Where within-row variation in yield was assessed, a split plot analysis was used where within-row spacing was the main plot, and plot row the split plot. All outputs were checked to ensure the data were normally distributed.

6.1.7 Variety assessment

Varieties planted are shown in Table 6.3. Although most varieties were planted with 3 three replicates, some were planted with single replicates for observation only, and not all varieties were used in all years. As a result of the 2008 variety trials, varieties were assessed against the industry standard 'Detroit Supreme' using a selection of their agronomic properties. Varieties that were judged to be an improvement on the standard were retained for next season's trials. In addition, some varieties were deleted by seed companies and new lines were supplied, and these were generally assessed in observation plots.

Table 6.3. Beetroot varieties used in all trials and seed company providers. Varieties grown in single observation plots only are denoted with *. The varieties listed below the lines dividing the table in two indicate those that were used only once.

Variety	Seed Company	Variety	Seed Company	Variety	Seed Company
2008		2009		2011	
Pablo	Bejo Seeds	Pablo	Bejo Seeds	Pablo	Bejo Seeds
Red Cloud	Bejo Seeds	Red Cloud	Bejo Seeds	Red Cloud	Bejo Seeds
BEE 6006	Fairbanks Seeds	BEE 6006	Fairbanks Seeds	BEE 6006	Fairbanks Seeds
		BEE 7007	Fairbanks Seeds	BEE 7007*	Fairbanks Seeds
Detroit Supreme	Terranova Seeds	Detroit Supreme	Terranova Seeds	Detroit Supreme	Terranova Seeds
TBT 9116	Terranova Seeds	TBT 9116	Terranova Seeds	TBT 9116	Terranova Seeds
		TBT 9117	Terranova Seeds	TBT 9117	Terranova Seeds
		Eagle	Lefroy Valley	Eagle	Lefroy Valley
BTT 5849*	Lefroy Valley	BTT 5849	Lefroy Valley		
Lion*	Lefroy Valley	Lion	Lefroy Valley		
247-4*	SPS	247-4	SPS		
Action (F1)	Bejo Seeds	Darko*	SPS	BTT90293	Lefroy Valley
Boro (F1)	Bejo Seeds	BTT 5868*	Lefroy Valley	Taunus	Bejo Seeds
Rhonda (F1)	Bejo Seeds	BTT 5869*	Lefroy Valley	Bettollo	Bejo Seeds
Red Comet	Fairbanks Seeds			BEE 0014*	Fairbanks Seeds
New Globe	S&G Seeds			BEE 0015*	Fairbanks Seeds
Crimson Glory	Terranova Seeds			Forono	Mr Fothergills
Early Wonder					
Tall Top	Terranova Seeds			Cylindra	Yates Seeds
TBT 9114	Terranova Seeds				
TBT 9115	Terranova Seeds				
Orbit	SPS				
246-4*	SPS				
696-5*	SPS				
BTT 6462*	Lefroy Valley				

Of the varieties in Table 6.3, most were globe-type varieties, but 'Taunus', 'Forono', and 'Cylindra' were cylindrical beets (Figure 6.4).

Figure 6.4 Globe and cylindrical beetroot.

6.1.7.1 Planting dates

The planting and harvest dates for variety trials are given in Table 6.4. In general, planting was in the later part of summer to allow rapid early growth, and for the growth to slow as winter approached, thus limiting the extra growth if rainfall delayed harvest. In addition, sugar accumulated more in the cooler weather.

Table 6.4. Year, farm, planting and harvest dates, and number of growing days for plantings of beetroot varieties.

Year	Farm	Planting Date	Harvest Date	Growing Days
2008	DEL	12 Feb	27 May	105
2008	DEL	26 Feb	17 July	140
2009	DEL	19 Feb	9 July	140
2009	PAC	27 Feb	1July	124
2011	DEL	3 March	14 July	133

6.1.7.2 Germination and singularity assessment

In January 2009, 50 seed clusters taken at random from seed packets, were placed on Petri dish plates. The varieties used were ‘Pablo’, ‘Red Cloud’, ‘BEE 6006’, Crimson Glory’, ‘Detroit Supreme’, ‘TBT 9116, ‘247-4’, ‘Lion’, ‘Eagle’, ‘TBT 9115’, ‘246-4’, ‘BTT 5849’, and ‘Taunus’. The suppliers are listed in Table 6.3. The dishes were lined with 2 sheets of Whatman No. 1 filter paper, sufficient distilled water added to saturate the filters, and the dishes and seed were placed in an incubator (Labtech fan-forced oven with BTC-9090 temperature controller, Marrickville, NSW) set at 25 °C in darkness. Twice daily for 2 days, then daily thereafter, filters were re-wet and emerged seedlings counted. Emergence was judged when the radicle was at least 1 mm long (Figure 6.5).


Figure 6.5 Germination from seed clusters.

In May 2009, 4 replicates of 25 seed clusters were placed on Petri dishes as above, and the germination monitored for ‘Pablo’, ‘Red Cloud’, ‘BEE 6006’, ‘Detroit Supreme’, ‘TBT 9116’, ‘Eagle’, ‘TBT 9117’, ‘BEE 7007’, ‘BTT 90293’, ‘Taunus’, ‘Bettollo’, ‘Cylindra’, ‘Forono’, ‘BEE 0015’, and ‘BEE 0015’.

In 2010, emergence of seedlings from single seed clusters planted into single plant cells was assessed in the glasshouse under ambient conditions (Figure 6.6).

The varieties selected were ‘Detroit Supreme’, ‘Eagle’, ‘BEE0014’, ‘Forono’, ‘BEE7007’, ‘Pablo’, ‘BEE0015’, ‘Bettollo’, ‘Taunus’, ‘Red Cloud’, ‘Cylindra’, ‘BEE6006’, ‘TBT9116’, ‘BTT90293’, and ‘TBT9117’.

Seed were randomly selected from the seed source and tested in three replications of 25 clusters run in time (23 May, 21 June, and 19 July in 2010). Single seed clusters were sown into a general purpose composted pine bark potting medium (Debco, Tyabb, Melbourne), and watered daily for 21-24 days after planting. The number of seedlings per plant cell was then counted and the mean number of seedlings per seed cluster computed. Polynomials were fitted using percent germination as the independent variable, and days as the dependent variable. Goodness of fit tests (adjusted R^2 and Akaike's Information Criterion (AIC)) were used to determine the appropriate level of the polynomial, and the data were tested for normality.

Figure 6.6 Determining singularity from single seed clusters in plant cells.

During growth of the crops on two farms in 2009, four harvests were carried out to determine the pattern of plant growth, and to determine whether there were differences by variety. Ten plants were hand-harvested at random from each plot, the plants were placed into plastic bags and then stored in an insulated container with ice until the weights were determined at the laboratory the following day. Fresh weight of the 10 plants per plot were determined. The data were analysed using non-linear (polynomial) regression, with day, or day and variety as the independent variable(s). The dependent variables were Log_{10} transformed to ensure the standardised residuals were normally distributed.

6.1.7.3 Experimental design and data analyses

The variety assessment and planting date experiments were randomised block designs with three replications. Each block was a separate bed of three rows on farm DEL, and two rows on farm PAC. Seed clusters were planted at different between-plant spacing for each experiment, based on what the farmer co-operator chose.

Yield data were analysed by analysis of variance (ANOVA) using a completely randomised block model. Sequential samples taken for analysis for fresh and dry weights during one season were analysed by non-linear regression. The glasshouse emergence and singularity data were analysed by ANOVA using a completely randomised design model, and non-linear regression. Significance between treatments was determined using the Least Significant Difference (LSD) test at the 5% level, or Tukey’s Honestly Significant Different (HSD) test, also at the 5% level. All residuals were checked to ensure normality of the data.

Statistical analyses were undertaken using Statistix 9 (Analytical Software, Tallahassee, USA) software.

7 Results

7.1 To identify the best plant density to optimise yield of beetroot in the 50-75 mm root diameter size range

7.1.1 2008 Trials

Some of the plants that emerged did not survive through to harvest (Figure 7.1). In planting 1, although there was a 25% reduction in numbers of plants growing through to harvest, there was no significant density effect. In planting 2, there were slightly more plants at emergence than in planting 1, but again, not all plants survived through to harvest, and there was no density effect at harvest.

Planting distance had no effect on numbers of seedling plants per cork (seed cluster), and in general, 1.3-1.5 seedlings emerged from each seed cluster (Figure 7.2).

Length of the longest leaf blade was determined at harvest for each plant, but there was no effect of density or planting date, and no consistent effect of density on circularity of the beetroot (Figure 7.2).

There was no significant effect of planting distance on total yield in either planting. Average yields were 35 tonnes per hectare (t/ha) for planting 1, and 41 t/ha for planting 2. In both plantings there was a trend towards higher total yield in the northern-facing rows of each bed. This is probably due to increased light interception and access to water and fertiliser from the tractor wheel rows.

Approximately 48-58% of beets in both plantings attained 50-75 cm root diameter (Figure 7.3). As planting distances got closer, approaching 3.8 cm, there was a slight reduction in the proportion of larger beets and a correspondingly slight increase in the number of smaller beets.

Soluble solids concentrations in harvested beet were not influenced by planting distance, although concentrations were slightly higher in planting 2. Nevertheless, soluble solids concentrations were satisfactory for processing.

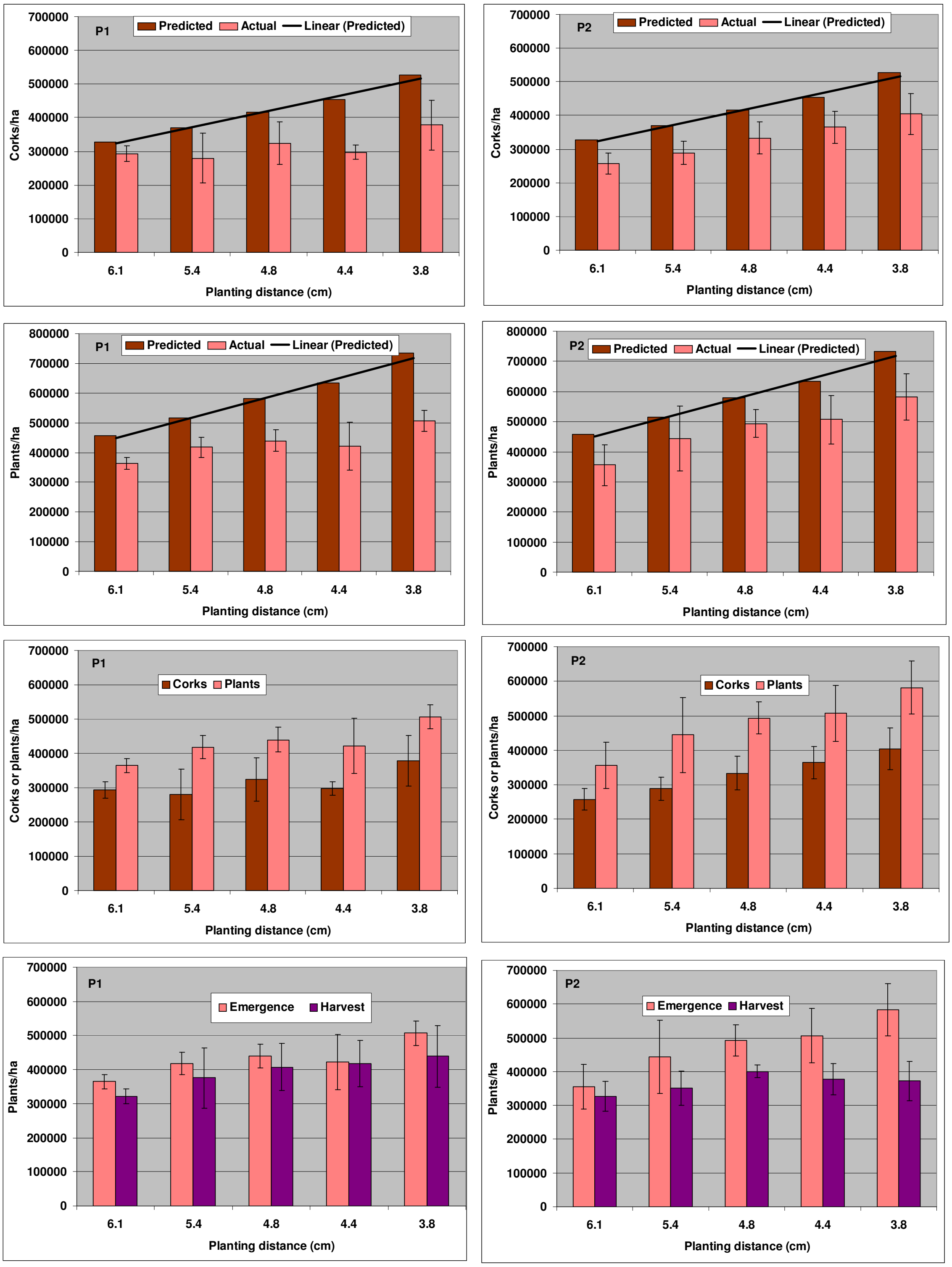


Figure 7.1. Predicted and actual corks per ha (top), predicted and actual plants per ha (centre, upper), actual corks and plants per ha (centre, lower), and number of plants per ha 3 weeks after emergence and at harvest (bottom), for two beetroot plantings (P1 and P2). Error bars are standard deviations.

