Final Report

Improving Processing Vegetable Yields Through Improved Production Practices

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Improving Processing Vegetable Yields Through Improved Production Practices – VG16011

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1 Content

2 Summary

The Improving processing vegetable yields through improved practices project, set out to identify ways to increase the average yields of the target processing vegetables. Australian frozen vegetable production continues to face increased competition from imported frozen vegetables. This competition from imported product is reducing margins for processors and growers alike. The industry must find ways to increase yields and/or reduce input costs to remain viable. Simplot Australia have set target average yields for the year 2020 as a benchmark for growers. Some growers have already achieved or exceeded these target yields.

The project set out to identify what the leading growers are doing, that the middle and lower cohort of growers aren't. The aim is to find ways to improve the average yields of broccoli, cauliflower, carrots, beans (green and yellow) and sweet corn, from the perspective of the growers, agronomists and industry personnel. The methodology used included a review of best practice and recent innovations for the target crops, as well as appreciative inquiry interviews with Simplot growers in Tasmania and New South Wales.

Appreciative inquiry is a semi-structured interview approach that seeks to engage stakeholders in self-determined change. The approach takes the emphasis away from "problem solving" and focuses on the positives. Using one-on-one interviews, the interviewees were encouraged to think about positive aspects of the processing vegetable crops they grow, and what could be explored or what was needed to solve the "puzzle" around ways to increase the productivity and profitability of these crops?

Five factsheets have been developed, based on the information collected during the project. The information collected from the interviews and the review of best practices and recent innovations was used to develop a plan for demonstrations/trials to be explored in a second phase of this project.

3 Keywords

Processing vegetables; Improved profitability; Participatory Research

4 Introduction

The viability of frozen vegetable production in Australia is currently under threat, as frozen produce continues to face increased competition from the import of processed vegetables across all segments. The value of trade balance in vegetables continues to lose ground falling by $74M in 2013/14. During this period processed imports increased by 19% and frozen imports by 12%. Processed vegetable exports in 2013/14 also fell 15% while the increase in frozen market imports was offset by a 5% increase in export[1]. The production and processing of broccoli, cauliflower, carrots and beans are fundamental to the financial viability of the Simplot Quoiba factory and complement processing peas, the main processing crop supplying the factory. Maintaining high yields and minimising input costs are fundamental to the ongoing success of the Simplot operations in Tasmania.

Simplot is a family owned multi-national with demonstrated interest in supporting growers and local economies. However, failure to increase pre-farm gate productivity gains places the long term viability of frozen vegetable production in Tasmania at risk. Given the heavy reliance of vegetable growing operations on processing contracts in Tasmania, and as recently demonstrated by the exit of McCain Food from this sector, loss of this channel would lead to severe financial hardship through a large and sudden structural shift within the industry.

The objective of this project was to provide the tools and information that ensures that supply to the frozen processing vegetable industry in Tasmania remains viable. For this to occur, given that processed vegetables complete in a global market, it is essential that growers are using world's best practice to grow and harvest their crops to achieve profitable levels of return on investment.

Simplot as the main processor of beans, broccoli, cauliflower and carrots also relies on a well-functioning and cost efficient supplier base who can supply product reliably, and at a competitive price.

Simplot operations in Tasmania: Tasmania is the only state in Australia that grows processing peas, green beans, cauliflower, broccoli and carrots for the frozen processing market. Growers in Tasmania provide produce to Simplot under contract, with payments based on net yield. Simplot's grower payments are strongly influenced by retailers and end users maintaining pressure on low prices. This situation means the only way of increasing profitability and living standards for growers is to increase net yield while making efficiency gains. To maintain viability of the production base, Simplot has set target yields and prices across the vegetable categories to the year 2020. Changes in grower practice are fundamental to achieving these goals, and Simplot has limited influence on this beyond contract pricing.

While some processing and packing companies in Tasmania provide agronomic advice to influence grower cropping practices, Simplot's contracting model does not permit this option. Instead, the majority of agronomic advice is provided by crop consultants, and crop husbandry practices are heavily influenced by grower expertise and motivation. Grower motivation to maximise net yield is complex, is not always driven by a desire for greater profits, and often influenced by competition to allocate resources (e.g. irrigation) to other crops in the rotation that are known or perceived as providing better returns and or environmental stewardship. Although all the crops grown for Simplot are economically viable if grown well, some crops are grown under contract purely to gain access to contracts for high value crops such as potatoes, from which Tasmanian vegetable operations derive 50% of their cash receipts. Consequently, Simplot although reliant on best practice cropping and the productivity growth from this, has a limited influence on grower motivation beyond contract pricing and the quality controls that determine net-yield.

The significance of processing vegetables to the State's economy is illustrated by the farm gate value (FGV) of the crops included in this project, estimated at $22.6M in 2014/15. This

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[1] AusVeg: Summary Trade in Vegetables, http://ausveg.com.au/resources/statistics/trade-in-vegetables/summary.htm, Accessed 3 Nov 2016.

was comprised of cauliflower 2014/15 production at 5,400 tonnes (FGV $3.1M), broccoli production of 7500 tonnes (FGV $5.2M), carrots at 18,000 tonnes (FGV $2.5M), bean yields of 11,700 tonnes (FGV $7.3M), and sweet corn production of 27,221 tonnes (FGV $4.5M).

Calculated on the basis of yield required to keep the factory and grower operations viable, Simplot has set productivity targets for each of these crops (Table 1).

Table 1 Simplot productivity targets for 2020

Crop	Average yield (4yr) (t/ha)	Target yield (2020) (t/ha)	Increase (%)
Cauliflower	24.5	30.0	23
Autumn Broccoli	20	25.0	24
Baby carrots	54.8	60	9
Ring carrots	51.1	90	76
Standard carrots	69.8	100	43
Yellow beans	11.6	14	21
Green beans (whole)	12.5	15	20
Green beans (cut)	16.6	21	26
Sweet corn	21.4	25	17

Changes in grower practice underpin increases in productivity and profitability, as even the success of new technologies is dependent on adoption and practice change.

5 Methodology

Establishment of a project reference group (project advisory panel)

A project reference group, consisting of nine members including growers, company personnel (Simplot, AHR and TIA) and agronomists were engaged to act as the project reference group. This ensured the issues investigated and the activities undertaken were locally relevant, and also will assist in the uptake of new practices and technologies to be developed under Phase 2 of the project.

Local discovery phase (semi-structured interviews)

Given that some growers already achieve the 2020 target yields, what are leading growers doing, that the middle and lower cohort of growers aren't?

Growers as people, reflect the full spectrum of personalities, aspirations and paradigms of success common to Australian society, and in particular, small business owners. While changes in grower practice can, to some extent, be facilitated by new technologies, at the heart of change is a convincing argument that appeals to the grower's business acumen, values, aspirations and attitude to risk.

Identification of both practice gaps and motivation between leading growers in Tasmania and the middle cohort can both be identified using Appreciative Inquiry, a well-documented approach used to achieve large scale changes in organisational behaviour. Using one-on-one interviews, this approach uses semi-structured interview techniques and is positive in nature; rather than approaching productions gaps as a problem to be solved, the basic assumption is that higher crop yields are a 'puzzle' to be welcomed.

Discovery is the first phase of appreciative inquiry, and is typically followed by imagining what could be, followed by planning and prioritization, and lastly implementation. These later phases will be employed in Phase 2 of the project.

The discovery phase of appreciative inquiry interviews was conducted across the Simplot processing vegetable categories of broccoli, cauliflower, carrots, beans and sweet corn.

Social Science Ethics approval was granted from the University of Tasmania for this process and will enable data analyses of responses for peer-reviewed publication. Grower contact listings were supplied by Simplot and individual participants independently contacted by project staff. Participation in the interview process was voluntary and participants could withdraw at any stage. Thirty five growers were approached with twenty-five agreeing to participate and be interviewed.

Appreciative Inquiry generates qualitative data, that is, data that cannot easily be captured as numbers. Analysis of the first round of information derived from initial interviews was collated and common themes captured using Voyant text analysis (Voyant is an open-source, web based application). Responses were then categorized by a factor of influence, and the intensity of responses then totalled to identify key issues. A second round of interviews with more specific probes (i.e. questions) was conducted where necessary to add detail for building the proposals for Phase 2 of the project.

Review of Australian and international best practice including recent innovations in the production of the target crops for processing.

This activity was conducted as a comprehensive literature review of Australian and international best practice to identify recent innovations in the production of the target processing vegetable crops. Simplot, agronomists and growers, were also consulted while producing this document to assist in the identification of the practical viability of potential solutions to current production issues.

Development of a full trial plan with budget for Phase 2 of the project.

A full trial plan and budget was developed based on the findings from the appreciative enquiry, literature search and consultations with industry personnel.

Development of best practice extension materials on processing green beans, carrots, broccoli, cauliflower and sweet corn.

Factsheets were produced for each of the five target crops identified in the RFP. The topics selected were based on reviewing of literature, and the outcomes of the consultations and interviews with growers and agronomists.

6 Outputs

Production as viewed from the literature

Introduction

The following document was completed to review Australian and international best practice and recent innovation in the production of target processing vegetable crops. Upon consultation with Simplot, agronomists and growers, five major crops and production issues were identified for review:

- broccoli – direct seeding and predictive modelling for forecasting broccoli harvest
- carrot – storage
- green bean – irrigation scheduling for management of Sclerotinia sclerotiorum
- cauliflower – direct seeding and strip tillage
- sweet corn – density and variable rate technologies.

The document integrates a review of literature with issues raised by Simplot and other industry members to identify the major issues for production of processing vegetables. Personal communications with industry members and growers based on their field experiences are presented in the text boxes titled, "From the field". This is subjective material and should be treated as anecdotal information.

Broccoli

Direct seeding of broccoli

Key findings

- There is limited research on direct seeding of broccoli and how it compares with transplanted broccoli;
- Direct seeding of broccoli can potentially reduce costs and increase yields, but risks of poor crop establishment and reduced plant stand uniformity are higher and need to be well managed e.g. through the use of a precision seeder;
- Various factors can affect direct seeding of broccoli, including growing conditions, plant vigour, planting depth, self-thinning, weed control, planting density, irrigation, and cultivar;
- Plant establishment is critical for direct seeded broccoli production and can be affected by various factors, including soil temperature, soil moisture, planting depth, seed size and vigour;
- Plant density is a major factor affecting broccoli yield and uniformity, but its optimisation is complex and requires effective cropping schedules to match cultivar;
- Manipulating plant density may allow head size to better meet market requirements, as well as potentially improve uniformity for mechanical harvesting.

Background

Worldwide-published research on direct seeding of broccoli is limited. In Australia, broccoli is mostly established using transplants grown in tray cells on-farm or bought from a seedling nursery (Heisswolf et al., 2004). In some countries such as the U.S., broccoli is often direct-seeded using precision planters to optimise plant spacing and reduce costs associated with seed loss and a requirement for hand-thinning (Welbaum, 2015).

Compared to transplanting, direct seeding of broccoli can potentially reduce costs (e.g. labour requirements are generally lower) and allow higher plant density and yield per area (Grabowska et al., 2009; Heisswolf et al., 2004). However, there are few studies directly comparing both systems. A two-year study in Romania showed that compared to transplant, directly seeded broccoli (cv 'Calabrese Natalino') resulted in yield increases of 18%, 33% and 35% when planted in April, May and June, respectively (Ardelean et al., 2013a). Effects on head size or quality were not reported. In a three-year study in Poland, compared to transplant, directly seeded broccoli (cv 'Lord F1') resulted in heads with reduced soluble sugar content and increased levels of phosphorus, potassium, calcium and magnesium, with no differences in dry matter (Grabowska et al., 2009). Effects on yield were not reported.

Direct seeding of broccoli can also potentially increase risks associated with pests and diseases, adverse weather, soil crusting and weed control during crop establishment, as well as requiring more water, thinning, and increasing field-growing time by about two weeks (Heisswolf et al., 2004). These risks can contribute to poor establishment of broccoli plants, which is a major constraint for direct seeding of this crop, together with increased crop variability resulting from irregular field emergence. Reduced crop uniformity (including maturity) increases harvest costs (Heisswolf et al., 2004).

Thus, direct-seeded results can vary. For example, in an earlier study in the U.S., directly seeded broccoli (cultivar not specified) resulted in higher profitability in the early harvest due to reduced cost of production compared to transplant (Sterrett et al., 1991). In contrast, direct seeding in the main-season resulted in reduced profitability due to reduced plant establishment and yield.

Several environmental and agronomic practices can affect the success of direct seeding and broccoli yield, as detailed below.

Growing climatic conditions

Broccoli germination and plant growth can be generally restricted by either excessively low (<5°C) or high (>30°C) temperatures (Jett et al., 1996), with an optimum range between 20-28°C (Heisswolf et al., 2004).

High-temperature inhibition of seed germination and seedling emergence is a potentially important factor limiting direct-seeded broccoli stands. A U.S. study showed that day temperatures higher than 30°C reduced emergence of broccoli seeds (cv 'Packman') by 31%, 85% and 100% at 32°C, 34°C and 36°C, respectively (Elson et al., 1992). Seeds exposed to 40°C for a single, four-hour period reduced seedling emergence to 60%. These results suggest that growers should adopt temperature-reducing cultural practices that can reduce soil temperature and improve stand establishment of broccoli during hot weather. Such practices could include planting at the coolest time possible (e.g. in the evening), frequent, light irrigations, and organic mulches.

In a two-year field study with directly seeded broccoli for processing (cvs 'Compact', 'Grande', 'Gran Vert', 'Packman', 'SG 301', and 'Toro') in Italy, a thirteen-day delay in seeding resulted in a twenty-six day delay in harvest of central heads, although there was little effect of sowing dates on total yield (Damato, 2000).

In a study with broccoli grown in the UK, late-sown crop (late July) resulted in lower yield with a lower harvest index, smaller and shallower heads with poorer colour and a greater plant-to-plant variability compared with crops from the earlier (late March) sowings (Salter et al., 1984). Results suggested that yield, maturity and quality were affected by environment.

Plant establishment, thinning and weed control

Several factors can affect stand establishment of direct-seeded broccoli, including soil temperature, soil moisture, planting depth, seed size, and seed vigour (Elson et al., 1992). Adequate plant establishment is a critical stage for broccoli production. An Australian study (as part of project VG06051) on transplanted broccoli (cv 'Marathon') showed a significant proportion of the variation in harvest maturity was introduced during early crop establishment and variability during the period of floral initiation (Brown et al., 2009).

To optimise establishment of direct seeded broccoli, the soil moisture and temperature should be adequate to promote rapid germination. Direct seeding is often done on raised beds to promote drainage and accommodate furrow irrigation (Welbaum, 2015). Seeding rates will vary with seed size, germination percentage and target plant density.

The beds should be cultivated to a fine tilth (after pre-plant fertiliser has been incorporated) to achieve good seed-to-soil contact and facilitate rapid uniform emergence (Heisswolf et al., 2004).

A precision vacuum seeder set up for planting brassica seed into the soil should be used. Precision planting aims to minimise the need to thin seedlings later. However, to ensure a good stand, broccoli is sometimes over-seeded and thinned when plants are in the seedling stage (Welbaum, 2015). If thinning is necessary, young seedlings should be removed when 3–5 cm tall and weed seedlings chipped out at the same time (Heisswolf et al., 2004).

Physical weed control strategies such as cultivation are key components in broccoli integrated weed management in countries such as the U.S., but they typically remove only the inter-row weeds, thus requiring costly hand weeding for commercially acceptable weed control (Lati et al., 2016). In a recent two-year study in California and Arizona, the use of a commercial robotic intra-row cultivator in direct-seeded broccoli (cv 'Marathon'), resulted in 18–41% more weeds removed at moderate to high weed densities and a reduction of hand-weeding times by 20–45% compared with the standard cultivator, with little effect on crop stand or marketable yield (Lati et al., 2016).

FROM THE FIELD

- Commercially, some broccoli growers have already implemented strip tillage and some have experienced gross margins gains of up to $500/ha, two- to three- years after adoption.
- Simplot have previously trialled strip-tilling to increase uniformity by providing increased and more uniform moisture to plants. This brought added challenges of weed control and increased damage from birds.
- Overall the broccoli industry perceives strip tillage as a success and it had already been well adopted. The benefits of further research in the field may be limited.

Plant density

Plant density is a major determinant of yield in broccoli production. Competition between broccoli plants affects head weight, a key commercial attribute for this crop (Francescangeli et al., 2006). Thus, manipulating plant density may allow head size to better meet market requirements, as well as potentially improving uniformity for mechanical harvesting (Chung, 1982; Salter et al., 1984).

For bunched broccoli, high plant populations with in-row spacing as close as 10 cm is generally recommended in the U.S. to create an optimum head size for bunching, whereas wider spacing of 20–60 cm can be used for production aimed to large-head single-stalk markets (Welbaum, 2015).

