RURAL INDUSTRIES RESEARCH
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Methodology and viability of re-establishing commercial *Boronia megastigma* plantations

A report for the Rural Industries Research and Development Corporation

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Foreword

The production of an essential oil from brown boronia (*Boronia megastigma*) has been developed in Tasmania over the last 17 years, with commercial production of large clonal plantations for the last 12 years. At present some 80% of the total boronia in Tasmania have been in commercial production for more than 7 years, and plant numbers have been decreasing due to mechanical damage and general decline.

Production and sales forecasts from oil processors indicate that unless replanting is initiated in the next 1-3 years, there will be a shortfall in supplying the demand for product. Replanting boronia in small areas of plantations has not been successful to date, and growers are concerned about the viability of replanting entire plantations. The cost of developing new land rather than replanting current sites would be prohibitive. As boronia has very specific soil requirements, there are also no economically viable alternative cropping options for the land developed for current boronia production.

This publication presents and discusses investigations into the methodology and viability of re-establishing boronia plantations on currently used sites. It discusses the results from trials into Specific Replant Disease, soil treatments for replanting, and an industry wide survey of the status of current plantations. It includes recommendations for management options when replanting, and for further investigation of findings that could not be fully addressed within the scope of this study.

This project was funded from industry revenue that is matched by funds provided by the Federal Government.

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Peter Core
Managing Director
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Serve-Ag staff who contributed to this project include Sophie Wadley, Pam Cox, Mary Trebilco and Dr Hoong Pung (Plant Pathology).

Contents

Executive Summary

The boronia industry became concerned about the viability of replanting their current plantations following unsuccessful efforts to re-establish plants in small areas. There was concern that boronia may be prone to 'specific replant problems' (soil sickness) as known from orchards and nurseries. Development and management of soil sickness are not yet fully understood.

The research on the methodology and viability of re-establishing commercial *Boronia megastigma* plantations concentrated on the following areas:

1. Confirmation of specific replant disease in a pot trial (soil sickness test).
2. Isolation of soil-borne fungi from current boronia plantations.
3. In-vitro screening of soil pathogenic fungi suppressive soil amendments.
4. Replant field trial, testing soil amendments, effects of fire, nutrients simulating an 'ash bed effect', and fungicides known to be active against *Phytophthora* spp.
5. Survey of Tasmanian boronia plantations and growers to investigate site factors and plant establishment, management and longevity.

The soil sickness test was conducted using soil taken from the replant field site. The test showed that the soil did not suffer from specific replant problems. The grower had reported that all boronia plants on the trial site had been removed due to the high plant mortality in that part of the plantation. The soil was also tested for the presence of *Phytophthora*. Soil samples from other plantations in the area were tested at the same time. Tests showed that either *Phytophthora* or *Pythium* spp. were present in soil from most sites.

Following these findings, the replant field trial was designed to include organic and fungicide treatments that might control or suppress soil-borne diseases, including mulches. Further treatments were selected to simulate conditions that encourage revegetation of boronia in its natural habitat. Revegetation was reported to be best after scrub fires (J. Plummer and D. Ward, personal communication). The assumption was that a scrub fire would smoke-sterilise the top centimetres of soil without heating it, and provide nutrients, especially calcium (CaO), to the plants. Therefore, further treatments included 'cool' fire by burning dry boronia plants, and a fertiliser mix that was designed to provide a nutrient combination similar to ash, without adding chloride or carbonate. Treatments were compared to the commercial standard nutrition and an untreated control. All plants were replanted into previously used rows, apart from one that looked at the effect of inter-row planting. Apart from the untreated control, all treatments that did not include nutrients were fertilised as per the commercial standard.

Severe plant losses (<50%) occurred in some trial treatments during the first year. They were highest in plots with the commercial standard nutrition, the untreated control, inter-row planting, and in plots treated with straw mulch and Ridomil granules. Results suggested that nutrition programs should be re-evaluated considering that treatments like fire, a worm casting product and the 'ash bed fertiliser mix' produced better results than the commercial standard. Best results in survival, growth and vigour were achieved using pine bark mulch. Even though the cost of mulching may seem prohibitive to most growers, it appears worthwhile to carefully consider possible financial benefits of mulching on plant survival and vigour, over the life of the planting on a per hectare basis (e.g. protection of young plants from injury through wind, yield increase, return on management inputs, longevity, etc).

Older boronia plantations had experienced decline problems that often started during establishment. Growers were able to explain some plant losses. In a lot of cases, however, single boronia or groups of plants had died suddenly for no obvious reason. A field survey was conducted to identify the

causes of plant losses to assure that replanted boronia would not suffer from the same problems. If problems were site or management related they could be addressed prior to or after replanting.
The survey results showed that previous site use had an effect on plant vigour. Plantations thrived on land that was not used for grazing or plant production prior to planting boronia. Most sites had experienced plant losses in water-logged areas. Even though boronia grows on wet heath land sites in its natural environment, the soil there is not water-logged for extended periods, and always maintains a certain proportion of large air filled pore space, supplying roots with oxygen (D, Ward, personal communication).

A number of plants were lost due to the use of pot bound or poorly rooted transplants. The transplants developed weak, sometimes self-strangling root systems. They were prone to wind and harvester damage (poor anchorage), as well as water and nutrient deficiency.

A relatively large number of boronia in each plantation showed deformations and swellings of the crown (stem area just above and below soil surface). The symptoms often resembled those of the bacterial crown gall disease, sometimes suggested nematode damage, but could also be a reaction to strong wind in some cases. The crown of dying plants often carried fungal pathogens that could have entered through roots or wounds in the crown area caused by machinery or wind. The origin and causal organisms of crown diseases could not be further investigated within the scope of this study.

Soil from one plantation was tested for plant parasitic nematodes. Two species, *Rotylenchus* sp. and *Hemicycliophora* sp. were found at relatively high numbers.

Based on the results of the trials and surveys, 'Replant Problems of Boronia' were defined as follows: "All factors that influence the successful re-establishment of boronia plantations on sites previously used for boronia production."

The following recommendations are made to assist with the successful re-establishment of boronia plantations that will not suffer from premature decline:

- ♦ Boronia plantations in Tasmania do not suffer from classical ‘soil sickness’ problems. This means that, with adequate management, sites can be replanted.
- ♦ Replanted sites may experience establishment, growth or early decline problems due to one or a combination of the following factors:
  1. Transplant quality (e.g. pot bound plants),
  2. Mechanical damage to young plants or plants with poor root systems by wind and harvesters.
  3. Soil heath/quality (decline in soil structure or organic matter content, soil borne diseases, e.g. *Phytophthora*, *Pythium* or nematodes),
  4. Nutrition (nutrient balance, e.g. N / Ca, K & Mg, fertiliser types, amounts & timing),
  5. Pests and diseases of shoots, foliage, crown and roots.

- ♦ Several soil treatments and nutritional inputs can improve plant establishment and may improve longevity on replanted sites. These are:
  1. Pine bark mulch with no added nitrogen during composting.
  2. Controlled burning of old plantation about four weeks prior to replanting creating a ‘cool fire’.
  3. Use of a fertiliser mix that is high in cations but does not contain chloride (e.g. sulfate forms of Ca, K, Mg).
  4. Use of ammonium nitrogen rather than nitrate nitrogen.

It is considered important that growers clearly identify the cause for decline in their current plantation to avoid the problem repeating itself when replanting. Possible causes for early decline:

- Wind stress, causing injury to the crown area when plants swirl and rub against soil or are blasted by sand. The resulting injuries are entry sites for pathogens.
- Pot bound roots due to planting later then the ‘ready date’ given to the nursery.
- Drip irrigation not providing sufficient lateral water distribution in sandy soils to establish plants with a healthy root system.
- Water-logging leading to a lack of oxygen in the root zone and root rots.
- *Phytophthora, Pythium* or other soil-borne fungal diseases attacking weak, stressed plants. The importance of *Phytophthora* and *Pythium* as pathogens of cultivated boronia requires further investigation.
- Crown deformation possibly caused by wind or harvester damage and subsequent pathogen invasion. The crown gall pathogen *Agrobacterium tumefaciens* should also be investigated as a possible cause of crown deformations in plantations.
- Imbalanced fertiliser programs. Cation (Ca, K, Mg NH_4) and trace element nutrition need to be better understood and monitored in relation to plant health.
- Nematodes which may play a role, and need further investigation.

Fungicides that may control *Pythium* and/or *Phytophthora* and other agricultural chemicals must not be used without confirming their efficacy and lack of phytotoxicity and residues in flowers. Appropriate trials would have to be conducted under GLP (Good Laboratory Practice) protocols to obtain use permits from the National Registration Authority (NRA) for the boronia industry.

The industry may benefit from producing a comprehensive boronia management guide and/or introducing a quality management system using HCCP (hazard audit, critical control point) principles.

Introduction

Boronia megastigma (Brown Boronia) is a native shrub of Western Australia. It is found in wet or seasonally wet sites, on poor acid soils. The shrub is upright and dense, and flowers from late July to October. In Tasmania, the production of an essential oil from clonal selections of *Boronia megastigma* has been developed over the last 17 years, with commercial production from plantations for the last 12 years.

More than 80% of Tasmania's larger boronia plantations have been in commercial production for more than seven years, and plant numbers, particularly of clone 250, are decreasing due to general health decline and removal by mechanical harvesters. Considerable capital expenditure has been outlaid in the establishment of these plantations. Permanent irrigation, drainage and fencing make up the major capital investment. Nutrition regimes utilising very expensive fertilisers have been developed by industry.

As boronia has such particular soil type requirements, there are no other conventional cropping options for this developed land. Considering the annual rental payments for the clonal material to the University of Tasmania for the originally planted numbers of boronia, there is little option but to investigate replanting of current sites rather than developing plantations on new ground to maintain a viable industry.

Considerable investment and research into improvements to growing, post-harvest handling and extraction of boronia has been undertaken, but no investigation has occurred into the potential for replanting existing sites to enable the continued profitable production of boronia.