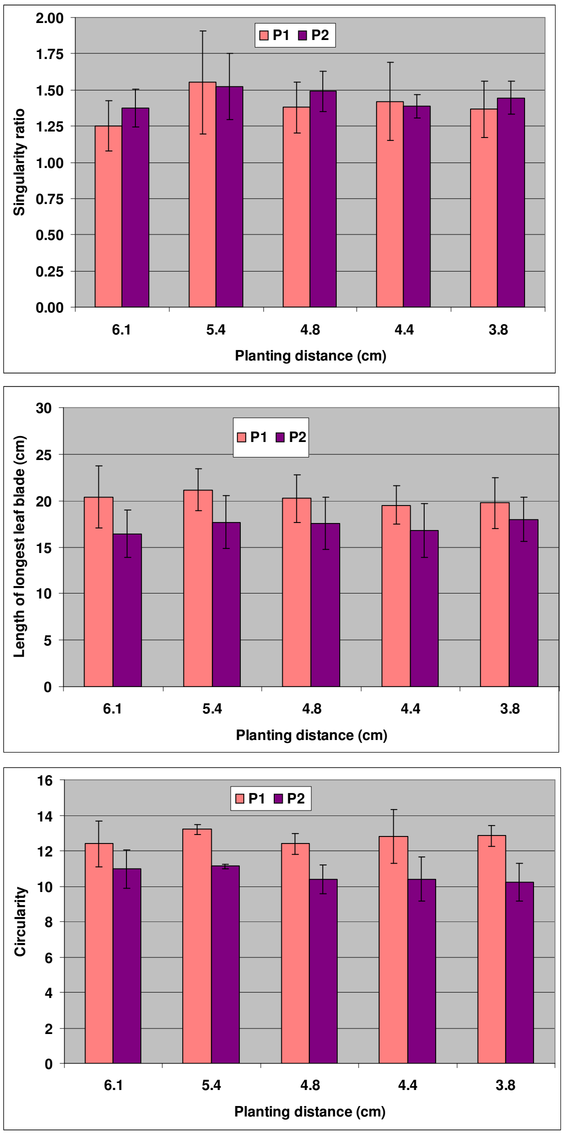


Figure 7.2. Singularity ratio (numbers of plants per cork) (top), length of the longest petiole (centre), and circularity (percentage difference between wide and narrow diameter) (bottom) of beetroot from two plantings (P1 and P2). Error bars are standard deviations.

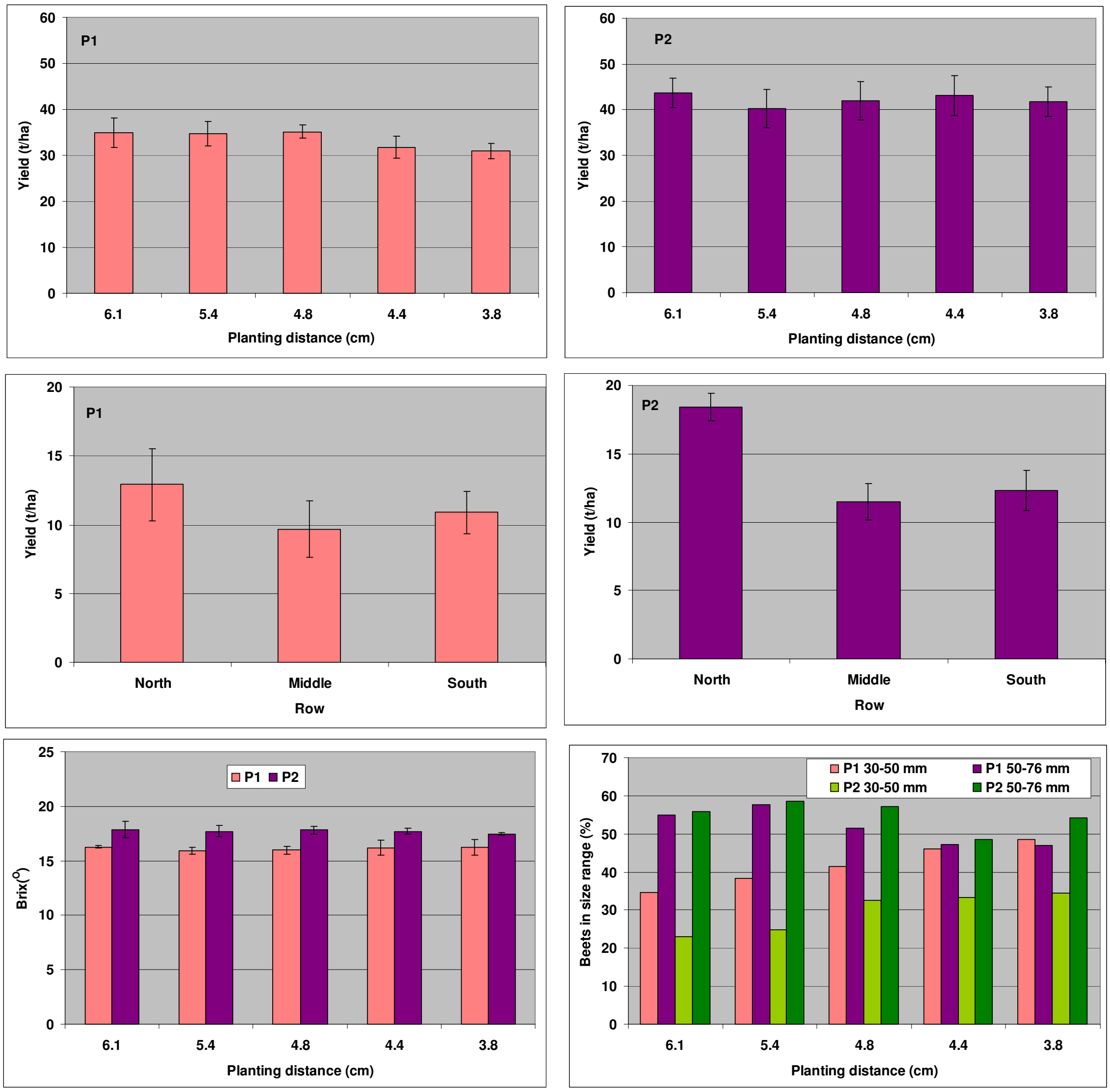


Figure 7.3. Total yield of beets (top), total yield of beets sampled from the 3 rows of each replicate (centre), soluble solids concentrations (°Brix, bottom, left), and size distribution (30-50 mm and 50-76 mm) (bottom, right) of beets from two plantings (P1 and P2). Error bars are standard deviations.

7.1.2 2009 Trials

'Detroit Supreme' growth rates at the two sites were very different. On farm DEL, planting was on 10 February and harvest took place 129 days later. On farm PAC, planting was on 19 February and harvest took place 112 days later, yet these beets were generally over-size. This may have been due to the extra space, nutrients, and water available to these plants as they were in two-row beds rather than three-row beds on farm DEL. Also, planting on farm PAC occurred in rotation after a corn crop which have a high nutrient requirement and tend to leave high residual soil nutrients.

On both farms, the numbers of predicted and observed seed clusters planted and emerged increased as planting distance decreased (Figure 7.4, top). Variation about the observed values indicated similar values to those predicted. The same trends were apparent with predicted and observed plants that emerged (Figure 7.4, centre upper). Populations were lower on farm PAC because only two rows were sown per bed. The standard deviation as a percentage (%) of the mean on DEL with a planting distance 5.1 cm or less was greater than

21% compared to less than 5% at planting distances of 6.1 cm or greater. A similar pattern occurred for seeds/ha, where the percentages were >19% and <10%, respectively. This suggests the seeder planted more variable numbers of seed clusters as the density increased. On farm PAC this pattern of variability was not as obvious. The differences between observed seed and plants (Figure 7.4, centre, lower) reflected the double-seeded nature of 'Detroit Supreme' seed clusters (Figure 7.5, top), as each seed cluster generally produced between 1.5-1.8 seedlings at all planting densities.

Plant numbers at harvest were only slightly lower than at emergence on farm DEL (Figure 7.4, bottom), but much lower, especially at high planting densities on farm PAC. This suggests that on farm DEL the plants survived until harvest, whereas on farm PAC at higher densities there is increased plant mortality. This may be due to larger beets out-competing the smaller less vigorous seedlings.

Planting density did not have any influence on circularity (Figure 7.5, bottom). On farm DEL, there was larger variation in sizes (larger standard deviation bars) whereas on farm PAC, variation was less. This lower variation was possibly due to the lower overall plant densities, although soil and water factors could also play a role. In general, the beets from PAC were more rounded (lower circularity index) than those from DEL.

Again this season, the total yield of beet was the same irrespective of the planting density (Figure 7.6, top). Total yield was around 40 t/ha for farm DEL and 50 t/ha for farm PAC. Please note that these values were calculated from 2 m-length sub-samples from each plot and do not account for variability within the plots.

The distribution of beetroot sizes is presented in Figure 7.6 (centre) for size grades 30-50 mm, 51-75 mm, and >76 mm. As plant spacing increased, there were large increases in the proportion of the crop harvested that was greater than 76 mm in diameter, especially at farm PAC where the highest % desired crop was at a spacing of 5.1 cm. On farm DEL most of the crop was within the required commercial size at all spacings. Both growers chose a planting distance of 6.1 cm for the 2009 season.

On farm PAC, the high percentage of large beets suggests the crop could be harvested earlier, or alternatively, planted later. The choice would depend on the competing priorities faced by the grower.

On both farms, crop row effects were statistically significant (Figure 7.6, lower), with mean differences in total yield around 6 t/ha between the centre and northern rows on farm DEL. On farm PAC, the differences between rows was 2 t/ha and the smaller differences probably relate to the wider spacings that allow for less mutual shading on the southern side of the rows and more even access to water and nutrients.