A three-year field study as part of project VG06053 involved a series of variety trials with transplanted broccoli at Brookstead, Qld using various Sakata cultivars bred for mechanical harvesting (Villalta and Porter, 2010). These included cvs ‘Atomic’, ‘Aurora’, ‘Bravo’, ‘Bridge’, ‘Brumby’, ‘Emerald Pride’, ‘Evergreen’, ‘Gypsy’, ’Mascot’, ‘Patron’, ‘1112–5’, ‘494–3’, ‘568–6’, and ‘608–6’.

Key results showed that:

- Increasing plant density from 60,000 to 90,000 plants/ha resulted in more uniform crop, smaller heads that were more resistant to damage, and heads with taller straighter stems that better suited mechanical harvesting;
- The average head weights suggested that varieties with larger heads may be more susceptible to mechanical damage, e.g. variety 608–6 had the largest heads and the most damage during mechanical harvesting in 2007, whereas the variety Patron had the lowest damage score and the lowest number of heads lodged in the field after mechanical harvesting in 2008;
- When damage severity, number lodged and yield were considered, cvs ‘Gypsy’ and ‘Atomic’ were a good compromise, i.e. they had tall straight stems which could make them more suitable for mechanical harvesting than some of the other ‘squatter’ varieties;
- The season (autumn or winter), and the district generally, had a greater influence on yield than cultivar alone, thus highlighting the importance of growing a crop in the correct seasonal window and geographic location for optimum yield and quality;
- Harvest maturity, cultivar and seasonal temperatures were important factors to be considered due to their impact on final head quality at harvest.

Additional trials in the same project/location as above looked at the impact of plant density on broccoli uniformity in one year (using most of the above varieties).

Key results were:

- The minimum head width at maturity was achieved at relatively low densities (32,500 plants/ha, north orientation);
- Increasing density increased yield without compromising head width (diameter), which is a critical factor for processed broccoli florets;
- If head width is within the specification for processing, these results suggest that increasing density may increase yield without decreasing quality;
- A single-row planting was recommended for mechanical harvesting, as it gives a more uniform plant stand and does not reduce plant head width compared to a double-row planting.

Conversely, results from a three-year study with transplanted broccoli (cv ‘Marathon’) for processing in Canada (Sanderson and Fillmore, 2010) showed that:

- Marketable yield was improved by approx. 25% by reducing in-row plant spacing from the traditional 35 cm to 20 cm in a single row, with only a slight increase in unmarketable yield i.e. net yield was higher;
- Average head weight, head diameter, and the incidence of hollow stem decreased as plant density increased from 3.2 to 6.4 plants/m^2;
- The highest marketable yield was achieved at 5.6 plants/m^2 when grown in an early transplanting with trickle irrigation in a single row with 90 cm between the row and 20 cm within the row;
- Planting broccoli earlier in the season resulted in higher marketable yield.

A recent two-year plant density study across two locations in the U.S. with broccoli (cvs 'Emerald Crown' and 'Durapak 19') grown for the fresh crown-cut market, showed that increasing plant density by reducing within-row spacing to 10 cm increased overall yield per hectare compared with 15 or 20 cm, with little effect on stem diameter and average head weight (Ward et al., 2015). However, the highest density increased the incidence of heads with lower quality characteristics (i.e. lower bead uniformity and/or larger bead size), so the 15 cm within-row spacing was recommended to balance yield and head quality attributes.

The above results are generally consistent with various earlier studies across different countries showing plant density effects on broccoli yield and or quality.

For example:

- In a two-year field study in Tasmania, total yield of direct seeded broccoli (hybrid cv ‘Futura’) using a ‘Stanhay’ drill increased from 12 to 23 t/ha when plant density increased from the standard 2.8 to 8.3 plants/m^2 (Chung, 1985);
- In a two-year field study with direct seeded broccoli for processing (cvs ‘Compact’, ‘Grande’, ‘Gran Vert’, ‘Packman’, ‘SG 301’ and ‘Toro’) in Italy, increasing plant density from 6.3, 8.3 and 12.5 plants/m^2, resulted in generally higher yield of central heads with reduced weight and diameter (Damato, 2000);
- In a two-year work with broccoli (cv ‘Legacy’) grown in pots in the greenhouse in Argentina, as density increased (from 2, 4, 6 and 8 plants/m^2), head weight decreased, but the effect was mostly due to the decrease in the weight of the stem portion of the head, without affecting floret weight (Francescangeli et al., 2006);
- In a two-year study with transplanted broccoli (cvs ‘Emperor’, ‘Neptune’ and ‘Corvet’) in Denmark, increasing plant density from 5 to 20 plants/m^2 reduced uniformity in head weight, head diameter, and floret length in late planting, but there was still sufficient uniformity to allow once-over mechanical harvesting (Sorensen and Grevsen, 1994);
- In a study with broccoli grown in the U.K., yield increased as densities increased from 2–20 plants/m^2, but reached a plateau after that, with mean head size there after not increasing with density.

FROM THE FIELD

- Spring planted broccoli on the north-west coast can be slow to establish, contributing to increased weed pressure. Optimum planting time for direct seeded broccoli crops is late-December through to late-January, which enables faster plant growth and allows crops to better compete with emerging weeds.
- Whilst some local growers and agronomists are keen to see more research on direct seeding, others share experiences of poor success with directly sown broccoli crops in Tasmania. A major issue for direct seeded crops is high insect pressure (e.g. heliothis and diamondback moth) at emergence. These insect pests fly in from neighbouring fodder crops causing severe damage to emerging seedling and leading to a heavy reliance on insecticides such as spinetoram (Success™ Neo). Direct seeded crops may also be more prone to poor establishment where high soil variability exists. These added pressures have resulted in direct seeded crops yielding 12-15t/ha whilst transplanted crops in similar condition achieved 22t/ha.

Simplot have recently conducted some direct seeding trials with the following key findings:

- cost saving was not as significant as anticipated due to lack of uniformity resulting in lower factory yield;
- uniformity was greater in transplanted broccoli;
- soil variability, especially in the northern midlands region, heavily influences plant uniformity.

Planting depth

In commercially planted direct-seeded broccoli crops, achieving a consistent depth of seed placement is influenced by many factors, including soil moisture and tilth at planting, and drill type. The optimal placement depth is a function of seed size and smaller seeded crops must be planted at shallower depths. Direct seeding of small-seeded crops such as broccoli generally requires use of precision planters in dry soil (Roberts et al., 2008).

Seeding depth is generally 1-2 cm, but it will depend on soil type and season, e.g. in lighter soils and warm weather is should be planted deeper, as conditions will make it more difficult to keep the top layer of soil moist (Heisswolf et al., 2004).

A survey conducted before the start of project VG06053 at Brookstead, Qld, showed that seeding depth (using a Monosem™ vacuum seeder) could vary widely within one field and planting, from as little as 2–3 mm below the surface, to as deep as 15–20 mm (Villalta and Porter, 2010). Key findings from the project showed that planting depth affected days to emergence and the final germination percentage of broccoli seeds (cultivar not specified), with the highest germination percentage (approx. 80%) achieved when seeds were planted at depths of 6–15 mm. Results also suggested that bed preparation is a critical step for ensuring a uniform plant stand suitable for mechanical harvesting of broccoli.

Conversely, an earlier study in the U.S. showed that when planting depth increased from 12 mm to 50 mm, germination, plant height, and fresh weight of broccoli (cv 'Waltham 29') grown in the greenhouse decreased by up to 56%, 28% and 43%, respectively, whereas plant weight in the field reduced by up to 77% at harvest (Alam and Locascio, 1966).

Irrigation

Used with direct seeding, solid-set irrigation can allow a whole paddocks surface soil to remain evenly moist until seedlings have emerged, minimises soil crusting and surface drying, and thus promotes more uniform germination (Heisswolf et al., 2004). For this reason it is often favoured in direct seeded vegetable cropping systems.

Results from one trial with transplanted broccoli (cv ‘Evergreen’) seedlings (four-week old), as part of project VG06053 (Villalta and Porter, 2010), showed that total yields were generally not highly dependent on the establishment and post-establishment methods of irrigation used (i.e. overhead, furrow and trickle) provided plant access to water during critical times was not compromised. Additionally rows on the north side of beds usually resulted in an above average head size (weights, widths and stems) on most irrigation systems except furrow.

In a three-year study with transplanted broccoli (cv ‘Marathon’) for processing in Canada, compared to no irrigation, trickle irrigation (i.e. supplied at least 25 mm total precipitation per week to meet crop needs) increased marketable yield by an average of 12%, but the study noted that the increase was likely not enough to recover the cost of irrigation (Sanderson and Fillmore, 2010).

In a study with subsurface drip irrigation in the U.S., Roberts et al. (2008) state that direct seeding tends to increase dependence on sprinklers for stand establishment of broccoli. Shallow seed placement requires higher volumes of water for germination and establishment and, as a result, more salts accumulate in the critical zone.

While sprinklers are useful for establishing stands of vegetable crops, the study authors argue that the use of sprinklers for germination can result in higher costs to growers.

FROM THE FIELD

- For optimal germination in direct seeded crops, pre- rather than post-plant irrigation is found to be more beneficial.
- Using irrigation water to supply nutrients (fertigation) combined with Variable Rate Technology (VRT) has already been implemented by some growers in Tasmania. This technology has the potential to significantly reduce input costs and may be of particular benefit in shoulder seasons and paddocks with high soil variability and could be an area potential area of further research.

Cultivar

The choice of cultivar is critical to broccoli production and should consider the specific growing conditions (climate) and time of the year.

An Australian study (as part of project VG06051) with transplanted broccoli (cv ‘Marathon’) showed that the more compact shape of cultivar ‘Shamrock’ resulted in a superior (low) ratio of the less valuable stem tissue to the more valuable floral tissue when compared to the elongated form associated with ‘Marathon’ (Brown et al., 2009). The architecture of the ‘Shamrock’ inflorescence also provided higher total floret yield, and making easier to manipulate the levels of stem material to suit seasonal requirements. The attributes associated with ‘Marathon’ resulted in greater processing efficiency, with the comparatively open branch structure of this variety producing more segments within factory specification, and a smaller proportion that required re-dicing. Results confirmed the significant impact of head shape on net yield and processing efficiency.

A study in Romania with direct-seeded broccoli (cvs ‘Calabrese Natalino’, ‘Cezar’, ‘Green Calabrese’, and ‘Ramoso Calabrese’) sowed at various times (early May, early June and mid July) showed large variation among cultivar and sowing times in total yield (e.g. from 16 to 26 t/ha), head diameter (0.52–0.90 cm) and daily growth (0.34–0.64 cm/day) (Ardelean et al., 2013b).

An earlier two-year field study with direct seeded broccoli for processing in Italy, showed large variability among sic cultivars in total yield (t/ha), e.g. ‘Compact’ (10.9), ‘Toro’ (9.7), ‘Gran Vert’ (7.1), ‘SG 301’ (6.2), ‘Packman’ (5.8), and ‘Grande’ (5.0) (Damato, 2000).

Seed treatments (i.e. priming or coating)

There is little evidence that seed treatments could be an effective tool to improve seed establishment of direct seeding broccoli.

In a trial at Brookstead, Qld (as part of project VG06053), priming or coating (type of coating not specified) of broccoli seeds (cv ‘Brumby’) did not improve germination rate or yield, nor it reduced crop variability at harvest (Villalta and Porter, 2010).

These results are consistent with an earlier study in Brazil reporting little differences in germination rate and vigour between coated (with hydroxyethyl-cellulose) and uncoated broccoli (cv ‘Ramoso de Brasilia’) seeds (Almeida et al., 2005).

In another earlier three-year study in the U.S. with primed broccoli (cv ‘Earlidawn’) seeds, the response to coating was inconsistent in terms of germination incidence depending on seasonal conditions, with little effect on yield or maturity in two out of three years (Jett et al., 1995).

In a recent greenhouse study in the U.S., broccoli (cv ‘Centura’) seeds coated with 30–50% soy flour after 30 days had greater weight (both fresh and dry), height, leaf development, and higher contents of chlorophyll and nitrogen than plants from non-coated seeds. This suggest growth-enhancing properties of the soy flour coating (Amirkhani et al., 2016). However, coating also reduced germination percentage and rate compared to uncoated seed.

Objective pre-harvest assessment of broccoli

Background

The primary driver for harvest maturity of processing broccoli is head size. Whilst larger heads denote larger yields, there is a point where heads can over mature i.e. the length of the flower peduncle reaches greater than 12mm increasing the risk of flowers breaking off during snap freezing. On the contrary, commencing harvest prior to a sufficient proportion of broccoli heads in a paddock reaching harvest maturity is also detrimental as it leads to costly multiple-cuts. Determining the optimum point at which enough of a paddock has reached harvest maturity for the first-cut is therefore critical to maximise yield and gross margin. The method currently employed is largely subjective, with field officers making a decision based on a visual assessment of bead size, compactness and head size. A method to objectively conduct pre-harvest assessments would enable a more precise harvest schedule, reduce costs and enable accurate forecasting for processing logistics.

Tools for objective pre-harvest assessment

A combination of remote sensing technology and predictive modelling could enable objective pre-harvest assessments and forecasting. Researchers at the Tasmanian Institute of Agriculture are currently leading research in this field.

Real-time head size data

- Drone-captured aerial images could provide a quantitative assessment of average head size as well as detail on the distribution of head size i.e. maturity uniformity across a paddock. Wrapping leaves may limit the application of this technology and requires further field validation. This may be achieved by collaborating with local remote sensing research groups (e.g. Terra Luma).

Forecasting increase in head size

- Head size data gathered using remote sensing could be fed into a calibrated linear climate-based model to forecast the rate of head growth. A model using parameters such as head diameter, temperature and intercepted radiation could simulate the increase in head size for different parts of a paddock, potentially for up to seven-days in advance. These models have been developed in other countries, are precise and simple.

Forecasting optimum harvest point

- In addition to forecasting the rate of head growth, predicting the length of time until optimum the harvest point (i.e. compact head and peduncle less than 12mm) is reached would also be beneficial. This may be achieved by gathering data on the rate of development relationships between different flower parts e.g. relating head diameter to peduncle length of the floret. With this data a predictive model for time to harvest maturity may be developed.

Carrots

Background

Carrot quality and freshness can deteriorate, especially during long-term storage, due to moisture loss, changes in composition (such as loss of sugars and increase in bitterness) caused by respiration and ethylene exposure, and microbial growth leading to decay (Crespo et al., 2012; Seljasen et al., 2013). Increased respiration and deterioration processes of carrots are related to effects of postharvest factors such as temperature, relative humidity (RH), air composition in packaging and storage, mechanical stress, and treatments such as washing (Ilic et al., 2013; Seljasen et al., 2013) as detailed below.

Carrot shelf-life has been defined as the number of days carrots remain at specified storage conditions before losing 8% moisture (Shibairo et al., 1997). A critical variable affecting its quality and consumers' selection of carrots is freshness, which has been defined as having no film and no bruises, with a shiny and not shrivelled surface without dried ends, firm texture and not gummy, moist area when cut without any sour, fermentation or strong sweet odours, and crisp, juicy and not fibrous texture in the mouth (Péneau et al., 2007).

Field storage of carrots

Under certain circumstances, carrots can be stored in the field and harvested as needed, but long delays in harvesting may increase fibre content and undesirable flavour (Welbaum, 2015).

A two-year study with carrots (cvs 'Minicor' and 'Nantura') in the Netherlands compared field storage (coverage with polyethylene film on 4 kg/m^2 straw mulch) and cold storage at 0–1°C in a wet cooling (ice bank) system (Schoneveld, 1993). After removal (storage length was not specified) and a seven-day holding period at 15°C and 95% RH, key results were:

- Field-stored carrots had better appearance, with brighter colour but poorer flavour (less sweet and more bitter) than cold-stored ones;
- Monthly weight loss in storage increased from 1% when carrots were not washed before cold storage to 1.5% otherwise;
- Weight loss was reduced to 0.5% or 0.1% by lining the boxes with either perforated or un-perforated polyethylene film, respectively;
- There were significant interactions between storing method and cultivar on carrot appearance after storage.

In a series of trials undertaken from 1985 to 1991 in the UK, carrot (cvs 'Berjo', 'Camden', 'Nandor' and 'Narman') sowed between late-April and mid-June to achieve maturity and covered during mid-October to mid-November with 30 t/ha straw over black polyethylene (150 gauge) resulted in satisfactory storage for all cultivars (Runham et al., 1992).

In a study in France, carrots (cv. 'Nandor') harvested in October and cold stored at 0–1°C and 95-98% RH, maintained better quality (in terms of sugar, fibre and carotenoid contents) for six months, compared to field storage (Dily et al., 1993).

