Management of vegetable diseases with Silicon

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This is a final report for Horticulture Australia Ltd. Project VG06009 'Management of vegetable diseases with silicon'. The project investigated the efficacy of various formulations of potassium silicate for management of disease and improving yields in vegetable crops (peas, beans, corn, broccoli and pumpkin).

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Media summary

There are numerous reports in the scientific literature that application of silicon to some species of plants can, i) improve photosynthesis, ii) enhance resistance to plant diseases and insect pests, iii) alleviate the effects of metal toxicity and nutrient imbalance, iv) alleviate the effects of salt stress, drought stress and temperature stress, and v) prevent lodging. Most of these studies have been undertaken with crops which accumulate silicon at high concentrations (e.g. rice and sugarcane). However, there has been less research on other crops which do not accumulate silicon to the same extent (e.g. many vegetable crops). This project demonstrated that potassium silicate was fungicidal and bactericidal, suppressing growth of several plant pathogenic fungi and bacteria, and suppressing spore germination of at least one fungus. Therefore as a foliar spray, potassium silicate can play a role in disease management through direct biocidal activity, in addition to its published ability to stimulate host resistance responses and strengthen cell walls to provide a physical barrier to infection. While results of three season's field trials were compromised by low disease pressure, foliar application of potassium silicate was observed to significantly increase yield of pea in three of seven trials, with estimated net benefits of $48 to $300/ha. Furthermore potassium silicate provided a marginally statistically significant increase in yield in a further two trials. Foliar application of potassium silicate significantly increased the yield of marketable pumpkin in one trial with a net benefit of $71 to $641/ha. Foliar application of potassium silicate also significantly reduced the resulting number of rotten fruit and severity of fungal rots after seven weeks in cool storage. Foliar application of potassium silicate to carrot crops increased the percentage of marketable carrots, mainly through a reduction in misshapen and split/cracked carrots, resulting in an estimated net benefit of $132-$235/ha. Potassium silicate had no beneficial effects on yield in two bean trials, two broccoli trials or one corn trial. Results support the conclusion that potassium silicate can be a useful treatment for a variety of vegetable crops both directly through its fungicidal action and indirectly through its ability to elicit beneficial physiological responses in plants.

Technical summary

There are numerous reports in the scientific literature that application of silicon to some species of plants can, i) improve photosynthesis, ii) enhance resistance to plant diseases and insect pests, iii) alleviate the effects of metal toxicity and nutrient imbalance, iv) alleviate the effects of salt stress, drought stress and temperature stress, and v) prevent lodging. Many of these reports have been for crops that are grown in weathered soils relatively low in silicon and which take up silicon in large quantities (e.g. rice and sugarcane) or in hydroponic culture (e.g. cucurbits). The effect of potassium silicon on plants which are not known to accumulate high concentrations of silicon and which are grown in soil has been less studied. In terms of reducing plant disease, the beneficial effects of silicon have been attributed to i) the development of a physical barrier to infection through the deposition of amorphous silicon in intracellular spaces, ii) enhancement of the systemic acquired resistance response in plants, and iii) the direct fungicidal effect of soluble silicon on plant pathogens.

This project examined the potential for potassium silicate to decrease disease and improve yield in several vegetable crops. Potassium silicate was found to directly inhibit growth of several plant pathogens *in vitro*. In agar plate tests in which the agar media was amended with different concentrations of potassium silicate, mycelial growth of *Botrytis allii*, *Botrytis cinerea* and *Sclerotinia sclerotiorum* was reduced by 96%, 88% and 100% respectively at 3000 µg SiO_2/ml in comparison to the control (Fig. 1). *Fusarium culmorum* and *Phoma ligulicola* were less sensitive with a maximum reduction in mycelial growth of 64% and 58% respectively in comparison to the control at 5000 µg SiO_2/ml. Potassium silicate was also inhibitory to germination of conidia of *P. ligulicola*, with complete inhibition at 5000 µg SiO_2/ml (Table 1). Two isolates of the bacterium *Xanthomonas campestris* were also inhibited by potassium silicate, with a 96-97% reduction in colony numbers at 5000 µg SiO_2/ml in comparison to the control.

In greenhouse tests, potato plants treated with foliar applications of potassium silicate for control of *Phytophthora infestans* had a significantly (P<0.001) higher percentage of leaves (45.1%) in the low severity class (0-10% of leaf surface affected) in comparison to the non treated (20.1% of leaves).

In seven field trials on pea, disease pressure was very low. In one trial, there was a slight and borderline statistically significant reduction in Ascochyta collar rot (P = 0.08) and downy mildew (P = 0.07) from potassium silicate treatment. In a second trial, there was a highly significant (P < 0.001) reduction pod infection by *Sclerotinia sclerotiorum* from potassium silicate treatment. However, disease incidence was low (< 10%) in this trial. Despite the low disease pressure in the pea trials, potassium silicate treatment gave a statistically significant (P < 0.05) increase in yield of pea in 3 of the 7 trials, equating to an increase of 29.3%, 21.7%-26.7%, and 8.5-11.6% in each trial respectively and estimated net benefits of between $48 to $300 per hectare. The increase in yield resulting from potassium silicate treatment in one trial appeared to have arisen from an increase in pods/plant, although the statistical significance was borderline (P = 0.07). In another, the increase in yield due to silicate treatment was associated with a statistically significant reduction in the percentage of small (< 5 mm) peas, and an increase in medium sized (5-7 mm) (P < 0.001). In a further two trials, potassium silicate gave a statistically borderline increase in yield (P < 0.10), equating to an increase of 24.8% and 15.0% respectively. In one of these trials, this increase appeared to be associated with an increase in pods/plant with potassium silicate treatment (P < 0.10). In a further two of the seven pea trials, potassium silicate treatment gave no statistically significant increase in yield, although there was a slight increase in pods/plant from potassium silicate treatment (P = 0.05) and a slight and statistically borderline increase in the number of nodes per plant with pods (P = 0.09) and number of nodes per plant with more than one pod (P = 0.06) in one of these trials.

In one field trial with pumpkin, marketable yield of pumpkin was significantly (P < 0.05) increased (7.3 to 19.2%) through foliar applications of potassium silicate with an estimated net benefit of $71 to $641/ha. Significantly ($P$ =

0.02) fewer pumpkins treated with AgSil 27™ developed fungal rots (*Sclerotinia sclerotiorum*, *Penicillium* sp., *Fusarium* sp.) after storage for 7 weeks at 10^{o}C, in comparison to the non treated, i.e. 13.3% and 41.4% respectively.

In one field trial with carrot, the percentage of marketable carrot was significantly (*P* = 0.001) increased by 5.0 to 5.9% by foliar applications of potassium silicate. The number and weight of misshapen carrots and carrots exhibiting splitting/cracking was significantly reduced. The estimated net benefit from potassium silicate due to increasing the percentage of marketable carrots was estimated at $132 to $235/ha.

Results from this project confirm the direct fungicidal and bactericidal nature of potassium silicate, in addition to its published ability to promote a systemic acquired resistance response in some plant species. Furthermore, evidence is provided that potassium silicate can increase yield of pea, increase marketable yield of pumpkin and suppress storage rots, and increase the percentage pack out of carrot crops through a reduction in carrot splitting/cracking and misshapen carrots.

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1. Introduction

Silicon (Si) is not considered an essential element for plant growth and development (Epstein 1994). However it has been shown to enhance the growth, development and yield of several plant species including rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), cereals and several dicotyledons (Belanger *et al*. 1995, Savant *et al.* 1997, Savant *et al.* 1999). The following introduction is a summary of some of the documented benefits of silicon to plants. For a fuller review, the reader is referred to the book of Datnoff *et al*. (2001a) which provides a comprehensive review of the literature.

Silicon is the second most abundant element in the earth's crust after oxygen (Epstein 1994). However, some highly weathered soils such as Oxisols, Ultisols and highly organic Histosols may contain little Si, and soils comprised mainly of quartz sand (SiO_2) may also be very low in plant available Si (Datnoff *et al*. 2001b). In other soils, repeated cropping can reduce the levels of plant available Si to the point that supplemental additions are necessary (Datnoff *et al*. 2001b).

Silicon is taken up by plants in the form silicic acid. Plant species can be divided into three general categories depending upon their SiO_2 content; wetland *Gramineae* such as wetland rice (10-15% of shoot dry weight), dryland *Gramineae*, such as sugarcane and most cereal crops (1-3%) and legumes and most dicotyledons (<0.5%). Although Si content is generally higher in monocots, dicots in the Urticaceae and Cucurbitaceae may also accumulate silicon.

Silicon has been demonstrated to protect plants from various abiotic stresses, for example, i) alleviating metal toxicity (Al, Cd, As, Mn, Fe), ii) improving nutrient imbalances, (e.g. N excess or P deficiency), iii) alleviating salt stress, iv) increasing tissue mechanical strength and preventing lodging in crops, v) increased resistance to low and high temperatures, vi) increased resistance to drought stress and vii) resistance to radiation stress (Epstein 1999, Ma and Yamaji 2006).

Silicon has also been demonstrated to protect plants from biotic stresses including insect pests and plant pathogenic fungi and bacteria. The ability of silicon to reduce plant diseases has been attributed to i) the development of a physical barrier to infection through the deposition of amorphous silicon in intracellular spaces (e.g. Carver *et al*. 1987) ii) enhancement of host resistance response in plants (e.g. Dann and Muir 2002, Fateux *et al*. 2005), and iii) the direct fungicidal effect of soluble silicon on plant pathogens (Bekker *et al*. 2006a, Bekker *et al.* 2006 b).

Silicon amendments are now used widely in the production of sugarcane and rice around the world, and in the horticultural greenhouse crops (Belanger *et al*. 1995), but are less used in field crops.

A formulation of potassium silicate, SilMatrix (PQ Corporation), has recently been registered in the USA for use on '*vegetables, fruits, nuts, vine crops, field crops, ornamentals and turf for control of fungal diseases, and suppression of spider mites, whiteflies and other insects*'. Several products which contain silicon are now commercially available in Australia, including AgSil (PQ Corporation), Maxsil (Advanced Plant Nutrition), and Stand SKH (Agrichem).