Individual replanting in established plantations has been mostly unsuccessful. There appears to be some form of inhibition of newly planted boronia transplants when replacing a mature, declined plant. The symptoms appear to be similar to those described as 'soil sickness' or 'replant disease' in fruit orchards and woody plant nurseries (e.g. fruit rootstock, roses).

Forecast production and sales estimates from Essential Oils of Tasmania indicate that unless replanting is initiated in the next two years, there will be a shortfall in supplying the current demands for raw product.

Objectives

- Investigate causes of replant problems in Tasmanian *Boronia megastigma* plantations.
- Determine the viability of replanting present boronia plantations.
- If replanting is found to be viable, identify the management procedures necessary to successfully re-establish Boronia plantations under their existing infrastructure.
- Investigate causes of premature plant decline and its relevance to possible replant problems.

Methodology
Trial 1 - Replant Disease Soil Test

Soil samples for a Specific Replant Disease test were collected from the site selected for the replant management field trial. The test had been developed for the assessment of orchard soils in Germany[1].

Trial Details

Grower	Serve-Ag Research
Location	Devonport, Tasmania
Soil Type	Podsol
Soil Texture	Sand
Soil pH (H_2O)	5.4
Potting Mix	Pot 'N' Peat, Horticultural Supplies Hobart
Boronia Clone	Clone 250
Transplant Source	John Hill Transplants Don Heads Road Devonport, Tas 7310
Trial Design	Latin Square
Pots per Replicate	4
Number of Replicates	4
Pot Size	12”
Planting Date	07/01/00

Treatments

Number	Substrate
1	Potting mix
2	70% potting mix plus 30% soil
3	70% potting mix plus (30% soil treated 1 hour at 50^{o}C)
4	70% potting mix plus (30% soil treated 1 hour at 100^{o}C)

If soil was affected by ‘soil sickness’, trees would grow best in potting mix (Treatment 1) and worst in potting mix with 30% soil added (Treatment 2). The expectation for treatments 3 and 4 would be that the higher the sterilisation temperature, the better the growth of trees.

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[1] Reference: Friedrich, G., Neumann, D. and Vogl, M., 1986: Physiology der Obstgehoelze, Springer Verlag, 2nd edition, ISBN 0-387-15268-7

Trial plan

Each cell in the trial plan represents 4 pots of the same treatment.

1	3	4	2	**Block 1**
4	2	1	3	**Block 2**
2	4	3	1	**Block 3**
3	1	2	4	**Block 4**

Assessments

Growth of boronia in “replant disease” soil test

DATE/S - 07/01/00, 17/07/00, 15/11/00

SAMPLE SIZE - All plants in the trial

METHOD - The height of each plant was recorded in centimetres [cm].

RESULTS - Graph 1

Trial 2 - Soil Baiting Trials

Procedure

Bait Preparation
A 20mm vermiculite layer was placed into a plastic container (approximate size 210cm x 140cm x 65cm). Blue lupin seeds were spread onto this layer and covered with another 20mm layer of vermiculite, then distilled water was added to the top of the container.

Seeds were left for two days, until germinated and a 2 - 3cm long shoot had developed.

Test Set-up
Fifty millilitres (50ml) of each soil sample to be tested were measured into polystyrene cups, with five replicates per sample, and covered with distilled water.

Plastic lids with five holes each were placed upside down on top of the cups. A germinated lupin seed was inserted into each hole so that the root touched the water.

The cups were left undisturbed at a temperature of 22°C for 3-8 days. Then the lupin stems were assessed for lesions at the waterline, and the roots were assessed for lesions on the tip that by then was immersed in the soil.

The presence of lesions on each lupin seedling was recorded and the damaged area was dissected into three pieces, which were placed onto P10 agar plates. P10 is a selective medium that only allows *Phytophthora* and very closely related fungi to grow. The plates were incubated in the dark at 22°C for 72 hours, then examined for growth of *Phytophthora*. If plates showed fungal growth from the lesions that were suspected to be *Phytophthora*, the fungi were subcultured to assist identification. Samples of fungi considered to be *Phytophthora* were sent to taxonomists to confirm the species.

Soil Baiting Samples

Soil samples for the baiting tests were collected from areas in plantations that showed plant decline, or from the vicinity of dead plants in most plantations. Samples were also taken from around healthy plants.

Soil from the intended field trial area, which came up positive in the first test, was mixed with a range of organic substances to assess whether these would eliminate or reduce *Phytophthora* infection of the bait plants. The substances were used at rates that could be translated to field applications to the boronia root zone.

The following table shows the origin of samples and their treatment with amendments.

Origin of soil samples for baiting tests, and their treatment with amendments

Grower/Source	Plant appearance in sampling area	Soil amendments
H1 (old plantation)	Old, dying	N/A
H2 (new plantation)	Healthy	N/A
	Unhealthy plants – little damage	N/A
	Dying plants – very damaged	N/A
L1	Trial area – no plants	N/A
Pot trial	Substrate from pot with dead plant	N/A
Fresh potting mix	N/A	N/A
ME1	Good growth	N/A
ME2	Poor growth	N/A
W1	Poor growth	N/A
W2	Good growth	N/A
W3	Poor growth	N/A
W4	Good growth	N/A
S	Poor growth	N/A
R	Poor growth	N/A
G	Poor growth	N/A
M clone 250	Poor growth	N/A
M clone 17	Poor growth	N/A
B 250	Poor growth	N/A
B clone 17	Poor growth	N/A
C	Poor growth	N/A
T (wet)	Poor growth	N/A
L2	Trial area –plants had been removed several months previously	N/A
		Worm casting product
		Dynamic lifter (ground)
		Soy meal
		Lucerne meal
		Mustard meal 1*
		Mustard meal 2*

*One source of mustard meal was a commercial supplier, the other was from mustard seed, usually used for green crops, which was ground with a coffee grinder.

Assessments

Lesions on Lupin Seedlings

DATES TESTS SET UP -	28/02/00, 09/06/01, 11/10/00
ASSESSMENT DATES -	06/03/00, 11/06/00, 13/10/00
SAMPLE SIZE -	Each seedling
METHOD -	Visual assessment
RESULTS -	Table 1, Graphs 2 - 4

Growth of *Phytophthora* on Agar Plates

DATE/S -	10/03/00, 15/06/00, 17/10/00
SAMPLE SIZE -	Each dissection on each plate
METHOD -	Microscopic investigation and taxonomy tests
RESULTS -	Table 1, Graphs 2 - 4

Trial 3 - Replant Field Trial

Trial Details

Grower	L1
Location	Bridport, Tasmania
Soil Type	Podsol
Soil Texture	Sand
Soil pH (H_2O)	5.4
Clones	Trial plants: Clone 17 Buffer plants: Clone 250
Trial Design	Complete randomised block
Replicates	5
Plot Size	4m x 2m
Plant Spacing	Double row, 0.5m x 0.5m
Row Spacing	1.9m between double rows
Plants per Plot	12 plus 2 buffer plants
Planting Date	17/05/00

Trial Plan

11	1	7	10	6	4	9	2	8	3	5	**Block 5**
6	9	5	2	11	3	10	7	4	8	1	**Block 4**
3	11	10	1	5	8	7	9	2	6	4	**Block 3**
10	5	2	7	3	1	4	8	6	11	9	**Block 2**
7	4	9	8	2	6	3	1	10	5	11	**Block 1**

←N

Treatment List

Number	Product		Schedule
	Name	**Application Rate**	
1	Nitrophoska Perfect = Industry Standard	5g/plant	7 weeks after planting
2	Alliette*	11g/m^2 in 5L water	Pre-plant as drench
3	Ridomil Granules*	1.2g/m row	Pre-plant in a 30cm wide band along rows
4	Terrazole*	8g/m^2 in 10L water	2, 16 and 24 weeks after planting as soil drench
5	Gypsum, Sulphate of Potash, Magnesium Oxide, Trifos, Urea	125g/m^2 95g/m^2 30g/m^2 30g/m^2 30g/m^2	2 weeks prior to planting
6	Pine bark*	0.1m^3/m^2	4 weeks prior to planting
7	Straw*	0.1m^3/m^2 (1 bale per plot)	At planting
8	Untreated	N/A	N/A
9	Worm Casting	100g/m^2	At planting
10	Fire	Burning of 10-12 mature size, dead boronia plants per plot	4 weeks prior to planting
11	Nitrophoska Perfect	5g/plant	Inter-row planting

* Nitrophoska added as per Treatment 1.

Product Details

Product		Active Ingredient (a.i.) or Nutrient		Comments
Name	Formulation	Name	Concentration	
Nitrophoska Perfect	Granule	Nitrate Nitrogen Ammonium Nitrogen Phosphate Potassium Sulphur Magnesium Calcium Boron Iron Zinc Manganese Copper	7% 8% 2.2% 16.6% 8% 1.2% 1.8% 0.02% 0.06% 0.01% 0.005% 0.0005%	Does not contain chloride, contains trace elements, near neutral
Alliette	Wettable granule	Fosetyl	800g/kg	As aluminium salt
Ridomil Granules	Granule	Metalaxyl - M	25g/kg	
Terrazole	Wettable powder	Etridiazole	350g/kg	
Gypsum	Powder	Calcium	21.6%	As sulphate
Sulphate of Potash [$K_2 SO_4$]	Granule	Potassium	41.5%	As sulphate
Magnit	Granule	Magnesium Oxide	55.6%	
Trifos	Granule	Phosphate	20.7%	
Urea	Granule	Nitrogen	46%	
Worm Casting (Pontec)	Powder containing larger particles	Nitrogen Phosphate Potassium Calcium Magnesium Manganese Zinc Boron Copper Molybdenum	3.48% 3.54% 1.06% 10.16% 0.67% 266ppm 202ppm 34.7ppm 35.2ppm 2,73ppm	

Chronology of Events

Date	Days after planting	Event
19/04/00	-28	Soil samples taken from replant trial site. Trial area measured and marked. Fire and pine bark treatments applied. Mature dead boronia plants to be used for burning were taken from a plantation adjacent to the trial. There about 75% of plants had died. The dead plants, which were about 1.2m high, were used to simulate the type of fire that would occur if an old plantation were to be burned. The fires burned out after about 20 minutes, which means they were not hot and were comparable to a scrub fire that would occur in natural boronia habitats. The pine bark layer was about 10cm thick.
03/05/00	-14	Fertiliser mix (Treatment 5) applied. Soil samples taken from plots treated with fire.
17/05/00	0	Planting of trial with clone 17, buffers planted with clone 250. Ridomil, Alliette, straw and worm casting product treatments applied.
05/07/00	49	Nitrophoska and 1st Terrazole application. 1st measurement of plant heights (= initial heights).
07/09/00	113	2nd Terrazole application, 2nd height measurement and 1st survival count.
03/11/00	170	3rd Terrazole application, 3rd height measurement and 2nd survival count.
29/11/00	196	According to commercial practice, each plant was cut back to a height of 20cm.
06/04/01	324	Final (4th) height assessment, vigour rating and 3rd survival count. Plants in pine bark treated plots appeared to be a lighter green than those from other treatments, suggesting a need for fertiliser.