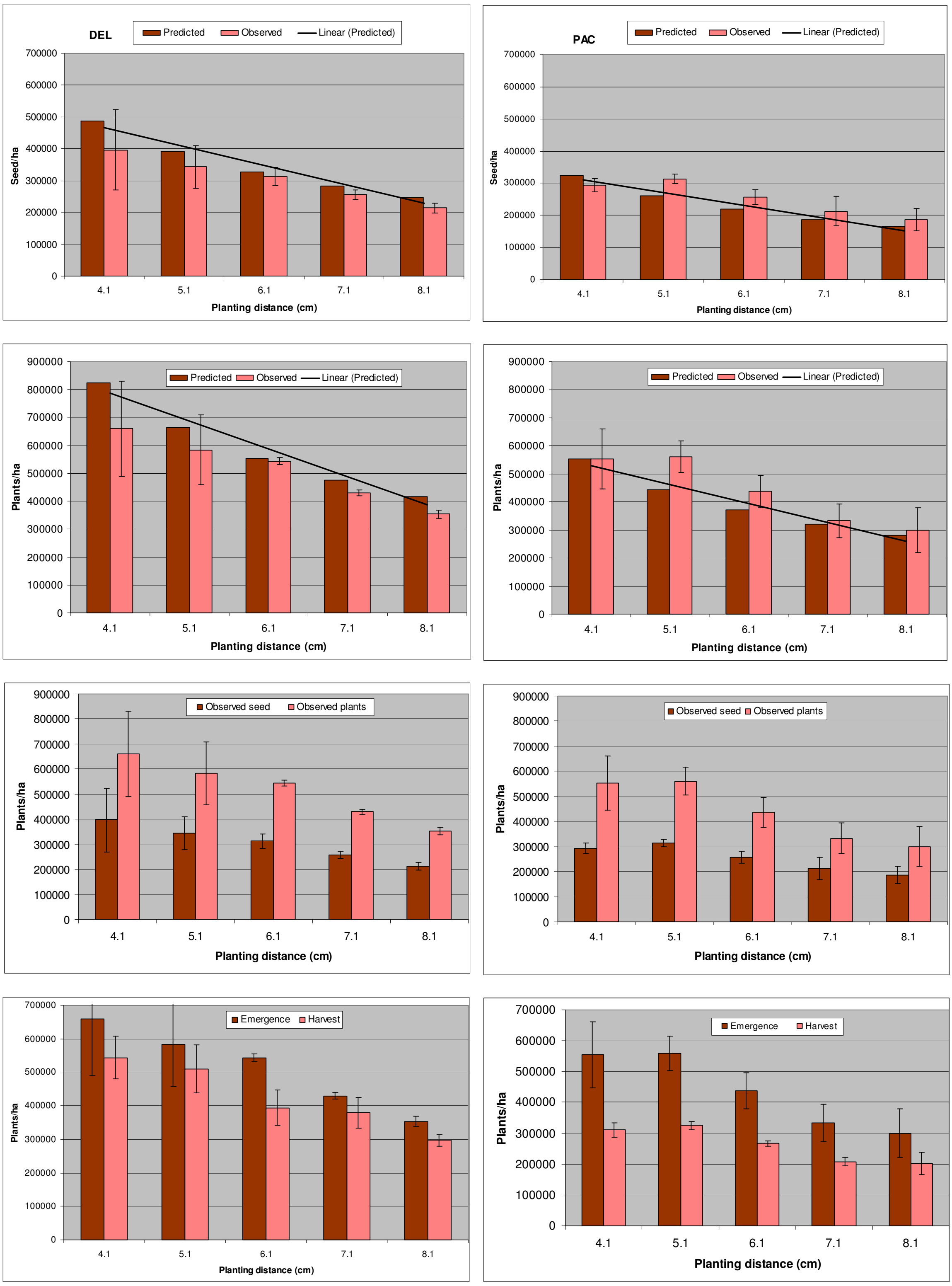
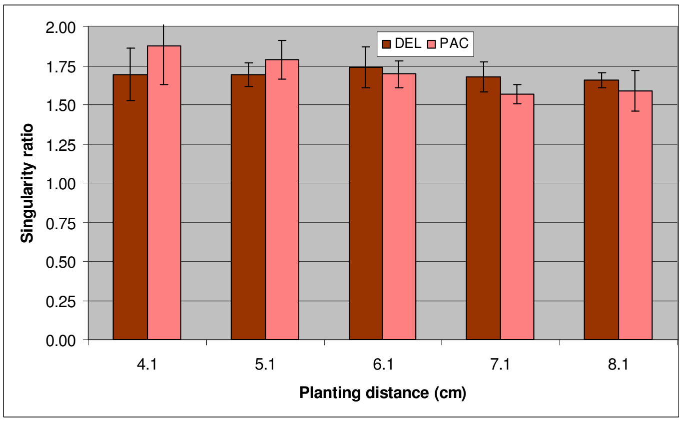


Figure 7.4. Predicted and actual seed clusters per ha (top), predicted and actual plants per ha (centre, upper), actual seed clusters and plants per ha at emergence (centre, lower), and number of plants per ha 3 weeks at emergence and at harvest (bottom), in a planting density trial for two farms (DEL and PAC). Vertical bars represent standard deviations.



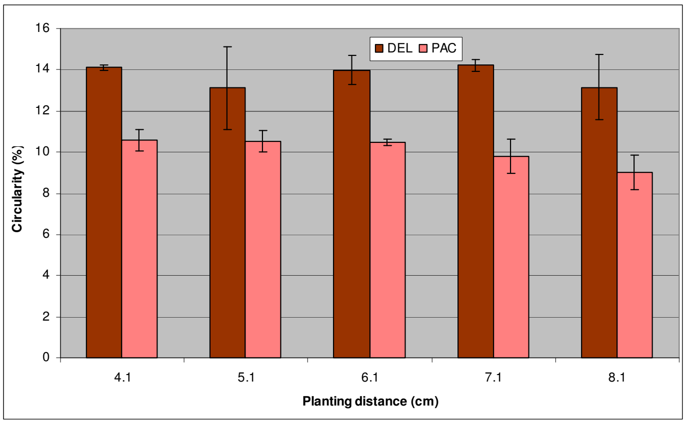


Figure 7.5. Singularity ratio (numbers of plants per seed cluster) (top), length of the longest petiole (centre), and circularity (percentage difference between wide and narrow diameter) (bottom) of beetroot in a planting density trial from two farms (DEL and PAC). Vertical bars represent standard deviations.

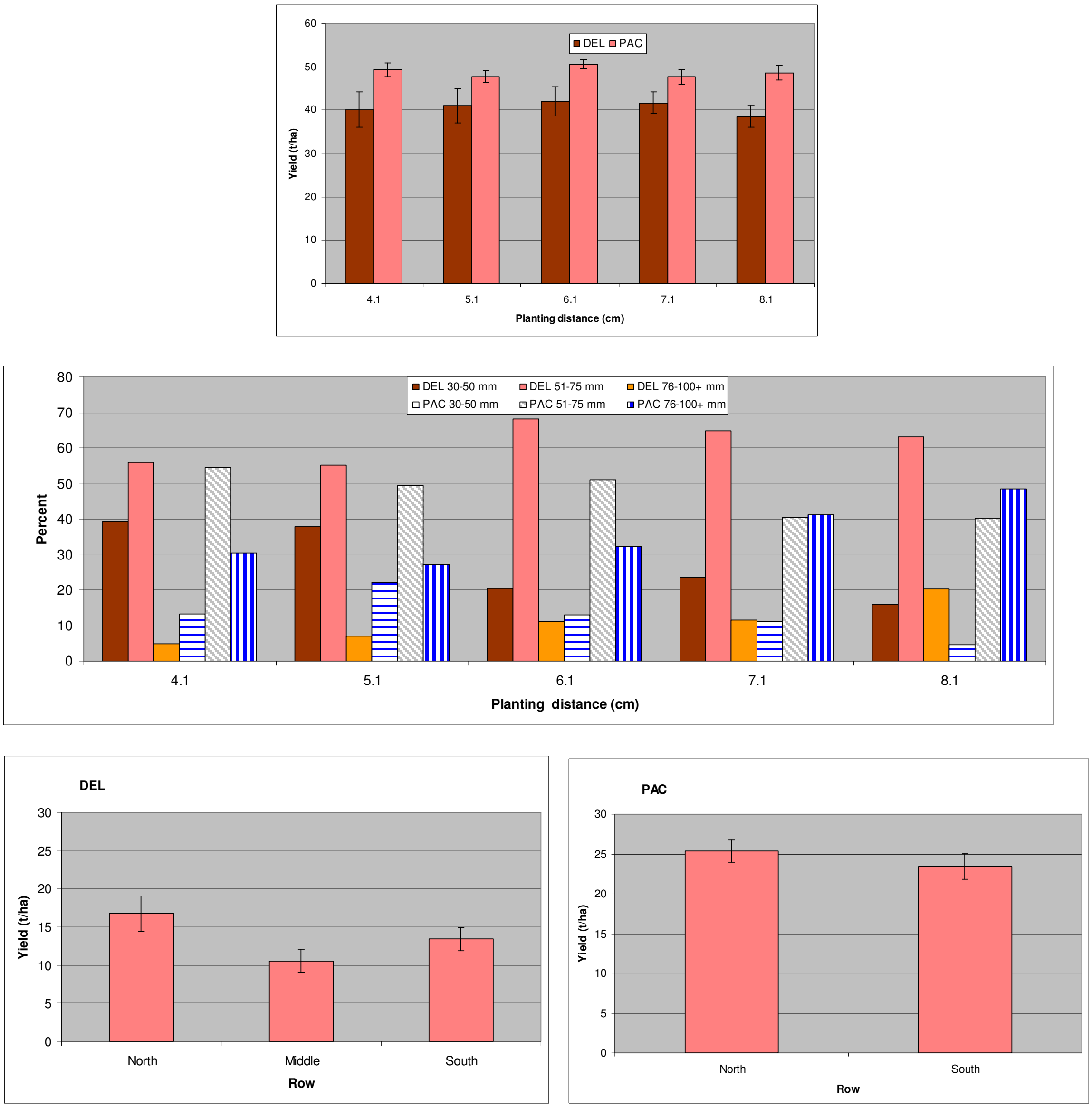


Figure 7.6. Total yield of beets (top), size distribution (30-50 mm and 51-75 mm, and 76-100+ mm (centre), and total yield of beets sampled from the rows of each replicate (bottom) in planting density trials from two farms (DEL and PAC). Vertical bars represent standard deviations.

7.1.3 2011 Trials

In 2011, only ‘Pablo’ variety data were analysed, as the establishment of the ‘Detroit Supreme’ was very poor this season.