Research with silicon has tended to concentrate on crop species which take up silicon in larger quantities (e.g. rice and sugarcane), or crops grown in hydroponic culture (e.g. Belanger *et al*. 1995). For these crops the benefits of silicon are well established. There has been less research to assess the effect of silicon when applied to vegetable crops which do not accumulate high concentrations of silicon, especially when grown in soil in which there is a source of silicon. However, the recent finding of the direct fungicidal nature of silicon (Bekker *et al* 2006 a,b) and of the ability of silicon to elicit a host resistance response to plant pathogenic fungi even in plants such as pea which are not regarded as high accumulators of silicon (Dann and Muir 2002) suggest that silicon may be effective at controlling plant pathogens in various vegetable crops.

This project aimed to assess the beneficial effects of silicon on field-grown horticultural crops and on a wider range of plant pathogens than studied previously.

2. Fungicidal and bactericidal activity of potassium silicate.

The benefits of silicon in improving plant resistance to plant pathogens have been attributed to i) the development of a physical barrier to infection through the deposition of amorphous silicon in intracellular spaces (e.g. Carver et al. 1987) and ii) enhancement of host resistance response in plants (e.g. Dann and Muir 2002, Fateux *et al*. 2005). However, recently there have been several reports (Kaiser *et al*. 2005, Bekker *et al*. 2006a, Bekker *et al.* 2006b) on the direct fungicidal effect of soluble silicon on a range of plant pathogens. This suggests that silicon may have beneficial effects even on those plant species which do not take up silicon in large quantities, e.g many vegetable crops.

2.1 Materials and methods

Potato dextrose agar (PDA) was autoclaved and maintained in a water bath at 60°C. Aliquots of AgSil 27™ (26.7% SiO_2, 13.3% K_2O) were added to autoclaved PDA to produce 0, 2000, 3000, 4000 and 5000 ug SiO_2/ml and poured into 9 cm diameter Petri dishes. For fungal pathogens, a cork boring (5 mm diameter) was taken from the edge of an actively growing colony on PDA and placed in the centre of the amended media. Three replicate plates of each concentration were inoculated for each pathogen. Plates were taped shut with cling film and placed in an incubator at 20°C. Plates were checked periodically for up to two weeks and assessed for colony radius when colonies on control plates had grown near the edge of the petri plate. For bacterial pathogens a loop of bacterial cells was removed from colonies growing on yeast-dextrose-carbonate agar and placed in 10 ml sterile water. A 100 µl aliquot was pipetted onto the surface of amended PDA and distributed over the surface with a bent glass rod. For each bacterial isolate there were three replicate plates of each Si concentration. Plates were taped shut and maintained at 20°C. The number of colonies per plate was assessed at two weeks.

A further trial was conducted to examine the effect of potassium silicate on germination of conidia of *Phoma ligulicola*. *P. ligulicola* was grown on V8 agar under fluorescent light at 20°C until formation of abundant pycnidia. A 1 cm^2 section from a colony of *P. ligulicola* on PDA was removed and placed in 10 ml sterile water and shaken to release spores. The spore concentration was measured by haemocytometer and adjusted to 500,000 conidia/ml Amended media was prepared as above except water agar was used in place of PDA and the concentrations were used were 0, 625, 1250, 2500 and 5000 µg SiO_2/ml. A 100 µl aliquot of conidial suspension was pipetted into the centre of each plate and spread over the surface with a bent glass rod. As before, there were three replicate plates of each concentration for each isolate. Plates were dried of surface water for 30 minutes in a laminar flow cabinet taped and incubated overnight at 20°C. After 24 hours a 2 cm^2 block of agar was removed from each plate, mounted on a slide and examined under a compound microscope. A total of 100 conidia were observed for germination on each plate, with a conidium considered germinated if its germ tube was over half the length of the conidium. Data was analysed by ANOVA using the statistical software package Genstat V9.1 and means separated by least significant difference (LSD) (P=0.05).

2.2 Results

Potassium silicate significantly reduced growth of all fungal pathogens in comparison to the control at 2000-3000 µg SiO_2/ml (Fig. 1). However, there were marked differences in the sensitivity of fungal species. *B. allii*, *B. cinerea* and *S. sclerotiorum* were particularly sensitive with 96%, 88% and 100% reduction in mycelial growth in comparison to the control at 3000 µg SiO_2/ml (Fig. 1). *F. culmorum* and *P. ligulicola* were less sensitive with a maximum reduction in mycelial growth of 64% and 58% respectively in comparison to the control at 5000 µg Si/ml (Fig. 1). Potassium silicate was also inhibitory to germination of conidia of *P. ligulicola*, with complete inhibition at 5000 µg SiO_2/ml (Table 1).

The two isolates of *Xanthomonas* were also inhibited by Si, with a 96-97% reduction in colony numbers at 5000 µg SiO_2/ml in comparison to the control (Fig. 2).

Figure 1. Effect of different concentrations of potassium silicate (µg SiO_2/ml) on colony radius (mm) of fungal plant pathogens. (Bars are $LSD_{0.05}$).

Fig. 1a *Botrytis allii* (*P*<0.001

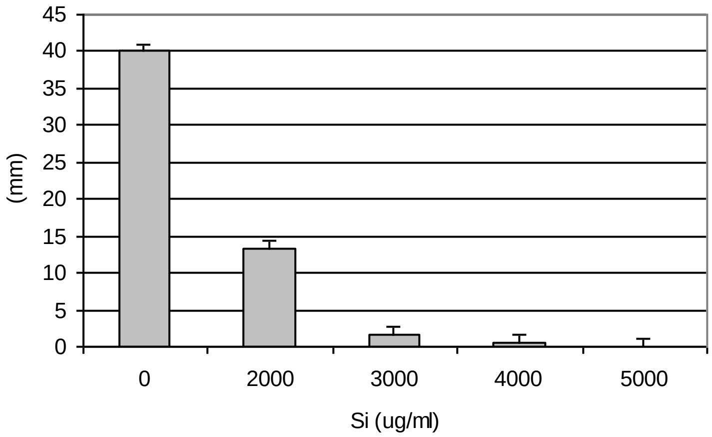


Fig. 1b *Botrytis cinerea* (*P*<0.001)

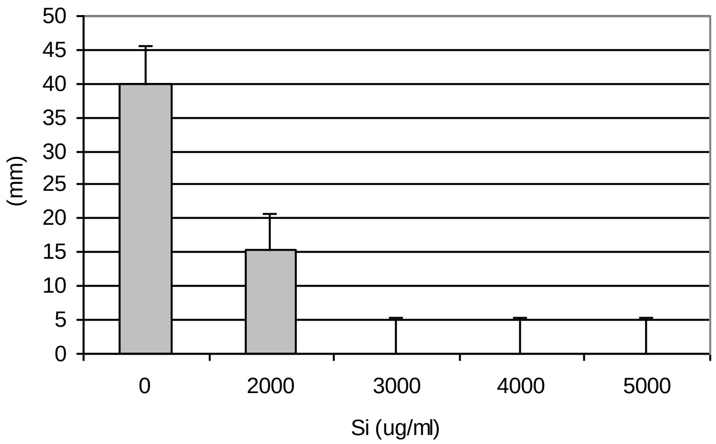


Fig. 1c *Sclerotinia sclerotiorum* (*P*<0.001)

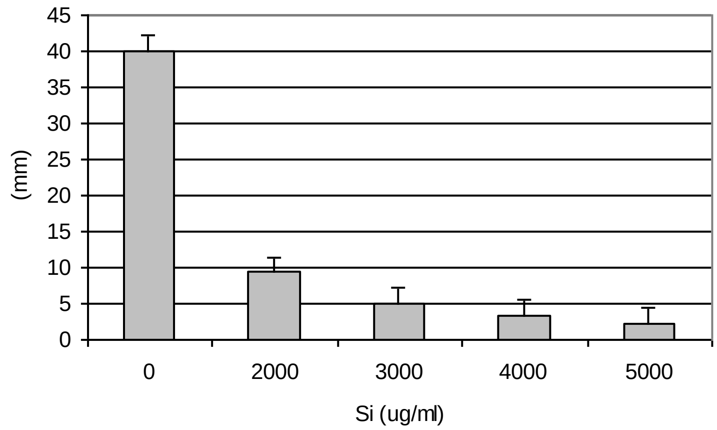


Fig. 1d *Fusarium culmorum* (*P*<0.001)

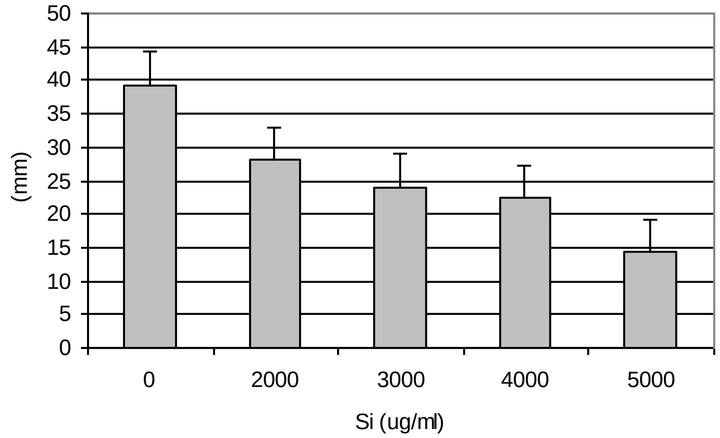


Fig. 1e *Phoma ligulicola* (*P*<0.001)

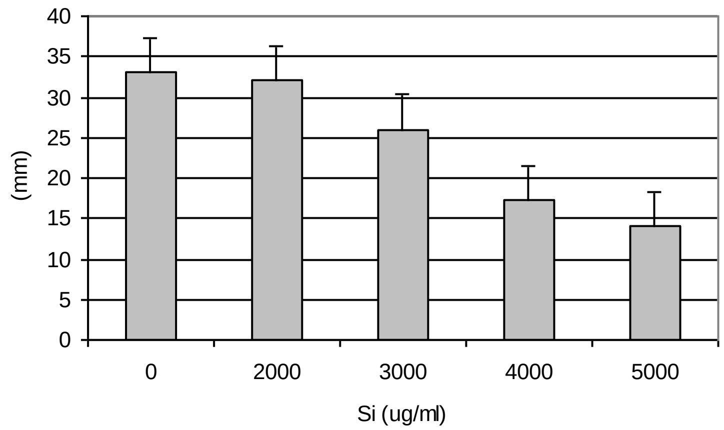


Table 1. Percentage germination of conidia of *Phoma ligulicola* on water agar plates amended with different rates of potassium silicate (P<0.001, $LSD_{0.05}$=1.24).