Long-term storage of carrots after harvesting

Under suitable conditions, mature carrots can be stored for prolonged periods, especially in areas where production is possible for only a few months of the year (Welbaum, 2015). For example, in European countries such as Norway and Serbia, carrots can be harvested and stored for six- to nine-months before packaging and retail (Ilic et al., 2016). However, there is little published data on long-term storage of carrots worldwide. There are reports of at least two different systems: either cold storing carrots in bulk bins or plastic crates straight after digging (thus applying postharvest treatments such as washing, sorting and packing after cold storage), or applying these treatment before cold storage.

Long-term storage before postharvest treatments

In a study in Switzerland, mature carrots (cv 'Bolero') were harvested in October and early

November into wooden bins (approx. 480 kg) either fitted or not fitted with polyethylene liners (0.3 mm thick, 50 holes/m^2), then cold stored in storehouses (set at 0–1°C, but actual at 0–4°C, RH>92%) of various sizes across different areas in the country for up to five months (Crespo et al., 2012). At removal from storage, carrots were washed (using a washing drum of industrial size equipped with a spraying system), manually sorted on a conveyer belt, weighed, packed into perforated polyethylene bags and held at 21°C for 8 days. Key results were:

- 6–8% of soil adhered to the carrots after harvest, reducing the marketable portion per bin;
- The use of perforated bin liners effectively reduced weight loss and decay in most cold rooms, and thus recommended for similar long-term storage conditions;
- 65% of carrots were marketable from bins with liners compared to 50% from bins without, with decay symptoms being the main cause of rejection after harvest;
- Excessive (3–5%) water losses resulted in carrot wilting (especially on the outer layers of bins), so maintaining high (above 92%) relative humidity was critical during the entire storage;
- Storage of carrots at 0–4°C prevented the development of black root rot (a prevalent disease in Switzerland);
- Adequate washing (using fresh tap water rather than recycled water) and the maintenance of a closed cool chain below 8°C after washing, packing and through the supply chain, were crucial to prevent black root and other decay at retail;
- Carrots from bins without liners had higher (by 60%) content of bitter compounds than those from bins with liner, suggesting poorer flavour.

In a three-year field trial in Poland, compared to non-stored (i.e. assessed after harvest), carrots (eight cultivars of various colours and shapes) that were stored for six months in 15kg plastic crates at 0–1°C and 97% RH immediately after harvest (with no indication of washing or any plastic liners used with the crates), were softer, had lower colour intensity, slightly higher contents of soluble solids, total sugars, phenolic and carotenoid compounds, and lower contents of nitrates (Gajewski et al., 2010). There was considerable variation among cultivars for most parameters. Other key quality parameters such as weight loss, external appearance or decay were not assessed.

Long-term storage after postharvest treatments

In a recent two-year field study in Serbia (Ilic et al., 2016), fully mature carrots (cv 'Bolero F1') harvested (mode not specified), washed (with hot water, hydrogen peroxide or chlorinated water, except control) and stored (packaging material not specified) for four- or six-months at 0°C and 95–98% RH had firmer texture and lost less weight (3.3–6.7%) than those stored at 0–2°C and 85–92% RH (13.5–20.2% weight loss). Similar results were shown by an earlier one-year study in Serbia (Ilic et al., 2013), in which mature carrots (cv 'Maestro') harvested, washed, and stored for 160 days at 0°C and 98% RH plus 20 days at 20°C days (market simulation), had firmer texture and lost less weight (3%) than those stored at 0–2°C and 79–94% RH (21% weight loss).

FROM THE FIELD

- Carrot storability is one of the biggest limitations for Simplot due to lack of storage for later processing at the factory.
- There is growing interest in trialing field storage or other alternate storage options, which may help alleviate the current processing challenges.

Postharvest factors affecting carrot storability and shelf life

Temperature and humidity

Exposure to high postharvest temperatures increases respiration rates and pathogen growth, as well as reducing shelf life and quality (including composition and sensory aspects) of fresh and minimally processed carrots growth (Seljasen et al., 2013). Thus, carrots should be cooled to 1–2°C as soon as possible after harvest to retain quality and reduce wilting, especially bunched carrots (Welbaum, 2015).

Carrot texture is also affected by temperature, with firmness, stiffness and turgor shown to be higher at lower tissue temperatures, reaching highest values at 5°C (Herppich et al., 2003). In long-term cold stored carrots, the texture properties changed due to physiological acclimation processes, known as cold-acclimation, with little variation in water potential.

In contrast, low-air humidity reduces shelf life by increasing carrot shrivelling due to its very thin and highly water-permeable peel (Shibairo et al., 1997), especially if they have been polished to remove the outer layer of skin, which is common in Australia (Ekman et al., 2016). High relative humidity (higher than 95%) is thus essential to prevent dryness and loss of crispness.

Critically, free moisture from the washing process or unevaporated condensation, common with plastic bin-liners (and due to fluctuating temperatures) will promote decay (Suslow et al., 2002).

Thus, to preserve quality and extend shelf-life, carrots should be stored at high (i.e. >95%) RH combined with temperatures close to 0°C for long-term storage (i.e. up to six-weeks for young immature carrots and for as long as six-months for large/mature carrots), whereas at 5°C storage life is reduced to two- to three-weeks (Ekman et al., 2016).

Ethylene production

Exposure of carrots to ethylene increases the production of bitter-tasting compounds (e.g. isocoumarin) and reduces total sugars, thus reducing flavour quality and acceptability (Lafuente et al., 1989; Seljasen et al., 2001b). For example, a study in Norway showed that after three-weeks of storage at 15°C, compared with ethylene level in regular air storage (0.5 ppm), storage of carrots in ethylene-enriched air (1 ppm) resulted in a 20-fold increase in tissue ethylene levels (up to 13 ppm at the end of storage) and a marked increase (of up to 13 ppm) in isocoumarin levels (Seljasen et al., 2001b). Those effects were associated with higher sensory scores for bitterness and terpene flavour and a lower score for sweetness, as measured by a tasting panel.

Exposure to as little as 0.5 ppm of exogenous ethylene can result in perceptible bitter flavour within two-weeks under normal storage conditions (Suslow et al., 2002). Therefore, carrots should not be stored with ethylene-producing crops such as apples and melons during long-term storage (Welbaum, 2015).

Air composition and packaging

Storage of fresh and minimally processed carrots under modified or controlled atmosphere (i.e. low O_2) should be generally avoided or used with discretion as it seems to adversely affect carrot sensory quality by increasing anaerobic respiration and ethanol content (Kato-Noguchi, 1998; Seljasen et al., 2004).

Controlled atmosphere generally does not extend postharvest life of carrots beyond that in air (Suslow et al., 2002). CO_2 concentrations above 5% have been shown to increase spoilage, whereas O_2 concentrations below 3% are not well tolerated and generally result in increased bacterial rot (Suslow et al., 2002).

The O_2 permeability of packages should also be sufficient to avoid an increase in both anaerobic respiration and ethanol content (Seljasen et al., 2013). For example, in a study in Norway, carrots stored at low O_2 (7%) in a modified atmosphere across various package types had higher ethanol content (from nil to 576 ppm) and lower sugar content after 10 days storage, thus reducing sensory (flavour) quality as assessed by a tasting panel (Seljasen et al., 2004). Those effects were exacerbated when storage temperature increased from 2 to 20°C. The results suggest that the gas exchange characteristics of packaging is important to avoid anaerobic conditions that can cause undesirable flavours.

Likewise, a recent study in Norway showed that, after cold (of 4°C for 6 d + 6°C for 9 d) or retail (4°C for 3 d, 20°C for 3 d and 6°C for 9 d) simulated storage, overall carrot (cv 'Romance') quality was best maintained in polypropylene packages with larger perforations (needle perforated as opposed to smaller ones which were laser perforated) and in higher number per area, giving the package a gas atmosphere close to air, resulting in no major weight loss, no ethanol formation and the lowest incidences of storage diseases at both cold and retail conditions (Larsen and Wold, 2016). The adverse effects of too small and/or too few perforations are more pronounced at higher temperatures.

Mechanical stress

Mechanical stress during and after harvest can increase metabolism (e.g. respiration) and susceptibility to microbial decay, adversely affecting quality and storability of carrots (Herppich et al., 1999; Seljasen et al., 2001a). Research conducted in Germany showed that, during cold storage at either 5°C for fifteen-days or 18°C for six-days, carrots (cv 'Nanthia') could metabolically adjust to maintain a positive turgor despite slow water losses. However, mechanical stress (caused by simulated falls from a 30cm height onto a belt), further reduced water status and the ability of carrots to adapt to water deficits, thus reducing their storability (Herppich et al., 2000).

Similarly, in a study in Norway, carrots that were mechanically stressed (i.e. shaken in a transport simulator) had higher rates of respiration and ethylene production, higher ethanol content (226 ppm compared to nil in untreated carrots) greater bitterness (a 14-fold increase in isocoumarin) and lower (-4%) sugars content, resulting in poorer sensory quality (flavour) as determined by a tasting panel (Seljasen et al., 2001a).

In another Norwegian study, carrots that were washed and packed mechanically had a higher level of microbial decay (suggesting shorter shelf life) and more undesirable flavour (e.g. higher scores for bitter taste, aftertaste, terpene flavour and odour, green odour and earthy flavour) compared to those washed and packed by hand (Seljasen et al., 2004).

In a study in Canada with carrots packaged into polyethylene bags, the incidence of black root rot increased after each step of the grading and packaging operation (washer, brush rollers, sizer and grader), especially when bags were held at room temperature rather than at 7–10°C (Punja and Gaye, 1993).

These results suggest that careful handling during harvest and postharvest operations is important to reduce mechanical stress and ensure optimum quality and shelf life of cold-stored carrots.

Washing and brushing/polishing

Washing carrots with cold (4°C) chlorinated water or hot (50°C) tap water can provide good microbiological safety for both fresh and minimally processed markets (Ilic et al., 2013).

Washing appears also to affect weight loss during storage. For example, in a recent two-year field study in Serbia, washing mature carrots (cv 'Bolero F1') after harvest with either hydrogen peroxide or chlorinated water reduced weight loss by 55% and 47%, respectively, compared to non-washed (with soil) control after storage at 0°C and 98% RH for four or six months (Ilic et al., 2016). Likewise, carrots (cv 'Maestro') washed with either hydrogen peroxide or chlorinated water reduced weight loss by 54% and 49%, respectively, compared to non-washed (with soil) control after storage for 160 days at 0°C and 95% RH plus 20 days at 20°C days to simulate market conditions (Ilic et al., 2013).

Carrots should not be stored wet to reduce bacterial soft rots and fungal diseases such as black root rot, grey mould and white mould (Ekman et al., 2016).

Brushing or polishing (removing the peel epidermis) before storage can increase the incidence of diseases such as black root rot (Eshel et al., 2009), thus restricting storability. Combined treatments using steam and hydrogen peroxide (Tsunami® 100) or a yeast commercial product (Shemer™) have been tested in Israel (Eshel et al., 2009).

Polishing also damages the outer cells in carrot skin, increasing its sensitivity to dehydration. These dry cells can also form an unattractive, chalky 'bloom' on the skin surface, which can be aggravated by lignin formation on damaged areas (Ekman et al., 2016).

Green beans

Background

Long-term control of *Sclerotinia sclerotiorum* is difficult in beans due to a number of factors such as: a wide host of range (bean, brassica, carrot, celery, lettuce, onion, pea, potato and tomato), long lived sclerotia in the soil (up to ten-years), formation of mycelium, release of ascospores into the air, lack of resistant varieties, reliance of fungicides for control, lack of a wide range of alternative modes-of-actions, multiple cropping and poor rotations (From project VG07109 *'Best Practice – Sclerotinia in green beans'* (Dal Santo and Holding, 2009).

Fungicides

Various field trials in VIC/TAS/QLD (project VG07126) identified potential alternatives for boscalid (e.g. Filan®) the only fungicide presently available for effective control of *S. sclerotiorum*, a major soil-borne disease challenge for vegetable growers in Australia (Villalta and Porter, 2010):

- Under high disease pressure, cyprodinil + fludioxinil (e.g. Switch®) applied during flowering was as effective as boscalid (e.g. Filan®), both with over 80% disease reduction, followed by fluazinam (e.g. Shirlan®) at 58%;
- Under low disease pressure, tebuconazole (e.g. Folicur®) was also effective;
- Applied to the soil surface before canopy closure, boscalid (e.g. Filan®) reduced disease by 72%, whereas fluazinam (e.g. Shirlan®) by 55%;
- A soil application of fluazinam (Shirlan®) combined with foliar applications of boscalid (e.g. Filan®) reduced disease by 91%.

The project outlined discussions from the 14th International Sclerotinia Workshop, including several promising combinations of fungicides for Sclerotinia control in Australian vegetable production regions, including:

- thiophanate-methyl (e.g. Topsin®-M);
- thiophanate-methyl (e.g. Topsin®-M) + boscalid (e.g. Filan®);
- boscalid + pyraclostrobin (e.g. Pristine®);
- mixtures containing iprodione (e.g. Rovral®) or chlorothalonil (e.g. Bravo®).

Recent research found the bio-control *Coniothyrium minitans* (e.g. Contans®) in combination with small dosage of fungicides against *S. sclerotiorum* resulted in a reduction of disease Elsheshtawi et al., 2017).

Results also showed that both *C. minitans* (e.g. Contans®) and thiophanate-methyl (e.g. Topsin®-M) significantly reduced the disease incidence caused by *S. sclerotiorum* by 90% and 95% survival, respectively when they were individually applied and compared to a control. Soil application of *C. minitans* (e.g. Contans®) + procymidone (e.g. Sumisclex®) was the most effective option to suppress white rot disease incidence. In summary the research suggests that application of *C. minitans* combined with the reduced doses of fungicides effectively controls white rot.

The project also identified several risk factors associated with disease occurrence on bean pods:

- High minimum temperatures 10–30 days before harvest, which may be related to cloud cover, rain, and/or solar radiation;
- Dense planting of beans;
- Planting of the cultivar 'Flavor Sweet';
- Timing of boscalid applications.

From project VG07109 *'Best Practice – Sclerotinia in green beans'* (Dal Santo and Holding, 2009):

- *S. sclerotiorum* produces long-lived sclerotes which can infest soil for many years;
- Reduction of the inoculum potential is a key to the long-term control;
- Azoxystrobin (e.g. Amistar®) and boscalid (e.g. Filan®) are the only fungicides available and can be used under an off-label permit;
- The appropriate use of chemical fungicides will prolong their useable life and reduce the potential for fungicide resistance to occur;
- Other chemical fungicides and bio-fungicides are under review and may achieve registration or off-label permit use in future;
- The EIQ system can be used as a guide by growers wishing to minimise effects on beneficial insects, workers, consumers, the environment and other crop management systems;
- Correct application techniques are essential for the most efficient use of fungicides;
- Integrated Crop Management (ICM) – the effective control of disease requires the use of all management options. This includes site selection, crop varieties, crop timing, biological options, monitoring and rouging;
- Only when all these options have been employed should fungicide be considered to: control / prevent / decrease / delay disease infection;
- Careful consideration of crop rotation is also a powerful management tool;
- At present no bio-fungicides are registered in Australia for *Sclerotinia spp*. control, although there are some products sold under various guises that claim disease control.

Cultural control

Research on *S. sclerotiorum* in green beans is limited. Recent studies in Egypt showed large variability in disease severity depending on cultivar (Hatamleh et al., 2013), growing season, i.e. higher incidence in winter than in autumn (Ali et al., 2016). Earlier studies in Tasmania recommended cultural practices, crop rotation and fungicide spray as control measures (Wong et al., 1980; Wong, 1978).

Several cultural control options may help reduce the inoculum level of *S. sclerotiorum* such as rotations with non-host plants, incorporating cover-crop residues and the use of biofumigation crops. Biofumigants release volatile compounds (isothiocyanate's) that can inhibit soil-borne pathogens.

Plant spacing could be another control measure. By increasing plant spacing, canopy conditions that favour disease are lessened by reducing the humidity, increasing airflow and light penetration.

Cultivars selection may reduce severity of disease, however, in work completed in VG07216 there was no difference in the susceptibility of four processing cultivars ('Celtic', 'Stanley', 'Flavor Sweet' and 'Montaro'). Reducing seedling density by 30% in the Flavor sweet cultivar also had no effect on white mould development as the plant canopy grew larger to cover available space.

FROM THE FIELD

- Waterlogging of soils and outbreaks of *Sclerotinia sclerotiorum* can be a significant limitation to green bean yield in some areas. Trials to demonstrate the benefits of strategic irrigation to overcome waterlogging and disease pressure could be very useful.
- Whilst chemical control provides an effective management tool for disease, product access and contamination issues, particularly with off-patent products, are becoming increasingly common.
- Cultural control options such as changing plant spacing (currently 50cm inter-row and 4cm intra row) to reduce disease severity could also be trialed.
- The use of biofumigant cover crops or other soil amendments that fit into Simplot rotations could also be further researched to reduce soil inoculum levels.