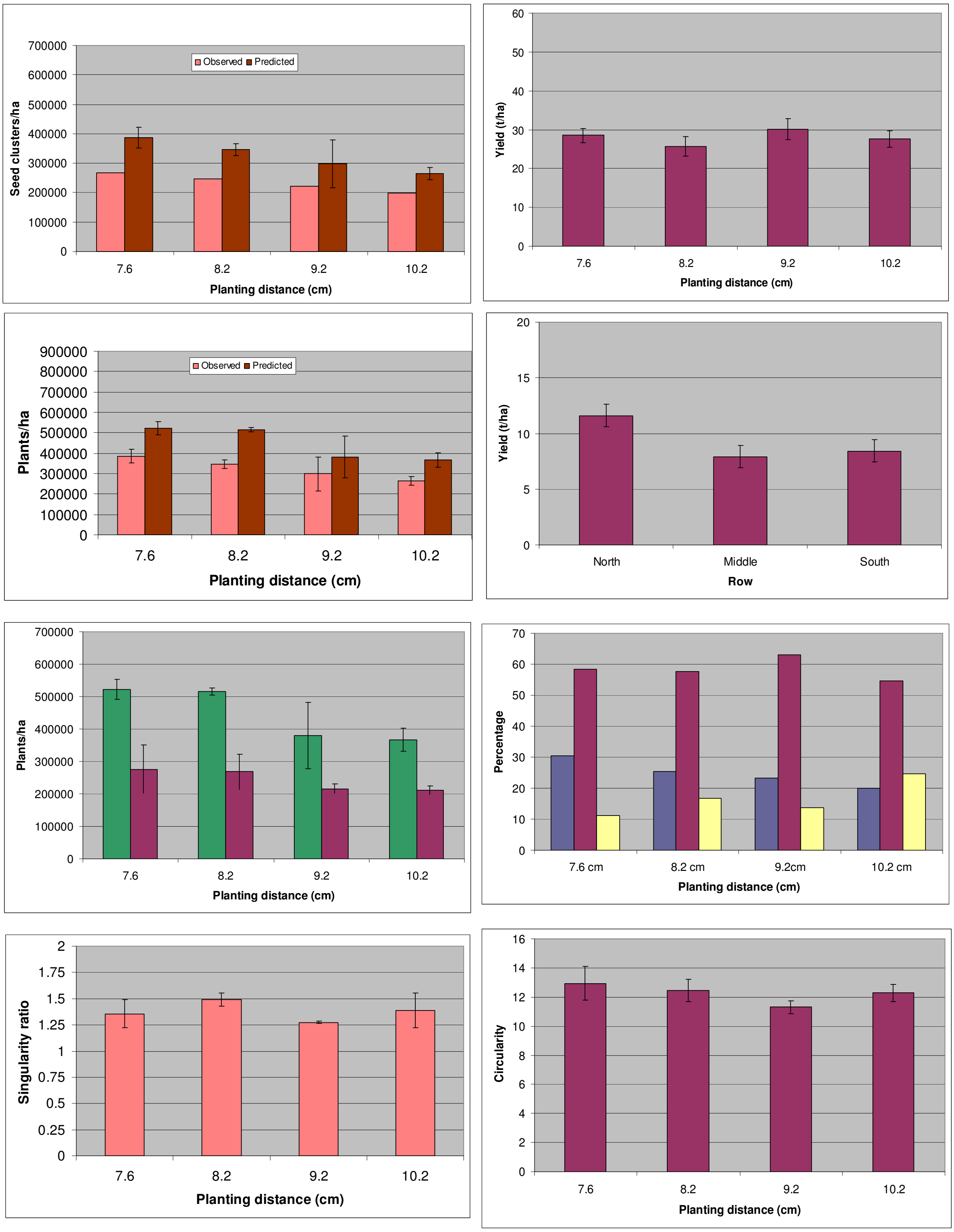


Figure 7.7. Left, from top to bottom: observed and predicted numbers of seed clusters planted, observed and predicted numbers of plants per ha at 3 weeks after planting, predicted numbers of plants at 3 weeks and observed numbers of plants per ha at harvest and singularity ratio, with planting distance. Right, from top to bottom: yield, effect of row on yield, percentage distribution of 30-49 mm, 50-75 mm and 76+ mm diameter beetroot and circularity index, with planting distance. Vertical bars represent standard deviations (n=3).

Numbers of seed clusters determined from seedling counts was much lower than predicted (Figure 7.7). At three weeks after planting, observed numbers of plants was also lower than predicted, and by harvest, about 50% of plants produced commercial-sized beetroot when compared with the numbers predicted.

Wider spacings were used this season as the planting was later, but by harvest, there were no significant differences (P>0.05) in total yield between densities (overall mean and standard error 41.1 ± 1.3, n = 12, Figure 7.7).

There was a significant effect (P<0.05) for row (Figure 7.7), with the most northern row yielding higher (16.6 t/ha) than the southern and middle rows (12.7 and 11.9 t/ha, respectively).

As expected, the percentage of smaller beetroot was higher as the planting distance was reduced from 10.2 to 7.6 cm (Figure 7.7). Conversely, as planting distance increased, the percentage of larger beetroot increased, although 55-62% of beetroot were in the 50-75 mm diameter range, with no effect of planting distance.

There were no significant effects of planting distance on singularity ratio and on circularity of beetroot (Figure 7.7).

7.2 To assess suitable varieties for Southern Australia, including monogerm types

7.2.1 2008 Trials

Some of the replicated varieties (‘Action’, ‘Boro’, ‘Pablo’, and ‘Crimson Glory’) yielded higher than ‘Detroit Supreme’ at one or other of the plantings (Table 7.1).

Most varieties were of similar shape (circularity) to ‘Detroit Supreme’, being slightly oval or tapered rather than spherical. ‘Red Cloud’ and ‘TBT 9115’ were more circular than ‘Detroit Supreme’, but ‘247-4’ had poor shape, although observations were based on a single plot (Table 7.1).

The crown area was larger in ‘Red Comet ‘and ‘Early Wonder Tall Top’ (a pink-skinned bunching beet) than in ‘Detroit Supreme’ or the others (Table 7.1). The large crown contributed to the cone shape of this variety (Table 7.1).

Brix (soluble solids content) was consistently higher in ‘Red Comet’ than in the other varieties, but levels were acceptable for processing in all varieties (Table 7.1).

Most of the varieties produced 1.3-1.5 seedlings per cluster. ‘Red Comet’ and ‘Early Wonder Tall Top’ produced closer to 2 seedlings per cluster (Figure 7.8).

Overall, the earlier planting (P1, in warmer weather) produced greater total yield, but the later planting (P2, in cooler weather) produced beetroot with higher soluble solids.

Several varieties were sampled at harvest, taken to SPC Ardmona, and tested for processing quality. ‘Action’, ‘Boro’, ‘Red Cloud’, and ‘Rhonda’ all passed the processing quality tests.

Table 7.1. Beetroot varieties trialled and quality parameters from 2 plantings (P1 and P2) in 2008.Varieties grown in single observation plots are indicated *. – indicates the variety was not tested. Data are sorted on yield for P1.

Variety	Yield (t/ha)		Circularity (%)		Crown Area (%)		Brix (°)	
	P1	P2	P1	P2	P1	P2	P1	P2
TBT 9116	49	-	10	-	28	-	14.2	-
Crimson Glory	48	38	13	11	21	21	14.9	17.9
247-4*	48	-	16	-	22	-	16.5	-
Pablo (F1)	47	40	11	11	21	15	15.5	18.4
246-4*	46	-	12	-	29	-	16.6	-
Boro (F1)	45	39	11	11	25	17	15.1	18.3
Action (F1)	45	44	11	11	26	15	15.9	17.7
Red Cloud (F1)	44	40	10	8	25	20	16.2	18.9
BEE 6006	43	-	12	-	26	-	18.1	-
TBT 9115	42	-	10	-	30	-	17.3	-
New Globe	41	37	14	11	25	19	16.5	19.5
Rhonda (F1)	41	38	12	11	26	20	17.5	19.5
Orbit	41	-	12	-	29	-	17.1	-
Detroit Supreme	40	30	13	11	24	21	15.6	18.8
TBT 9114	36	-	14	-	24	-	16.7	-
696-5*	35	-	11	-	27	-	15.9	-
Early Wonder Tall Top	34	30	11	10	37	31	17.2	19.9
Red Comet	29	28	12	11	36	29	18.0	21.5
BTT 5849*	-	30	-	10	-	27		20.7
BTT 6462*	-	33	-	14	-	25		18.0
Lion*	-	41	-	11	-	27		17.9

Yield = total weight of beets/ha, Circularity = percent difference between wide and narrow diameter, Crown Area = area of crown/ average diameter, Brix = total soluble solids concentration. 'New Globe' is equivalent to 'Detroit Supreme'.

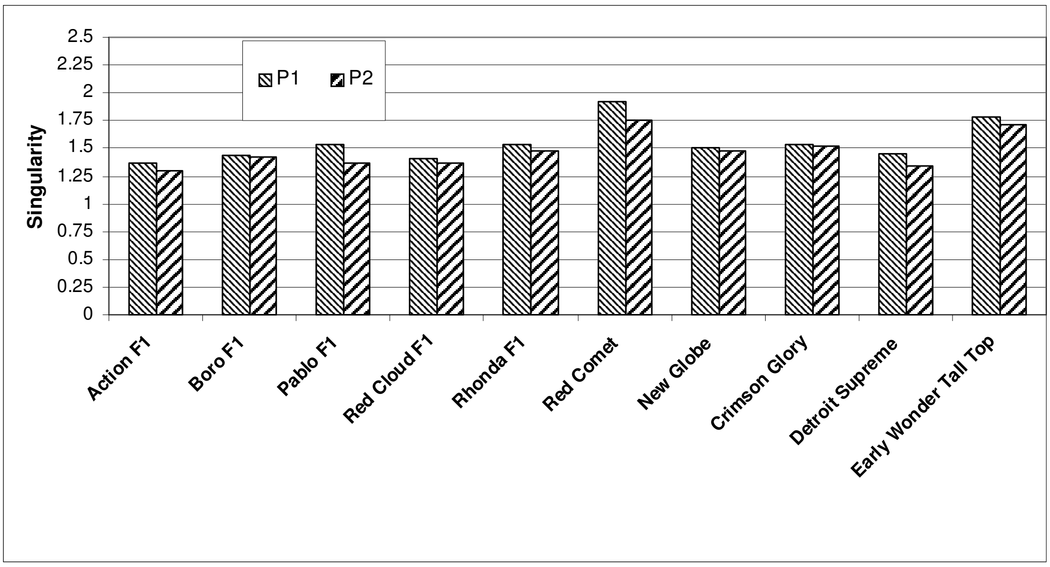


Figure 7.8. Singularity ratio of beet seedlings (seedlings/cork) in two plantings (P1 and P2).

7.2.2 2009 Trials

Yields of the replicated varieties were not significantly different to those of the standard variety ‘Detroit Supreme’ on farm DEL (Figure 7.9). The exception was ‘247-4’ and yield was lower due to a low yield in replicate 2. On farm PAC, ‘Pablo’ and ‘TBT 9116’ significantly ($P<0.05$) out-yielded ‘Detroit Supreme’.

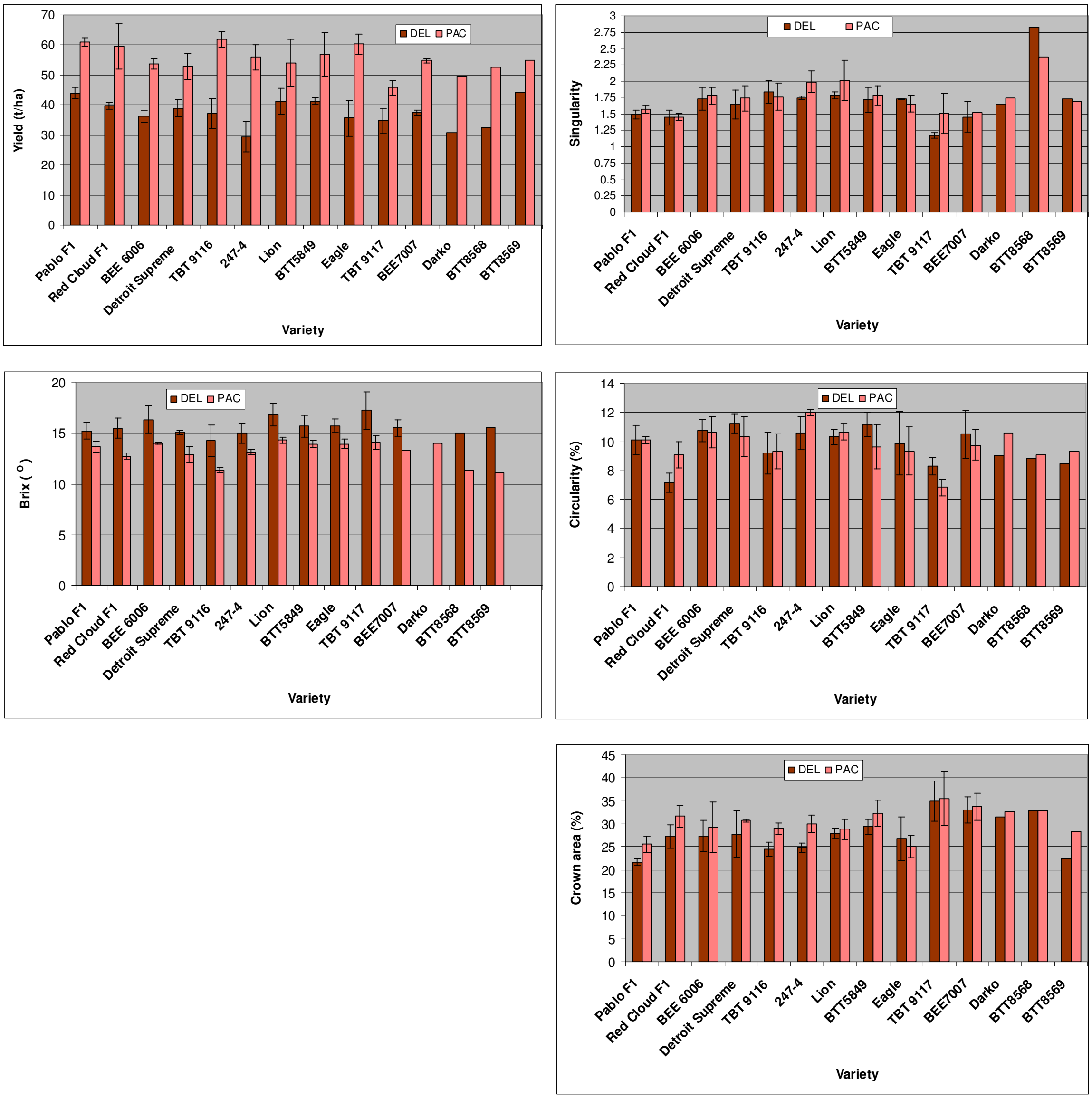


Figure 7.9. Varieties trialled and quality parameters on two farms (DEL and PAC) in 2009. Yield = total weight of beets/ha; singularity = number of seedling emerged/estimated number of seed clusters planted; Brix = total soluble solids concentration; Circularity = percent difference between wide and narrow diameter; Crown area = area of crown/ area of beet at widest circumference. Vertical bars represent standard deviations, and where absent, varieties were not replicated.