µg SiO_2/ml	0	625	1250	2500	5000
Germination (%)	100	100	100	96.7	0.0

Figure 2. Effect of amending media with different concentrations of potassium silicate (µg SiO_2/ml) on number of bacterial colonies per Petri plate. (Bars are $LSD_{0.05}$)

Fig. 2a *Xanthomonas campestris* DAR (P<0.001)

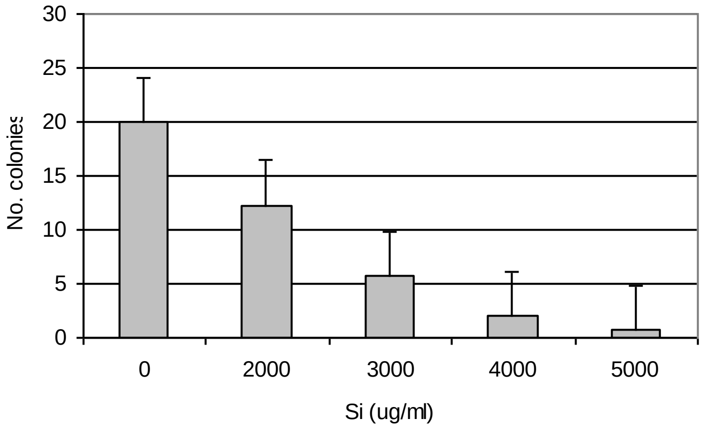
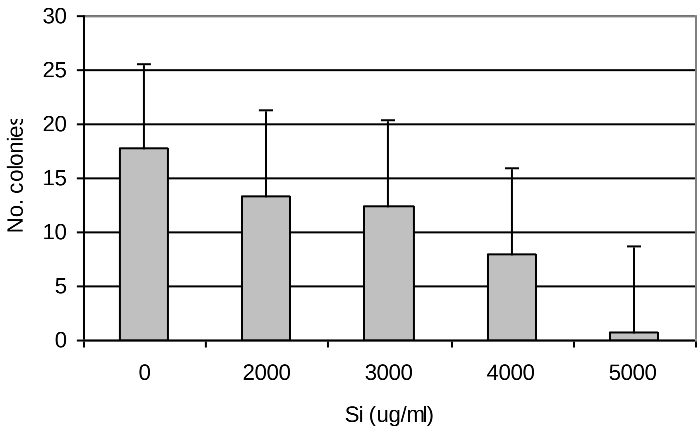


Fig. 2b *Xanthomonas* sp. BVN3 (P=0.009)



2.3 Discussion

In laboratory experiments Kaiser *et al*. (2005) demonstrated that potassium silicate caused complete inhibition of mycelial growth of *Colletotrichum coccodes, Sclerotinia sclerotiorum, Sclerotium rolfsii* and *Phytophthora capsici* at 1000 µg/ml, *Pythium* sp. at 2100 µg/ml, and *Alternaria solani, Curvularia lunata, Stemphylium herbarum, Fusarium oxysporum, Fusarium solani, Verticillium fungicola*, and *Phytophthora capsici* at 4000 µg/ml. Similarly Bekker *et al*. (2006) demonstrated inhibition of several fungal pathogens of avocado *in vitro*, including *Phytophthora cinnamomi*, *Phomopsis perniciosa* and *Pestalotiopsis maculans*. The inhibitory response of fungi was shown to be greater than simply a pH effect due to the alkalinity of silicon formulations, and suggested silicon to be fungicidal in nature. Our results confirmed that potassium silicate was fungicidal, inhibiting mycelial growth *in vitro*. However, fungal species varied in their sensitivity to silicon, similar to the results of Kaiser *et al*. (2005) and Bekker *et al*. (2006a). Furthermore our results demonstrated that potassium silicate was able to completely inhibit spore germination of at least one fungal pathogen, suggesting that potassium silicate may act in a manner similar to a protectant fungicide. Our results also demonstrated that potassium silicate had direct inhibitory effect against plant pathogenic bacteria, for which there are few current management options in vegetable and fruit crops.

3. Greenhouse trial

Although not considered under the vegetable levy, potato was used as a model system to determine the effect of potassium silicate against other potential pathogens of vegetables (e.g. *Alternaria* and *Phytophthora*).

3.1 Materials and methods

Two tubers (cv. 'Russet Burbank') were planted per 20 cm pot in potting mix on 5 October 2006 and maintained in a greenhouse at 16-22/8-12^{o}C day/night temperatures. Treatments were non treated, AgSil 27™ (26.7% potassium silicate), with 25 replicate pots per treatment. Treatments were applied with a Solo hand pump sprayer at 10 ml/L to the point of run-off on 26 November 2006 and again on 19 December 2006 when plants were approximately 20 cm and 30 cm tall respectively. Plants were fertilised with Thrive (8 g/4.5L) on 20 December 2006 and 11 January 2007 and treated with pyrethroid insecticide for aphid control. Symptoms of late blight were evident on 19 December 2006 and were assessed on 11 January 2007 using the key of Cruikshank *et al*. (1982). Stems of potato plants were allocated to categories of severity of 71-100%, 41-70%, 11-40%, or 0-10% defoliation due to late blight and results subjected to Chi squared analysis using the statistical software Genstat V. 9.1.

3.2 Results

Despite a protracted time period between the last application of AgSil 27™ (19 December 2006) and disease assessment (11 January 2007), AgSil 27™ treated plants had significantly more stems in the lower disease severity categories than the non treated (Table 2). This suggested that the activity of AgSil 27™ was through enhanced resistance of the plants to late blight, rather than a direct fungicidal effect. Given that potassium silicate is also fungicidal to *Phytophthora* spp., more regular applications may have improved the result. However, the experiment indicated that AgSil 27™ treatment could reduce the severity of late blight disease caused by *Phytophthora infestans*.

Table 2. Effect of treatment with potassium silicate on the number (percentage) of stems in different late blight disease severity categories.

	Amount of necrotic tissue (%)				Total stems
Treatment	0-10%	11-40%	41-70%	71-100%	
Non treated	24 (20.1)	22 (18.5)	14 (11.8)	59 (49.6)	119
AgSil 27™	55 (45.1)	21 (17.2)	6 (4.9)	37 (30.3)	122

χ^2 (calculated) between non treated and AgSil = 19.0 (P<0.0001)

3.3 Discussion

Treatment with potassium silicate was able to significantly reduce the severity of late blight of potato in comparison to a non treated control. However, a proportion of leaves were still severely affected, suggesting that more regular applications would be required to achieve a higher level of control.

4. Field trials

Several field trials were conducted over three seasons to assess the effect of potassium silicate on yield and disease of pea, bean, corn, broccoli, carrot and pumpkin. All trials were conducted at the TIAR Vegetable Research Facility at Forth, Tasmania on a Krasnozem soil type.

4.1 Pea

A total of seven field trials were conducted over three seasons to determine the effect of applications of potassium silicate on disease incidence and severity and yield and quality of processing pea.

4.1.1 Method

Irrigation was applied to all trials by solid set sprinklers as required. All soil analyses were conducted by CSBP laboratories (Bibra Lake, Western Australia). Specific aspects of each trial are documented below.

Pea field trial 1 (2006/2007)

The trial site was previously in pasture (2005/2006) and carrots (2004/2005) and prior to sowing, the site had a pH of 7.0 and phosphorus and potassium concentration of 68 ppm and 184 ppm respectively. Triple superphosphate fertiliser was predrilled at 118 kg/ha prior to sowing.

The trial was conducted as a factorial experiment with three pea cultivars (‘Ashton’, ‘Hagley’ and the industry standard ‘Small Sieve Freezer’) and two silicate treatments (non treated or treated with five foliar applications of AgSil 27™ over the season). For each cultivar by treatment combination there were 5 replicate plots, each 5 m long by 8 rows wide (6 m^2).

Peas were sown at a density of 120 seeds/m^2 with an Oyjord drill (8 rows wide by 150 mm row spacing) on 21 July 2006. Weed control included a pre-emergent application of Stomp™ (330 g/L pendimethalin, 578 g/L hydrocarbon) at 2 L/ha and Spray.Seed™ (135 g/L paraquat, 115 g/L diquat) at 2L/ha, and a post-emergent application of Basagran™ (480 g/L bentazone) at 2 L/ha. Plant counts were conducted 3 weeks after emergence

AgSil 27™ (26.7% SiO_2, 13.3% K_2O) was applied on 3 October 2006, 17 October 2006, 30 October 2006, 16 November 2006 and 29 November 2006. AgSil 27™ was mixed with water at 10 ml/L and was applied with a motorised Solo™ knapsack sprayer fitted with a 1.6 m boom and hollow cone nozzles, delivering an equivalent volume of 300 L/ha.