Cauliflower

Direct seeding cauliflower

Research on direct seeding of cauliflower has been scarce. Cauliflower can potentially be established by direct seeding, but are more often transplanted in the U.S. to avoid environmental stress and its negative consequences (Welbaum, 2015). Cauliflower is relatively easy to transplant as plants easily establish effective root systems and little root mass is required for successful establishment. In Queensland, most brassica crops are transplanted (Heisswolf et al., 2004). Similarly, recent grower survey in Germany showed that transplanting is the system adopted (Lindemann and Dirksmeyer, 2015).

A field study in Romania showed that compared to transplant, directly seeded cauliflower (cv 'Avalanche') resulted in yield increases of 30% and 32% when planted in May and June, respectively, and a reduction of 4% when planted in April (Apahidean et al., 2014).

In a two-year field study in the U.S., cauliflower (cv 'White Cloud') directly seeded to a stand using a precision vacuum seeder at one seed per hill and a 20-cm spacing and without thinning, produced yields and head weights similar to cauliflower seeded 10 cm apart and thinned to 30 cm, the seeding method used by some commercial operators (Bracy et al., 1995).

FROM THE FIELD

- Cauliflower in Tasmania is grown mostly on even red clay-loam soils, which would be favourable for direct seeding where uniform plant establishment is crucial.
- Optimal planting time for direct seeding may be mid-February to early-March under centre pivot or linear move irrigation to maximize germination, plant establishment and early crop growth.

Sweet corn

Plant density

A U.S. study with six common processing sweet corn hybrids grown across several areas showed that increasing plant density of from 43–86k plants/ha linearly increased canopy density, light interception, and length of the vegetative period, while linearly decreasing filled ear length and recovery – the percentage of kernel mass represented in green ear mass (Williams, 2012). The processing hybrids used in the study varied not only in processing yield potential (15.3–19.8 t/ha), but also in their ability to tolerate high populations, i.e. higher-yielding hybrids generally performed best at higher populations.

Strip tillage

Strip tillage can increase soil temperature in the top 5cm over no-tillage, contributing to an increased plant emergence rate (Licht *et al*., 2005). A rotary strip tillage system produced 900 kg/ha greater corn yields than conventional tillage and reduced total tillage cost by an average of $38.50/ha compared to conventional tillage. A shank/coulter strip tillage system produced similar yields to conventional tillage and reduced tillage costs by $36.50/ha. Rotary and coulter strip systems reduced machinery operating time by 0.59 and 0.47 h/ha respectively (Luna *et al*., 2002).

Precision agriculture

Project VG07035 – Understanding Spatial Variability in Sweet Corn Production conducted by the Australia Centre for Precision Agriculture at the University of Sydney identified that there was sufficient variation in sweet corn yield and quality to make Precision Agriculture (PA) practical in the industry. The range in yield was spatially coherent giving the growers the option to manage the crop site-specifically. Variable rate fertiliser application is an easy to implement cost-saving adoption, and an economic analysis in the project showed possible savings of $100/ha on nitrogen budgets (Taylor *et al*., 2008)**.** The study identified that information from early to mid-season canopy sensors provide the best data for constructing management classes (areas of low and high fertiliser). Indicating that current on-the-go variable-rate fertiliser systems, such as the N-sensor™, Greenseeker® and CropCircle™, may be adequate for sweet corn production, negating need for management classes (Taylor *et al*., 2008).

FROM THE FIELD

- A major constraint to sweet corn production identified by Simplot is inefficient application of inputs such as water and nutrients. This is particularly an issue in paddocks with high variability. Adoption of variable rate technology could help improve this however, preliminary modeling for crop growth needs to be adapted for sweet corn. Adoption of yield and quality monitoring sensors in Simplot headers would also be beneficial.
- There is keen interest in further research into strip tillage and or deep ripping for sweet corn production system to help alleviate soil compaction, which is a prominent issue in wet harvest years. Growers that have already adopted strip tillage have seen gross margin benefits from reduction in tillage costs.
- Insect control, particularly heliothis is always a challenge for sweet corn growers. Biological control options (e.g. Gemstar®) or conventional chemistries such as methomyl (Lannate®) and alpha-cypermethrin (Fastac Duo®) are the most commonly used products. Chemigation through pivots is currently providing the cheapest application method. Demonstration trials showing product, application timing and application method may be beneficial.

Figure 1. Strip tillage in sweet corn

7 Production opportunities as viewed by the growers

Identification of both practice gaps and motivation between leading growers of processing vegetables and the middle and lower cohort can both be identified using Appreciative Inquiry, a well-documented approach used to achieve large scale changes in organisational behaviour.

Discovery is the first phase of appreciative inquiry, and is typically followed by imagining what could be, followed by planning and prioritization, and lastly implementation. The discovery phase of appreciative inquiry interviews were conducted across the Simplot processing vegetable categories of broccoli, cauliflower, carrots, beans and sweet corn. The process encourages growers to think about production gaps as a positive to be welcomed rather than a negative. By focusing on what may be possible the semi-structured interviews produced a number of thoughts on practice gaps that could be addressed in Phase 2 of the project.

Word Frequency Analysis

Notes, across all crops, from the Appreciative Inquiry interviews were analysed textually using the open source *Voyant Tools* (Figure 2). Excluding stop words (e.g. crop) the top five most frequently used words were irrigation > fertiliser > management > soil > yield. While the use of these five terms does indicate the topics interviewees were most interested in discussing, these results reflect but do not necessarily directly relate to the prioritisation of development opportunities.

Figure 2. Word cloud created from high-frequency grower responses (55 terms) during Appreciative Inquiry interviews.

Response categorisation

To assist in the identification of research and development opportunities growers were interested in for each crop, results from the grower interviews were scored by frequency of mention and cross tabulated by issue and crop (Table 2 and Table 3).

Table 2. Cross tabulation of the frequency issues were raised across the target crops (number of stars (*) = frequency). Issues mentioned three or more times for a specific crop are in red.

Issue	Cauliflower	Broccoli	Carrots	Yellow Beans	Green Beans	Sweet Corn	Total
Irrigation management advice	*	*	***	***	***	****	15
Precision crop growth	**	***	*	**	***		11
Nitrogen management – amount and timing		***	****	*	*		9
Pre-spread fertiliser – amount and timing		****	****				8
Insect pressure challenging	***	***				**	8
Fungal control challenging/options limited				*	****		5
Hand cutting model – external management	**	***					5
Strip-till technology used	**	**				*	5
Varietal trials	**	**		*			5
Agronomist relationship important			**	*	*		4
Crop evenness at harvest	*	**	*				4
Harvest timing	*	**			*		4
Paddock preparation extensive			**		*	*	4
Fungicide timing for efficacy				*	**		3
General crop timeliness		*		*	*		3
IPM – Insect pressure increasing		***					3
Planting schedule suits farm management	*		*	*			3
Seed sizing/grading			***				3
Strip-till technology trial to minimise compaction	*	*			*		3
Weed control challenging/options limited				**	*		3
Wind damage				*	**		3

Table 3. Less frequently mentioned issues. Cross tabulation of the frequency issues were raised across the target crops (number of stars (*) = frequency).

Issue	*Cauliflower*	*Broccoli*	*Carrots*	*Yellow Beans*	*Green Beans*	*Sweet Corn*	*Total*
Crop development timing		**					2
Deep soil N testing				*	*		2
Local trial information		*	*				2
New research projects vital – no revisited work		*			*		2
Paddock preparation poor contributes to loss				*	*		2
Spatial density of the crop			**				2
Crop allocation doesn't suit paddock size				*			1
Drainage		*					1
Drilling compaction					*		1
Drilling fertiliser options					*		1
Higher level of infield processing – a major saving		*					1
Insecticide use high		*					1
Inter-row weeding machine trial					*		1
Nutrient removal from harvest				*			1
Row width incompatible with a crop sprayer				*			1
Stale seedbed important to preparation					*		1
Volunteer weeds – potato, carrot					*		1

Analysis of grower response by key issues

Irrigation management

Grower desire for irrigation management advice was of particular concern for carrots, beans and sweet corn. Growers and agronomists were concerned with irrigation issues surrounding drainage, over watering, the influence of water on floral disease, the high water volume required for carrots and irrigation requirements during crop establishment and growth (how much and when). Crops such as beans and carrots, for example, are usually in planted in warm and dry conditions and successful yield relies heavily on even establishment. Pre- and post-drilling irrigation management are critical for even emergence and regular follow-up applications ensure best possible maturation for machine harvest. Each crop has its own nuances but in particular, carrots require deep and even moisture early to establish root depth and later for plant development to meet factory specification.

Precision crop growth (Reducing variability)

Precision crop growth rated highly in grower discussion responses, in particular for broccoli and green beans. Successful establishment was clearly recognised as a key component by respondents as it leads to better crop performance across all categories with more effective crop protection products (i.e. there is less crop damage if all plants are at the same growth stage). Processing crops have a narrow band of optimum population per square metre and smaller, weaker seedlings have a lower survival tolerance, in some cases, from herbicides. Fungal disease symptoms on crops are commonly grouped by district and seasonal pressure varies dependant on prevailing weather conditions and microclimates. Effective *Sclerotinia* control in beans is reliant on accurate prediction of initial flowering and timely fungicide application. As new chemistry is slow to emerge and the sector is geared to machine harvest by factory demand and/or calendar, growers are under constant pressure to meet crop quota and specification.

Nitrogen fertiliser management

Nitrogen fertiliser management in the crop was rated highly as a key issue for broccoli and carrots. Growers are requesting guidance on the application of additional nitrogenous fertilisers. Some farms have success using N-Check® soil tests to assist in managing this important process. Some bean growers reported paddocks having no additional nitrogen applied to crops after the initial drilling application. Crops vary widely in relative nutrient requirements during growth and development, highlighting the need to monitor and understand plant nutrient concentrations as they respond to a dynamic environment.

Fertiliser amendments

Grower interests in fertiliser application were varied, some feeling the amount required as well understood and adequate, others indicating that they had no guidelines, and others wondering if they could push yields further by applying more. Fertiliser amendments for processing crops are initially managed by soil nutrient tests which are routinely conducted prior to sowing in commercial settings. These tests alone are not always a good reflection of plant nutrient requirements, final crop yield, and/or quality. This is due to the wide-ranging soil types found in Tasmanian cropping districts and the complexity of crop nutrition itself. By necessity, simple and homogenous fertiliser regimes are routinely used to manage commercial crops, with these applications founded on the total plant recovery at harvest, soil assessment including nutrient tests and professional experience. In essence, as fertilisers are a relatively cheap form of insurance, they are most likely over applied. The over-arching requirement for growers and Simplot is the reliable production and supply of good quality produce to the factory.

Insect pressure

Integrated pest management (IPM) concerns were raised for broccoli and cauliflower, as these crops experience high insect pressure from diamond back moths and cabbage butterfly. Growers and agronomists discussed the high use of insecticides applied to crops and the implications for food safety programs. Forage crops cultivated in surrounding paddocks for livestock was viewed as a compounding problem for monitoring insect populations as it acts as a host and pest populations increase very quickly in processing crops. Comments were noted that IPM strategies need to be developed to suit local conditions as Victorian strategies were generally unsuitable for Northern Tasmanian broccoli in particular. A relatively new insect pest species has also been identified in the Devonport / Sassafras cropping regions. Winter crane fly is increasingly active in the north-west district of Tasmania in cauliflower crops, with significant curd damage resulting from infestations. Little local knowledge is available on the management and identification of this pest although it is referenced in global literature.

Analysis of grower response by crop

Cauliflower

Winter crane fly was the predominant issue associated with cauliflower production. An introduced pest to Tasmania, and problematic in other global regions, means further expansion of this pest presents a risk to future production. This issue is dicussed in more detail in Section 9.

Broccoli

Achieving quota on a short-lived (72 days) broccoli crop, which for example, is cultivated on a sand over clay with sections of heavy black soil adds significant complexity to the production model. Growers suggest research on developing a variable rate fertiliser assessment system that compensates for different soil types across the same paddock. Modelling could incorporate soil type (GIS), NDVI input and historical agronomic assessments of the area to allow their machinery to compensate for areas with slower growth.

Carrots

Processing carrots have the largest percentage increase required from the four-year average of all the crops with ring a 76% increase, and standard 43%, to achieve the 2020 yield targets. Growers and agronomists suggested the 2020 carrot targets would need significant agronomic and research input to enable this target to be achieved. Seed sizing of processing carrot seed was suggested as requiring investigation, as current factory advice suggests it doesn’t change yield, although seed sizing is a common practice in fresh market crops as it contributes to even establishment. Different seed spatial arrangement can also contribute to crop evenness and yield, and could be demonstrated with different irrigation equipment as different irrigation systems provide differential outcomes. Growers report standard seeding rates under linear irrigation achieve small root diameters (20 cent piece), due to better plant emergence. Altered seed rates were also suggested for hard hose irrigators due to the method of application leading to a lower plant establishment. Research into fertiliser recommendations would be beneficial as standard quantities (i.e. not prescriptive) are routinely applied, in at least one instance, for the past 8 seasons. Growers report no background research on the application of either additional fertiliser or N-Check use.

Beans

Growers report green and yellow beans are a good crop to grow. Planting time (January) suits their water management scheduling and growers are able to devote resources to beans. Simplot has a target 2020 yield of ~20% increase over current four-year averages.

A fungal disease, *Sclerotinia*, was flagged as a serious problem with limited option for control. Application of three fungicides through the life of the crop is seen as standard best practice. The timing of fungicide applications could also play an important role in incidence, as irrigation of early unprotected flowers and humid weather can cause an outbreak of disease. Growers and agronomists may be unaware of the risk involved with irrigation or rain around flowering, and fungicide timing demonstration plots may be valuable. Consideration of row orientation to allow prevailing winds to move up between the developing beans may assist where it is possible.

Sweet Corn

Clear responses were received that the largest possible gains in the average yield of sweet corn were from improving irrigation management. Both over and under-watering are issues negatively impacting yield of sweet corn, especially with the unique rotation practices used across these farms.

8 Production opportunities as viewed by Simplot

Cauliflower

Winter crane fly, *Trichocerus sp*., is an introduced pest to Tasmania (Figure 3**Error! Reference source not found.**) and the potential population spread is unknown. Currently, cauliflower crops at Sassafras and Wesley Vale have sustained damage and further study is required to understand the life cycle and potential ideal conditions for the insect. All fresh market and cauliflower processing crops could be affected by an infestation of this species.

The first damage from winter crane fly was reported by Simplot in July 2017 and the species identified by D.P.I.P.W.E. entomology staff. Winter crane fly is generally observed in open cauliflower curds (heads), which is thought to provide shelter; it is believed frost damage may give an entry site for the insect. The larvae present a significant food quality risk as larvae could potentially be processed and found by a consumer in frozen produce.

Figure 3. Winter crane fly, adult and larvae (BugGuide ; Insects of)

Currently, little is known of the pest in Tasmania although winter crane fly has a long history in Europe (Dahl 1969) and is also described in the United States (Pratt 2003). Simplot has suggested a seasonal study of the pest including a literature review to establish its potential for damage, population spread, and to identify opportunities for control.

Broccoli

Harvest maturity timing for broccoli is currently judged by head diameter and subjective assessment of other characteristics based on field officer experience. Operational timing of associated actions such as number of bins required, transport logistics and advising the factory intake staff of prospective quantities are all estimated using this experiential model. Prediction of broccoli growth and development for processing is quite accurate at 72 days from a mid-December planting, though temperature and the seasonal conditions influence the ratio of heads that meet factory specification in the initial cut. Two cuts (harvests) are normal but three is not economically viable.

Dr Mark Boersma (Tasmanian Institute of Agriculture) has identified ways in which harvest prediction could be made more objective. The first is to rate the development of individual florets. This is possible as the individual parts of each flower progress at a rate proportional to each other. For instance, the ovary is initially the most developed organ, and as the flower grows the anthers then progressively match it in size. Last to develop are the petals. This development is also proportional to bead size, and the length of the pedicel (flower stalk). Hence it is possible to use the bead size and or the size of the petals in relation to the ovary to estimate the point at which peduncles will be at 12mm, and also if the head is about to stop increasing in diameter. In addition to this, working closely with remote sensing providers and using their algorithms would allow us to use a drone to capture head diameter across a field (presuming the leaves aren't wrapping). This would provide information on head size across the paddock. Putting these two concepts together with a simple linear model to estimate the increase in head diameter base on temperature and sunlight, Simplot could generate objective information that would allow for more precise harvest management.