Most seed clusters produced around 1.8 seedlings per cluster and there were no varieties that consistently produced significantly ($P<0.05$) fewer seedlings per cluster than ‘Detroit Supreme’. One variety (‘TBT 9117’) nearly produced one seedling per cluster on farm DEL and in a laboratory test (Table 7.2). However, this variety had a lower yield on farm PAC. ‘TBT 9116’ produced 1.1 plants per seed cluster (Table 7.2), and still produced yields comparable to, or better than, ‘Detroit Supreme’ (Figure 7.9).

Varieties 'TBT 9117' and 'Red Cloud' produced more circular beets than did 'Detroit Supreme', but the differences were only significant (P<0.05) on farm DEL for 'Red Cloud' and on farm PAC for 'TBT 9117'. In general, there were no other significant differences between the replicated varieties for circularity, and the differences in diameters were small and acceptable for rounded beets.

The variation in crown areas is shown in Figure 7.9 (lower right). Within farm DEL, 'TBT 9117' had significantly (P<0.05) greater crown area than 'Detroit Supreme' (35% versus 28%), whereas 'Pablo' had a significantly (P<0.05) smaller crown area than 'Detroit Supreme' (22% versus 28%). No such differences occurred in farm PAC, and the overall mean crown area was 30%.

Table 7.2. Beetroot varieties and mean numbers of seedlings per seed cluster after emergence in greenhouse trials. Means followed by the same letter are not significantly different (P<0.05) based on Tukey's HSD test.

Code	Variety	Mean seedlings/cluster
19	Lion	1.8 A
22	Eagle	1.6 A
10	Detroit Supreme	1.5 AB
24	BEE 7007	1.5 AB
17	247-4	1.5 AB
3	Pablo (F1)	1.3 AB
20	BTT 5849	1.3 AB
25	Darko	1.3 AB
4	Red Cloud (F1)	1.2 AB
7	BEE 6006	1.2 AB
14	TBT 9116	1.1 AB
23	TBT 9117	0.7 B

There were no significant effects of variety on Brix (total soluble solids) levels on farm DEL: the means ranged between 15 and 16 °Brix (Figure 7.9). For farm PAC, mean values were a little lower (13-14 °Brix) and variety 'TBT 9116' had significantly (P<0.05) lower Brix (11.3% °Brix) when compared with 'Detroit Supreme' (12.9 °Brix).

There were no significant differences in the components of flesh colour between the tested varieties and the 'Detroit Supreme' standard. Overall mean a* values, an indicator of 'redness,' were 28.0 ± 3.9 and 30 ± 3.9 for farms DEL and PAC, respectively. The mean hue value was 16 ± 1.8, and indicated a dark-red colour as seen by the human eye. During slicing of the beets for colour and TSS measurement, no white rings or white starch granule deposits were observed.

Growth rates of whole plants were determined from samples taken during the season on two farms. A representative polynomial growth curve determined for $\log_{10}$ transformed plant fresh weight growth is shown in Figure 7.10. Day was used as the dependent variable, and plant weight was transformed to ensure the data were normally-distributed.

In this season, maximum growth was achieved at around 115 days after planting (Figure 7.10). When the factor 'variety' was included in the regression, the variance explained was not improved, leading to the conclusion that all the beetroot varieties assessed grew at similar rates.

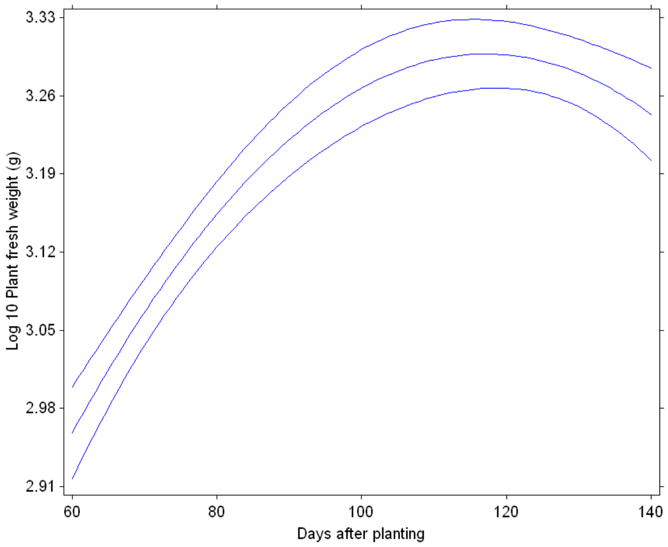


Figure 7.10 Plant fresh weight (log_{10} transformed) for 10 plants per sample combined, with 95% confidence intervals (upper and lower lines).

7.2.3 2011 Trials

The yield data are presented in Figure 7.11. Analysis of variance using the two-sided Dunnett test indicated that yields for 'Eagle' and 'BEE 6006' were significantly (P<0.05) higher than those for the other varieties included in the analysis. The other varieties yielded similarly, including the cylindrical 'Taunus'.

The only difference between the varieties for Brix was that 'TBT 9116' was slightly lower than 'Detroit Supreme', 'BEE 6006', and 'Bettollo' (Figure 7.11). 'Taunus' was the only cylindrical variety included in the analysis, and it had similar Brix to 'Detroit Supreme'.

Crown area was smaller (P<0.05) in 'Pablo' and 'Eagle', and larger in 'BTT 90293' and 'Taunus' compared with 'Detroit Supreme' (Figure 7.11). The larger crown area means loss of harvestable root (Navazio et al., 2010) and those with larger crowns need more peeling in the factory to produce a suitable final sliced beet, although it can mean stronger tops when top-pulling harvesters are used.

'Pablo', 'TBT 9117', 'BTT 90293', and 'Bettollo' produced 1.2-1.3 plants per seed cluster when assessed three weeks after planting (Figure 7.11). These values were significantly (P<0.05) less than for 'Detroit Supreme' and 'Taunus' (1.6).

Circularity scores were lower (more circular, P<0.05) for 'TBT 9117' and 'Bettollo' than for 'Detroit Supreme' when they were compared using Dunnett's two-sided test (Figure 7.11). These two varieties are close to being monogerm types (i.e. having no near neighbouring plants to interfere with shape), but interestingly, 'BTT 90293', also a monogerm variety, was less cylindrical and similar to 'Detroit Supreme'. The cylindrical variety 'Taunus' was as circular as the best varieties.

Colour scores were similar for most of the varieties (Table 7.3). 'Detroit Supreme' was one of the darkest in red colour, but 'Bettollo' and 'Pablo' were similarly dark red. Although the differences between varieties were statistically significant, in practise, these differences were quite small.

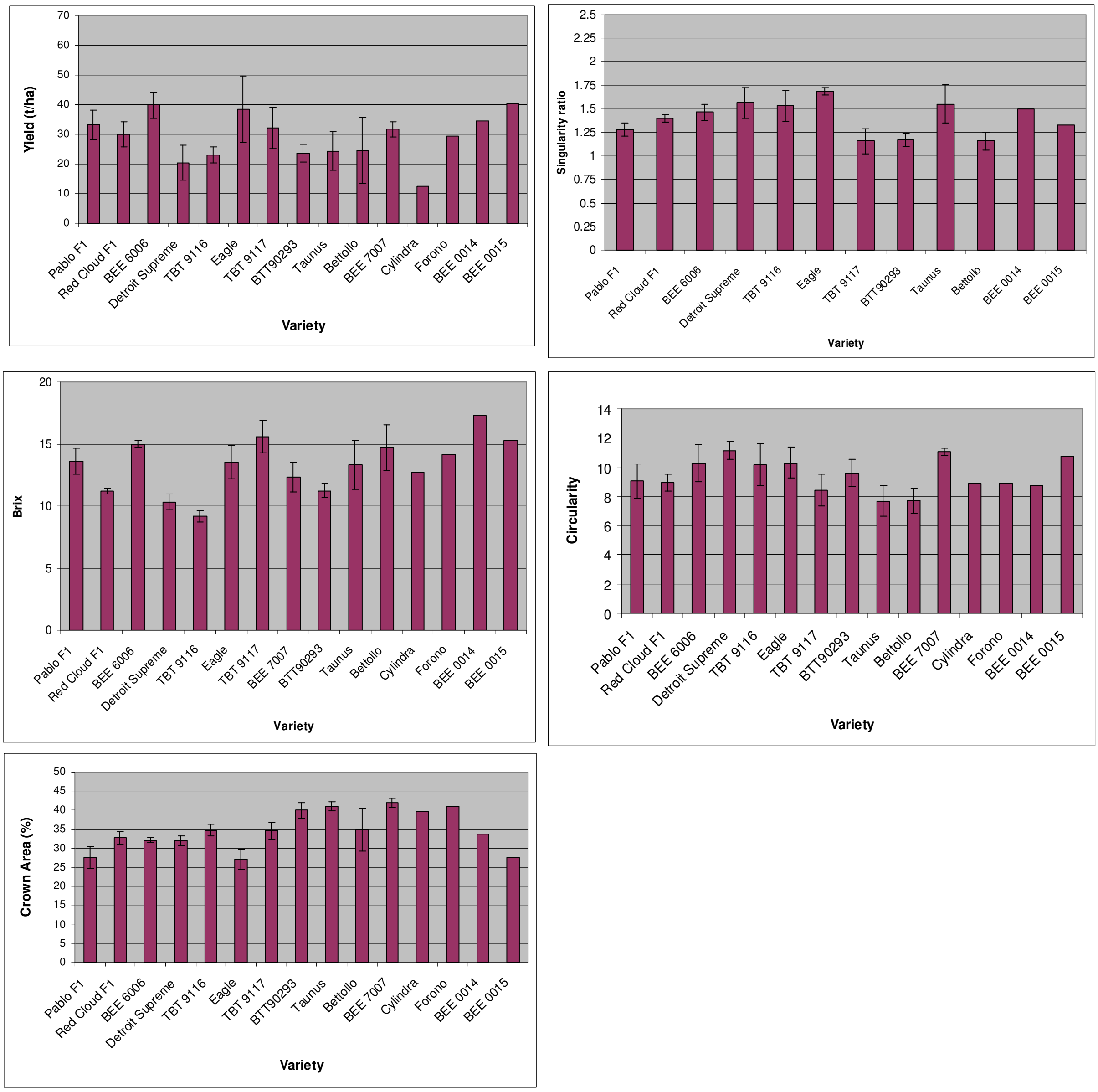


Figure 7.11 Yield, Brix (total soluble solids), crown area, singularity ratio, and circularity (where 0 = both main axes are the same length and the beetroot is round), for 2011 variety trials.