Assessments

1. GROWTH ASSESSMENT

DATES -	05/07/00, 07/09/00, 03/11/00 and 06/04/01
SAMPLE SIZE -	All plants in all plots
METHOD -	The height of each plant was measured in centimetres [cm].
RESULTS -	Graphs 5, 6 and 8

3. SURVIVAL COUNT

DATES -	07/09/00, 03/11/00 and 06/04/01
SAMPLE SIZE -	All plants in plots
METHOD -	The number of living plants displaying green foliage was counted.
RESULTS -	Graphs 7 and 8

4. VIGOUR RATING

DATE -	06/04/01
SAMPLE SIZE -	All plants in plots
METHOD -	Visual rating; 1 = very poor, 2 = poor, 3 = moderate, 4 = vigorous, 5 = very vigorous (see photographs on next page)
RESULTS -	Graph 8

5. SOIL ANALYSES

DATES -	(1) 19/04/00 and (2) 03/05/00
SAMPLE SIZE -	(1) Composite sample from the entire trial site and (2) Composite sample from plots treated with fire.
METHOD -	Standard soil sampling auger (15cm depth)
RESULTS -	Table 2

Vigour ratings, from left to right: rating 1, rating 2, rating 3, rating 5

Statistical Analyses

Data from the pot and field trials were analysed using a one-way Analysis of Variance (ANOVA). The method used to discriminate among the mean values was Duncan's multiple comparison procedure. With this method there is a 5% risk of calling one or more pairs significantly different when an actual difference does not exist. Within the same series in graphs, the same letter denotes no significant difference between treatments at the 95% confidence level.

Trial 4 - Plantation and Grower Surveys

According to information from boronia growers and the writer's observations, current plantations have decline problems that often commenced right after planting. Growers estimated to have lost several hundred plants per year in their plantation. Nearly all plantations were visited and growers interviewed to investigate possible reasons for plant decline. The reason was that if decline problems were site specific, they might need to be addressed prior to replanting. If they were management specific, practices might need to be revised.

Survey Details

Nº	Grower	Location	Field Survey
1	L1 ex bush	North East Tasmania	24/02/00
2	L2 ex pasture		24/02/00
3	H1		24/02/00
4	H2		24/02/00
5	W	North West Tasmania	18/08/00
6	M	Southern Tasmania	27/09/00
7	ME	Southern Tasmania	27/09/00
8	B	Bruny Island	28/09/00
9	T	Bruny Island	28/09/00
10	G	Bruny Island	28/09/00
11	C	Bruny Island	28/09/00
12	R	East Coast, Tasmania	29/09/00
13	D	East Coast, Tasmania	29/09/00
14	S	East Coast, Tasmania	29/09/00

Four plantations in the northeast region of Tasmania were investigated in February 2000, one in the northwest in August 2000. Plantations in southern and eastern areas of Tasmania were surveyed between the 27/09/00 and the 29/09/00.

Assessments

Hand drawn maps were prepared for each plantation showing location of clones, areas of poor growth, water-logging, diseases, and other relevant observations. In addition, most growers completed a survey form providing information on:

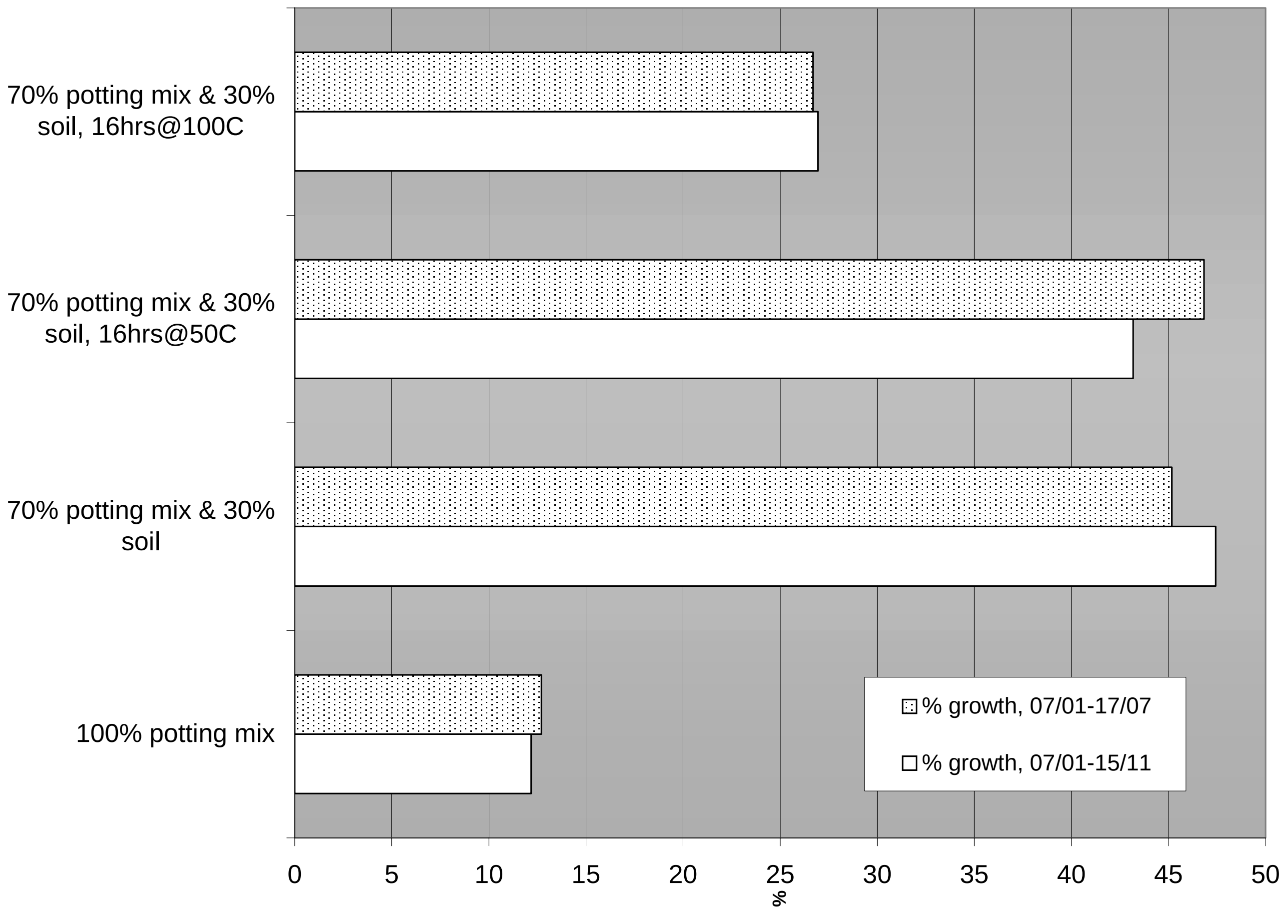
- Previous use of site,
- Soil type,
- Soil pH,
- Soil preparation prior to planting,
- Drainage, water-logging, hard pans,
- Salinity (sea air, water),
- Planting dates,
- Configuration/spacing of plants,
- Status of the plants when planted, eg. root quality,
- Establishment problems,
- Irrigation details,
- Nutrition (type of fertiliser, rates, timing),
- Soil management practices,
- Weed control, types of weeds,
- Diseases and control strategies,
- Decline problems, suspected or identified reasons and timing of decline (eg. years after planting, after certain activity or event susceptibility of clones),
- Results of replanting,
- Wind, harvester and other mechanical damage,
- Clonal differences.

The maps and survey forms were used to investigate relationships between plant decline or possible replant problems, and environmental or management factors.

Results

Trial 1 - Replant Disease Soil Test

Graph 1 - Growth of boronia transplants (%) 07/01/00 - 17/07/00, and 07/01/00 - 15/11/00, as affected by substrate mix and treatment



Differences between treatments are not significant.