Plots were harvested on 4 December 2006. Pea yield was determined by harvesting a subplot of 1.2 m^2, consisting of 8 rows of peas (1.2 m) by 1 m long. Peas were graded for size (<5 mm, 5-7 mm, >7 mm) and weighed. The weight of pods per unit area harvested was converted to an estimated yield/ha. Three sub samples were taken for maturity index, based on pressure plate apparatus. A further 10 plants in each plot were assessed for morphological characteristics, including vine length, number of nodes to first flower, number of productive nodes and number of nodes with 2, 3 or more pods. The number of peas in five pods from each plant was counted to determine the mean number of peas per pod. Pods were assessed for the presence or absence of *Sclerotinia sclerotiorum*. The 10 pea plants were also assessed for the presence/absence of downy mildew, powdery mildew and Ascochyta on a 0 to 3 scale, where 0 = no sign of infection, 1 = symptoms on stems, 2 = symptoms on stems and leaves, 3 = symptoms on stems, leaves and pods.

The trial was analysed by ANOVA as a factorial (cultivar by potassium silicate treatment) using the statistical software package Genstat V. 9.1 (VSN International Ltd.). Note significant cultivar effects are not presented and the interaction between cultivar and treatment was not significant.

Pea field trial 2 (2006/2007)

The trial site was previously in peas (2005/2006) and pasture (2004/2005) and prior to sowing the soil had a pH of 5.7 and phosphorus and potassium concentration of 73 ppm and 486 ppm respectively. The site was chosen due to the high incidence of Ascochyta in peas the previous season. Triple superphosphate fertiliser was predrilled at 118 kg/ha prior to sowing.

The trial was a completely randomised design with two treatments, either non treated or treated with 5 foliar applications of AgSil 27™ over the season, with 6 replicate plots of each. Each plot was 5 m long by 8 rows wide (6 m^2).

Pea cultivar 'Small Sieve Freezer' was sown with a Oyjord drill on 9/8/2006 (as described above). Weed control included a pre-emergent application of Stomp™ (2 L/ha) and Sprayseed™ (2L/ha) as described for trial 1, and a post-emergent application of Sencor™ (480 g/L metribuzin) at 0.435 L/ha. Plant counts were conducted 3 weeks after emergence.

AgSil 27™ was applied on the same dates and with the same methodology as described for pea trial 1 (above). The trial was harvested on 7 December 2006 and assessed as for trial 1 (above). The trial was analysed as a completely randomised design by ANOVA using the statistical software package Genstat V. 9.1.

Pea field trial 3 (2006/2007).

The trial site was previously in pasture (2005/2006) and carrot (2004/2005) and prior to sowing the soil had a pH 7.0 and phosphorus and potassium concentration of 68 ppm and 184 ppm respectively. Triple superphosphate fertiliser was predrilled at 118 kg/ha prior to sowing.

The trial was a completely randomised design with two silicate treatments (non treated or treated with five foliar applications of AgSil 27™ over the season). There were three replicate plots per treatment, each 5 m x 8 rows (6 m^2). Weed control included a pre-emergent application of Stomp™ (2 L/ha) and Spray.Seed™ (2L/ha), and a post-emergent application of Basagran™ (2 L/ha) as described for trial 1. Plant counts were conducted 3 weeks after emergence. AgSil 27™ was applied on the same dates and with the same methodology as described for pea trial 1 (above).

The trial was harvested on 12 December 2006 from subplots 8 rows wide (1.2 m) by 1 m long (1.2 m^2). Peas were harvested and assessed as for trial 1 (above). The trial was analysed as a completely randomised design by ANOVA using the statistical software package Genstat V. 9.1.

Pea field trials 4 and 5 (2007/2008)

The trial site was previously cropped with pasture (2006/2007) and carrot (2005/2006). Prior to planting, soil analysis by CSBP Laboratories was: nitrate-N (9 mg/kg), ammonium-N (3 mg/kg), phosphorus (75 mg/kg), potassium (74 mg/kg), sulphur (8.6 mg/kg), boron (0.7 mg/kg), chloride (6 mg/kg), silicon (11.9 mg/kg), iron (4120 mg/kg), organic-C (3.1%), conductivity (0.06 dS/m), pH $CaCl_2$ (6.5), pH H_2O (7.3), Cu DTPA (1.28 mg/kg), Zn DTPA (0.39 mg/kg), Mn DTPA (21.59 mg/kg), Fe DTPA (13.91 mg/kg), exchangeable Ca (17.03 meq/100g), Mg (6.19 meq/100g), Na (0.23 meq/100g), K (0.22 meq/100g).

The trials were arranged as in a completely randomised design with three treatments i) non treated, ii) basal application of potassium silicate or iii) foliar applications of potassium silicate during the season. There were six replicate plots per treatment, each 10 x 2 m in size. Basal treatments in trial 4 received 0.5 kg AgSil 25A™ (71% SiO_2) per 20 m^2 plot, to give an equivalent rate of 250 kg product/ha (177.5 kg SiO_2 /ha). For each plot the required amount of powder was mixed with 10 L of water and applied with a watering can to the surface. Foliar applications were of 20 mL/L AgSil 27™ liquid potassium silicate applied on 26 September 2007, 9 October 2007, 24 October 2007, 8 November 2007, 21 November 2007 when peas were 9 cm, 11 cm, 13 cm in height, at flowering or at pod filling respectively. Basal treatments for trial 5 received 2.5 L of AgSil 27™ (26.7% Si) per plot (20 m^2) to give an equivalent rate of 1250 L product/ha (333.8 kg Si/ha). AgSil 27™ was diluted to 10 L with water and applied with a watering can over the surface of plots. Foliar applications were of 20 ml/L AgSil 27™, applied at 300 L/ha on 21 November 2007, 5 December 2007 and 21 December 2007. In both trials foliar application was with a Solo backpack sprayer as described for pea trial 1 (above).

Prior to sowing both trials, ground was cultivated and the basal treatment applied (above). Triple superphosphate fertiliser (155 kg/ha) was spread and incorporated with a roterra. Pea seed (cv. 'Small Sieve Freezer') was drilled with an Oyjord drill at 100 plants/m^2 on 6 August 2007 (trial 4) and 15 October 2007 (trial 5),

For trial 4, weeds were controlled by hand weeding as required and Stomp™ (2L/ha) and Basagran™ (2L/ha) with wetter (100 mL/100L) as described for trial 1 were applied on 20 August 2007 and 12 September 2007 respectively. For trial 5, weeds were controlled by hand weeding and with Stomp™ (2 L/ha) on 24 October 2007 and Bladex™ (900 g/kg cyanazine) at 1 kg/ha and Lexone™ (750 g/kg metribuzin) at 0.100 kg/ha on 8 November 2007.

Plant counts were conducted at 3 weeks after emergence in 1 m sections of each of two rows per plot (0.3 m^2). Plots were harvested on 7 December 2007 and 4 January 2008 for trials 4 and 5 respectively. Within each plot a subplot consisting of 8 rows wide (1.2 m) x 2.1 m long (2.52 m^2) was harvested and graded for size as described for trial 1. Morphological characteristics and disease was assessed on 10 plants per plot as described for trial 1 (above). Trials were analysed by ANOVA using the statistical software package Genstat V. 9.1.

Pea trials 6 and 7 (2008/2009)

The trial area had been previously in pasture (2007/2008) and carrots (2005/2006). The trial area was broadcast with 114 kg/ha triple superphosphate and incorporated with a roterra at the final working. Seed (cv. 'Small Sieve Freezer') was sown with an Oyjord drill into plots 2 m by 10 m long on 26 Aug 2008 (trial 6) and 13 October 2008 (trial 7). The trials were arranged in a completely randomised design with three treatments (i) control, (ii) AgSil 27™ and (iii) Stand SKH™ (20% silica, 15% potassium, 1% humic acids). AgSil 27™ and Stand SKH™ were applied at 20 mL/L as described for trial 1. For each treatment there were 6 replicate plots (ea. 20 m^2) For trial 6, AgSil 27™ and Stand SKH™ were applied on 8 October, 21 October, 6 November (flowering), 21 November (pod formation) and 4 December (pod filling). For trial 7, AgSil 27™ and Stand SKH™ were applied on 6 November, 21 November, 4 December (flowering) and 17 December 2008 (pod formation).

Plant counts were conducted on 1 m length of each of 2 rows in each replicate plot (0.3 m^2) at 3 weeks after emergence. Peas were harvested from one subplot (5.04 m^2), consisting of 16 rows of peas (2.1 m) by 2.4 m long, within each plot on 23 December 2008 (trial 6) and 16 January 2009 (trial 7) and graded for size, as described for trial 1. A further 5 plants in each plot were assessed for morphological characteristics and disease as described for trial 1. A further 10 plants in each plot were assessed for severity of Ascochyta and powdery mildew on pods. Pods were stripped from 10 plants and 50 pods assessed for disease severity by comparison to the disease severity diagram of Falloon *et al*. (1995).

4.1.2 Results

Yield response of pea to potassium silicate treatments

Five of the seven pea trials gave some indication of a yield response to potassium silicate treatment. In three trials (trials 2, 5 and 6) potassium silicate treatment gave a statistically significant ($P < 0.05$) increase in yield (Tables 4, 7 and 8). This equated to an increase of 29.3% (trial 2), 21.7%-26.7% (trial 5) and 8.5-11.6% (trial 6) In trial 2, the increase in yield resulting from potassium silicate treatment appeared to have arisen from an increase in pods/plant (Table 4), although the statistical significance was borderline (P = 0.07). In trial 5, the increase in yield due to potassium silicate treatment was associated with a statistically significant ($P < 0.001$) reduction in the percentage of small (< 5 mm) peas, and an increase in medium sized (5-7 mm) (Table 7).

In a further two trials (trials 3 and 4), potassium silicate treatment resulted in a statistically borderline increase in yield ($P < 0.10$), equating to an increase of 24.8% (trial 3) and 15.0% for the foliar treatment (trial 4) (Tables 5 and 6). In trial 3, this increase appeared to be associated with an increase in pods/plant with potassium silicate treatment (Table 5), but again the statistical significance was borderline ($P = 0.10$).

In two of the seven pea trials (trials 1 and 7), potassium silicate treatment gave no statistically significant increase in yield (Tables 4 and 9). However, there was a slight increase in the number of pods per plant from silicate treatment ($P = 0.05$) in trial 1 and a slight and statistically borderline increase in the number of nodes per plant with pods ($P = 0.09$) and number of nodes per plant with more than one pod ($P = 0.06$) (Table 4).