Table 7.3. Beetroot varieties and mean ‘a*’ value (red scale) of harvested beetroot flesh. Means followed by the same letter are not significantly different (P<0.05) based on Tukey’s HSD test.

Code	Variety	Mean a*	
7	BEE 6006	28.388	A
28	BTT 90293	27.911	AB
14	TBT 9116	27.792	AB
22	Eagle	27.526	AB
23	TBT 9117	27.336	AB
29	Taunus	26.047	ABC
4	Red Cloud	26.01	ABC
10	Detroit Supreme	25.62	ABC
30	Bettollo	25.158	BC
3	Pablo	23.637	C

8 To understand the role of seed germination as a factor controlling yield

Germination of a test batch of seed clusters on filter papers in the laboratory was variable (Figure 8.1). Most seed clusters of 'Eagle', 'Taunus' and 'Crimson Glory' germinated, whereas less than 15 (30%) of 'TBT5849', 'TBT9116' and 'Detroit Supreme' seed clusters had germinated by 11 days. Most seed clusters had germinated by 10 days after imbibition at 25 °C.

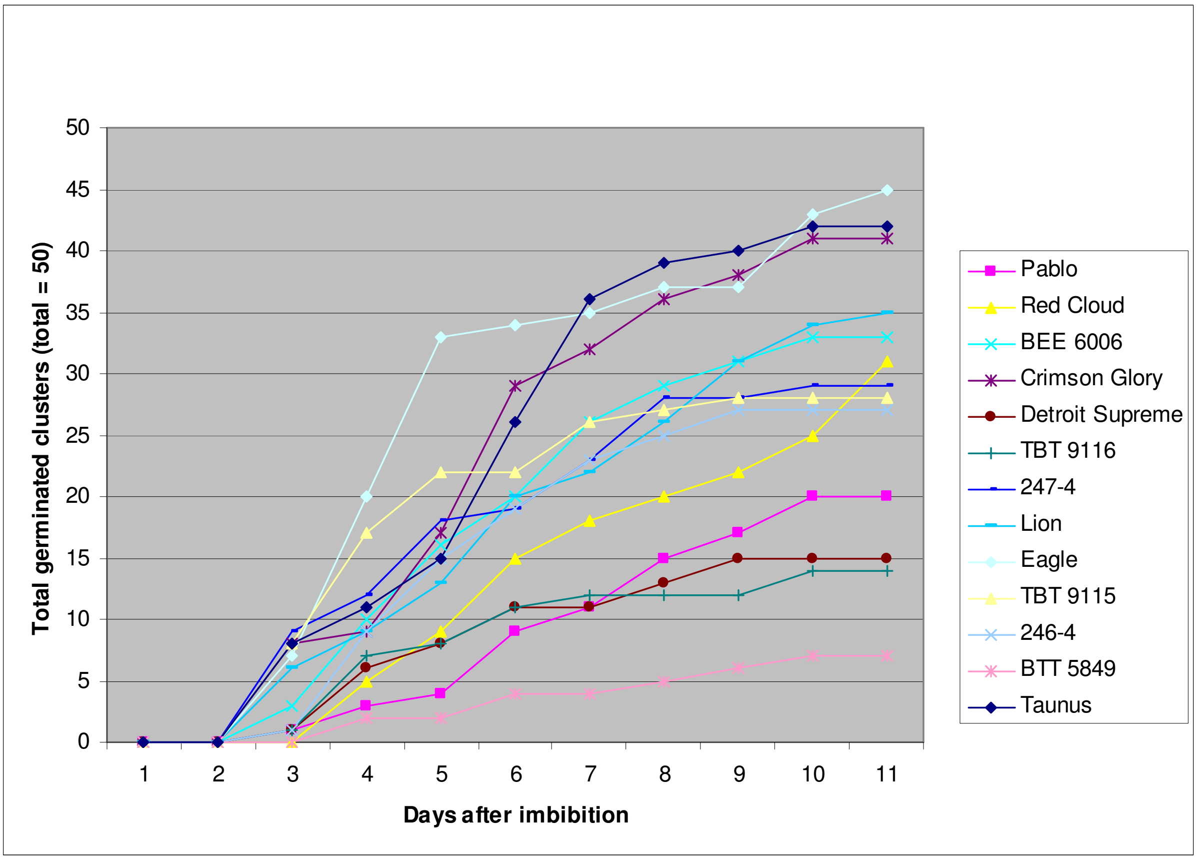


Figure 8.1. Germination of seed clusters on filter papers in the laboratory at 25 °C.

A further experiment in May 2009 utilised 4 replicates of 25 seeds per replicate placed in Petri dishes at 25 °C. The germination data were fitted to regression equations using a goodness of fit test and Akaike's Information Criterion (AIC). The data indicated that third (e.g. 'Lion') and second (e.g. 'Pablo') order polynomials using days after imbibition as the dependent variable reasonably described the germination patterns, but it some instances linear regressions (e.g. 'BEE 6006') gave a better fit. For higher order polynomials, the data indicated that germination and emergence was completed around 11-15 days after imbibition. Where a linear model best fitted the data, this indicates that germination was continuing. Although the data are not presented, percentage germination was >84% except for 'BEE 6006' (40%), 'Detroit Supreme' (64%), and 'TBT 9117' (24%).

Two of the factors that may relate to production are germination percentage and the time it takes to germinate. Both are probably influenced by seed source and age (time and conditions of storage). In some of our trials, poor establishment in 2010 may have been due to these factors, as some of the seed was stored.

The germination experiment using single cluster seed trays in the greenhouse indicated that 'Detroit Supreme' and 'Eagle' produced nearly 2 seedlings per cluster, on average (Table 8.1). 'TBT 9117', 'TBT 9116', 'BTT 90293', 'BEE 6006', and 'Cylindra' were probably monogerm. However, based on the Least Significant Difference test, 'Forono' down to 'BTT 90293' (Table 8.1) had the same mean singularity index, suggesting these could also be classed as monogerm.

Table 8.1. Mean singularity index (SI) and significance for varietal evaluation of emergence in the glasshouse evaluated by LSD (5%).

Variety	Mean SI	LSD Group
Detroit Supreme	1.9	A
Eagle	1.8	AB
BEE 0014	1.5	BC
Forono	1.4	CD
BEE 7007	1.4	CD
Pablo	1.4	CD
BEE 0015	1.3	CD
Bettollo	1.2	CD
Taunus	1.2	CD
Red Cloud	1.2	CD
Cylindra	1.1	DE
BEE 6006	1.1	DE
TBT 9116	1.1	DE
BTT 90293	1.1	DE
TBT 9117	0.8	E

At the end of the greenhouse germination and singularity index trial, plants were maintained in their single cells for 81 days to determine if there was mortality similar to that determined in the field. The results for all varieties are shown in Figure 8.2. The result of this unreplicated trial showed there was very little mortality over the 81 days, suggesting the mortality observed in the field trials was due largely to soil and field factors.

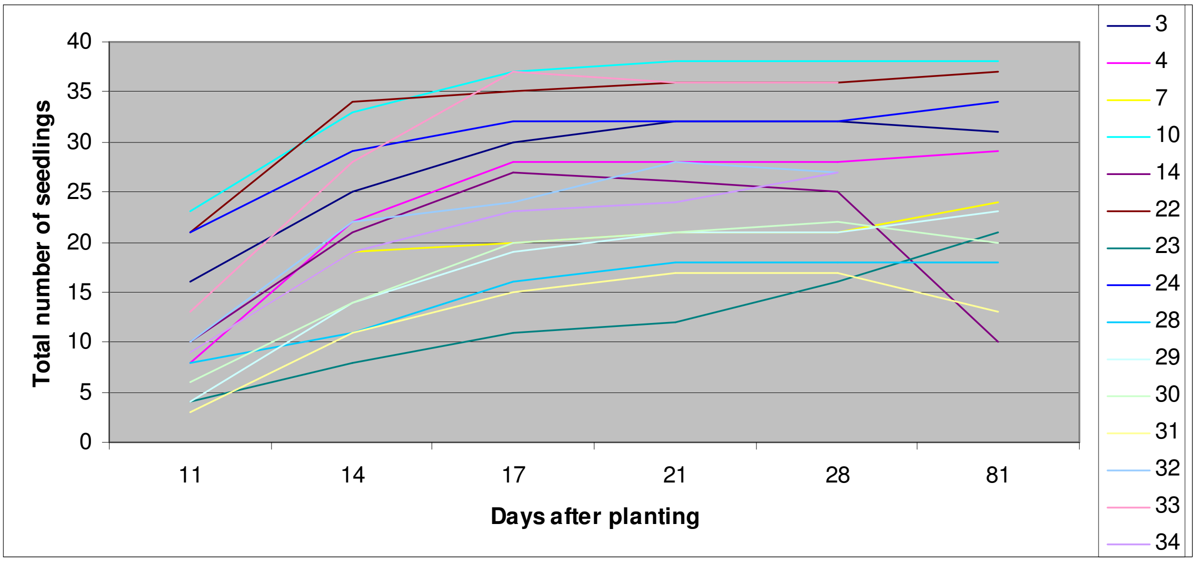


Figure 8.2. Total number of seedlings of several varieties (codes only given here) surviving in single seed cells for up to 81 days. Variety names are given in Appendix 1.

9 Discussion

9.1 Planting density

Despite the unavoidable use of a range of beetroot genotypes in these trials, large losses of plants occurred during the growing seasons. Plant populations were varied using different planting distances and genotypes (‘Detroit Supreme’ and ‘Pablo’). This range of varieties evolved with the project, and the main co-operator phased out ‘Detroit Supreme’ in favour of the F1 hybrid ‘Pablo’.

Although a range of populations was established, by harvest, such were the losses during growth and development that harvested yields were barely affected by planting density. For example, in 2009 on farm DEL, seedlings at all the planting densities consistently grew to a similar harvestable size. Some of the variation may have been due to the numbers of seedling emerging from each seed cluster, but during the research, from counting emerged seedlings three weeks after planting, and from the proximity of the seedling clusters to one another, we estimated that 1.25-1.4 plants emerged from each cluster. The exception was in 2009, when 1.6-1.8 plants emerged per cluster. In 2009 on farm PAC, large numbers of seedlings did not survive through to harvest, especially at the closer spacings. It is possible that the larger beetroot out-competed weaker seedlings, whereas on farm DEL, competition was not as intense and the weaker seedlings were able to survive until harvest.

This indicates the kind of variation grower’s face from year to year changes in seed sources, but over all the trials, density had no impact on the “singularity” index.

There was no effect of planting distance on circularity. There was a tendency for beet to be more circular on farm PAC in 2009, and this may be due to the wider spacings between the rows, but not for within-row spacing. In general, suggestions (Peck and Wilczynski (1967, cited in Benjamin et al. 1985)) that density affects circularity is not supported in this study, possibly because there are few years where all germs emerging from seed clusters develop to commercial size, and secondly, because decortication of seed clusters now reduces the numbers of germs per seed cluster to 1-2 in commercial seed supplies. Possibly due to the higher planting densities, smaller beets and slower growth rates, beetroot were less circular on farm DEL than on farm PAC in 2009. However, the difference between the diameters was quite small, and equivalent to about 3 mm on a 75 mm-diameter beet.

It is of interest that we did not find a clear density effect during this research. We used commercial practises throughout the field trials in order to ensure the data emerging were applicable to the growers. As such, we did not thin the crop after planting, and as a result, relied on nature and genetic effects to determine the crop after the initial planting density was determined by the seeder. One might suspect that the seeder was dropping more seed than expected, especially at higher densities. The plots were about 20 m long and the gearing was changed every plot. The farmers suggested that it may take some hundred meters or so in order for the seeding rate to become stable. This may be a possible topic of interest for any further studies.