Simplot have had a number of discussions with Dr Boersma with a view to supporting the research required to develop this objective predictive harvest model.

Carrots

Simplot flagged interest in methods of on farm storage processing carrots. Their requirement is to understand both bulk and wooden bin storage principles. The time period required for storage is short-term (7-14 days) and longer term (3-6 weeks). This process, if successful, could ease pressure on factory intake and allow buffer storage for inclement weather breaks in the harvest. Bin or under straw storage is common in Europe (Geeson, Browne & Everson 1988) due to wet cold winters and for the same production reasons as Simplot. Fungal disease of carrots in storage and resulting product loss is potentially very high (Von Elbe, Artz & Johnson 1977). This type of storage can also result in loss of sugars and increase in lignification (i.e. woody carrots) causing a serious deterioration in product quality (Geeson, Browne & Everson 1988).

Successfully storing carrots in this manner would potentially alleviate product shortages for the factory at peak times, allow harvest to progress at a normal pace in good conditions, lessen soil compaction and soil structural damage to paddocks for the growers.

Sweet Corn

Simplot indicated from their farming operation that the largest possible gains in the average yield of sweet corn were from improving irrigation management. Strip-till was not of benefit in their sweet corn farming model, as it is in Tasmania with cauliflowers and broccoli. This is a direct effect of crop rotation and the soil not drying sufficiently between corn crops to allow for normal rip-shattering of the compacted soil profile.

Beans

Simplot flagged increased disease and crop losses occurring due to water management. Waterlogging can occur due to overwatering, inefficient infiltration, insufficient surface and subsurface drainage. Indications are that only several hours of waterlogged soils are required to rot fine bean roots. Green beans are very sensitive to waterlogged soil conditions and short periods of high soil moisture can reduce yields significantly. Demonstration of strategic irrigation requirements of processing crops based on crop physiology and disease management could help to reduce over-application of water and improve productivity.

Key areas of irrigation management for demonstration are:

- Adequate moisture to encourage even emergence;
- Adequate moisture to encourage even early flowering;
- Assessing moisture at full flowering to reduce late flowering and dry canopies to assist with sclerotinia management;
- Adequate moisture during bean pod formation to maximise yield.

9 Factsheets

Five factsheets have been produced. The topics are:

1. Maximising Uniformity at Harvest Maturity in Processing Broccoli
2. Optimising Crop Establishment in Processing Carrots
3. Winter Crane Fly (*Trichocera annulata)*
4. Sclerotinia Rot of Green Beans
5. Irrigation Management in Sweet Corn

These factsheet are attached as Appendix 3.

10 Processing vegetable production opportunity in Tasmania – Setting Priorities

A significant proportion of Tasmania's vegetable produce is forward contracted, and in the processing sector, product price is set through bulk negotiation between grower representatives and processors. This negotiation process introduces a natural tension between processors and growers, and a certain level of distrust regarding company objectives. In setting research priorities it is essential to recognise this tension and seek optimal research solutions that successfully address both company and grower interests simultaneously.

This tension is illustrated by the different aspirations between Simplot and its growers in carrot production. While both groups benefit from increased productivity, there is a difference in opinion on the most effective way to achieve this. Growers on one hand would like to see research conducted on carrot establishment particularly seed grading, whilst Simplot recognises the significant advantages of in crop tap root storage.

Both of these concepts are valid, and both would benefit all parties. Consequently the projects recommended by this report have been considered in this context, seeking to establish a balance between both grower and company interests, and prioritising those most likely to achieve a change in productivity. We also note that change in the sector is heavily influenced by both grower and field officer practice, and highlight that successful change is most likely to occur not through the traditional 'top down' approach, but where research outcomes are strongly supported through social intervention; this is best accomplished through the development of innovation platforms and extension practices such as appreciative inquiry and peer to peer learning.

11 Phase 2 trial delineation and budget

Phase 1 of the project set out to identify the reasons for sub-optimal processing yields for each of the focus vegetable crops. Methodology included a review of best practices and recent innovations for target crops, as well as appreciative inquiry interviews with Simplot growers. The findings from these tasks have provided the focus of field trials and demonstrations, to be implemented in Phase 2 of the project.

The aim of these trials and demonstrations is to convert the information gathered in Phase 1, into new practices that could be adopted by each of the focus vegetable sectors to increase nett yield and profitability. To maximize the likelihood of change in practice, we propose that these demonstration and research projects be accompanied by a facilitator at 0.4 FTE tasked with continuing the appreciative enquiry and peer to peer learning process.

Proposed Research and Demonstration Trials

It is proposed that one trial protocol be developed for each focus crop and this is to be implemented in at least one principle grower/crop walk region. Trials will be located in the principle Simplot supply areas for the focus crops i.e. northern Tasmania (e.g. Sassafras and Cressy) and central western NSW. There may also be some laboratory work at AHR facilities in Sydney or at the TIA Vegetable Research Facility in Forth.

To facilitate easy interpretation and extension of trial data, trial design and treatment structure should be kept simple. Consideration should be given to any existing or proposed Simplot R & D trials that may be leveraged.

The following table summarises the proposed topics and budget for each of focus crop trials. For some crops **two** potential trial topics have been proposed, however it is anticipated that only **one** topic will be selected for each crop.

Crop	Proposed Topic	Proposed budget over 2 years
1.Carrots	**Research** trials on options for field storage of carrots	$81,000
2.Broccoli	**a) Research** trial on predictive tool for precise harvest forecast **OR**	$232,609
	b) Demonstration trial on minimising variability of harvest maturity.	$70,000
3.Green beans	**Demonstration** trial on integrated crop management trial for *Sclerotinia* control in green beans.	$75,000
4.Cauliflower	**Demonstration** trial on strategic irrigation in cauliflower with potential for incorporation of winter crane fly monitoring	$75,000
5.Sweet corn	**a) Demonstration** trial on strategic irrigation in sweet corn **OR**	$44,400
	b) Research trial on strip tillage in sweet corn	$62,000

Carrots

Trial	VG16011.1 – Research trial on field storage options for carrots
Hypothesis/ objective	Carrots can be stored in the field for up to 6-weeks using a commercially viable and economically feasible method without significant loss to carrot yield or quality.
Site	Phase I Field TVRF / Lab – Tasmania/Sydney Phase II Commercial carrot farms, Tasmania
Background	• Simplot have identified carrot storability as one of its biggest limitations in the processing carrot sector due to a lack of capacity at the factory. • Growers are consequently leaving carrots in the ground for longer than ideal periods which is impacting on quality. • The ability for growers to dig and store carrots on farm, without compromising quality would therefore be highly advantageous. • Conduct field trials to evaluate the effectiveness, practicality and economic feasibility of short-term (up to 6 weeks) on farm storage options for carrots. • A laboratory component may also be included to pre-test some of the storage options before going to the field.
Planting Rate	Commercial crops
Crop management	Carrot crop will be managed following current best commercial practice up until harvest maturity. Treatments will be implemented once crop has reached harvest maturity.
Design	**Stage I - Undertake replicated research trials at TVRF** Post-harvest treatments will be tested to identify any promising treatments to test in the field in Stage 2. Examples for treatments may include: 1. Freshly dug carrots, unwashed, mounded on soil and covered with plastic for 4 to 6 weeks. 2. Freshly dug carrots, unwashed, placed in plastic-lined field storage bin for 4 to 6 weeks. 3. Polythene cover over trimmed carrots left in the ground 4. Straw or cellulose cover over trimmed carrots left in the ground 5. Straw or cellulose/polythene “sandwich” over trimmed carrots left in the ground 6. Slash off the tops and store in ground 7. Untreated control (not harvested – left in ground) 8. Harvest control Quality parameters of stored carrots would be evaluated at the end of the storage period. Quality would be compared to freshly harvested carrots that had not been stored to quantify any loss in quality. **Stage 2- Field trial validation** The most promising one or two treatments identified in Stage 1 studies will be validated in the field during Stage 2.

	The trials will be set up on commercial farms over three locations and the yield and quality compared to normal commercial operations.
Plot size/Total trial size	Plots size depends on farm but could be large commercial plots. 4 treatments with 3 replicates (farms)
Measurements	Carrot yield and quality parameters which are relevant for processing carrots will be assessed at 4 and 6 weeks post treatment application.
Responsibilities	UTAS staff will identify an appropriate trial sites in phase 2. AHR and UTAS staff will work together to setup the trial. AHR staff will be responsible for trial assessment. The group will meet once a month (by teleconference) to discuss trial management.

Budget	**Unit Cost**	**Stage I**	**Stage II**
Stage I – Laboratory testing			
AHR Consultants time to finalise trial plan and oversee setup, data collection etc. @ 10 days	1200	12,000	
AHR Technicians time (set-up, monitoring, data collection) @10 days	800	8,000	
Lab space/controlled environment chamber hire (AHR)		4,000	
TVRF (land, preparation, irrigation, and fertiliser)		5,000	
AHR Travel (airfares, accom+meals)	2500	2,500	
Consumables (AHR)		3,000	
TIA technician @ 5 days	800	4,000	
Stage II - Field trial testing			
AHR Agronomist time plan, visit sites and assess @ 5 days/yr	1200		6,000
AHR Technician time @ 10 days/yr find trial site, set-up, harvest etc.	800		8,000
AHR Travel (airfares, accom+meals)	2500		2,500
Consumables -poly cover for crops etc.			2,000
Field day/crop walk- catering, agronomists time, admin (AHR/TIA)			5,000
Trial costs (land, preparation, irrigation, and fertiliser)			5,000
TIA Technician (5 days)	800		4,000
TIA Intrastate Travel	125	1,500	1,500
Data analysis and reporting (TIA / AHR) - 2 days each per year	1200	4,800	4,800
TOTAL		**42,300**	**38,800**
GRAND TOTAL			**81,100**

Broccoli

Trial Name	VG16011.2a Predictive model to forecast broccoli harvest
Hypothesis/objective	A predictive model combined with remote sensing technology can forecast optimum time for broccoli harvest and improve forecast accuracy and efficiency compared to the current subjective method of visual assessment.
Site/s	The models predictions will need to be validated across a number of sites to establish the models performance across difference soil types, crop residues etc. There will also be extensive glasshouse work involved in this trial Potential locations: • Burnie, Tasmania • Cressy, Tasmania • Forthside Research Facility, Forth, Tasmania
Background	• The primary driver for harvest maturity of processing broccoli is head size and the method currently used to determine harvest time is subjective visual assessments by a field officer. • Whilst larger heads denote larger yields, there is a point where heads can over mature. On the contrary, commencing harvest prior to a sufficient proportion of broccoli heads in a block reaching harvest maturity is also detrimental as it leads to costly multiple harvest events. • Determining the optimum point at which enough of a paddock has reached harvest maturity for the first-cut is therefore critical to maximise yield and gross margin. • A method to objectively conduct pre-harvest assessments would enable a more precise harvest schedule, reduce costs and enable accurate forecasting for processing logistics.
Planting Rate	Current commercial density for processing broccoli.
Crop management	Crops will be managed in accordance with current best practice for processing broccoli. For field sites located in commercial broccoli crops, the grower's current management practices will be followed.
Design	The trial will have at least three components: 1. Glasshouse/laboratory work to detail crop phenology i.e. establish proportional rate of development for different flower parts. 2. Remote sensing and development of methodology to capture real-time head size 3. Combining data collected in parts 1 and 2 to develop predictive model.
Plot /Total trial size	N/A
Measurements	Glasshouse and laboratory work will collect detailed information on flower development. Local remote sensing research groups e.g. Terra Luma can be used to assist in the development of algorithms to analyse drone images of maturing broccoli heads.
Statistical analysis	Spatial data analysis, curve fitting
Responsibilities	Dr Mark Boersma, University of Tasmania will be responsible for design and implementation of this trial.

	AHR may provide support for the field components where required. The group will meet once a month (by teleconference) to discuss trial management.

Budget	**PER YEAR**	**2 YEAR TOTAL**
Salary (Full-time tech support + M. Boersma @0.10)	94,140	188,279
Field travel	2,778	5,555
Microscope	5,500	11,000
Glasshouse space	13,888	27,775
TOTAL	**116,305**	**232,609**

<table>
<tr><th>Trial Name/Number</th><th>VG16011.2b Reducing variability in processing broccoli.</th></tr>
<tr><td>Hypothesis/objective</td><td>Investigate and demonstrate good management and how the adoption of innovative agronomic practices can help manage variability in the production of broccoli.</td></tr>
<tr><td>Site</td><td>Cressy, Tasmania</td></tr>
<tr><td>Background</td><td>A high level of variability in broccoli plants at harvest maturity, means multiple cuts are required to harvest the crop, adding to labour and handling costs.
Variation in harvest maturity is also one of the most significant barriers to the adoption of mechanical harvesting.
Good agronomic management, from pre-planting to 28 days post-plant, can significantly reduce crop variability and decrease the number of harvest cuts required. Previous studies on processing broccoli in SE Qld indicated that high planting density can increase uniformity without impacting floret size.</td></tr>
<tr><td>Planting Rate</td><td>3 different planting densities to demonstrate influence of planting rate on crop variability, yield, floret and head size. i.e. can higher plant density improve uniformity</td></tr>
<tr><td>Crop management</td><td>The trial will demonstrate that planting density and good agronomic practice can reduce crop variability e.g. planting density, row configuration seedling placement, good insect and disease management.

Planting may need to be slightly offset from commercial practice to ensure that the field day/crop walk to demonstrate uniformity in harvest maturity doesn’t clash with grower’s own harvest time.</td></tr>
<tr><td>Design</td><td>Randomized complete block design (n=5).
Current best practice
30,000 plants/ha
40,000 plants/ha
60,000 plants/ha</td></tr>
<tr><td>Plot size/Total trial size</td><td>Plot size: 20 m x double rows per plot to allow for demonstration in a field day. Exact layout will be determined by configuration of the chosen farm and block.</td></tr>
<tr><td>Measurements</td><td>Yield, head size and weight, floret size for each harvest.</td></tr>
<tr><td>Statistical analysis</td><td>ANOVA</td></tr>
<tr><td>Responsibilities</td><td>UTAS staff will identify an appropriate trial site.
AHR and UTAS staff will work together to setup the trial.
UTAS staff will ensure the site is closely managed throughout the growing season.
The group will meet once a month (by teleconference) to discuss trial management.
AHR and UTAS staff will collaboratively host a field day/crop walk.</td></tr>
</table>

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
AHR Agronomists time plan, visit sites and assess @ 5 days/yr.	1200	6,000	12,000
AHR Technicians time for trial set up etc. @ 5 days/year	800	4000	8,000
AHR Travel (airfares, accom+meals) 2 trips per year	2,200	2,200	4,400
TIA Investigator @ 5 days/yr	1200	6,000	12,000
TIA technician @ 5 days/yr	800	4000	8,000
TIA Intrastate Travel	125	1500	3000
Consumables - fungicide treatments etc.		1,500	3,000
Field day/crop walk- catering, agronomists time, admin		5,000	10,000
Data analysis and reporting (TIA / AHR) - 2 days each per year	1200	4800	9600
		35,000	**70,000**

Note: It may be possible to complete this trial in one year, in which case the budget for year 2 would not be required.

Green Beans

Trial Name/Number	**VG16011.3 Sclerotinia management in green beans**
Hypothesis/objective	Demonstrate how the adoption of integrated crop management approach can help control *Sclerotinia sclerotiorum* in green beans.
Site	Hagley, Tasmania
Background	• White mould (*Sclerotinia sclerotiorum*) is one of the major diseases of green beans in Tasmania causing yield loss as well as post-harvest damage resulting in processing. • Adopting of an integrated crop management approach in green beans can help significantly reduce disease pressure and increase crop yields.
Treatments	Some options that growers have in crop management such as planting density and the use of irrigation management tools will be set up in a demonstration trial on a commercial farm. The treatments can be determined with the grower and with Simplot, but comparing things like two different planting densities, the use of soil moisture monitoring (e.g. WildEyes® or The Yield®) and good fungicide usage can be applied.
Crop management	The trial will demonstrate integrated crop management strategies can effectively reduce incidence of Sclerotinia in green beans. The trial will demonstrate best practice and will be the focus of a field day aimed at growers where the best practice trial can be used as a focus of discussion, or could also be compared to the growers' commercial crop. Focus management factors will include planting density, irrigation (guided by management tools) and timely fungicide applications.
Design	Unreplicated. 4 side-by-side demonstration plots.
Plot size/Total trial size	2 x large plots. e.g. 6m x 20m =120m^2 Exact dimensions will be determined by configuration of the chosen farm and block.
Measurements	NA
Statistical analysis	NA
Responsibilities	UTAS staff will identify an appropriate trial site. AHR and UTAS staff will work together to setup the trial. UTAS staff will ensure the site is closely managed throughout the growing season. The group will meet once a month (by teleconference) to discuss trial management. Harvest assessment AHR and UTAS staff will collaboratively host the field day/crop walk.