Effect of potassium silicate treatment on disease

Disease pressure was very low in all seven pea trials. In trial 2, there was a very slight and borderline statistically significant reduction in severity of

Ascochyta collar rot (*P* = 0.08) and downy mildew (*P* = 0.07) from potassium silicate treatment (Table 4). In trial 4, there was a significant (*P* < 0.001) reduction in *Sclerotinia sclerotiorum* on pods from potassium silicate treatment (Table 6). However, disease incidence was low (< 10%) in this trial.

Soil analyses after harvest

After harvest, soil analyses were conducted after harvest for trials 4, 5 and 7. In trial 4 in the non treated, base treatment of potassium silicate and foliar treatment of potassium silicate, levels of potassium were 111.0, 167.7 and 142.7 mg/kg respectively, levels of silicon were 16.7, 16.0 and 14.8 mg/kg respectively and pH (H_2O) was 7.2, 7.5 and 7.6 respectively. For the non treated, base treatment of potassium silicate and foliar treatment in trial 5, levels of potassium were 94, 217, 102 mg/kg respectively, levels of silicon were 17.1, 23.7 and 17.3 mg/kg respectively and pH (H_2O) was 7.1, 7.2 and 7.2 respectively. For the non treated, foliar treatment with AgSil 27™ and foliar treatment with Stand SKH™ in trial 7, levels of potassium were 201, 214 and 220 mg/kg respectively, levels of silicon were 22.5, 23.4 and 23.0 mg/kg respectively and pH (H_2O) was 7.3, 7.0 and 7.2 respectively.

Cost benefit of potassium silicate

A cost benefit analysis was conducted for those trials in which potassium silicate gave a significant (*P*<0.05) or marginally significant (*P*<0.1) yield response (Table 10). The cost of all potassium silicate treatments was estimated at $8.13/L which was the current pricing for Stand SKH (Youssef Fares pers. comm.). The cost of spray application was based on a contract rate of $41/ha and the grower's return on peas estimated at 0.40 c/kg. In the three field trials where statistically significant differences in yield were noted, the net benefit of potassium silicate application was estimated at $48/ha (trial 2), $147/ha (trial 5) and $104-$300/ha (trial 6) (Table 10). For the two trials with marginally statistical differences in yield the estimated net benefit was $616/ha (trial 3) and $362/ha (trial 4) (Table 10).

Table 3. Effect of foliar applications of potassium silicate on pea yield, quality and morphological characteristics averaged across cultivar (Pea field trial 1 2006/2007).

	Non treated	AgSil 27™	*P*=	LSD
Plant density (/m^2)	114.6	115.6	ns[3]	-
Maturity index	184	196	ns	-
Estimated yield (kg/ha)	14,933	15,932	ns	-
Peas < 5 mm (% by weight)	17.4	17.6	ns	-
Peas 5-7 mm (% by weight)	55.0	55.2	ns	-
Peas >7 mm (% by weight)	27.6	27.2	ns	-
No. pods per plant	6.6	7.6	0.05	0.99
No. peas/pod	6.8	6.8	ns	-
Vine length (mm)	776	835	ns	-
No. nodes to first flower	11.5	11.8	ns	-
No. nodes with pods/plant	3.7	4.0	0.09	-
No. nodes with doubles[1]	2.6	3.0	0.06	-
Ascochyta collar rot[2]	1.6	1.5	ns	-

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

Table 4. Effect of foliar applications of potassium silicate on pea yield, quality and morphological characteristics (Pea field trial 2, 2006/2007).

	Non treated	AgSil 27™	*P*=	LSD
Plant density (/m^2)	121.9	123.9	ns	-
Maturity index	111.3	115.1	ns	-
Estimated yield (kg/ha)	3196	4132	0.008	631.7
No. pods/plant	5.3	5.8	0.07	-
No. peas/pod	6.0	5.9	ns	-
No. nodes to first flower	13.0	13.1	ns	-
No. nodes with pods/plant	3.8	4.2	ns	-
No. nodes with doubles[1]	1.42	1.68	ns	-
Vine length (mm)	810	876	ns	-
Ascochyta collar rot[2]	2.02	1.92	0.08	-
Downy mildew[2]	0.22	0	0.07	-

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

Table 5. Effect of foliar applications of potassium silicate on yield, quality and morphological characteristics (Pea field trial 3, 2006/2007).

	Non treated	AgSil27™	*P*=
Plant density (/m^2)	103	103	ns[3]
Maturity index	163.4	171.3	ns
Estimated yield (kg/ha)	10,778	13,453	0.10
Peas <5 mm (g)	238	142	ns
Peas 5-7 mm (g)	371	389	ns
Peas > 7 mm (g)	379	476	ns
No. pods/plant	5.5	6.5	0.10
No. peas/pod	5.6	5.8	ns
No. nodes to first flower	13.9	13.3	ns
No. nodes with pods/plant	3.4	3.8	ns
No. nodes with doubles[1]	2.5	2.9	ns
Vine length (mm)	930	869	ns
Ascochyta collar rot[2]	2.3	2.1	ns

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

Table 6. Effect of basal or foliar treatment with potassium silicate on pea yield, quality and morphological characteristics (Trial 4, 2007/2008)

	Control	Basal application	Foliar application	***P*=**
Plants per m^2	125.8	129.7	129.2	ns
Maturity index	195.5	213.0	203.3	ns
Estimated yield (kg/ha)	11,467	11,687	13,495	0.078
Mean pods per plant	5.3	5.7	5.4	ns
<5mm (g)	37.3	37.3	37.2	ns
5-7 mm (g)	186.7	176.2	160.5	ns
>7mm (g)	318.0	313.0	327.0	ns
<5mm (% by wt.	6.9	7.0	7.0	ns
>7mm (% by wt.)	58.8	59.5	62.5	ns
5-7 mm (% by wt.)	34.3	33.5	30.5	ns
Peas per pod	4.90	4.67	5.01	ns
Vine length (mm)	96.2	95.7	99.9	ns
Nodes to first flower	15.5	15.6	15.3	ns
Productive nodes	3.52	3.85	3.72	ns
Doubles[1]	1.77	1.88	1.68	ns
Downy mildew[2]	1.0	0.7	0.3	ns
Botrytis cinerea[2]	1.35	1.42	1.36	ns
Sclerotinia (no. of pods/10)	8.7 a[4]	6.8 b	4.5 c	<0.001 (LSD=1.41)

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

[4] means within rows followed by the same letter are not significantly different

Table 7. Effect of basal or foliar treatment with potassium silicate on pea yield, quality and morphological characteristics (Trial 5, 2007/2008).

	Control	**Basal application**	**Foliar application**	***P*=**	**LSD**
Plants per m^2	128.9	125.3	129.4	ns[3]	-
Maturity index	153.3	153.8	154.0	ns	-
Estimated yield (kg/ha)	4809	6095	5851	0.023	928.1
Mean pods per plant	4.6	5.4	5.2	ns	-
<5mm (g)	178.7	181.3	147.8	<0.001	14.39
5-7 mm (g)	227.7	230.8	262.0	0.007	21.74
>7mm (g)	112.5	112.7	114.8	ns	-
<5mm (% by wt.	34.4	34.6	28.2	<0.001	1.95
>7mm (% by wt.)	21.7	21.4	21.9	ns	-
5-7 mm (% by wt.)	43.9	43.9	49.9	<0.001	1.76
Peas per pod	4.7	5.0	4.5	ns	-
Vine length (mm)	101.6	103.8	102.7	ns	-
Nodes to first flower	14.5	14.0	14.3	ns	-
Productive nodes	3.5	4.1	3.6	ns	-
Doubles[1]	1.1	1.3	1.6	ns	-
Powdery mildew[2]	3.0	3.0	3.0	ns	-
Ascochyta collar rot[2]	2.0	2.0	2.0	ns	-

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

Table 8. Effect of potassium silicate treatment on pea yield, quality and morphological characteristics (Pea trial 6, 2008/2009).

	Control	**AgSil 27™**	**Stand SKH™**	***P* = (LSD)**
Mean plant density (/m^2)	78.9	72.2	69.7	0.087
Estimated yield (kg/ha)	16,298 b	18,196 a	17,679 ab	0.029 (1391.6)
Maturity Index	218.5	223.8	227.8	ns[3]
Mean vine length (cm)	872	850	836	ns
Mean number of productive nodes	5.3	5.1	6.2	ns
Mean number of nodes to first flower	10.7	10.4	10.4	ns
Mean number of pods per plant	7.8	7.8	9.0	ns
Mean number of nodes with doubles per plant[1]	2.5	2.7	2.8	ns
Mean number of peas per pod	6.9	6.7	7.1	ns
Pods < 5 mm (% by weight)	7.2	10.1	7.8	ns
Pods 5-7 mm (% by weight)	32.3	30.3	28.5	ns
Pods > 7mm (% by weight)	57.6	62.5	63.7	ns
Mean incidence of Botrytis[2]	0.5	0.2	0.2	ns
Mean incidence of Downy mildew[2]	0.8	0.7	0	ns
Mean incidence of Sclerotinia (/5 pods)	0.7	0.2	1.1	ns

[1] number of nodes with two or more pods

[2] scale of: no symptoms = 0, symptoms on stems = 1, symptoms on stems and leaves = 2, symptoms on stems, leaves and pods = 3.

[3] ns = not statistically significantly different

Table 9. Effect of potassium silicate treatment on pea yield, quality and morphological characteristics (Pea trial 7, 2008/2009).