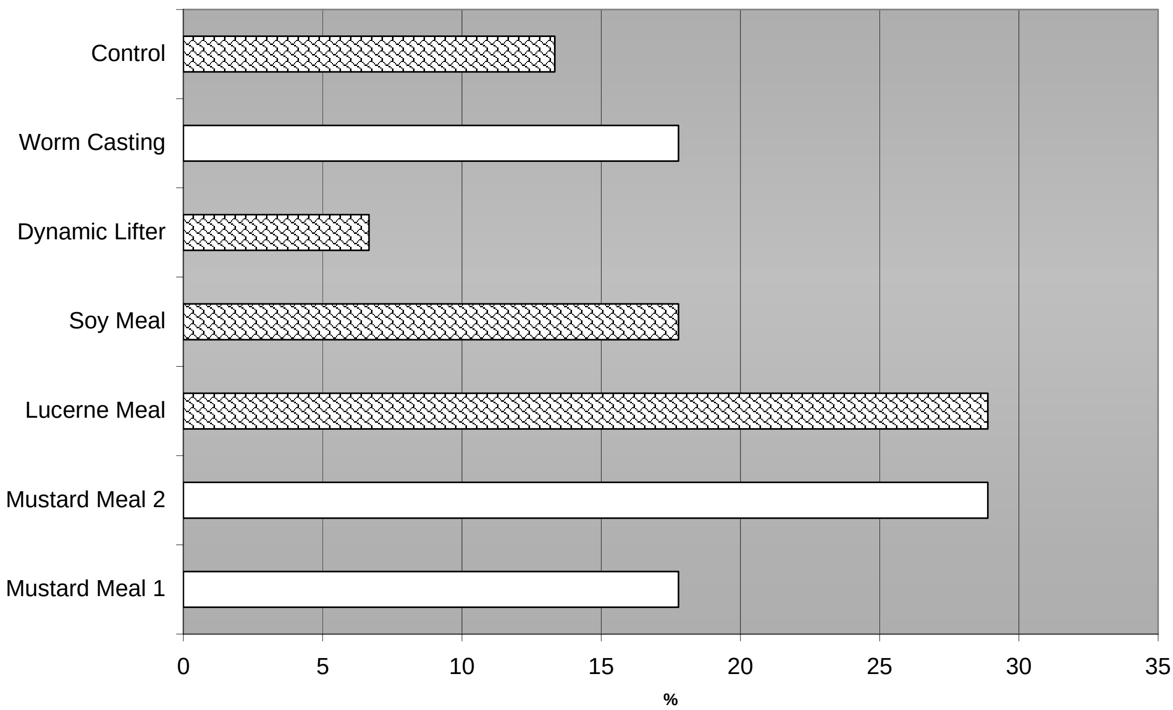
The average plant height at the start of the trial was 16.2 cm, with little variation between plants.

Trial 2 - Soil Baiting Trials

Table 1 - Results from soil baiting tests conducted for three plantations located in northeast Tasmania, tests set up 28/02/00

Grower	Plant appearance in sampling area	*Phytophthora cinnamoni*	Other *Phytophthora* species
H1	Old, dying	Yes	No
H2	Healthy	Yes	No
	Unhealthy	Yes	No
	Very unhealthy	Yes	No
L1	Trial area – no plants	No	Yes

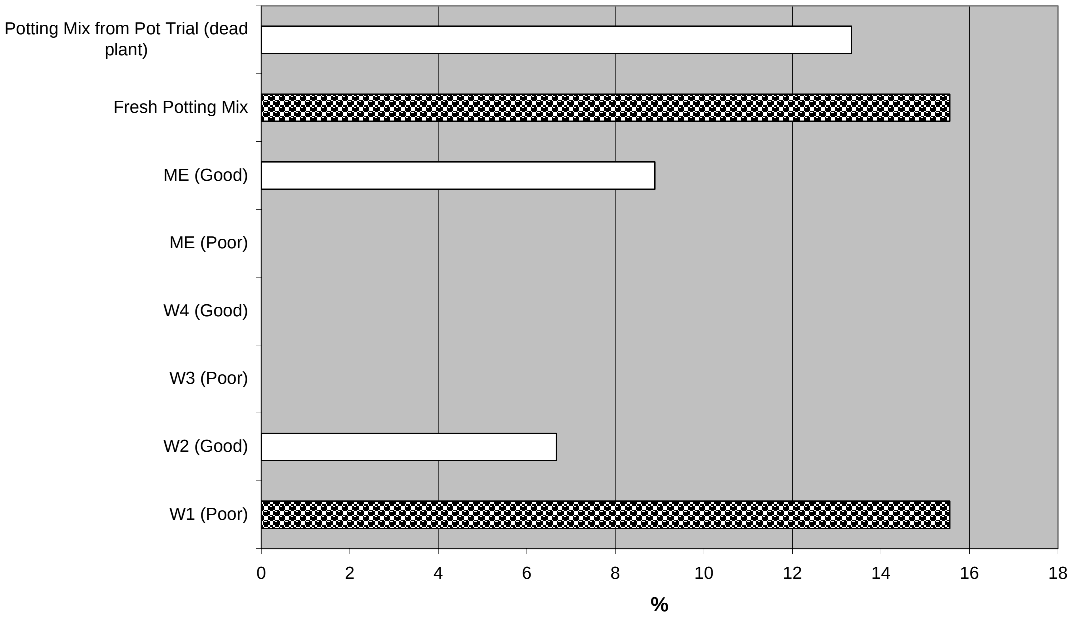
Graph 2 - Percentage of lupin plants with root lesions and *Phytophthora* infection in the in-vitro soil amendment trial.



The test was set up 09/06/00 with amendments to soil from which Phytophthora spp. had been baited The textured columns mark treatments with Phytophthora isolates from lupin root lesions. Other fungi were not identified.

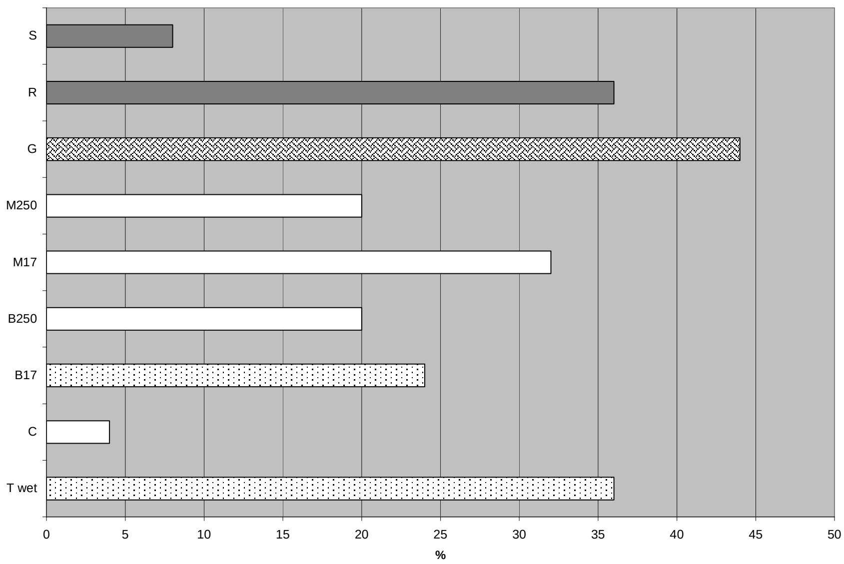
Graph 3 - Percentage of lupin plants with root lesions and *Phytophthora* infection.

The test was set up 09/06/00 with soils from different areas within plantations, and two potting mix



samples. The textured columns mark treatments with Phytophthora isolates from lupin root lesions. Other fungi were not identified.

Graph 4 - Percentage of lupin plants with root lesions and *Phytophthora* infection.



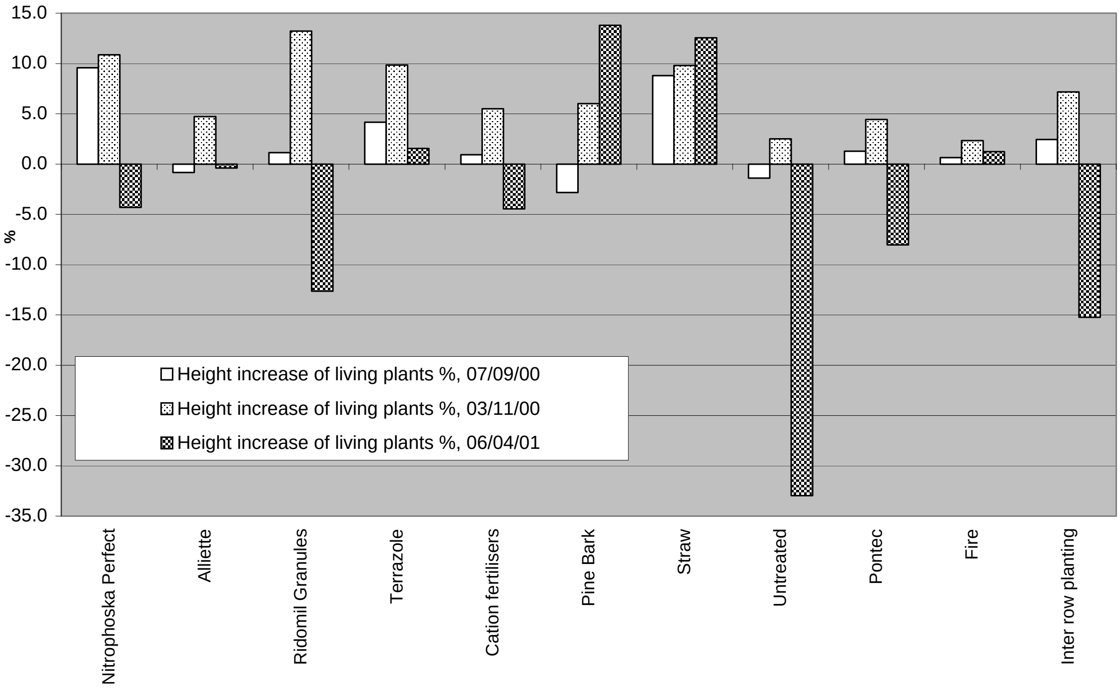
The test was set up 11/10/00 with soils from different plantations. The numbers behind plantation names identify clones. The textured column marks Phytophthora spp. isolates from lesions. The dark columns mark Phytophthora cinamomi isolates. The dotted columns mark Pythium isolates. Other fungi were not identified.