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
AHR Agronomists time plan, visit sites and assess @ 5 days/yr.	1200	6,000	12,000
AHR Technicians time for trial set up etc. @ 5 days/year	800	4000	8,000
AHR Travel (airfares, accom+meals) 2 trips per year	2,200	2,200	4,400
TIA Investigator @ 5 days/yr	1200	6,000	12,000
TIA technician @ 5 days/yr	800	4000	8,000
TIA Intrastate Travel	125	1500	3000
Irrigation monitoring equipment		5000	
Consumables - fungicide treatments etc.		1,500	3,000
Field day/crop walk- catering, agronomists time, admin		5,000	10,000
Data analysis and reporting (TIA / AHR) - 2 days each per year	1200	4800	9600
		40,000	**75,000**

Note: It may be possible to complete this trial in one year, in which case the budget for year 2 would not be required.

Cauliflower

Trial Name/Number	**VG16011.4 Strategic irrigation in cauliflower for optimisation of yield**
Hypothesis/objective	Demonstrate that the adoption strategic irrigation at critical crop growth stage can improve cauliflower yield. Possible further opportunistic monitoring of winter crane fly.
Site	North-west Tasmania (e.g. Sassafras/Wesley Vale)
Background	• Tasmanian cauliflower growers tend to under irrigate cauliflower, often deceived by cooler weather when the crop water use is still high. • Strategic irrigation at critical growth stages could potentially increase crop yield. • Winter crane fly (*Trichocera annulata*) is an emerging pest in cauliflower in some cauliflower growing regions in Tasmania during July harvest, yet little is known about it. • Further research to better understand its life cycle and control options is required.
Planting Rate	Current commercial best practice for cauliflower
Treatments	Some options that growers have in crop management such as the use of irrigation management tools will be set up in a demonstration trial on a commercial farm. The treatments can be determined with the grower and with Simplot, but comparing things like two different planting densities, the use of soil moisture monitoring (e.g. WildEyes® or The Yield®)
Crop management	Best practice will be adopted for crop management. The trial will demonstrate best practice and the use of tools to strategically apply water at critical growth stages. There will be a field day aimed at growers where the best practice trial can be used as a focus of discussion, or could also be compared to the growers' commercial crop.
Design	Unreplicated. 2 side-by-side demonstration plots. Strategic irrigation for yield optimisation vs. normal irrigation practice (commercial crop).
Plot size/Total trial size	2 x large plots. e.g. 6m x 20m =120m^2 Exact dimensions will be determined by configuration of the chosen farm and block.
Measurements	If winter crane fly is present in the trial data may be collected on conditions at time of appearance, growth stage, numbers, % crop damage etc.
Statistical analysis	NA
Responsibilities	UTAS staff will identify an appropriate trial site. AHR and UTAS staff will work together to setup the trial. UTAS staff will ensure the site is closely managed throughout the growing season. The group will meet once a month (by teleconference) to discuss trial management. AHR and UTAS staff will collaboratively host the field day/crop walk.

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
AHR Agronomists time plan, visit sites and assess @ 5 days/yr.	1200	6,000	12,000
AHR Technicians time for trial set up etc. @ 5 days/year	800	4000	8,000
AHR Travel (airfares, accom+meals) 2 trips per year	2,200	2,200	4,400
TIA Investigator @ 5 days/yr	1200	6,000	12,000
TIA technician @ 5 days/yr	800	4000	8,000
TIA Intrastate Travel	125	1500	3000
Irrigation monitoring equipment		5000	
Consumables - fungicide treatments etc.		1,500	3,000
Field day/crop walk- catering, agronomists time, admin		5,000	10,000
Data analysis and reporting (TIA / AHR) - 2 days each per year	1200	4800	9600
		40,000	**75,000**

Note: It may be possible to complete this trial in one year, in which case the budget for year 2 would not be required.

Sweet corn

Trial Name/Number	VG16011.5a. Demonstration of strategic irrigation in sweet corn
Hypothesis/objective	Demonstrate that the adoption strategic irrigation at critical crop growth stage can improve sweet corn yield.
Site	Cowra, NSW
Background	• Both over and under-watering have been identified as issues reducing potential sweet corn yield. • An irrigation trial could demonstrate how strategic irrigation scheduling at critical growth stages can help improve crop yield.
Planting Rate	Current commercial best practice for sweet corn.
Treatments	Some options that growers have in crop management such as planting density and the use of irrigation management tools will be set up in a demonstration trial on a commercial farm. The treatments can be determined with the grower and with Simplot, but comparing things like two different planting densities, the use of soil moisture monitoring (e.g. WildEyes® or The Yield®) and good fungicide usage can be applied.
Crop management	The trial will demonstrate integrated crop management strategies for sweet corn.The trial will demonstrate best practice and will be the focus of a field day aimed at growers where the best practice trial can be used as a focus of discussion, or could also be compared to the growers' commercial crop. Focus management factors will include irrigation (guided by management tools) and timely pesticide applications.
Design	Unreplicated. 2 side-by-side demonstration plots.
Plot size/Total trial size	2 x large plots. e.g. 6m x 20m =120m^2 Exact dimensions will be determined by configuration of the chosen farm and block.
Measurements	If winter crane fly is present in the trial data may be collected on conditions at time of appearance, growth stage, numbers, % crop damage etc.
Statistical analysis	NA
Responsibilities	AHR staff will find appropriate trial site, lead trial setup and ensure the site is closely managed throughout the growing season. The group will meet once a month (by teleconference) to discuss trial management. AHR and UTAS staff will collaboratively host the field day/crop walk.

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
Agronomists time plan, visit sites and assess @ 4 days/yr	1200	4,800	9,600
Technicians time to set up irrigation etc. @4 days	800	3,200	6,400
Travel (airfares Tas to Syd, 2 nights accom+meals)	1100	2,200	4,400
TIA Investigator	2500	2,500	5,000
Consumables - insecticide treatments etc.		1,500	3,000
Field day/crop walk- catering, agronomists time, admin		5,000	10,000
		20,200	**40,400**

Note: It may be possible to complete this trial in one year, in which case the budget for year 2 would not be required.

Trial Name/Number	VG16011.5b. Research trial on the potential for strip tillage in sweet corn
Hypothesis/objective	Adoption of strip tillage in sweet corn production systems can improve soil structure, tillage costs and yield.
Site	Cowra, NSW
Background	• Strip tillage has been identified as a potential means of alleviating soil compaction and improving crop uniformity which are major issues in sweet corn production. • Growers that have already adopted strip tillage have also seen gross margin benefits from reduction in tillage costs. • Establish trials with different tillage regimes can help determine the potential agronomic and economic benefits of strip tillage.
Planting Rate	Current commercial best practice for sweet corn.
Treatments	Comparing strip tillage to conventional crop establishment
Crop management	Sites will need to be established early on so that management can begin following the harvest of the previous winter crop i.e. stubble retained, and conventional tillage not employed across the whole block. Some plots will be subject to conventional tillage and the other will be strip tilled. The crop will be managed according to current best commercial practice in sweet corn.
Design	Randomised Complete Block (RCBD) with 3 replicates. 2 treatments – strip tillage vs conventional tillage
Plot size/Total trial size	Exact dimensions need to be determined by row configuration and machinery. Approx. 80m^2 per plot. 80 x 3 reps x 2 treatments = 480m^2
Measurements	Plant density at crop establishment, Final yield. Economic analysis – gross margin of conventional vs strip tillage.
Statistical analysis	ANOVA
Responsibilities	AHR staff will find appropriate trial site, lead trial setup and ensure the site is closely managed throughout the growing season. The group will meet once a month (by teleconference) to discuss trial management. AHR and UTAS staff will collaboratively host the field day/crop walk.

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
AHR Agronomists time plan, visit sites and assess @ 5 days/yr.	1200	6,000	12,000
AHR Technicians time for trial set up etc. @ 5 days/year	800	4000	8,000
AHR Travel	125	1500	3000
TIA Investigator @ 5 days/yr	1200	6,000	12,000
TIA interstate travel	2,200	2,200	4,400
Strip tillage equipment hire		5000	
Consumables - fungicide treatments etc.		1,500	3,000
Field day/crop walk- catering, agronomists time, admin		5,000	10,000
Data analysis and reporting (TIA / AHR) - 2 days each per year	1200	4800	9600
		36,000	**62,000**

Note: It may be possible to complete this trial in one year, in which case the budget for year 2 would not be required.

Option: Project Facilitator

This project has provided evidence of a gap in practice between leading growers that for most crops already achieve yields consistent with Simplot's 2020 yield targets, and growers not yet achieving these targets. The only exception to this is carrot production, with the targeted yields well beyond that currently achieved. Growers already achieving target yields are doing so not through access to novel technologies, but through the adoption of practice that has already been established through past research and development. Indeed while it is recognised that research is fundamental to long term productivity growth, critics amongst growers and extension personnel argue that research could stop, and significant gains still made if the existing body of knowledge was successfully incorporated on farm.

This gap highlighted by this study demonstrates that while yield gains can to some extent be addressed by the introduction of new technology, facilitating a change in grower practice is essential. It is increasingly recognised that the 'top-down' extension model used in past decades has had an effect, but a limited one. Hence this report recommends the employment of a trained facilitator and agronomist to integrate the demonstration options of Phase II into a programme focused on collaborative practice change using modern concepts such as peer-to-peer learning, innovation platforms, participatory research and appreciative enquiry.

Budget	Unit Cost	PER YEAR	2 YEAR TOTAL
Facilitator / Agronomist (UTAS)		**52,322**	**104,644**

Essential: Project Manager

Successful delivery of Phase II will require a project manager dedicated to providing coordination, project administration and to facilitate effective communication. This position is budgeted by UTAS at 0.1 FTE HEO LEVEL 8.

Budget	**Unit Cost**	**PER YEAR**	**2 YEAR TOTAL**
Project Manager		**12,688**	**25,376**

12 Vegetable Processing – Cost-Benefit Analysis

The objective of the project is to provide the tools and information to ensure the processing vegetable industry in Tasmania remains viable for the long term. Given that processed vegetables compete in a global market it is essential that growers are using world's best practice to grow and harvest their crops to achieve the level of return on investment they need to remain competitive.

Innovative methods to improve yields of vegetables commonly grown for the processing industry in Australia are assessed here for economic performance, such as strip tillage in sweet corn, field storage of carrots, irrigation management for control of Sclerotinia in green beans, management of winter crane fly in cauliflowers and the predictive modelling of broccoli yields.

Financial analysis method

Net Present Value

Net present value (NPV) is the sum of the flow of annual net returns, each of which is expressed as a present value. It is calculated by subtracting the present value of costs from the present value of revenues associated with an investment. A present value is the equivalent value today of a future cost or revenue. For this appraisal, all present values are in 2018 prices. Discount rates are used to calculate present values of costs and revenues that occur at different times. The following formula is used to derive NPV:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

where B_t is the value of benefits in year t, C_t is the value of costs in year t and r is the discount.

Sweet corn (strip tillage)

Scenario 1	Scenario 2
Conventional deep ripping tillage Economic advantages: ▪ Equipment is already owned ▪ Slug control	Strip tillage Economic advantages: ▪ Efficient land preparation (labour and fuel) ▪ Higher yield

Strip tillage provides the opportunity for greater yields and lower land preparation costs, however, careful management is needed. Luna and Staben (2002) found in well-replicated trial that rotary strip tillage generated an average yield 900kg.ha^{-1} greater than conventional tillage while requiring $US38.50 less in land preparation costs (or 0.59 hr.ha^{-1} less machinery time). Slug baits were required when using strip tillage and similar level of herbicides were effective under both tillage regimes.

Typical sweet corn yield in NSW is 25t.ha^{-1} and price is $210 per tonne (NSW DPI, 2013)

The major capital investment of converting to strip tillage is a new strip tiller which can be purchased for $43,000 (Farm Machinery Sales, 2018) or used equipment can be purchased for approximately $25,000 (Farm Machinery Sales, 2018). Alternatively, a contractor can be hired to perform single-pass planting, which includes all strip tillage land preparations at $200 per hectare plus fuel costs.

Table 4: Partial budget of strip tillage sweet corn compared to conventional tillage

Strip Tillage	per ha
Variable cash flows	
Field productivity	$ 189.00
Land preparation - labour	$ 14.75
Land preparation - fuel	$ 10.18
Pesticide input - slug baits	($91.65)
Change to cash flow	$ 122.28

A partial budget of strip tillage using the yield improvements and machinery time savings reported above shows that there would be a net gain of $122 per hectare compared to conventional tillage. Anecdotally, it has been reported that conventional tillage can yield sweet corn growers more than conventional tillage, however, the overwhelming research contradicts this.

There are also significant unaccounted medium to long-term environmental benefits of strip tillage such as higher soil organic matter, increased water-holding capacity and reduced erosion (Reicosky D.C. (2003). Furthermore, banding fertiliser with the fall-strip operation is an efficiency that is not considered here (Nowatzki, 2008).

Table 5: Financial analysis of strip tillage compared to conventional tillage using a partial budget over five years at the Australian average of 46 $ha.yr^{-1}$ per grower of sweet corn. Cash flows are discounted using a 10% discount rate, capital purchases are not considered here and calculations are listed in Appendix 1.

Strip Tillage	**per ha**	**Upfront**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
	21 $t.ha^{-1}$		46 $ha.yr^{-1}$	46 $ha.yr^{-1}$	46 $ha.yr^{-1}$	46 $ha.yr^{-1}$	46 $ha.yr^{-1}$
Equipment (strip tiller)		x					
Variable cash flows							
Marketable yield (5% gain)	$189		$8,694	$8,694	$8,694	$8,694	$8,694
Land preparation - labour	$15		$679	$679	$679	$679	$679
Land preparation - fuel	$10		$468	$468	$468	$468	$468
Pesticide input - slug baits	($92)		($4,216)	($4,216)	($4,216)	($4,216)	($4,216)
Change to cash flow	$122		$5,625	$5,625	$5,625	$5,625	$5,625
Discounted cash flow		x	$5,113	$4,649	$4,226	$3,842	$3,493
						NPV	$21,322

Net Present Value = $\boldsymbol{Y0} + \frac{\boldsymbol{Y1}}{(\mathbf{1.1})} + \frac{\boldsymbol{Y2}}{(\mathbf{1.1^2})} + \frac{\boldsymbol{Y3}}{(\mathbf{1.1^3})} + \frac{\boldsymbol{Y4}}{(\mathbf{1.1^4})} + \frac{\boldsymbol{Y5}}{(\mathbf{1.1^5})}$

Net Present Value = $21,322

The net present value of converting the average sweet corn farm growing 46ha per year is $21,322 when considering modest yield and land-preparation efficiency gains and adequate slug baiting. The cost of purchasing or modifying equipment is dependent on each farm's requirements and would need to be subtracted from this sum.

For example, a used strip till rig purchased for $25,000 (Farm Machinery Sales, 2018) would yield a positive investment at 5 years when 55$ha.yr^{-1}$ is cultivated, as shown in Table 5. A costlier investment in equipment would require greater utilisation or higher realised yields to be economical. For example, a new strip till rig at $40,000 would require utilisation of 90$ha.yr^{-1}$ to realise a positive Net Present Value, shown inFigure 4.

Table 6: Financial analysis of strip tillage compared to conventional tillage using a partial budget over five years at a rate of 55ha.yr^{-1} of sweet corn. Cash flows are discounted using a 10% discount rate and calculations are listed in Appendix 1.