	Control	**AgSil 27™**	**Stand SKH™**	***P*=**
Mean plant density (/m^2)	80.3	84.4	83.9	ns[2]
Estimated yield (kg/ha)	10,905	11,585	11,173	ns
Maturity Index	221.2	206.9	199.5	ns
Mean vine length (cm)	958	946	975	ns
Mean number of productive nodes	5.3	6.2	5.9	ns
Mean number of nodes to first flower	11.9	11.7	12.1	ns
Mean number of pods per plant	8.5	9.8	9.4	ns
Mean number of nodes with doubles per plant	3.7	3.3	3.5	ns
Mean number of peas per pod	6.2	6.6	6.7	ns
Pods < 5 mm (% by weight)	16.2	15.7	15.8	ns
Pods 5-7 mm (% by weight)	44.5	43.1	45.2	ns
Pods > 7mm (% by weight)	39.3	41.3	38.9	ns
Severity of Ascochyta (% of pod surface)[1]	42.0	37.0	34.1	ns
Severity of downy mildew (% of pod surface)[1]	8.2	8.1	5.4	ns

[1]Percentage of pod surface affected by disease on 50 pods collected from 10 plants per plot.

[2] ns = not statistically significantly different

Table 10. Cost benefit of potassium silicate applications in pea trials which yielded a statistically significant (*P*<0.05) or marginally significant (*P*<0.1) effect on yield.

	Non treated	Potassium silicate
Pea field trial 2		
Yield (kg/ha)	3,196	4,132
Gross return ($/ha)	$1,278	$1,653
Cost of potassium silicate (5 applications at 3 L/ha each) ($/ha)	$0	$122
Cost of tractor operation (5 applications at $41 each) ($/ha)	$0	$205
Net benefit over non treated ($/ha)		$48
Pea field trial 3		
Yield (kg/ha)	10,778	13,453
Gross return ($/ha)	$4,311	$5,381
Cost of potassium silicate (5 applications at 3 L/ha each) ($/ha)	$0	$122
Cost of tractor operation (5 applications at $41 each) ($/ha)	$0	$205
Net benefit over non treated ($/ha)		$616
Pea trial 4		
Yield (kg/ha)	11,467	13,495[1]
Gross return ($/ha)	$4,587	$5,398
Cost of potassium silicate (5 applications at 6 L/ha each) ($/ha)		$244
Cost of tractor operation (5 applications at $41 each) ($/ha)		$205
Net benefit over non treated ($/ha)		$362
Pea trial 5		
Yield (kg/ha)	4,809	5,851
Gross return ($/ha)	$1,924	$2,340
Cost of potassium silicate (3 applications at 6 L/ha each) ($/ha)		$146
Cost of tractor operation (3 applications at $41 each) ($/ha)		$123
Net benefit over non treated ($/ha)		$147
Pea trial 6		
Yield (kg/ha)	16,298	17,679-18,169
Gross return ($/ha)	$6,519	$7,072-$7,268
Cost of potassium silicate (5 applications at 6 L/ha each) ($/ha)		$244
Cost of tractor operation (5 applications at $41 each) ($/ha)		$205
Net benefit over non treated ($/ha)		$104-$300

[1] Yield of foliar treatment only

4.1.3 Discussion

Although there were some indications that potassium silicate treatment reduced disease in peas in two of our trials, disease pressure was very low in all trials. Therefore the impact of potassium silicate on disease could not be adequately assessed. Silicon has been demonstrated to reduce disease in pea in other studies. Dann and Muir (2002) reported an association in pea between available silicon in growth media, accumulation of Si in the plant, higher activity of chitinase and β-1,3-glucanase and subsequent resistance to fungal pathogens. The number of lesions in leaves following inoculation with *Mycosphaerella pinodes* was reduced by some 40-70% in pea plants grown in media containing silicon in comparison to media without silicon.

Our trials gave indications that potassium silicate treatment could increase pea yield in the absence of significant disease pressure, with three of seven trials having significantly ($P < 0.05$) higher yields and a further two of the seven trials giving a statistically borderline ($P < 0.10$) increase in yield in comparison to non treated. In three of the trials, the level of potassium in the soil was measured at harvest. This indicated that there was a sufficiency of potassium for pea growth in all treatments including the non treated control. Similarly commercial rates of NPK fertiliser were applied at planting to all trials to ensure sufficiency of all nutrients across all treatments. The increased yield in some trials due to potassium silicate treatment is therefore considered to have resulted from the silicon component rather than the addition of extra potassium. Silicon is reported to elicit a range of physiological responses in plants, including i) improved photosynthesis, ii) enhanced resistance to plant diseases and insect pests, iii) alleviating the effects of metal toxicity and nutrient imbalance, iv) alleviating the effects of salt stress, drought stress and temperature stress, and v) preventing lodging (Datnoff et al. 2001a). It is speculated that potassium silicate treatment provided some physiological advantage to pea in our trials, resulting in a yield advantage in at least some trials.

4.2 Bean

Three field trials were conducted to assess the effect of potassium silicate on disease, yield and quality of bean.

4.2.1 Materials and methods

Bean trial 1 (2006/2007)

Prior to planting, soil had a pH 7.0, and P and K concentrations of 68 ppm and 184 ppm respectively. The previous crops grown at the trial site were carrot in 2004/2005 and pasture in 2005/2006. Pivot Gold fertiliser (13:14:13 + trace elements) was predrilled at a rate of 523 kg/ha. Bean cv. ‘Stanley’ was sown at 40 seeds/m^2 with an Oyjord plot seeder on the 19/12/2006. The plots were five metres long with four rows wide at 375mm spacing. The trial was arranged in a completely randomised design with 6 replicates treated with AgSil 27™ and 6 replicates non treated. AgSil 27™ was applied with a Solo™ petrol-driven backpack sprayer at 10 ml/L on 10 January, 24 January and 7 February 2007 as described previously for pea experiments (section 4.1).

Weed control consisted of a pre-emergent application of Stomp™ (330 g/L pendimethalin, 578 g/L hydrocarbon) on 20/12/2006, one application of Basagran™ (480 g/L bentazone) at label rates on the 23/1/2007. Weeds were subsequently controlled with hand hoeing. There were no chemical applications for disease and insect control. Initially, irrigation was applied to field capacity whenever the estimated soil water deficit approached 20 mm, however frequency of irrigation was reduced approximately 2 weeks prior to maturity so that application occurred when estimated soil water deficit approached 35mm.

The trial was harvested on 27 February 2007 at 70 days to maturity. A subplot consisting of 1.3 m length of two inner rows (0.975 m^2) was harvested for yield and quality assessments (appendix 1).

Bean trials 2 and 3 (2007/2008)

Bean trials 2 and 3 were also conducted on the TIAR Vegetable Research Facility at Forthside on a Krasnozem soil type. Nutrient analysis of soil prior to planting was as described for pea trials 4 and 5 (Section 4.1). Two bean trials were conducted each with two varieties; 'Montano' (trial 2) and 'Roma 2' (trial 3). Each trial was established as a completely randomised design with three treatments, i) non treated, ii) basal treatment of potassium silicate, iii) foliar applications of potassium silicate during the season. For each treatment there were six plots, each 5 m x 2 m. Beds were cultivated on 5 December 2007 and the basal treatment of AgSil applied to plots. Each plot received 1.25 L/plot of AgSil 27™ (26.7% potassium silicate) diluted to 10 L and applied with a watering can, for an equivalent rate of 330 kg potassium silicate/ha. Beds were then cultivated with a roterra and 514 kg/ha Pivot Gold (13:14:13 & trace elements) predrilled in two laterally placed bands 60 mm apart with a 1.6 m wide Fiona drill. Seed was sown with an Oyjord drill at a density of 50 seeds/m^2 to achieve a density of 40/m^2. Each bed consisted of 4 rows, 375 mm apart. Beds were rolled on 6 December 2007 and irrigated prior to application of herbicide. Weeds were controlled with Stomp™ (330 g/L pendimethalin, 578 g/L hydrocarbon) at 3 L/ha (7 December 2007) and Basagran™ (480 g/L bentazone) at 1.5 L/ha (10 January 2008), with further hand weeding as required. Foliar treatments were applied on 21 December 2007 (plants approximately 100 mm high), 8 January 2008, 18 January 2008 (plants in flower), 30 January 2008 (plants with pods). AgSil 27™ (26.7%) was applied at 20 ml/L at a equivalent volume of 300 L/ha with a Solo 432 motorised backpack sprayer. Plots were harvested on 18 February 2008 at 56 days to maturity. Beans were harvested along a 1.3 m section of the two middle rows (0.975 m2), i.e. approximately 50-60 plants per plot and assessed for yield and quality (appendix 1).

4.2.2 Results

Bean trial 1 (2006/2007)

The dry conditions resulted in the trial remaining free of common bean diseases. In the absence of disease there was no significant difference in yield or seed and pod characteristics between non treated plants and those treated with potassium silicate (Table 11). There was a marginal statistical difference (P = 0.10) in pod weight in favour of potassium silicate (Table 11).

Table 11. Effect of potassium silicate treatment on bean yield and characteristics (Bean trial 1, 2006/2007).

	Control	AgSil 27™	*P*=
% by wt. stalks on pod	51.0	52.6	ns[1]
Diseased pods as % of wt.	1.6	1.4	ns
Diseased pod wt (g)	37.5	36.8	ns
No. diseased plants	0.50	0.17	ns
No. plants	52.3	59.7	ns
Seed length (mm)	8.6	8.5	ns
Pod yield per plant (g)	46.6	42.7	ns
Pod yield (kg/ha)	24,768	25,964	ns
10 pod sample:			
Weight 10 pods (g)	47.3	50.2	0.09
Mean pod length (mm)	118.7	120.2	ns
Mean pod width (mm)	7.7	7.7	ns
Section (1-5 scale)	4.4	4.4	ns
Cavity (1-5 scale)	1.9	1.8	ns
Shape (1-5 scale)	4.1	4.1	ns

[1] ns = not statistically significantly different

Bean trials 2 and 3 (2007/2008)

Treatment had no significant effect on plant density, yield, the percentage of diseased plants or pods, pod or seed size, shape, section or cavity in either trial 2 or trial 3 (Table 12). Treatment had a significant effect on the percentage by weight of stalks on the pods for Montano in trial 2, with control being significantly higher than basal application, and foliar application intermediate between, and statistically indistinguishable, from the latter two treatments (Table 12).