Trial 3 - Replant Field Trial

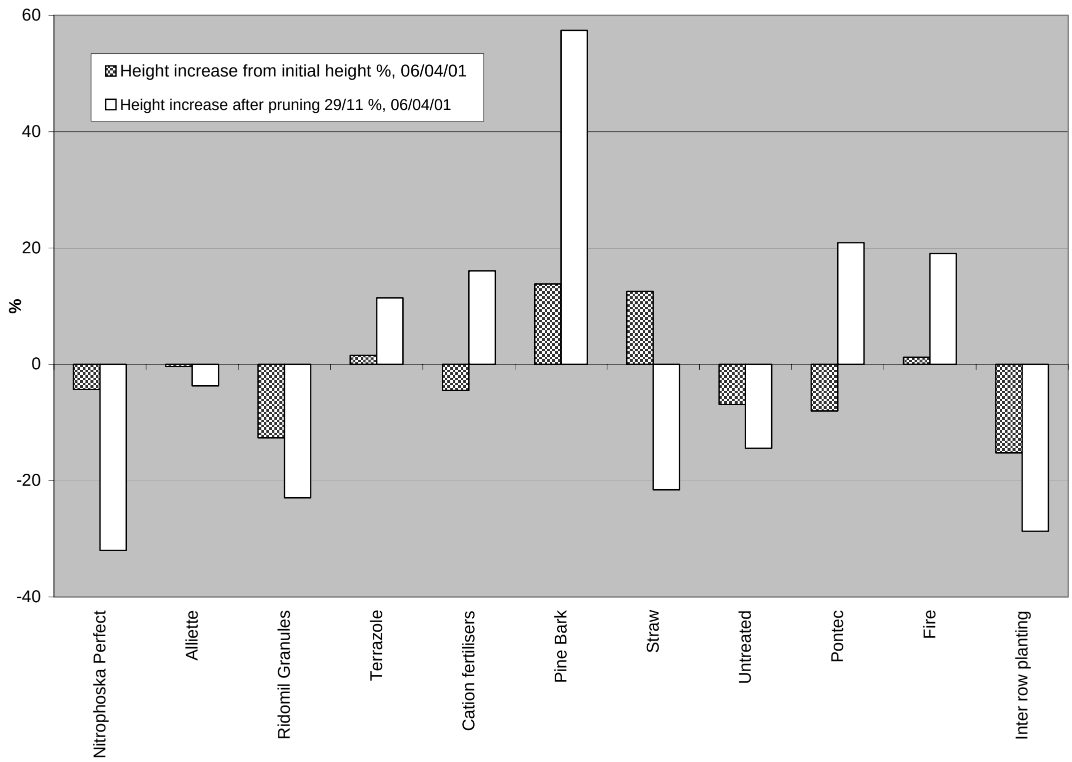
Table 2 - Soil analysis results from the replant trial site prior to planting and for plots treated with fire (samples taken two weeks after fire)

TEST and UNIT	Trial site 19/04/00		Fire treatments 03/05/00		Changes	
Nitrate Nitrogen (NO_3, mg/kg)	2.9		2.6		**-0.3**	
Phosphorous (Colwell P, mg/kg)	5.0		26.0		**+21**	
Available Potassium (K, mg/kg)	49.0		110.0		**+61**	
Available Sulphur (S, mg/kg)	3.7		9.6		**+5.9**	
Zinc (Zn, mg/kg)	0.54		1.11		**+0.57**	
Copper (Co, mg/kg)	0.13		0.23		**+0.1**	
Manganese (Mn, mg/kg)	19.0		31.0		**+12**	
Boron (B, mg/kg)	0.29		0.6		**+0.31**	
Chloride (Cl, mg/kg)	10.0		47.0		**+37.0**	
Electrical Conductivity (EC, dS/m)	0.05		0.06		**+0.01**	
EC of saturated extract (Ece, dS/m)	1.1		1.32		**+0.22**	
Organic Carbon (%)	2.2		3.0		**+0.8**	
pH H_2O	5.4		5.8		**+0.4**	
pH $CaCl_2$	4.5		4.7		**+0.2**	
Soil Texture	Sand		Sand		**None**	
Soil Colour	Grey		Black		**Darker**	
Free Carbonate	Not present		Not present		**N/A**	
Total Cation Exchange Capacity (CEC meq/100g)	5.18		8.42		**+3.24**	
Cation Exchange Capacity	meq/ 100g	%CEC	meq/ 100g	%CEC	meq/ 100g	%CEC
Aluminium (Al)	0.06	1	0.06	1	**0**	**0**
Calcium (Ca)	3.3	64	5.5	65	**+2.2**	**+1**
Magnesium (Mg)	1.67	32	2.5	30	**+0.83**	**-2**
Sodium (Na)	0.05	1	0.12	1	**+0.07**	**0**
Potassium (K)	0.11	2	0.25	3	**+0.14**	**+1**
Ca : Mg Ratio	1.98		2.2		**+0.22**	
K : Mg Ratio	0.07		0.1		**+0.03**	

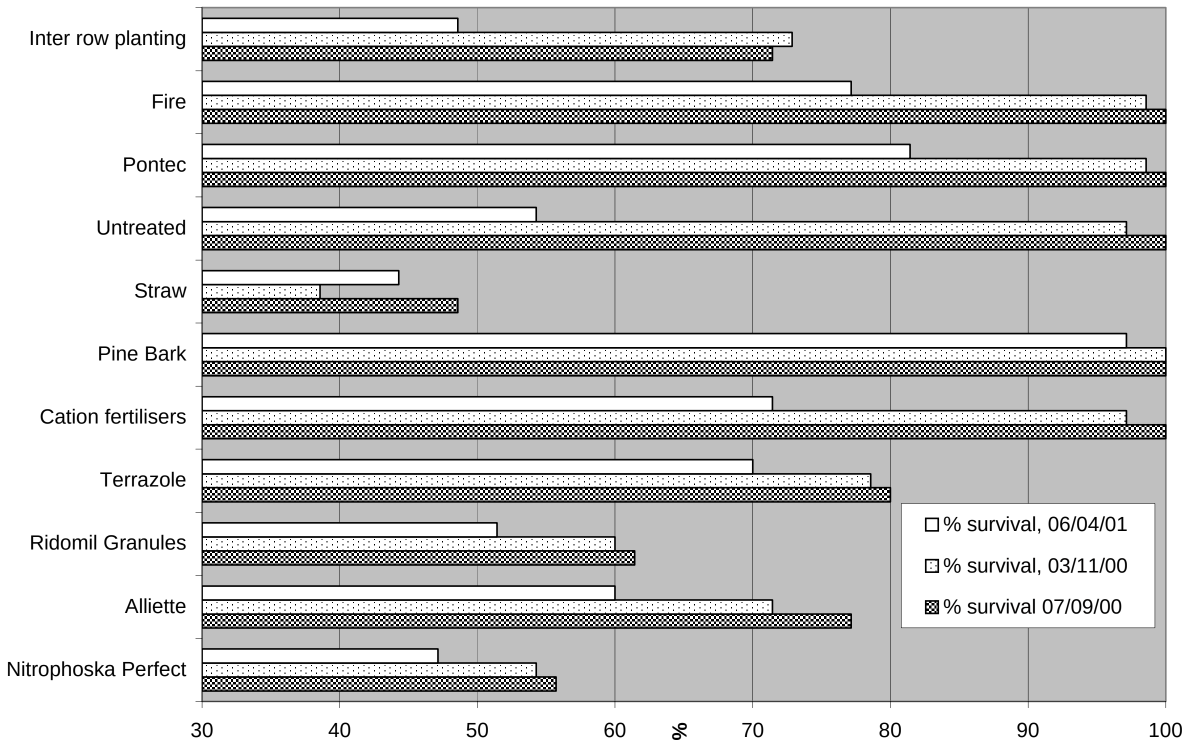
Graph 5 - Plant height variation (%) from initial height at planting as influenced by soil treatment



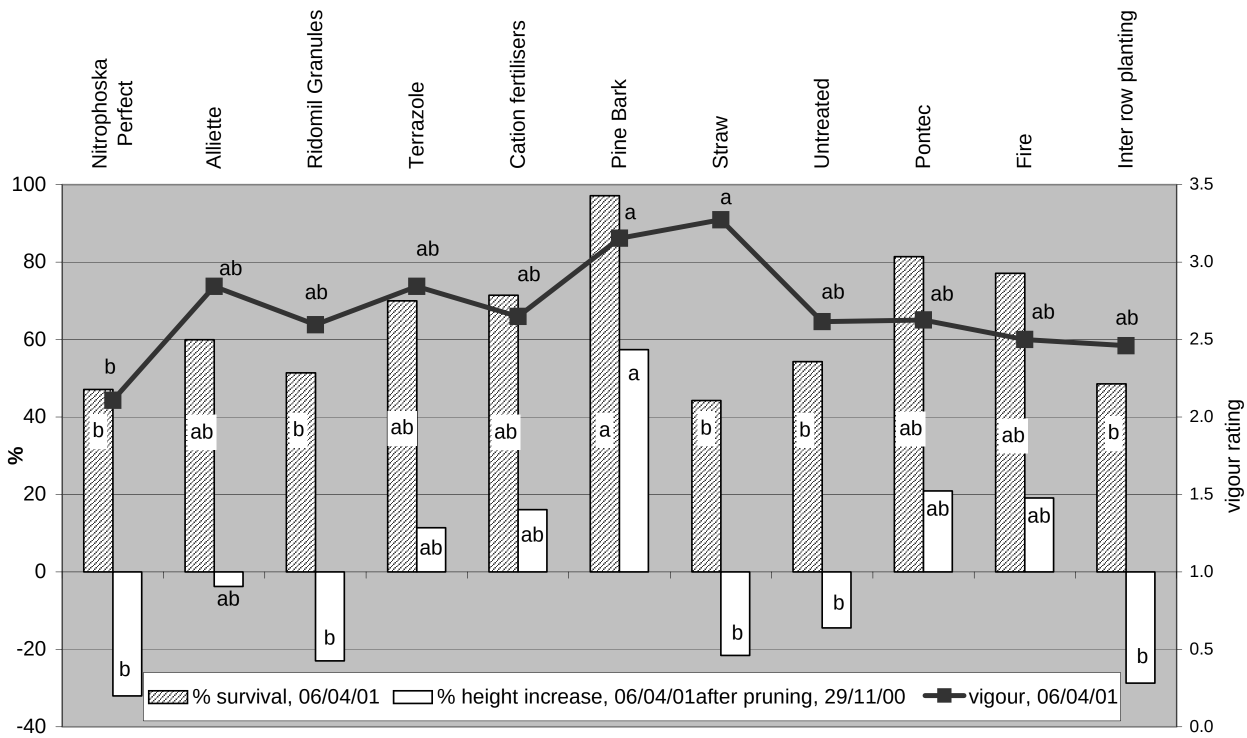
Graph 6 - Comparison of plant height variation (%) between initial height at planting & final height, and height at pruning (=20cm, 29/11/00) & final height, 06/04/01



Graph 7 - Survival rates (%) as influenced by soil treatment



Graph 8 - Height increase after pruning (%), survival (%) and vigour at final assessment (06/04/01), as influenced by soil treatment



Trial 4 - Plantation and Grower Surveys

In the opinion of growers, boronia production was affected by:

- ♦ Soil preparation & management,
- ♦ Nutrition,
- ♦ Irrigation,
- ♦ Pests and diseases (Scale, Rust, Nematodes),
- ♦ Weed control,
- ♦ Establishment and decline problems.