The spread in plant densities resulted in no influence of density on singularity, beetroot shape, or total yield. All this data suggests that populations were self-thinning to some extent, and that crop size distribution was controllable by altering the harvest date. Season, farm management, and planting system also influence crop growth and development. For example, in 2008 and 2009, February 12 and 10 plantings on farm DEL were harvested at 105 and 129 days in each year. In 2009, a 27 February planting on farm PAC was harvested at 112 days. These variations make it difficult to forecast harvest on a fixed date. However, by monitoring beetroot diameter, growers can decide to harvest earlier if temperatures have been generally higher, or later if cooler, and beetroot growth is commensurately altered. The incidence of larger beetroot in the two-row bed system could be reduced by this monitoring, but the presence of rainfall can impede entry of harvesting equipment into the crop. The growers could therefore choose any density within those tested here based on the cost of the seed and maintenance costs of the crop, and harvest the crop when sample size distribution is acceptable.

Row orientation did influence yield within the beds, with the northerly aspect rows being the most productive in the three-row flat bed system. In the two-row raised bed system, we found a small influence of row, suggesting that self-shading affects the middle and southerly rows in the three-row bed. The reduction in yield on the three-row bed is of the order of 3-4 t/ha, and the economic impact of this must be weighed up by the grower. A north-south orientation should even out the row yields, but sometimes, due to farm geography, it is not possible to have north-south rows.

Soluble solids concentrations in the beetroot were more than adequate for processing, and in these trials, plant spacing did not have an impact on Brix.

9.2 Variety trials

In general, all the varieties and selections assessed performed similarly to 'Detroit Supreme'. Although there were some specific differences between varieties on the same and different farms, there was no consistent evidence of superior production by any of the varieties in the trials. However, 'Pablo' and 'TBT 9116' generally performed well, and would be suitable varieties to replace 'Detroit Supreme'.

'Action', 'Boro', 'Pablo', 'Crimson Glory', 'TBT 9116', 'Eagle', and 'BT 6006' out-yielded 'Detroit Supreme' at different years and farms, but they did not out-yield 'Detroit Supreme' consistently. The cylindrical variety 'Taunus' yielded as well as 'Detroit Supreme' at the standard spacing used in 2011. It would be of interest to know whether per hectare yields can be increased in 'Taunus' using closer spacings, given that the harvestable root of cylindrical types will explore deeper soils than those of the globe types.

Singularity is an important attribute for the grower, as it means seed can be planted at consistent densities using precision machinery and produce a single plant from each seed. In general, all the varieties we assessed produced 1.3-1.5 plants per seed cluster. The values can change for the same variety depending on whether the assessment is made in the field or the glasshouse. For example, in 2009, the field average was 1.8 plants per seed cluster, but in the glasshouse test, most produced 1.2-1.3 plants per seed cluster.

Assessment of singularity in the field is subject to possible errors in interpretation. It was based on the proximity of seedlings to one another around three weeks after planting, when the majority of seedlings had emerged. It is possible that two or more seed clusters were dropped close together, but there is no evidence of a consistent difference in the ratio in the planting distance trials that one might expect at the higher densities used if more seed were deposited closer together. It is more likely that the soil environment had an influence on the germination and/or emergence of seedlings. In addition, year-to-year variation in seed batches may have contributed to slight changes in singularity.

A value of 1.3 is probably close to the desired as it allows for unviable seed and some clusters that produce 2 plants. 'Pablo' generally produced 1.3 plants per seed cluster, and this was undoubtedly one reason why one of our co-operating growers transferred his production from 'Detroit Supreme' to 'Pablo' during the course of this study.

Circularity was also a factor that was not consistent between years and farms. For example, 'Red Cloud' was more circular than 'Detroit Supreme' in 2008, and on property DEL in 2009, but not on property PAC. 'TBT 9117' was also better than 'Detroit Supreme' on farm PAC in 2009 and on farm DEL in 2011. 'Red Cloud' was not available for testing in the 2011 trials.

Crown area is an indication of the possible strength of the tops if the beetroot are harvested by top-pulling machinery, rather than using conventional potato/onion-type harvesters. Top-pulling harvesters reduce the possibilty of mineral or other inorganic foreign material being harvested with the crop. The year-to-year variation found in crown area of varieties when compared with 'Detroit Supreme' suggests growing environment may also have a large effect, particularly since those varieties with crown areas that are too large would be misshapen and selected out during breeding. In the single year of assessment, 'Taunus' had a larger crown diameter than 'Detroit Supreme', and this may be an advantage as cylindrical roots would penetrate deeper into the soil and may require a slightly higher pulling force to remove.

Soluble solids content (Brix) was also not consistent between years and farms. For example, 'TBT 9116' was lower than 'Detroit Supreme' in 2009 on farm PAC, but higher in 2011 on property DEL. Differences between farms may be related to nutritional input or perhaps because the beetroot were slightly smaller on farm DEL than on farm PAC, where different planting systems were used. In the past, there had been seasons where Brix levels were too low and this necessitated additional sugar (and the associated cost) being added prior to canning. It is of interest that the cylindrical 'Taunus' produced beetroot of similar Brix to 'Detroit Supreme' in the 2011 trial.

During this study, we assessed the varieties for their production characteristics and not their pest and disease resistance. However, during the study on farm DEL, only two samples were found with the aphid belonging to *Pemphigus* sp. and some minor infestations of Green Peach aphid (*Myzus persicae*) werenoted on the leaves. The other pest damage noted was root damage caused by hares.

9.3 Seed germination effects

Germination in the laboratory varies according to variety and possibly batch (age). These factors can influence the emerging crop, and in 2010 there was very poor crop establishment by 'Detroit Supreme' most likely because we used stored seed rather than fresh seed.

Most varieties had fully germinated by 10-15 days after imbibing started. It is likely that in the field, such time would be sufficient for germination if moisture was satisfactory and temperature around 25 °C. This temperature would be experienced during planting in Cowra during the late January and February planting times. Some varieties may continue to germinate after 15 days, and if so, they should have been included in field population counts that were made around 21 days after planting. This time was chosen so as to best discern the source of seedlings from the planted seed clusters. If further seed germinated, they may not have necessarily developed into harvestable product as they may have subsequently died, or their development arrested. Many plants in a cluster pulled at harvest time had not developed much past the seedling stage, and there was no visible swelling of the main root. These plants would not have been counted at harvest time. The cause of this arrested development, but continued survival, would be a very interesting research project. Competition from adjacent plants could contribute, but the effect may be mediated by plant growth regulator levels in the affected plants.

Seedlings of all varieties tested survived for up to 81 days in the greenhouse trial. This trial utilised a commercial potting medium that should have been largely pathogen-free. This suggests that field mortality is due to the small undeveloped plants that were not counted, or more likely, due to mortality from soil pathogens or competition from adjacent plants.

10 Technology Transfer

Meetings were held with co-operators prior, during, and after each season to discuss the trials. In some instances, samples of soil and plants were analysed for nutrient content, and crop management recommendations were made.

During the course of this study, one grower changed his production from 100% ‘Detroit Supreme’ to 100% ‘Pablo’. The change was made because the ‘Pablo’ variety was suitably coloured for processing, the crop was vigorous, the beetroot of good shape, and the seed effectively monogerm meaning that single seeds would produce a single plant.

Publications arising during the course of the project were:

- Donald Irving, Alan Boulton and Stephen Wade 2011. Fitting beetroot slices into ‘Fridge Packs’ - manipulating crop density and cultivar. Joint Australasian Postharvest Horticulture/Australian Society of Horticultural Science/New Zealand Institute for Agriculture and Horticulture Science Conference, Mantra Erskine Beach Resort, Lorne, Victoria, Australia, 18 – 22 September.

- Size does matter – beetroot quality paramount. Agriculture Today, October 6, 2011, page 12.

- Smaller beetroot in bigger demand. Agriculture Today, September 2, 2010, page 4.

- Donald Irving, Alan Boulton and Stephen Wade 2009. Processing Beetroot Variety Trials. Vegebites 37. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/311915/Vegie-Bites-37.pdf. Accessed 17-02-10.

- Better sized beets. THE LAND Thursday, September 3, 2009, page 10.

- Beetroot – more or less. Vegetables Australia 2009.

- Radio interview ‘On Target in Agriculture for 31st October 2008’ to the Riverina.

- Donald Irving, Alan Boulton and Stephen Wade 2012. Beetroot evaluation in the Central West’ is being prepared for Vegebites.

- Two scientific papers (relating to planting densities and varieties) are being prepared.

11 Recommendations – Scientific and Industry

During the course of this research, seed companies made available a range of new genetic material producing "monogerm" seed. These need to be more extensively tested for production in southern Australia, especially for processing yield, given the changing temperature and rainfall regimes predicted for the future.

The cause of the high mortality of plants needs further investigation. On the basis of the research here, farmers could sow much less seed (with commensurate cost savings). In addition, the reason plant growth and development are arrested in many seedling clusters is an interesting research topic from a scientific viewpoint.

Farmers can obtain suitably sized beetroot by monitoring beetroot size leading up to harvest. A suitable protocol (frequency and numbers of beetroots measured) needs to be established to assist the farmer schedule harvest.

The cylindrical variety ('Taunus') yielded as well as 'Detroit Supreme' in planting distance trials. As its root could explore deeper soil, yields may be increased above those of traditional globe beetroot crops, but production trials should be undertaken to ensure diameter growth is contained. If yields were increased, the 'Taunus' variety could be very suitable for the industry, but the slicing method in the factory would need to be changed.

12 Acknowledgements

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13 Appendix 1

Varieties evaluated during the course of the project.

Variety code	Variety name	Seed Company
1	Action F1	Bejo Seeds
2	Boro F1	Bejo Seeds
3	Pablo F1	Bejo Seeds
4	Red Cloud F1	Bejo Seeds
5	Rhonda F1	Bejo Seeds
6	Red Comet	Fairbanks Seeds
7	BEE 6006	Fairbanks Seeds
8	New Globe	S&G Seeds
9	Crimson Glory	Terranova Seeds
10	Detroit Supreme	Terranova Seeds
11	Early Wonder Tall Top	Terranova Seeds
12	TBT 9114	Terranova Seeds
13	TBT 9115	Terranova Seeds
14	TBT 9116	Terranova Seeds
15	Orbit	South Pacific Seeds
16	246-4	South Pacific Seeds
17	247-4	South Pacific Seeds
18	696-5	South Pacific Seeds
19	Lion	Lefroy Valley
20	BTT 5849	Lefroy Valley
21	BTT 6462	Lefroy Valley
22	Eagle	Lefroy Valley
23	TBT 9117	Terranova Seeds
24	BEE 7007	Fairbanks Seeds
25	Darko	South Pacific Seeds
26	BTT 8568	Lefroy Valley
27	BTT 8569	Lefroy Valley
28	BTT 90293	Lefroy Valley
29	Taunus F1	Bejo Seeds
30	Bettollo F1	Bejo Seeds
31	Cylindra	Yates Seeds
32	Forono	Mr Fothergills
33	BEE 0014	Fairbanks Seeds
34	BEE 0015	Fairbanks Seeds

14 Appendix 2

Related studies

Zelinski, A. VG04062 Study tour to analyse the processes and operations of the American and European beetroot industry, September 2004.

Wolens, T. VG05083 Development of integrated strategies for sustainable processing beetroot production.

Grant, L. VG06140 Beetroot variety isolation in relation to colour pigmentation.

Martin, H. VG00084 Improving the reliability and consistency of processing beetroot production

15 Literature cited

Acree, T.E., C.Y. Lee, R.M. Butts, and J. Barnard. 1976. Geosmin, the earthy component of table beet odor. Journal of Agricultural and Food Chemistry. 24: 430-431.

Akeson, W.R., A.H. Freytag, and M.A. Henson. 1981. Improvement of sugarbeet seed emergence with dilute acid and growth regulator treatments. Crop Science. 21: 307-312.