Table 12. Effect of treatments with potassium silicate on yield and quality parameters of bean cultivars 'Montano' and 'Roma 2' (Bean trials 2 and 3, 2007/2008).

	Trial 2 cv. 'Montano'				Trial 3 cv. 'Roma 2'			
	Control	**Basal application**	**Foliar application**	***P*=**	**Control**	**Basal application**	**Foliar application**	***P*=**
No. plants/m^2	32.1	32.8	34.9	ns[1]	46.3	43.2	49.7	ns[1]
Diseased plants (%)	6.4	11.4	7.3	ns	36.4	31.6	23.3	ns
Yield (kg/ha)	18, 359	20,244	20,144	ns	25,848	25,964	25,520	ns
Diseased pods (%)	0.50	0.51	0.05	ns	11.8	10.2	9.8	ns
Wt. stalk (%)	19.3 a	7.9 b	13.2 ab	0.025 LSD=7.9	48.7	43.6	42.0	ns
Seed length (mm)	10.6	10.6	10.4	ns	10.7	11.2	10.9	ns
Pod length (mm)	115.7	113.3	111.7	ns	140.7	146.0	145.3	ns
Pod width (mm)	10.0	9.9	10.1	ns	9.2	9.1	9.4	ns
Mean pod weight (g)	7.0	7.0	7.1	ns	13.3	13.2	13.2	ns
Cavity (1-5 scale)	2.3	1.4	1.3	ns	1.0	1.0	1.0	-
Section (1-5 scale)	4.5	4.6	4.7	ns	1.9	1.9	1.8	ns
Shape (1-5 scale)	3.9	3.8	4.0	ns	3.7	3.8	3.5	ns

[1] ns = not statistically significantly different

4.2.3 Discussion

The three trials demonstrated no improvement in the yield or quality of bean from potassium silicate in the absence of disease, although there was a marginal statistical increase (*P* = 0.10) in individual pod weight due to potassium silicate in trial 1.

Moraes *et al*. (2006) recently reported that the application of sodium silicate to leaves of bean resulted in a 62.4% reduction in the area under the disease progress curve of bean anthracnose (*Colletotrichum lindemuthianum*), suggesting that silicate application could be highly beneficial to bean under conditions conducive to disease. However, disease pressure was low in our trials and the effect of potassium silicate against disease in bean was unable to be examined.

4.3 Corn

One field trial was conducted in the 2006/2007 season to examine the effect of potassium silicate application on yield and disease of corn.

4.3.1 Materials and methods

Soil analysis (CSBP Laboratories) prior to planting gave a pH 7.0, and P and K concentrations of 68 ppm and 184 ppm respectively. The previous crops were carrot in 2004/2005 and pasture in 2005/2006. Fertiliser (13:14:13 + trace elements) was predrilled on 13/12/2006. Corn cv. 'Supersweet' was sown at 10 seeds/m^2 with an Oyjord drill on 19 December 2006. Plots consisted of 5 m length of bed, with beds 2 m wide. Each bed had 4 rows of corn spaced 375 mm apart. Plants were hand thinned to approximately four per m^2 after emergence. Irrigation was applied at 35 mm estimated deficit and weed control conducted as per standard commercial practice. AgSil 27™ was applied on 10 January, 24 January, 7 February, 21 February and 7 March 2007 at 10 mL/L as previously described (Section 5.1). Corn was harvested from a 1.3 m length of the 2 central rows in the bed (0.975m^2).

4.3.2 Results and conclusion

Treatment with foliar applications of potassium silicate had no significant effect on yield and quality of corn in this trial (Table 13). Disease incidence was low which prevented an assessment of the effect of potassium silicate on disease.

Table 13. Effect of foliar application of potassium silicate on yield and quality of corn.

	AgSil 27™	Non treated	*P*=
Primary cobs:			
Yield (t/ha)	97.3	92.1	ns[1]
Number of cobs (per 0.975 m^2)	24.0	23.7	ns
Ave. cob wt. with husk (g)	395.6	379.4	ns
Ave. cob wt. without husk (g)	255.3	245.4	0.08
Ave. cob length (cm)	196.8	197.4	ns
Secondary cobs:			
Yield (t/ha)	22.1	23.8	ns
Average cob weight	126	138	ns
Number of cobs (per 0.975 m^2)	16.8	16.8	ns

[1] ns = not statistically significantly different

4.4 Broccoli

Two field trials were conducted to assess the effect of potassium silicate on yield and disease in broccoli.

4.4.1 Materials and methods

Broccoli trial 1 (2007/2008)

Nutrient analysis of soil prior to planting was as described for pea trials 4 and 5 (Section 5.1). The trial was established as a completely randomised design with three treatments i) non treated, ii) basal treatment of potassium silicate, iii) foliar applications of potassium silicate during the season. There were six replicate plots per treatment, each 5 x 3.24 m. Ground was cultivated on 15 October 2007 and basal treatment of AgSil applied. The basal treatment received 2L/plot of AgSil 27™ (26.7% potassium silicate) for an equivalent rate of 330 kg/ha. AgSil 27™ was incorporated with a roterra and plots pre-drilled with 600 kg/ha 14:16:11 applied as 2 lateral and 1 inferior band. Broccoli cv. 'Marathon' seedlings were obtained from Hills Transplants and transplanted on 17 October 2007 at 250 mm spacing. Insecticide was applied on 20 November 2007 and weeds controlled by hand weeding. Foliar applications were of 20 ml/L AgSil 27™ applied at 300 L/ha equivalent on 21 November, 5 December and 21 December 2007. Plots were harvested on 3 January 2008.

Broccoli trial 2 (2008/2009)

Broccoli cv. 'Marathon' seedlings were obtained from Hills Transplants and transplanted on 3/10/2008. Plots were 4.8 m wide by 5.0 m long (24 m^2), and consisted of 3 beds, each 1.6 m wide. Broccoli received 5 applications of potassium silicate as AgSil 27™ (26.7% potassium silicate) or Stand SKH™ (20% silica, 15% potassium, 1% humic acids) as a foliar spray on 8 October, 21 October, 6 November, 21 November and 4 December 2008. Potassium silicate was applied at 20 mL/L at 300 L/ha with a Solo™ petrol driven backpack sprayer. The crop received no applications of pesticides other than insecticide (Success 2™ @ 200 ml/ha) on 28 November 2008. Broccoli was harvested from the whole plot on 28 December 2008.

Ten fully expanded leaves from each plot were assessed for severity (% of leaf surface) of damage due to diamond back moth, white blister caused by the fungus *Albugo candida* and black rot caused by the bacterium *Xanthomonas campestris*.

4.4.2 Results

Broccoli trial 1 (2007/2008)

Treatment with potassium silicate had no significant effect on the number or weight of broccoli heads, undersize heads, or heads with head rot or disease (Table 14). Diseases were insignificant in the trial and were not assessed. Soil analyses of the non treated, base application of potassium silicate and foliar application of potassium silicate after harvest gave a pH (H_2O) of 7.3, 7.0 and 7.2 respectively, levels of potassium of 137, 160 and 179 mg/kg respectively, and levels of silicon of 25.2, 35.3 and 25.4 mg/kg respectively.

Table 14. Effect of treatments with potassium silicate on yield parameters of broccoli (Broccoli field trial 1, 2007/2008).

	Non treated	Base	Foliar	*P* =
Number of heads per ha.				
Total no.	49,383	49,177	49,280	ns[1]
Undersize	4835	6173	5658	ns
Head rot	720	412	412	ns
Diseased	412	309	309	ns
Weight of heads (kg/ha)				
Total	9206	9336	9567	ns
Undersize	416	662	630	ns
Head rot	129	49	53	ns
Diseased	78	77	77	ns

[1] ns = not statistically significantly different

Broccoli trial 2 (2008/2009).

Treatment with potassium silicate had no effect on the weight or number of marketable, oversize or undersize heads per plot (Table 15). The incidence of hollow stem, white blister and head rot was low (Table 15). Treatment with potassium silicate had no significant effect on the yield of heads with white blister, while the incidence of head rot was too low to statistically analyse (Table 14). Similarly, treatment with potassium silicate had no significant effect on the yield of heads exhibiting hollow stem (Table 15).

Following harvest, soil analysis by CSBP laboratories for the non treated, foliar treatment with AgSil 27™ and foliar treatment with Stand SKH™ gave mean concentrations of potassium of 229, 262 and 265 mg/kg respectively and mean concentrations of silicon of 33.0, 34.1 and 34.2 mg/kg respectively. The mean pH (H_2O) of all treatments was 6.8.

Table 15. Effect of treatment on broccoli yield and quality. (Broccoli field trial 2, 2008/2009)

	Non treated	**AgSil 27™**	**Stand SKH™**	***P* =**
Severity of diamond back moth damage (% of leaf surface)[1]	2.3	2.0	1.9	ns[2]
Severity of white blister (% of leaf surface) [1]	0.1	0.1	0.1	ns
Severity of black rot (% of leaf surface) [1]	0.3	0.9	0.9	ns
Mean wt. (g per plot)				
Marketable	16,725	16,793	16,763	ns
Oversize	4862	7393	7877	ns
Undersize	697	337	352	ns
Hollow stem	3158	3442	2957	ns
White blister	1315	272	668	ns
Head rot	0	0	98	-[3]
Total yield	26,757	28,237	28715	0.748
Mean number heads per plot				
Marketable	41.7	40.8	38.2	ns
Oversize	8.0	11.7	12.7	ns
Undersize	5.0	3.2	2.8	ns
Hollow stem	4.5	5.3	4.7	ns
White blister	2.5	0.5	1.5	ns
Head rot	0	0	0.2	-[3]
Total heads	61.7	61.5	60.0	ns
Estimated total yield (kg/ha)	11,149	11,765	11,149	ns
Estimated marketable yield (kg/ha)	6969	6997	6985	ns

[1]Mean percentage of leaf area of broccoli plants affected by diamond back moth damage, white blister (*Albugo candida*) or black rot (*Xanthomonas campestris*).