The analysis of survey results identified the following factors contributing to boronia decline in existing plantations aged 5-12 years:

- ♦ Previous site use,
- ♦ Water-logging,
- ♦ Status of plants at planting,
- ♦ Root distribution,
- ♦ Clonal differences,
- ♦ Health of crown area (crown = stem area just above and below soil surface).

Soil preparation

When preparing the land, vegetation was removed mechanically and using herbicides as required. Prior to planting, beds were rotary hoed, disced and harrowed, depending on site condition and grower preference. The mostly sandy soils retained their pH of 4.4-5.4. In some cases, tree stumps and roots were burned. Growers observed that boronia did not thrive in the areas that were subjected to fire. In one case, it became evident that plants grew quite vigorously on the margins of burned areas where the fire did not heat the soil to very high temperatures.

Nutrition

Fertiliser programs are based on Nitrophoska Perfect (15-2-17 +TE), which is recommended for use in horticultural soils with good to high phosphorus levels, for ornamentals and chloride sensitive crops. The nitrogen component consists of 7% nitrate and 8% ammonium N. All other nutrients are in the sulphate or oxide form. Some growers applied additional Nitram in some years. Most growers observed an improvement in plant appearance when applying additional amounts of magnesium (magnesium sulfate, dolomite, epsom salts, CoarseMag). Generally, growers considered foliar applications of molybdenum or the trace element fertiliser ‘Fertilon’ to be beneficial. A regular soil and plant analysis to monitor and balance nutrition is not used by the industry.

Soil management and weed control

Ongoing soil management is not taking place. Weeds are mainly controlled using herbicides (Round Up, Basta, Spray Seed, Brush Off) and some hand weeding. One grower uses sheep to graze grass and weeds. Mulches were applied in two plantations, either with various organic materials, prunings and material mowed from between rows. In both instances, the grower considered this practice to be beneficial.

Irrigation
Growers use drip tape or mini sprinklers. Some were commenting on drip tape not being suitable during plant establishment, as drippers do not allow good lateral water movement in sandy soils. Growers do not use soil moisture monitoring systems to manage irrigation frequency and amounts.

Pests and diseases (Scale, Rust, Nematodes)
Apart from one, all growers experienced problems with scale insects and rust. Psyllids were found in one plantation. Comments were made that rust often follows scale infestations. Most growers needed to control pests and diseases with products like Dithane, Tilt and White Oil. Two types of plant parasitic nematodes, *Rotylenchus* sp. and *Hemicycliophora* sp., were found at relatively high numbers in soil from one plantation with suspicious symptoms.

Establishment and decline observations
Nearly all growers reported plant losses due to harvester or wind damage (Photograph 1). They commented that poor root development and distribution (often resulting from pot-bound roots) were to blame for this. Losses due to lack of water were said to be due to rooting problems in combination with drip irrigation systems. All but one grower had to replant up to 10% of plants that were lost during establishment. Seventy five percent of growers experienced decline problems, often starting in the first season. In most cases, parts of plants or the entire plants turned orange and died relatively quickly. Growers commented that dead plants often had poor root systems. Some growers replanted with little success, while others managed to establish new plants where losses had occurred. Most growers did not replant small gaps in older plantations, as managing a range of ages within one plantation did not seem feasible.

Photograph 1 - Wind damage to shallow rooted boronia plant

Previous site use

The survey showed that survival and appearance of plants were influenced by the previous use of the site. In general, plantations had less decline problems if planted on land that had not been used for plant production or grazing before. Plantations established after removal of native bushland or forest appeared healthy and vigorous compared to those planted on previously cultivated sites.

Status of plants at planting

Growers who planted later than initially planned experienced problems because the transplants had to remain in the nursery in propagation trays for too long. The finally planted pot-bound boronia developed poor root systems, resulting in poorly anchored plants with poor water and nutrient soil exploitation capability. Pot-bound plants of the clone 250 had a tendency to strangle themselves (Photograph 2).

Photograph 2 - Crown and strangling roots of a plant from clone 250, suspected to have been pot-bound

Root distribution and health

Growers had observed that a number of plants developed only one major root to one side of the plant. This was confirmed during the survey, when poor looking plants were dug up (Photograph 3). In one plantation, roots from plants at the margin of an expanding area where plants were dying, appeared knobbly. A nematode test from surrounding soil did not find plant parasitic nematodes as suspected. The reason for the dieback and root appearance in the particular plantation could not be identified.

Photograph 3 - Poorly developed root system with only one strong lateral root

Health of the crown area[2]

An investigation of dying and dead plants revealed that most showed a thickening of the crown area (Photograph 4, 5 and 6), and/or fungal growth inside the wood of the crown (Photograph 7). When the crown of partially dead bushes (some branches alive, others dead) was cut open, it became evident that the part of the crown below the dead branches had died (Photograph 8). Attempts to isolate and identify pathogenic organisms from dead parts of the crown were not successful. A reason could be that the crown had already deteriorated too far at the time of sampling. Saprophytic organisms had become established, which outgrew pathogens during isolation attempts.

Photograph 4 - Deformed crown area on dying plant

Photograph 5 - Deformed crown area on dying plant (from different plantation than photograph 4)

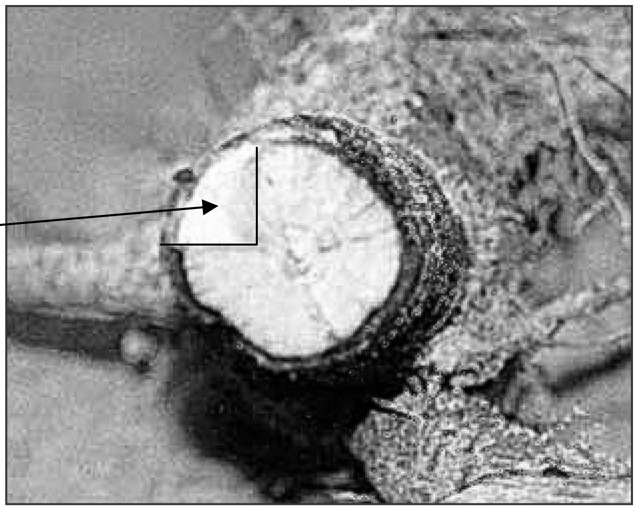
[2] crown = stem area just above and below the soil surface

Photograph 6 - Deformed crown area (from different plantation than photographs 4 & 5)

Photograph 7 - Crown of plant that had recently died, with black discolouration and white fungal growth

Photograph 8 - Cut through stem just above crown, showing wood that lead to the dead part of the plant

Dead area leading to dead plant part



Clonal differences

In all plantations, clone 250 had the worst decline problems. Growers also commented that this clone seems to be more susceptible to rust and scale infection. The clone produces vigorous plants with relatively poor root systems that were often found to self strangle (Photograph 2). The clone also seemed to be most sensitive to water-logging. Clones 3 and 5 appeared to have generally better developed, healthier root systems. Some growers experienced losses of Clone 17 due to using pot-bound transplants.

Water-logging

Most plantations were affected by water-logging to some extent. Plants that were exposed to extended periods of water-logging showed signs of stress (partial yellowing, poor vigour) or had died.

Photograph 9 - Water logged area with severe plant losses in a boronia plantation

Technology Transfer

Progress reports and trial results were discussed with boronia growers at their meetings on 18/05/00 and 09/11/00. Individual growers were updated during field surveys and telephone conversations.

Discussion

Trial 1 - Replant Disease Soil Test

The definition of ‘Specific Replant Disease’ or ‘Soil Sickness’ that has been reported from orchards and nurseries is defined as a reduction in growth and yield of still unknown causes, occurring under repeated cultivation of the same species. It is believed to be due to a build-up of harmful organisms or substances in the soil. It persists over many years. No single pathogen or substance could be identified and confirmed as the cause of the problem. Nematodes are often associated with soil sickness but are not its primary cause. Replant disease symptoms can be reduced or eliminated by soil fumigation, heat sterilisation and addition of fresh organic matter. Nutritional and chemical treatments have improved growth on soils affected by Specific Replant Disease in some cases[3].

The replant disease soil test showed that boronia does not suffer from 'Soil Sickness' (Graph 1). Plants grew better when soil was added to the potting mix, even though *Phytophthora* spp were baited from the soil (Table 1). When the soil was heat sterilised prior to adding it to the potting mix, plant growth was improved compared to pure potting mix, but not as much as with non-sterilised soil. In soil baiting tests conducted after the pot trial was set up, *Phytophthora* spp were also found in the potting mix (Graph 3). The result suggests that the soil used for the test not only contained potentially harmful organisms, but also beneficial ones that can suppress soil-borne fungal diseases like *Phytophthora* spp under certain conditions.

Even in the absence of a Specific Replant Disease Complex, boronia growers might experience replant problems. For this study 'Replant Problems of Boronia' was defined as follows:

"All factors that influence the successful re-establishment of boronia plantations on sites previously used for boronia production." The factors could be one or a combination of the following:

- Transplant quality (genotype or production related),
- Soil heath/quality (chemical, physical or microbiological properties) as influenced by soil type, previous land use, topography and management,
- Nutrition (nutrient balance, fertiliser types, amounts & timing),
- Pests and diseases of above and below ground plant organs.