Bailey, S.J., P. Winyard, A. Vanhatalo, J.R. Blackwell, F.J. DiMenna, D.P. Wilkerson, J. Tarr, N. Benjamin, and A.M. Jones. 2009. Dietary nitrate supplementation reduces the O_2 cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans. Journal of Applied Physiology. 107: 1144-1155.

Barański, R., D. Grzebelus, and L. Frese. 2001. Estimation of genetic diversity in a collection of the Garden Beet Group. Euphytica. 122: 19-29.

Benjamin, L.R. 1987. The relative importance of cluster size, sowing depth, time of seedling emergence and between-plant spacing on variation in plant size in red beet (*Beta vulgaris* L.) crops. The Journal of Agricultural Science. 108: 221-230.

Benjamin, L.R., R.A. Sutherland, and D. Senior. 1985. The influence of sowing rate and row spacing on the plant density and yield of red beet. The Journal of Agricultural Science. 104: 615-624.

Bralewski, T.W.and R. Holubowicz. 2008. Relationship between seed germination capacity of 10 species of vegetables and their emergence in the field. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 36: 68-72.

Braun, H., J.C. Lopes, L.T. de Souza, E.R. Schmildt, R.P.Q. Cavatte, and P.C. Cavatte. 2010. In vitro germination of beetroot seeds treated with GA_3 and sucrose. Semina-Ciencias Agrarias. 31: 539-545.

Catusse, J., J.-M. Strub, C. Job, A. Van Dorsselaer, and D. Job. 2008. Proteome-wide characterization of sugarbeet seed vigor and its tissue specific expression. Proceedings of the National Academy of Sciences. 105: 10262-10267.

Cserni, G.and L. Kocsis. 2008. The case of the purple colon. Virchows Arch. 452: 703.

De Azeredo, H.M.C., A.C. Pereira, A.C.R. De Souza, S.T. Gouveia, and K.C.B. Mendes. 2009. Study on efficiency of betacyanin extraction from red beetroots. International Journal of Food Science & Technology. 44: 2464-2469.

Feller, C.and M. Fink. 2002. Nitrogen uptake by table beet - validation of a model. Journal of the American Society for Horticultural Science. 127: 1013-1017.

Feller, C.and M. Fink. 2004. Nitrate content, soluble solids content, and yield of table beet as affected by cultivar, sowing date and nitrogen supply. HortScience. 39: 1255-1259.

Gaertner, V.L.and I.L. Goldman. 2005. Pigment distribution and total dissolved solids of selected cycles of table beet from a recurrent selection program for increased pigment. Journal of the American Society for Horticultural Science. 130: 424-433.

Gasztonyi, M.N., H. Daood, M.T. Hájos, and P. Biacs. 2001. Comparison of red beet (*Beta vulgaris* var *conditiva*) varieties on the basis of their pigment components. Journal of the Science of Food and Agriculture. 81: 932-933.

Goldman, I. 2010. Vegetable cultivar descriptions for North America: Beet, lists 1-26 combined http://cuke.hort.ncsu.edu/cucurbit/wehner/vegcult/beet.html, North Carolina State University, Raleigh, NC 27695-7609.

Goldman, I.L. 1995. Differential effect of population density on shape and size of cylindrical red beet (*Beta vulgaris* L.) genotypes. Journal of the American Society for Horticultural Science. 120: 906-908.

Goldman, I.L.and J.P. Navazio. 2003. History and breeding of table beet in the United States. Plant Breeding Reviews. 22: 357-388.

Handysides, J. and S. Handysides. 2005. Stains on the carpet. British Medical Journal. 331: 1501.
Hayward, H. 1938. The Structure of Economic Plants. The MacMillan Company, New York.
Hoffmann, C.M. 2010. Sucrose accumulation in sugar beet under drought stress. Journal of Agronomy and Crop Science. 196: 243-252.
Kenter, C., C.M. Hoffmann, and B. Märländer. 2006. Effects of weather variables on sugar beet yield development (*Beta vulgaris* L.). European Journal of Agronomy. 24: 62-69.
Khan, A.A., N.H. Peck, A.G. Taylor, and C. Samimy. 1983. Osmoconditioning of beet seeds to improve emergence and yield in cold soil. Agronomy Journal. 75: 788-794.
Kikkert, J.R., S. Reiners, and B.K. Gugino. 2010. Row width, population density, and harvest date effects on marketable yield of table beet. HortTechnology. 20: 560-567.
Kujala, T.S., J.M. Loponen, K.D. Klika, and K. Pihlaja. 2000. Phenolics and betacyanins in red beetroot (*Beta vulgaris*) root: distribution and effect of cold storage on the content of total phenolics and three individual compounds. Journal of Agricultural and Food Chemistry. 48: 5338-5342.
Lange, W., W.A. Brandenburg, and T.S.M.D. Bock. 1999. Taxonomy and cultonomy of beet (*Beta vulgaris* L.). Botanical Journal of the Linnean Society. 130: 81-96.
Larsen, F.J., T.A. Schiffer, S. Borniquel, K. Sahlin, B. Ekblom, J.O. Lundberg, and E. Weitzberg. 2011. Dietary inorganic nitrate improves mitochondrial efficiency in humans. Cell Metabolism. 13: 149-159.
Lee, C.-H., M. Wettasinghe, B.W. Bolling, L.-L. Ji, and K.L. Parkin. 2005. Betalains, phase II enzyme-inducing components from red beetroot (*Beta vulgaris* L.) extracts. Nutrition and Cancer. 53: 91 - 103.
Lee, C.Y., R.S. Shallenberger, D.L. Downing, G.S. Stoewsand, and N.M. Peck. 1971. Nitrate and nitrite nitrogen in fresh, stored and processed table beets and spinach from different levels of field nitrogen fertilisation. Journal of the Science of Food and Agriculture. 22: 90-92.
Lee, J.S., W.G. Pill, B.B. Cobb, and M. Olszewski. 2004. Seed treatments to advance greenhouse establishment of beet and chard microgreens. Journal of Horticultural Science & Biotechnology. 79: 565-570.
Liere, D. 1984. Relationship of seed size, seed washing, plant density and harvest date to yield and plant stand in table beet (*Beta vulgaris* L.). M.S. Thesis, Oregon State University.
Longden, P.C., R.K. Scott, and D.W. Wood. 1974. Grading monogerm sugar beet seed and its influence on performance. Jounal of Agricultural Science. 83: 125-135.
Lu, G., C.G. Edwards, J.K. Fellman, D.S. Mattinson, and J. Navazio. 2003a. Biosynthetic origin of geosmin in red beets (*Beta vulgaris* L.). Journal of Agricultural and Food Chemistry. 51: 1026-1029.
Lu, G., J.K. Fellman, C.G. Edwards, D.S. Mattinson, and J. Navazio. 2003b. Quantitative determination of geosmin in red beets (*Beta vulgaris* L.) using headspace solid-phase microextraction. Journal of Agricultural and Food Chemistry 51: 1021-1025.
Mack, H.J. 1979. Effects of row spacings, fertilizers, and harvest dates on table beets. Journal of the American Society for Horticultural Science. 104: 717-720.
McGrath, J.M., M. Saccomani, P. Stevanato, and E. Biancardi. 2007. Chapter 6 Beet, p. 191-207. In: C. Kole (ed.). Genome Mapping and Molecular Breeding in Plants, Volume 5 Vegetables. Springer-Verlag, Berlin.
Meikle, R.A.R. 1981. Factors affecting the germination and establishment of monogerm sugar beet. B.Sc. Hons Thesis, University of Edinburgh, Edinburgh.
Milosevic, M., J. Rajnpreht, and P. Dokic. 1992. Effect of different seed size fractions on germination in sugarbeet (*Beta vulgaris* L.). Seed Science and Technology. 20: 703-710.
Navazio, J., M. Colley, and J. Zyskowski. 2010. Principles and practices of organic beet seed production in the pacific northwest, Organic Seed Alliance.

Nirmala, K.and R. Umarani. 2008. Evaluation of seed priming methods to improve seed vigour of okra (*Abelmoschus esculentus*) and beetroot (*Beta vulgaris*). Seed Science and Technology. 36: 56-65.

Nottingham, S. 2004. Beetroot (2004) http://www.stephennottingham.co.uk/beetroot.htm Vol. 2012.

Peck, N.H., B.E. Clark, and J.J. Natti. 1967. Effect of decortication and fungicide on performance of table beet seed. Agronomy Journal. 59: 78-80.

Peck, N.M.and H. Wilczynski. 1967. Narrow rows for table beets. New York Agricultural Experimental Station Farm Research. 33: 6-7.

Redfearn, M.and D.J. Osborne. 1997. Effects of advancement on nucleic acids in sugarbeet (*Beta vulgaris*) seeds. Seed Science Research. 7: 261-268.

Santamaria, P. 2006. Nitrate in vegetables: toxicity, content, intake and EC regulation. Journal of the Science of Food and Agriculture. 86: 10-17.

Silva, J.B., R.D. Vieira, and M. Panobianco. 2006. Accelerated ageing and controlled deterioration in beetroot seeds. Seed Science and Technology. 34: 265-271.

Sistrunk, W.A.and G.A. Bradley. 1970. Influences of various field practices on quality of canned red beets. Arkansas Farm Research. 19: 9.

Song, S., H. He, X. Tang, and W. Wang. 2010. Determination of polyphenols and chlorogenic acid in artichoke (*Cynara scolymus* L.). Acta Horticulturae. 856: 167-172.

Stintzing, F.C.and R. Carle. 2007. Betalains - emerging prospects for food scientists. Trends in Food Science & Technology. 18: 514-525.

Takacs-Hajos, M. 2009. The effect of heat on table beet (*Beta vulgaris* ssp esculenta var. rubra) quality. Cereal Research Communications. 37: 221-224.

Taylor, A.G., M.C. Goffinet, S.A. Pikuz, T.A. Shelkovenko, M.D. Mitchell, K.M. Chandler, and D.A. Hammer. 2003. Physico-chemical factors influence beet (*Beta vulgaris* L.) seed germination., p. 443-440. In: G. Nicolás, K.J. Bradford, D. Côme, and H.W. Pritchard (eds.). The Biology of Seeds: Recent Research Advances. CAB.

TeKrony, D.M.and E.E. Hardin. 1969. Germination potential of monogerm sugarbeet seed as determined by field emergence and laboratory germination. Journal of the American Society of Sugar Beet Technologists. 15: 607-616.

University, O.S. 2004. Beets and Chard: *Beta vulgaris* http://nwrec.hort.oregonstate.edu/beetch.html.

Warne, L.G.G. 1951. Spacing experiments on vegetables IV. The yield of globe beet grown at twelve spacings and two manurial levels, in Cheshire, 1948. The Journal of Horticultural Science & Biotechnology 26: 296-303

Watson, J.F.and I.L. Goldman. 1997. Inheritance of a gene conditioning blotchy root color in table beet (*Beta vulgaris* L.). Journal of Heredity. 88: 540-543.

Watts, A.R., M.S. Lennard, S.L. Mason, G.T. Tucker, and H.F. Woods. 1993. Beeturia and the biological fate of beetroot pigments. Pharmacogenetics and Genomics. 3: 302-311.

Webb, A.J., N. Patel, S. Loukogeorgakis, M. Okorie, Z. Aboud, S. Misra, R. Rashid, P. Miall, J. Deanfield, N. Benjamin, R. MacAllister, A.J. Hobbs, and A. Ahluwalia. 2008. Acute blood pressure lowering, vasoprotective, and antiplatelet properties of dietary nitrate via bioconversion to nitrite. Hypertension. 51: 784-790.

Wettasinghe, M., B. Bolling, L. Plhak, H. Xiao, and K. Parkin. 2002. Phase II enzyme-inducing and antioxidant activities of beetroot (*Beta vulgaris* L.) extracts from phenotypes of different pigmentation. Journal of Agricultural and Food Chemistry. 50: 6704-6709.

Wolyn, D.J.and W.H. Gabelman. 1990. Selection for betalain pigment concentrations and total dissolved solids in red table beets. Journal of the American Society for Horticultural Science. 115: 165-169.