Strip Tillage	**per ha**	**Upfront**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
			55 ha.yr^{-1}	55 ha.yr^{-1}	55 ha.yr^{-1}	55 ha.yr^{-1}	55 ha.yr^{-1}
Equipment (strip tiller)		($25,000)					
Variable cash flows							
Marketable yield (5% gain)	$189		$10,395	$10,395	$10,395	$10,395	$10,395
Land preparation - labour	$15		$811	$811	$811	$811	$811
Land preparation - fuel	$10		$560	$560	$560	$560	$560
Pesticide input - slug baits	($92)		($5,041)	($5,041)	($5,041)	($5,041)	($5,041)
Change to cash flow	$122		$6,725	$6,725	$6,725	$6,725	$6,725
Discounted Cash flow		($25,000)	$6,114	$5,558	$5,053	$4,593	$4,176
						NPV	$494

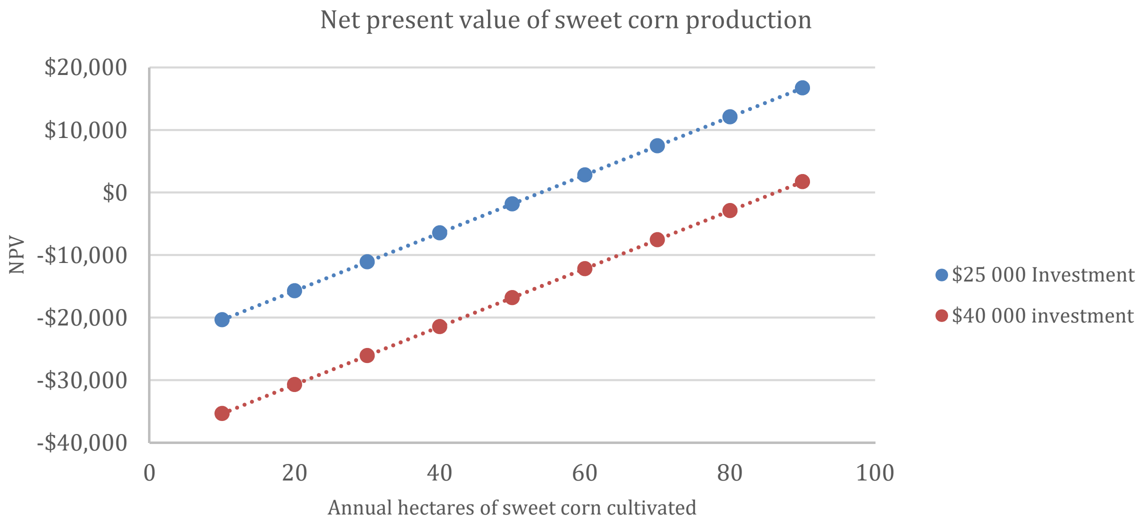

Figure 4: The relationship between annual hectares of sweet corn cultivated, using data from Table 2, at two levels of capital investment in tillage equipment.

Carrots (Field storage)

Scenario 1
Delayed harvest (ground storage)
Economic advantages:
- Efficient handling

Scenario 2
Field storage
Economic advantages:
- Avoided yield loss
- Reduced paddock damage

Scheduling requirements of vegetable processing factories often require carrot harvesting to be delayed past the optimal date, which leads to declining quality and reduced marketable yield. Current losses of ground-stored carrots are estimated to be approximately 10% and field storage may be an attractive option for processing growers to reduce rots and oversized carrots.

A late harvest can often coincide with winter rainfall leading to significant environmental damage to the paddock and represents an unaccounted external cost of delayed harvest. The flexibility of field storage allows harvest to be scheduled according to weather conditions and helps prevent paddock damage.

Table 7: Sensitivity analysis of increased cash flow from avoided loss of carrot yield crossed with the expense of additional handling times required for field storage. Values are expressed as additional cash flow per hectare.

	Extra handling time (per hectare)		
Avoided yield loss	1 minute	3 minutes	5 minutes
3%	$ 278	$ 278	$ 52
5%	$ 502	**$ 388**	$ 275
7%	$ 725	$ 612	$ 499

There is no significant capital investment required for the field storage of carrots and primary cost of field storage is the extra handling time required to stack with a front-end loader or a forklift, cover carrots in the field and retrieve when ready for processing. Three minutes per tonne is likely a generous estimation of the extra handling time required, given the significant volume of carrots, in the order of $80t.ha^{-1}$, likely to be stored in a single operation. The financial gain from the avoided losses of delaying harvest significantly outweighs the fuel and labour costs of extra handling.

Adoption of field storage does not require new capital investment but has an estimated potential gain of $16,199 over five years.

Table 8: Financial analysis of field storage of carrots compared to conventional ground storage using a partial budget over five years at a rate of 11 ha.yr^{-1}. Additional product handling has been estimated at 3 minutes per tonne and avoided losses at 5%. Cash flows are discounted using a 10% discount rate and calculations are listed in Appendix 1.

Field storage	per ha	Upfront	Year 1	Year 2	Year 3	Year 4	Year 5
	80 t.ha^{-1}		11 ha.yr^{-1}	11 ha.yr^{-1}	11 ha.yr^{-1}	11 ha.yr^{-1}	11 ha.yr^{-1}
Variable cash flows							
Product handling (3 min)	($170)	-	($1,868)	($1,868)	($1,868)	($1,868)	($1,868)
Avoided losses (5%)	$558	-	$6,142	$6,142	$6,142	$6,142	$6,142
Change to cash flow	$388		$4,273	$4,273	$4,273	$4,273	$4,273
Discounted Cash flow			$3,885	$3,532	$3,211	$2,919	$2,653
						NPV	$16,199

Net Present Value = $Y0+\frac{Y1}{(1.1)}+\frac{Y2}{(1.1^2)}+\frac{Y3}{(1.1^3)}+\frac{Y4}{(1.1^4)}+\frac{Y5}{(1.1^5)}$

Net Present Value = $16,199

Green beans (Sclerotinia)

<u>Scenario 1</u>
Conventional irrigation
Economic advantages:
- No new equipment required

<u>Scenario 2</u>
Optimised irrigation
Economic advantages:
- Improved yield (avoided disease loss)
- Reduced irrigation cost

Sclerotinia disease pressure is significant on green beans grown for processing, with outbreaks ranging from localised yield loss to total crop failure. Current industry losses are estimated at 10% of total production and it would be prudent to develop methods to better control the disease.

Over-irrigation and waterlogged soil is a common cause of Sclerotinia outbreaks (Steadman, 1979) and optimised irrigation using soil-moisture monitoring equipment is one control method that could be investigated.

Optimised irrigation management would need to return a 2% yield improvement to justify the purchase cost and annual subscription fees for three soil moisture probes, shown below in

Table 9.

Table 9: Financial analysis of optimised irrigation managed with soil moisture probes using a partial budget over five years at 10 ha.yr^{-1} per grower of green beans. Cash flows are discounted using a 10% discount rate and calculations are listed in Appendix 1.

Optimised Irrigation	**per ha**	**Upfront**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
	12.5 t.ha^{-1}		10 ha.yr^{-1}	10 ha.yr^{-1}	10 ha.yr^{-1}	10 ha.yr^{-1}	10 ha.yr^{-1}
Equipment (3x soil moisture)	-	($1,797)	($1,078)	($1,078)	($1,078)	($1,078)	($1,078)
Variable cash flows							
Marketable yield (2% gain)	$156	-	$1,560	$1,560	$1,560	$1,560	$1,560
Change to cash flow		($1,797)	$482	$482	$482	$482	$482
Discounted cash flow		($1,797)	$438	$398	$362	$329	$299
						NPV	$29

$$\text{Net Present Value} = Y0 + \frac{Y1}{(1.1)} + \frac{Y2}{(1.1^2)} + \frac{Y3}{(1.1^3)} + \frac{Y4}{(1.1^4)} + \frac{Y5}{(1.1^5)}$$

$$\text{Net Present Value} = \$29$$

Cauliflower (winter crane fly)

Scenario 1
Conventional management
Economic advantages:
- Efficient labour

Scenario 2
Winter crane fly management
Economic advantages:
- Improved yield (avoided disease loss)

Options for the management of winter crane fly include stringent water management to avoid waterlogging soil, which could be achieved with soil-moisture monitoring equipment, similar to the management of Sclerotinia in green beans (Table 9). The risk of a crane fly infestation is currently unlikely although the impact can be significant on both current and future crops, which warrants a medium-level of risk management.

The parasitic nematode *Steinernema feltiae* is an effective biological control against winter crane fly larvae but are not economically viable as a broad control in Australia. Application at the recommended rate would cost $3,860 per ha, which exceeds the average gross margin of processing cauliflowers in Tasmania. *Steinernema feltiae* could be used economically as a spot treatment to protect against further infestation of crane fly.

Broccoli

Scenario 1
Conventional hand measurements
Economic advantages:
- nil

Scenario 2
Predictive modelling
Economic advantages:
- Efficient factory scheduling
- Efficient picker scheduling
- Improved yield

The economics of predictive modelling of broccoli yield is difficult to assess as there is no investment direct required directly by a farm. Outputs from a predictive model would likely be available to the industry at no cost and therefore provide immediate benefits that require no investment analysis.

13 Outcomes

The outcomes of Phase 1 of Improving processing vegetable yields through improved production practices include:

1. Positive engagement with growers and agronomists through the appreciative inquiry semi-structured interview technique which was used. Requests for grower and agronomist interviews were received positively and discussion, in some cases, lasted several hours. Growers and agronomists, were forthright and constructive with their thoughts on the various categories. Some growers hold contracts for several different processing crops and are contracted to supply Simplot over successive years. Some grower responses were related to improved crop returns from Simplot, generally though discussion relating to nett yield results (crop quality reflecting on grower returns) were most important. Timeliness of operational growing requirements featured as a necessity rather than an option or choice. Growers and agronomists were open to research projects and welcomed the opportunity to have input into potential extension work to assist their sector of the industry. This will ensure that growers and agronomists will engage in Phase 2 of the project.

2. Based on this positive engagement, is a plan for Phase 2 which considers input from growers, Simplot company representatives, agronomists and researchers.

3. A number of key areas/ topics have been identified as the demonstration and extension activities presented in the plan for Phase 2 of the project, to assist with improving yields through improved production practices.

14 Monitoring and evaluation

The project monitoring and evaluation approach will be developed once the final project plan for Phase 2 is developed and agreed to by Hort Innovation.

15 Recommendations

Opportunities for demonstration and extension have been identified during Phase 1 of the project. The gaps in knowledge identified by growers, agronomists, Simplot personnel and researchers have been synthesised into a plan for Phase 2 of the project. The proposed plan includes:

1. Options for short term storage of carrots.
2. Demonstration trial on managing variability in broccoli production and/or development of a predictive tool to forecast broccoli harvest.
3. Demonstration trial on integrated crop management for *Sclerotinia* control in green and yellow beans.
4. Demonstration trial on strategic irrigation in cauliflower and monitoring of winter crane fly.
5. Demonstration trial on strategic irrigation in sweet corn and/or Research trial on strip tillage in sweet corn.
6. Employment of a facilitator to maximise the chance of adoption using appreciative inquiry, peer-to-peer learning, participatory research or other suitable interventions.

These demonstrations will play a key role in engaging growers in group activities, like farm walks.

Some growers are already achieving or exceeding the Simplot productivity targets set for each crop by the year 2020. Demonstration and targeted grower group activities using a participatory research and extension process will assist the dissemination of knowledge and lead to better uptake of improved production practices. The use of the participatory research and extension process incorporating appreciative inquiry methods will continue to be used in phase 2 of this project.

A peer-to-peer learning approach is effective for sharing knowledge between growers and facilitating the uptake of improved practices. A peer-to-peer environment in which growers have been involved in developing the demonstrations and topics for group discussions has been successfully used in other projects within TIA e.g. Water for Profit.

Improving production practices to improve processing vegetable yields will support the viability of the Tasmanian Simplot factory and growers that supply the factory. Changes in grower practice will underpin increases in productivity and profitability. This will depend on adoption and practice change which will be facilitated by the use of appreciative inquiry methods and peer-to-peer learning.

16 Refereed scientific publications

None to report.

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Carrot

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18 Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

19 Acknowledgements

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20 Appendices

1. Cost benefit calculations
2. Interview notes (anonymised)
3. Fact sheets (5)

Appendix 1 Cost Benefit Calculations

Sweet corn

Field productivity improvement		
Yield	0.9	**t/ha**
Price	$165	**t**
Value	$149	ha
Fuel savings		
Fuel Consumption	15	L/hr
Time saving	0.59	hr/ha
Fuel Cost	$1.15	L
Value	$10.18	ha
Labour savings		
Labour cost	$25	hr
Time saving	0.59	hr/ha
Value	$14.75	ha
Pesticide input - slug baits		
Cost	$14.10	kg
Rate	6.5	kg/ha
Value	$91.65	ha

Carrots

Product handling	1	3	5	min/tonne
Hourly cost of labour	$25	$25	$25	hr
Total cost of labour	$0.42	$1.25	$2.08	t
Fuel consumption	15	15	15	L/hr
Fuel cost	$1.15	$1.15	$1.15	L
Total cost of fuel	$0.29	$0.86	$1.44	t
Cost of extract product handling	$0.70	$2.11	$3.52	t
Cost of extract product handling	$57	$170	$283	ha
Packout rate				
Delayed harvest losses (%)	10			
Field storage losses (%)	5			
Net gain from field storage	3%	5%	7%	
Net gain from field storage	2.412	4.02	5.628	t/ha
Net gain from field storage	$ 558.33	**ha**	$ 335.00	$ 781.67

Green beans

Typical Yield	12.5	t/ha
Industry Output	11700	t/yr
FG Price	$624	t
Equipment		
Wild Eye	$599	unit
Wild Eye Subscription	$359	yr
Packout rate		
Net gain from irrigation management	2%	
Net gain from irrigation management	0.25	t/ha
Net gain from irrigation management	$155.98	ha

Appendix 2 Grower Interview Summaries

Improving processing vegetable yields through improved production practices

Record of interview – facilitator; Tim Smallbon

Broccoli Grower

1. Broccoli yields currently above 2020 target
2. Harvest timing critical to yield outcome
3. Factory spec on size is tight and even head size of crop important
4. Has embraced strip till technology due to soil type
5. IPM a concern as chemical use is high and surrounding forage crop an issue
6. Fertiliser usage ok
7. Crop is sensitive to waterlogging (especially comparative to potatoes) and 25/30mm unscheduled effects crop
8. Drainage important
9. Crop income tight (lease) needs to follow short lived crop like peas
10. Wants new research not 20 year old subjects redone
11. Infield floretting a major opportunity to cut freight/factory cost but hesitant on going ahead as sees this operation as “factory” based.

Private Agronomist - Broccoli

1. Overuse of insecticides, MRL concerns
2. Insect resistance management
3. IPM strategies developed to suit local conditions
4. Victorian strategies not suitable
5. Local trials (Longford/Cressy) very important

Yellow Bean Grower

1. Bean yields currently 2t above 2020 target
2. Seed cost is high
3. Row width doesn’t match 1.83 metre centre to centre therefore beans squashed and opportunity for disease, can bean rows be altered without yield penalty
4. Any gap in planting an opportunity for wind damage
5. Agronomist important part of management (relationship)
6. Good crop to grow and generally tidy
7. Planting time suits water management and able to devote resources to beans
8. Radish control is a challenge
9. Would grow more beans if available
10. Tonnage quotas don’t generally suit watered area
11. Hopes beans are kept in Tasmania and not grown on Mainland

Green Bean Grower

1. Bean yields currently 5t above 2020 target

2. Sclerotinia a serious problem with limited control since product removal of Sumisclex. Applying 2 x Filan and 1 x Rovral as standard practice. Would like screening of further fungicide options.

3. Is varietal screening showing positive opportunities?

4. Nitrogen management important with some paddocks having nil N after sowing

5. N Check is valuable

6. Harvest timing critical to yield outcomes

7. Stale seed bed with minimal drill disturbance key to weed control

8. Amaranthus control becoming a major weed problem

9. Timeliness of workings and application critical to staying in business.

Green Bean Grower

1. Sclerotinia –Filan is the most effective option but quite expensive. A cheaper fungicide alternative is highly desired but results of trials by Peracto suggest Filan gives the best protection. Amistar 250 is thought by some to give good control but growers and agronomists are divided on the matter.

2. Considering row orientation to allow prevailing winds to move up the rows may assist where it is possible.

3. Timing of fungicide application plays an important role, as irrigation of early unprotected flowers and humid weather can cause an outbreak of disease. It may help to communicate this to growers and agronomists if they are unaware of the risk involved with irrigation or rain around flowering.

4. Volunteer potatoes remain a significant problem. Current remedy is for harvesters to increase their fan speed, potentially disposing of 1-2t/ha of marketable product along with potato stems. Hand weeding can cost upwards of $500/ha and is generally viewed as out of the question to growers. Inter row spraying unsuccessful, however another option may be trialling finger weeding.

5. Wind stress and scar is another yield and quality constraint but difficult to address aside from paddock selection.

6. Drill compaction and efficiency is an issue with the current set up, as beans hate compaction and the cost per ha of drilling is high in comparison to other crops.

7. If band placed fertiliser is required, Microstar PMX or similar fertiliser may be trialled as an alternative to conventional fertilisers, it is applied at 30kg/ha, costs $5/kg and significantly reduces handling and refilling costs and reduces drill weight.

8. Strip tilling/no till drilling still an option if the issue of mounding between rows and soil loosening can be addressed. Could be a case of trial and error over a few seasons. Significant potential to reduce prep costs and irrigation requirements.

Carrot Growers – Region meeting, involved 3 participants

1. Growing standard carrots at a current average of ~80 tonne. Suggested the 100 tonne 2020 target would need significant agronomic and research input.