Trial 2 - Soil Baiting Trials

Soil baiting trials were used to investigate whether boronia soils, other than that of the trial site, carried *Phytophthora* spp. One reason for conducting the tests was that the sudden plant death described by boronia growers was consistent with the description of plant deaths caused by *Phytophthora* root infection. It can be difficult to isolate *Phytophthora* from root samples. Once roots deteriorate a range of saprophytic or pathogenic fungi attack them. The level of deterioration of roots and secondary infections can hamper isolation, even if selective media are used. Soil-baiting tests allow the isolation of *Phytophthora* from soils via a bait plant. However, finding the fungus, in the soil does not necessarily mean that it is the cause of plant death. To verify the pathogenicity of the fungus boronia plants have to be infected with the baited fungus and develop the same symptoms as affected plants in plantations (Koch's Postulate). These pathogenicity tests have not been conducted, as they exceeded the scope of this study.

Graphs 3 and 4 show that soil from several plantations carried either *Phytophthora* or *Pythium*, either of which could cause sudden plant death, especially of already stressed plants (disease, nutrition) under wet conditions. Graph 3 highlights that fungi were not baited from all soils classified as 'poor' in regards to boronia survival.

Graph 2 shows the results of soil baiting tests after organic amendments had been added to the soil. In these tests, *Phytophthora* and *Pythium* species were not baited after treatment with mustard meal and worm casting. Dynamic Lifter, a mix of chicken manure, blood and bone, seaweed, zeolite and fishmeal that contains a range of amino acids, reduced the incidence of *Phytophthora* root lesions. The amendments were selected using information from biofumigation research (Harding R., personal communication) and reports on the use of organic amendments to suppress *Phytophthora*

[3] **Reference:** Acta Horticulturae 233: Workshop on Replant Problems with Fruit Trees; 103-112

[4]. Organic amendments may have a range of effects on soil-borne plant diseases. They would be strongly related to the type of material, its stage of decomposition and the conditions it is brought into. Amendments could enhance or suppress a disease depending on the pathogen and whether the additional substrate supports specific stages of its life cycle or that of antagonistic microbes under certain conditions.[4]

Trial 3 - Replant Field Trial

In its natural environment, light summer fires every 3-4 years rejuvenate boronia ('ash bed effect'). Spring fires are not effective because young plants die during the dry summer. According to David Ward (Conservation and Land Management Western Australia), the rejuvenating effect is due to smoke /heat fumigation of the soil. Fire also affects soil pH through cations in the ash. Boronia is not found in natural environments with a pH below 5, even if other factors are favourable. The calcium form in ash is CaO, which is slaked to $Ca(OH)_2$ by rain. This form of calcium may have a different effect to agricultural lime or dolomite. Fire effects may also suppress harmful insects for some time.

Being physiologically adapted to poor acid soils, boronia does not thrive in soils with high nitrate and phosphorus levels. As known from other plant species, which rely on mycorrhiza associations, excessive nitrogen and phosphorus levels are detrimental to the symbiotic relationship. Low levels or absence of mycorrhiza increases the plants' susceptibility to fungal attack[5].

The treatment selection for the re-plant trial was aimed at controlling *Phytophthora* (Aliette, Ridomil, Terrazole) or providing a soil environment similar to that of the natural boronia habitat (fire). Treatment 5, which consisted of fertilisers with a neutral or acidifying effect, was selected to provide cations (Ca, Mg & K) similar to ash. Urea was used as a nitrogen source because some reports mention that one of its breakdown products, ammonia (NH_3), may inhibit *Phytophthora*. The fact that nutritional treatments, inter-row planting and soil amelioration with organic matter were successful in replant trials with fruit trees was taken into consideration[6].

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[4] **References**: Erwin D.C. and Ribeiro O.K., 1996: Phytophthora Diseases Worldwide. APS Press, St Paul, Minnesota, ISBN 0-89054-212-0
Erwin D.C., Bartnicki-Garcia and P.H. Tsao (Editors), 1983: Phytophthora, Its Biology, Taxonomy, Ecology, and Pathology. APS Press, St Paul, Minnesota, ISBN0-89054-050-0
[5] **Reference**: Harley, J.L. and Smith, S.E., 1983: Mycorrhizal Symbiosis. Academic Press, London.
[6] **Reference**: Acta Horticulturae 233: Workshop on Replant Problems with Fruit Trees; 103-112

Table 2 shows the soil analysis results for the trial site prior to treatment application, and for the fire treated plots after burning. The fire, which would not have heated the soil to high temperatures, increased all nutrient levels, apart from nitrogen and copper. Organic carbon and pH were slightly elevated. The total cation exchange capacity (CEC) increased but the contribution (%) of each cation to total CEC remained unchanged. From the trial results, it is not possible to say whether the fire effect was mainly nutritional or included smoke sterilisation effects.

Graph 5 gives an indication of plant growth in differently treated plots over a period of approximately one year. During winter 2000, all plants grew, with the Nitrophoska, Ridomil, Terrazole, pine bark and straw treatments increasing their height by about 10%. Alliette, Cation Fertilisers, Pontec (worm casting product) and inter-row planting treatments grew at least 5% in height. By April 2001, only the Terrazole, pine bark, straw and fire treatments showed a height increase compared to the height of plants at planting.

Graph 6 gives a comparison of the percentage of height increase/decrease of final heights (April 2001) in relation to planting height, and the percentage of height increase/decrease of final height in relation to the height at pruning[7]. The graph shows that, after pruning, the following treatments led to plant decline rather than growth: Nitrophoska Perfect, Aliette, Ridomil Granules, straw, 'untreated' and inter-row planting. Plants mulched with pine bark increased their height by about 60% in the four months after pruning. Fire and Pontec treatments achieved an increase of about 20%, Terrazole and cation fertilisers 15% and 18% respectively. When related to initial height, Pontec and cation fertilisers came up with an overall height decline while plant growth was good in these treatments after pruning. In the straw treatment, plants increased in height, when compared to their height at planting, but declined after pruning in November.

Plant growth in Graphs 5 and 6 is expressed as an average over all surviving plants per treatment. Graph 7 shows survival rates. At the first assessment, a maximum of 60% of plants had survived in plots treated with Nitrophoska Perfect, Ridomil Granules, and straw. Aliette, Terrazole and inter-row planting plots retained less than 80% of plants. Plant losses had not changed markedly at the second assessment. Only plots mulched with straw had declined further. However, the last assessment revealed that some plants mulched with straw had been rated dead due to a lack of green foliage at the second assessment, but were actually alive at the third.

Graphs 7 and 8 show that in the pine bark treated plots, nearly all plants survived until the final assessment. However, the survival rate in this treatment was not significantly different to that in plots treated with Aliette, Terrazole, cation fertilisers, Pontec, or fire. Graph 8 also shows that vigour was best in the mulched plots (pine bark and straw) and worst in the plots treated with Nitrophoska. Vigour of all other treatments was not significantly different from the best (pine bark) or worst (Nitrophoska).

Graph 8 allows an overall assessment of treatment effects. Five treatments produced acceptable results with vigour rating of above 2.5, survival above 60% and positive growth rates after pruning. Pine bark mulch gave the best overall results, which may be due to the following factors:

- Good soil moisture retention (the trial site could not be irrigated),
- Even soil temperatures,
- Positive effect of fresh organic material on soil organisms.

Cation fertilisers, Pontec (worm casting product) and fire produced comparable results, probably due to a balanced nutrient supply. Terrazole, which is registered for the control of root and stem rot caused by *Phytophthora* and *Pythium* fungi in ornamentals, produced similar results. Rather than

[7] At 29/11/00 all plants were pruned to a height of 20cm, as per commercial practice.

applying it to the soil, it could be used as a pre-plant dip or drench of transplant trays. However, Terrazole should not be used indiscriminately without confirmation of *Phytophthora* in the soil. If the industry intended to apply for a use permit with the National Registration Authority, further trials to confirm efficacy, crop safety and lack of residues in flowers would have to be conducted. A withholding period for applications prior to harvest may have to be established. Considering these requirements, associated costs and the uncertainty of achieving consistent control with the same fungicide over varying conditions for a number of years[8], it would be preferable to further investigate and develop non-chemical treatments.

A further evaluation of Ridomil granules is not recommended. If the industry wanted to develop chemical solutions, a soil fungicide with activity against *Pythium* and *Phytophthora* called Fongarid could be investigated instead of Ridomil. Comments as made for Terrazole apply.

Alliette has been used to control *P.cinnamomi* in native plants in their natural environment, mainly via stem injections. It controls other *Phytophthora* species, but not *Pythium*. It is a systemic fungicide that is transported both upward and downward in plants, and is taken up by roots. It could be applied to transplants prior to planting at sites with confirmed *Phytophthora* in the soil. If required, Alliette may be applied twice per season e.g. as recommended for apples. It has to be noted that the Alliette registration for ornamentals only covers a soil drench, and a permit would have to be granted by the National Registration Authority (NRA) for other ways of application. It may be worth testing Alliette as an emergency treatment for dying plants, if *Phytophthora* spp. have been isolated from surrounding soil. Alliette did not lead to a height increase in plants, but vigour was good. The fungicide may produce good results when tried in combination with one of the previously discussed non-chemical treatments or when used as a last resort to 'rescue' sick plants. Comments made for Terrazole in regards to efficay, crop safety and residues apply.

The industry standard, Nitrophoska Perfect, produced poor establishment results, which were similar to inter-row planting and the untreated plots. Inter-row planted plots, fungicide treatments, pine bark and straw plots received Nitrophoska at the same rate as the industry standard treatment. However, Nitrophoska did not affect boronia negatively during establishment when used in combination with mulch or fungicides. One explanation could be that the relatively high amount of available nitrogen in Nitrophoska affected root growth and mycorrhiza levels. Mulch could have lessened this effect through temporary N-fixation while it was breaking down.