2. Seed sizing of standard carrot seed requires investigation, as current advice suggests it doesn't change yield.

3. Paddock preparation is extensive to remove stones, have purchased own destoner.

4. Chemical use is low and a fungicide has only just been recommended for the first time.

5. Irrigation management is difficult as 30mm per week is applied as standard practice. Linear's easier to get crop numbers established.

6. Fertiliser management – pre-spread, 800 kg of 9-14-17/ha is routinely applied as standard practice, used this amount for the past 8 seasons.

7. Fertiliser management – in crop, have no guidance on application of additional fertiliser or N check etc.

8. Calcium Nitrate at 100 kg/ha has been raised as a viable option for improvement of carrots, need replicated trials to define quality benefit?

9. Seed spacing longitudinally, different irrigation equipment delivers different crop establishment. Therefore standard seeding rates mean carrots under linear machine achieve small root diameter (20 cent piece).

Broccoli Grower

1. Has embraced strip till technology due to soil type

2. IPM a concern as chemical use is high and surrounding forage crop an issue

3. Large operation employing many cutters on contract, can harvest 20ha at a time.

4. Broccoli cutting productivity has doubled in the past 5 years to an efficient process.

5. Labour is not the major cost of production.

6. Broccoli growth is very temperature related and although days to maturity are clear (72) variance of overnight temperature changes head sizing dramatically.

7. Current assessment model is based on historical and experiential knowledge of Harvest Manager.

8. Hand harvesting has a natural preference on quality over size, cutters quickly learn correct assessment.

9. Any predictive model comprising ratio of heads ready to harvest at 72 days would need to be done with mechanical harvest rather than hand cutting – existing UK model has been previously developed for this.

10. Hand cutting predictive model is gauged with time to completion in mind so the ratio of harvest-ready heads has a time component requirement.

11. Previous research by Joe Cook Ag on box depth of harvested crop has shown loss of crop at any level over current standard. This relates to potential savings in transport cost to the factory and box hire etc.

12. Infield floretting would significantly add to production cost but save large amounts of freight and factory cost, seen as a next step in the production model.

13. Variable fertiliser application on different soil types across the same paddock would be an advantage. Model would incorporate soil type (GIS), NDVI input and quality assessments of the area to allow/compensate for wet areas slowing growth.

Cauliflower Grower

1. Currently 2t/ha over 2020 target.

2. Quota system has bonus scheme attached for accurate prediction so attention paid to this point.

3. Noted factory wants all crop possible.
4. Face cutting crop with Joe Cook labour.
5. Harvests approximately 750 t/week.
6. Smaller Growers would be around 100 t/week.
7. Planting and establishment key points to success.
8. Low input crop, 2 insecticides and 1 fungicide.
9. No crane fly at Kindred.
10. Strip till is excellent and minimises weed burden.
11. Irrigation is applied by linear or hardhose and penetration is good.
12. Strip till leaves surface flat for cutters.
13. Crop around 5cm higher makes for easier harvest with shorter stem and better quality – from 11.
14. Less loose soil in paddock for the winter.
15. Evenness of plants key to application.
16. Club root an issue and farm is on second rotation so will watch crops, possibility of control trials?
17. Leon Hingston advises club root resistant varieties are available from Syngenta but poor yield means low take up.

Carrot Grower

1. Ground preparation is sufficient without use of a destoner
2. Fertiliser recommendations cover the crop requirements.
3. Irrigation requirement can be fitted to farm management.
4. Plant densities as specified by Simplot show adequate returns.
5. Relationship with Agronomist important.

Production Agronomist - Carrots

1. Seed grading trials showed positive results.
2. Calcium Nitrate applications helping with crop quality.
3. Pre-spread fertiliser quantities adequate.
4. Care needed so excessive tops growth is avoided.
5. Even emergence is important.
6. Irrigation timing at establishment and finish important for carrots.
7. Irrigation sensors handy but paddock inspection is more important.

Facilitator – Susan Hinton

Field Service Manager – Sweet Corn

1. Number 1 issue impacting yield is water (over and under watering is an issue).
2. Weeds result in loss of yield – Johnson grass, nut grass, castor oil – grass herbicide resistance a concern.

3. Fertiliser management.

4. Grub control - growers are becoming complacent as control approach has worked well – 3 crops lost this season because control measures not used.

5. Changed approaches to irrigation are achieving increased yields. Splitting large irrigations into 2 or 3 smaller more frequent irrigations is increasing yield consistently.

6. Simplot grow approximately 25% of their own corn.

Sweet Corn Grower

1. Uses strip tillage – keen for research to help improve yields – believes this is the way to go.

2. Yields still below the district average, but have been steadily improving over the last seven years – research reason for yields being below average.

3. Is harvesting negatively impacting soil and we don't deep rip? Interested in how to overcome compaction from harvesting.

Sweet Corn Grower

1. Continue research into irrigation management.

2. Have started to use probes to monitor soil moisture and are achieving good results. This year yield about 7 to 8 t/ha above the current average. Using cheap easy to install sensors as a guide.

3. Seeing benefits in yield of chickpeas because monitoring soil moisture.

4. Interested in fertiliser to see if yields can be pushed further.

Agronomist – Beans

1. Often grower activities in crop are by habit not by need or current best practice knowledge.

2. Deep soil N testing at 3-4 leaf stage to determine if N required will reduce the risk of sclerotinia when unnecessary N is applied to the crop.

3. Filan is heavily relied on and is not that good –more fungicide options are required.

4. Poor paddock preparation is a major reason for below average yields in bean crops.

5. Irrigation at establishment is important for an even crop. Generally irrigation is pretty good once it starts.

Agronomist - Carrots

1. Growers that irrigate well often get to size early and so they tend to hold crops back from what is ideal for growing.

2. Big plus if short term storage was available. Growers could grow crops more optimally. There are potential benefits to soil from more timely harvesting.

Grower – Beans

1. Would like to find ways to reduce costs of production.

2. Fungicides – not many alternatives to Filan. Current ones are much more expensive.

3. Nutrient removal – understanding better what is removed by the crop so that fertiliser

strategies can be targeted.

4. Irrigation management – would like a better understanding of when to water and when it is okay to stress the crop for water.

5. Raised beds – as a risk mitigation strategy.

Farm Manager – Cauliflowers (2 involved in interview process)

1. Planting and establishment key points to success.
2. Low input crop, inmost seasons.
3. Crane fly not a problem for most crops but concerned it may spread into other areas.
4. Strip till is excellent and minimises weed burden.
5. Irrigation is varied depending on the growers.
6. Strip till leaves surface flat for cutters.
7. Less loose soil in paddock for the winter.
8. Evenness of plants key to application.
9. Club root an issue, for some, possibility of control trials?

Farm Manager – Broccoli (2 involved in the interview process)

1. Strip till technology is being used by some
2. IPM a concern as chemical use is high and surrounding forage crop an issue
3. Broccoli cutting productivity has increase significantly in the last 5 years
4. Labour is not the major cost of production.
5. Broccoli growth is very temperature related and although days to maturity are clear (72) variance of overnight temperature changes head sizing dramatically.
6. Current assessment model is based on historical and experiential knowledge of Harvest Manager (Joe Cook).
7. A predictive model for harvesting would be beneficial.
8. Infield floretting would significantly add to production cost but save large amounts of freight and factory cost, seen as a next step in the production model.
9. Variable fertiliser application on different soil types across the same paddock would be an advantage.
10. Can we incorporate soil type (GIS), NDVI input and quality assessments of the area to allow/compensate for wet areas slowing growth.

Appendix 3 Fact Sheets

[Embedded PDF – right click and select Adobe Document to open]

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Well-established and uniform seedling improves broccoli uniformity at harvest maturity, reducing labour and handling costs. Image source: Shutterstock.

MAXIMISING UNIFORMITY AT HARVEST MATURITY IN PROCESSING BROCCOLI

THE IMPORTANCE OF CROP UNIFORMITY

A high level of variability in broccoli plants at harvest maturity, means multiple cuts are required to harvest the crop, adding to labour and handling costs. Most crops can be harvested in two cuts, but when variability levels are high this can extend to five hand-cut harvests spread over a 7-day period[1]. Variation in harvest maturity is also one of the most significant barriers to the adoption of mechanical harvesting[2].

Once broccoli has entered its reproductive phase (i.e. heads begin to form) there are limited management options available to improve crop uniformity. It is therefore critical to make decisions in the pre-plant and early crop establishment phases that will result in a crop that matures evenly across the block. Good agronomic management, from pre-planting to 28 days post-plant, can significantly reduce crop variability and decrease the number of harvest cuts required[1].

MANAGEMENT STRATEGIES TO IMPROVE CROP UNIFORMITY

Pre-plant

Paddock selection

Ideally, select blocks that are relatively uniform in soil type and gradient. Variations in soil moisture, soil tilth and temperature will all influence the uniformity of seedling establishment and early growth[2].

Cultivar choice

Genetic differences among broccoli cultivars can influence uniformity in their development. For example, an open-pollinated variety may have more variability than a hybrid.

Broccoli varieties are highly dependent on climate and season. It is important to select a variety that has been proven to perform well in your location and in the production slot you are targeting[2].

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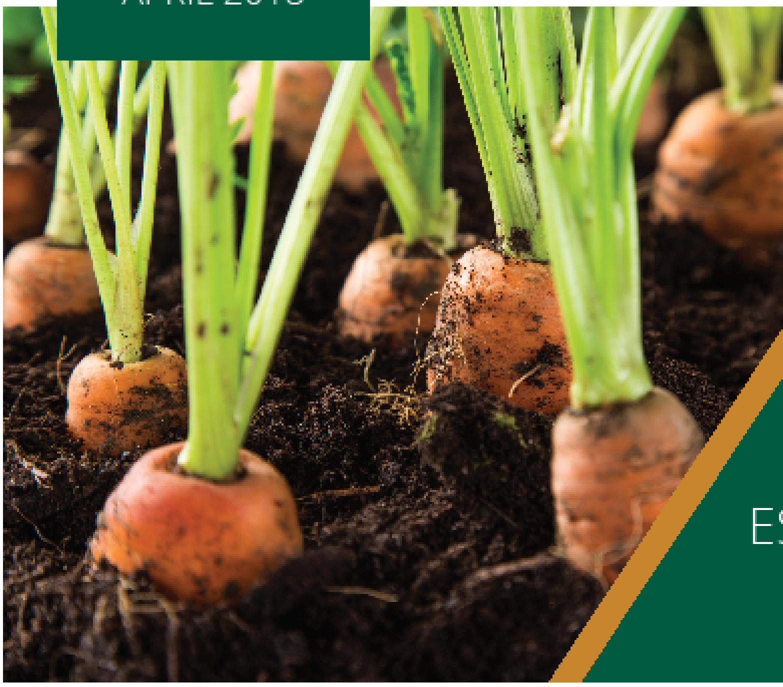

OPTIMISING CROP ESTABLISHMENT IN PROCESSING CARROTS

THE IMPORTANCE OF ESTABLISHING A GOOD CROP

A key factor in maximising the yield of carrots for processing is promoting the establishment of rapid and uniform early crop. Speedy early leaf growth and establishment of a strong root system will help minimise crop variability and maximise carrot yield[1,2]. Getting optimum carrot establishment relies on good pre-sowing planning, followed up with careful post-emergent crop management.

Carrot seed

Carrot seeds are very small, and while they have the energy required for germination, the embryo inside has not fully formed when the seed is harvested. The embryo is very important as it will develop into the first leaves and root shoots of the carrot plant. As a result, carrot seeds require some time before germination, while the seed prepares its embryo for early plant growth. Seeds can be graded based on the

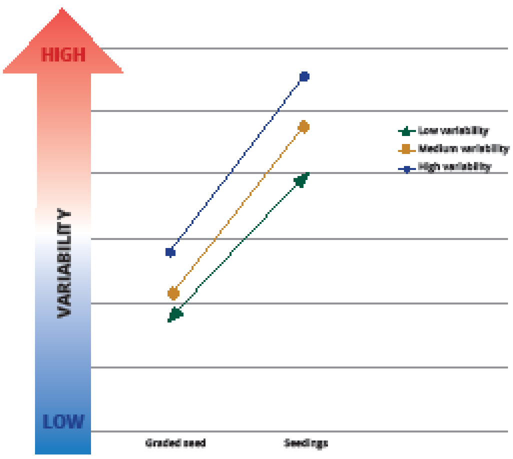

Figure 1. Impact of seed grading on seedling variability. Carrot seeds were graded based on embryo size and grouped based on the level of variability i.e. low variability meant that seeds were mostly of the same size while the high variability group contained seeds of different sizes. High variability in seed also led to high variability in seedling size.

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SCLEROTINIA ROT OF GREEN BEANS

1 (a) **Source:** Hoong Pung, Peracto Pty Ltd,Tas.

Sclerotinia rot, also known as white mould, is one of the major diseases of green beans in Australia. It is caused by the fungi *Sclerotinia sclerotiorum*. Sclerotinia rot can cause significant yield losses during the cropping season as well as post-harvest damage.

Sclerotinia can survive in the soil for more than five years and has a wide host range (e.g. beans, lettuce, carrots, potatoes), which makes control of the disease a challenge.

IDENTIFYING SCLEROTINIA

Sclerotinia fungi can induce a variety of distinctive symptoms including yellowing, water-soaked lesions and collapse of bean pods, followed by the appearance of fluffy white fungal threads studded with black resting bodies of the fungus, called sclerotia (figures 1a and 1b). Sclerotia are irregular in shape, up to 1–1.5cm long and resemble rat faeces1.

Sclerotia can also form inside stems, flowers and fruit of affected plants.

Figure 1. (a) Fluffy white fungal growth and (b) black resting bodies (sclerotia) on bean pods infected with sclerotinia.

2 (b) **Source:** John Duff, Qld Primary Industries and Fisheries Primary Industry and Fisheries

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Figure 1. Crane fly adult (image: ladybirdplantcare.co.uk)

WINTER CRANE FLY

(Trichocera annulata)

The Winter crane fly is part of the large insect family *Tipulidae*. The adult looks like a large mosquito with long legs and long thin wings, however, they do not bite or sting. They are sometimes called "daddy long legs" but should not be confused with a type of spider (Pholcus phalangioides) that has the same common name. In Europe and North America some species of crane fly are pests of turf – their larvae can cause serious damage by their feeding on grass roots. These larvae are sometimes called "leatherjackets".

In Australia, the winter crane fly larvae feed on rotting organic matter and, possibly, on frost-damaged or waterlogged plants. They breed in wet or moist areas with poor soil drainage and as the name suggests are active in the cooler weather of autumn and spring[1]. Without moisture the larvae will not survive.

DAMAGE

Given the right conditions the winter crane fly can be found in some horticultural crops and they have been observed in cauliflower in Northern Tasmania. A mild, wet winter in southern Australia is ideal for larvae development. It is unusual for these crane flies to cause significant damage here, but in Canada they can be a serious pest of turf, pasture grass, and field crops. The larvae could be a contaminant in processing vegetables. Feeding damage from larvae could allow pathogens to infect plants.

LIFE CYCLE

Adult winter crane fly live for a short time before they lay eggs in the soil surface in autumn. There is just one generation per year. Dry soil conditions at that time can result in many of the eggs failing to hatch, so large numbers of adult flies does not necessarily mean that there will be large numbers of larvae.
The eggs hatch after a few weeks and the larvae burrow into the soil and start feeding on decomposing vegetation and some plant roots.
Larvae are white to yellowy greenish grubs; plump and segmented with a definite head and with tiny, fleshy projections at the hind end and no legs. They may grow

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IRRIGATION MANAGEMENT IN SWEET CORN

KEY IRRIGATION TIPS

- Pay more attention when the crop canopy is rapidly growing, and corn ear size is determined. Crop water use at this time can be increasing by more than 400%, making irrigation management tricky. Even a small delay in irrigation can decrease yield substantially
- Use evapotranspiration forecasts to manage irrigation when a run of windy, hot weather spikes crop-water use
- Most irrigation systems will be running flat out to keep up with crop water requirements once the canopy closes. As a result, there is little capacity to catch up on irrigation if the system has a down time, or during a run of high reference crop evapotranspiration (ET_o)
- Soil moisture reserves are important in helping the crop get through peak water use, typically when the crop is setting and filling the corn cobs. Make sure soil moisture levels are not run down heading into January
- Don't delay restarting irrigation after in-crop rainfall

IRRIGATION AND SWEET CORN

Sweet corn has a high water requirement. The most sensitive growth stages (3–5) is also when crop water usage skyrockets, increasing by more than 400% over a few weeks. This rapid increase in crop water use can catch growers out and reduce yield and quality.

This factsheet provides a refresher on irrigation scheduling and outlines how new tools can help manage irrigation, especially when crop water use is changing rapidly. The factsheet uses as an example sweet corn crop grown in Cowra, NSW during 2017–18 to highlight crop development and evapotranspiration combined to change irrigation requirements (figure 1).

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