The replant field trial shows that different treatments at planting affect growth and survival in the first season. When evaluating the treatments, it has to be considered that they were obtained from one site only, over one season. Results indicate that the sole use of Nitrophoska Perfect should be critically assessed in comparison to a nutrition program that is well-balanced and high in cations. Even though pine bark mulch appears to be an expensive and difficult to use option, growers should evaluate possible gains carefully, if the material is obtainable at a reasonable cost in the area. Factors to be considered in the evaluation are:

- Cost of lost plants and associated expenses over the life of the plantation (royalties, planting, fertiliser etc.).
- Saving of herbicides and application costs during the first eighteen months.
- Loss of income from oil production over the life of the plantation.
- Savings in herbicide, fungicide, foliar fertiliser and water costs over the life of the plantation, (i.e. spreading the costs per hectare of the above mentioned items over a plantation with a 100% plant population, compared to one with a 70% population).
- Saving in removal costs of dead plants.

[8] **Reference**: Cohen, Y., Coffey, M.D. 1986: Systemic fungicides and the control of oomycetes. Ann. Rev. Phytopathol 24: 311-338

Mulches should be applied to rows two to four weeks prior to planting at 100-150 cm width. Even though a 10cm thick pine bark mulch was used in this trial, half the rate is also expected to be beneficial compared to 'no mulch'.

Trial 4 - Plantation and Grower Surveys

The field survey was conducted after growers indicated that the longevity of boronia was not as expected, and that several plantations were experiencing decline problems since planting.

It was considered important to investigate whether decline problems were due to site conditions (soil, climate), soil-borne pathogens or other factors. If the reasons for decline were different in each plantation, replanting would have to be handled on a case by case basis rather than using a blanket approach based on results from a field trial. If decline problems were related to management, the management factors that were responsible would have to be identified, to avoid repeating the same practices in a re-established plantation.

The survey results highlighted that boronia thrived on sites that had no previous use for cropping or grazing. Thriving plantations did not have agricultural or pasture weeds. Previous research by one of the authors, on site factors affecting the growth of highbush blueberries, which are a native heathland plant of North America, showed similar results[9]. There, it was shown that agricultural use had changed the composition of organic matter, which affected mycorrhiza levels in roots, root distribution and root colonisation by pathogens.

Nearly all plantations included areas where plants were affected by water-logging (Photograph 9 shows an example). Clone 250 seemed to be especially sensitive. Water-logging causes stress due to a lack of oxygen being available to roots. Fine roots die off, which helps pathogens such as *Pythium* and *Phytophthora* to penetrate the root system.

Most growers mentioned that they planted later than they had initially indicated to the nursery. By the time the plants were used, most root systems were pot bound. This, and probably poor root development of some plants during propagation (Photograph 3), caused plant death from the first year on. Pot bound plants developed poorly anchored or self-strangling root systems, making them prone to harvester and wind damage (Photographs 1, 2 and 3). The poor root distribution also reduced the soil volume available to roots for water and nutrient exploitation, leading to water and nutrient stress. The fact that magnesium and foliar molybdenum applications improved plant appearance suggests that, under certain conditions, uptake of these elements was not sufficient, either due to a low level/imbalance in the root zone or poor uptake conditions (pH, small root system).

In some cases, plant establishment problems were exacerbated by the use of drip irrigation. Lateral water distribution from drippers was not sufficient in the mostly sandy soils, especially for poorly rooted plants. Mini sprinklers produced better results.

Growers observed that poorly growing plants seemed to suffer more severely from rust and scale attack. Generally, stressed plants (e.g. due to water-logging, extreme temperatures or wind), are more prone to pests and diseases. Nutrient imbalances or rapid growth brought on by high nitrogen inputs can also cause stress to plants. Nutrition programs should be re-evaluated with an emphasis on nitrogen source, amounts and timing in relation to plant growth stage (i.e. young plants vs plants in production). Concurrently, a balanced cation and trace element nutrition needs to be

[9] **Reference**: Blaesing, D., 1988: *Vaccinium* following an arable crop, why is it a failure?, Acta Horticulturae 233: Workshop on Replant Problems with Fruit Trees; 103-112

investigated. The use of soil and plant analyses is recommended to develop desirable nutrient levels for optimum yield and oil quality. The aim should be to understand the relationship between the nutrient composition of selected plant parts (e.g. young vegetative growth) prior to flower initiation and flower or oil yield. This would allow growers to correct nutrient imbalances before they affect production.

Plants with swollen or severely deformed crown areas were prevalent in most plantations (Photographs 4 to 6). The swellings were relatively small in the more thrifty plantations. Symptoms shown in photographs 4 and 5 suggest that crown gall (*Agrobacterium tumefaciens*) infection should be investigated and if confirmed, the source of infection identified and eliminated. *Agrobacterium* can only invade plants through injuries, not through intact surfaces. Erosion of bark, caused when boronia plants sway in, or are sandblasted by, strong wind may cause suitable injuries . A layer of mulch would protect plants from both types of damage. The Australian blueberry industry had experienced widespread problems with crown gall introduced and multiplied during in-vitro propagation (Australian Blueberry Growers Association, personal communication).

The swelling in photograph 4 could have been caused by wind, without the involvement of a pathogen. It has been reported that, in forests, the enlarged base or butt swell of trees is at least partly caused by swaying on the wind[10].

The crown deformation shown in photograph 6 was typical for only one plantation. Affected boronia had died over time in a circular pattern. Nematodes were investigated as a possible cause, because of the appearance of roots, and the way the problem had spread through the crop. However, plant parasitic nematodes could not be confirmed at the time of soil testing. Soil and root nematode tests may have to be repeated as some nematodes may not be isolated at certain times of the year, depending on their life cycle.

The crown area of dead or dying plants was often affected by fungal pathogens (Photographs 6 and 7). Unfortunately it was not possible to fully investigate the cause of crown infections and its relationship to plant decline. Some growers suggested that the crown swelling was due to callus formation during propagation. But, as mentioned above, some plantations on virgin land or very extensively used land did not have severely deformed crowns even though crown areas with fungal infections were found. It is important to understand the cause(s) of crown infections and deformation, before replanting. If they are due to soil or management factors these have to be adjusted to avoid recurrence of problems.

The observed fungal crown infections may not necessarily be related to their injury or deformation, but could also be caused by pathogens that have entered through damaged or even healthy roots. A lack of mycorrhiza may make roots more susceptible to invasion by pathogens. It has been reported that nitrogen and phosphorus fertiliser inputs can reduce mycorrhiza levels in roots[11]. In natural environments, mycorrhiza assists plants in P and N uptake and protects against invasion of pathogens. It is possible that pathogens enter crowns through wounds created by machinery or wind damage at any stage of production.

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[10] **Reference**: Kramer,P.J. and Kozlowski, T.T., 1979: Physiology of Woody Plants. Academic Press, London.
[11] **Reference**: Harley, J.L. and Smith, S.E., 1983: Mycorrhizal Symbiosis. Academic Press, London.

Conclusions and Recommendations

The study into the viability and methodology of re-establishing boronia plantations on currently used sites in Tasmania produced the following results and recommendations.

- Boronia plantations in Tasmania do not suffer from classical ‘soil sickness’ problems. This means that, with adequate management, sites can be replanted.
- Replanted sites may experience establishment, growth or early decline problems due to one or a combination of the following factors:
  1. Transplant quality (e.g. pot bound plants),
  2. Mechanical damage to young plants or plants with poor root systems by wind and harvesters.
  3. Soil heath/quality (decline in soil structure or organic matter content, soil borne diseases, e.g. *Phytophthora, Pythium* or nematodes),
  4. Nutrition (nutrient balance, e.g. N / Ca, K & Mg, fertiliser types, amounts & timing),
  5. Pests and diseases of shoots, foliage, crown and roots.

- Several soil treatments and nutritional inputs can improve plant establishment and may improve longevity on replanted sites. These are:
  1. Pine bark mulch (*effects*: no soil temperature extremes, preservation of soil moisture, weed control, improvement of soil organic matter content and microbial activity, wind damage protection for young plants). It is important to use mulch with no added nitrogen during composting.
  2. Controlled burning of old plantation about four weeks prior to replanting creating a ‘cool fire’ (*effects*: smoke sterilisation of top centimetres of soil, provision of nutrients).
  3. Use of a fertiliser mix that is high in cations but does not contain chloride (e.g. sulfate forms of Ca, K, Mg).
  4. Use of ammonium nitrogen rather than nitrate nitrogen.

A survey of existing plantations revealed that some plants are declining faster than expected. This is believed to be due to a combination of site specific, establishment and management factors. It is considered important that growers clearly identify the cause for decline in their plantation to avoid the problem repeating itself when replanting. Possible causes for early decline are:

- Wind stress, causing injury to the crown area when plants swirl and rub against soil or are blasted by sand. The resulting injuries are entry sites for pathogens.
- Pot bound roots due to planting later then the ‘ready date’ given to the nursery.
- Drip irrigation not providing sufficient lateral water distribution in sandy soils to establish plants with a healthy root system.
- Water-logging leading to a lack of oxygen in the root zone and root rots.
- *Phytophthora, Pythium* or other soil-borne fungal diseases attacking weak, stressed plants. The importance of *Phytophthora* and *Pythium* as pathogens of cultivated boronia requires further investigation.

- ♦ Crown deformation possibly caused by wind or harvester damage and subsequent pathogen invasion. The crown gall pathogen *Agrobacterium tumefaciens* should also be investigated as a possible cause of crown deformations in plantations.
- ♦ Imbalanced fertiliser programs. Cation (Ca, K, Mg NH_4) and trace element nutrition need to be better understood and monitored in relation to plant health.
- ♦ Nematodes which may play a role, and need further investigation.

Fungicides that may control *Pythium* and/or *Phytophthora* and other agricultural chemicals must not be used without confirming their efficacy and lack of phytotoxicity and residues in flowers. Appropriate trials would have to be conducted under GLP (Good Laboratory Practice) protocols to obtain use permits from the National Registration Authority (NRA) for the boronia industry.

The industry may benefit from producing a comprehensive boronia management guide and/or introducing a quality management system using HCCP (hazard audit, critical control point) principles.