[2]not statistically significantly different

[3]not analysed due to low incidence of head rot.

4.5. Carrot

One field trial was conducted during the 2008/2009 season to assess the effect of potassium silicate on yield and disease in carrot.

4.5.1 Materials and methods

Fertiliser (500 kg/ha) 13-14-13 +trace elements was applied and beds (1.6 m wide) were formed on 18 November 2008. Seed of cv. 'Stefano' was sown on 11 December 2008. There were 6 replicate plots of each of the following treatments (i) control, (ii) AgSil 27™ (26.7% potassium silicate) and (iii) Stand SKH™ (20% silica, 15% potassium, 1% humic acids). AgSil 27™ and Stand SKH™ were applied at a rate of 20 mL/L on 4 February, 12 February, 23 February, 6 March, 13 March and 23 March 2009. Carrots were harvested on 8 April 2009 from subplots (2 x 4 m) within each replicate. A subsample of 20 carrots from each plot was assessed for length and diameter at the shoulder using a vernier caliper. Carrots were then graded into categories of 'marketable', 'misshapen', 'split/cracked' or forked and counted and weighed. In addition, a further 20 carrots were chosen at random and measured for length and maximum diameter.

4.5.2 Results

Yield from the carrot trial was high in comparison to normal commercial practice, with an estimated mean of 103.4 t/ha for the control (Table 16). There was no significant effect of treatment on estimated marketable yield (t/ha), although the mean estimated marketable yield of the non treated was lower than that of the two silicate treatments (Table 16). However, treatment had a highly significant ($P < 0.001$) effect on pack out (marketable yield as a percentage of total yield), with AgSil 27™ and Stand SKH™ having a pack out of 87.2 and 88.1 % (by weight) respectively, in comparison to 82.2% for the control (Table 16). The improvement in pack out as a result of the potassium silicate treatments appeared to be in reducing the weight (and

Table 16. Effect of treatment with potassium silicate on carrot yield and quality (carrot trial, 2008/2009)

	Control	AgSil 27™	Stand SKH™	*P* =	LSD
Mean wt. of carrots (g per 8m^2)					
Marketable	68,015	73,338	72,047	ns[1]	-
Misshapen	10,119 a	6,736 b	6,330 b	0.001	1796.4
Split/cracked	651 a	263 b	274 b	0.006	242.6
Forked	3,839	3,762.3	2,998.3	ns	-
Total	82,681	84,100	81,728	ns	-
Mean number of carrots per 8 m^2					
Marketable	724.2	778.5	763.5	ns	-
Misshapen	109.8 a[2]	69.7 b	67.3 b	0.001	17.8
Split/cracked	5.0 a	2.0 b	2.0 b	0.010	2.1
Forked	35.3	35.8	32.8	ns	-
Total	874.8	886.0	866.3	ns	-
Mean length of taproot (mm)	164.2	165.5	170.6	ns	-
Mean shoulder diameter of taproot (mm)	33.0	31.2	32.0	ns	-
Estimated total yield (t/ha)	103.4	105.1	102.2	ns	-
Estimated marketable yield (t/ha)	85.0	91.7	90.1	ns	-
Pack out (weight of marketable carrots as a % of total weight)	82.2 a	87.2 b	88.1 b	0.001	2.8

[1] Not statistically significantly different.
[2] Means within rows followed by the same letter are not statistically significantly different.

number) of carrots either misshapen or split/cracked (Table 16). Silicate treatment had no significant effect on forking of carrot roots. The incidence of disease on carrot roots in this trial was low and unable to be analysed statistically.

Assuming an average carrot crop producing a total yield of 97 t/ha (DPIWE 2007), the improvements to percentage pack out as a result of silicon treatment in our trial would have led to a gross return of between $10,127 to $10,230 per hectare in comparison to $9,546/ha for the non treated (Table 17). The cost of five applications of potassium silicate (each 6 L/ha) was estimated at $244/ha and the cost of boom spraying at $205/ha (Table 17). This led to positive net benefit from application of potassium silicate of $132 to $235/ha (Table 17).

Table 17. Cost benefit analysis of improvement to pack out from applications of potassium silicate to an average carrot crop yielding 97 t/ha.

	Non treated	Potassium silicate
Average commercial yield (t/ha)	97.0[1]	97.0[1]
Pack out (%)	82.2	87.2 – 88.1
Marketable yield (t/ha)	74.0	78.5 - 79.3
Price ($/t)	$129[2]	$129[2]
Gross return ($/ha)	$9,546	$10,127 - $10,230
Cost of potassium silicate ($/ha)[3]	-	$244
Cost of boom spraying (5 applications @ $41/ha[4])	-	$205
Net benefit from potassium silicate ($/ha)	-	$132 - $235

[1]Information sourced from Department of Primary Industries Water and Environment (2007)

[2]Information sourced local farming operation.

[3] Five applications of 6 L/ha each @ $162.50 per 20 L.

[4]Information sourced from local spray contracting firm.

4.5.3 Conclusion

Percent pack out of carrot was increased by 5.0 to 5.9 percent from the application of potassium silicate during the growth of the crop, mainly through a reduction in the number and weight of carrots either misshapen or exhibiting splitting/cracking. It is common for some 5-10% of taproots within a crop to be split (Gracie and Brown 2004), however levels exceeding 25% have been reported (McGarry 1993). Splitting renders the taproot unsaleable, thereby reducing marketable yield for the grower. The improvements to pack out were estimated to result in a net benefit of $93 to $178/ha to the grower for an average crop yielding 97 t/ha. Splitting also leads to inefficiencies and additional costs at grading because split carrots need to be manually removed from the grading line, and unmarketable carrots incur disposal costs. Silicon is known to improve the strength of plant cell walls and tissues (e.g. Dakora and Nelwamondo 2003), and can reduce lodging in crops (Ma and Yamaji 2006). Therefore it is possible that application of potassium silicate may strengthen the carrot taproot rendering it less susceptible to splitting. Similarly silicon may strengthen the developing tap root rendering it less susceptible to being misshapen. The shape and size of carrots is an important quality characteristic to the industry which has been the subject of previous research through Horticulture Australia (Brown and Gracie 2000). These results suggest that potassium silicate may play a role in improving carrot shape. However, this result is based on one trial only and requires further confirmation before potassium silicate could be recommended.

Potassium silicate may have other advantages in carrot crops. Potassium silicate has been shown to be effective against powdery mildew in a range of crops including *Uncinula necator* in grapes (Bowen *et al.* 1992), *Sphaerotheca fuliginea* in cucumbers (Adatia and Besford 1986, Belanger *et al.* 1995), *Sphaerotheca aphanis* in strawberry (Kanto *et al*. 2004), and *Erysiphe cichoracearum* in muskmelon (Menzies *et al*. 1992). Powdery mildew (*Erysiphe heraclei*) has recently been reported in carrot crops in Australia (Watson and Napier 2007) causing loss of foliage, lower yields and poor seed quality. Therefore potassium silicate may have some application in the control of this disease. Furthermore, one of the effects of the disease is to weaken the carrot top, leading to difficulties in harvesting carrots. Although not demonstrated in this trial, potassium silicate may confer some additional advantages in terms of strengthening carrot tops and improving harvest efficiency in diseased crops.

4.6 Pumpkin

One field trial was conducted during the 2008/2009 season to assess the effect of potassium silicate on yield and disease in pumpkin.

4.6.1 Materials and methods

Fertiliser (13-14-13 plus trace elements) was applied and beds were formed on 18 November 2008. Butternut pumpkin cv. ‘Waltham’ (Henderson Seed) was planted on 12/12/2008. The trial was established as a completely randomised design with 6 replicate plots (ea. 24 m^2) of each of the following (i) non treated, (ii) AgSil 27™ (26.7% potassium silicate) and (iii) Stand SKH™ (20% silica, 15% potassium, 1% humic acids). Treatments were applied on 4 February (beginning of flowering), 12 February (first fruit set), 23 February, 6 March, 13 March, 23 March, 3 April and 14 April 2009 (vines beginning to die off). Treatments were AgSil 27™ or Stand SKH™ applied at 20 mL/L with a Solo™ petrol driven backpack sprayer delivering an equivalent volume of 300 L/ha. Fruit were harvested from whole plots by hand on 20 May 2009, and graded into categories of ‘marketable’, ‘blemished’, ‘immature’, ‘rots’ and weighed. Twenty pumpkins from each of three replicates of each treatment with no obvious signs of rots were placed in cool storage (10^{o}C) and assessed for fungal storage rots on 30 June and 13 July 2009, by visually assessing the percentage of the pumpkin surface covered by mycelium.

4.6.2 Results

Treatment had no significant effect on the total yield of pumpkins, either in terms of number or weight (Table 18). However, treatment with Stand SKH™ increased the number of marketable pumpkins in comparison to the non treated, with AgSil 27™ treatment intermediate between and statistically indistinguishable from either of the other treatments (Table 18). Stand SKH™ had significantly higher yield of marketable pumpkins than either the non treated or AgSil 27™ treatment, equating to some 19.2 and 7.3% higher respectively (Table 18). Similarly the AgSil 27™ treatment had higher yield of marketable pumpkins than the non treated, equating to an increase of 11.1%. Assuming a return to the grower of $300/tonne of marketable pumpkins, the estimated net benefit from the potassium silicate treatments ranged from $74 to $641/ha (Table 19).

On 30 June 2009 there was a statistically significantly (*P* = 0.025) higher percentage of pumpkins with fungal rots in the non treated than either the AgSil 27™ or Stand SKH™ treatments (Table 20). On average, the severity of fungal rots was low at this time, (<2%) with no statistical difference between treatments. By 13 July 2009, the mean incidence of diseased pumpkins had increased, with a mean of 41.4% of pumpkins in the non treated with fungal rots. Pumpkins treated with AgSil 27™ had significantly (*P* = 0.020) lower mean incidence of rots (13.3%) than the non treated, with Stand SKH™ having a mean of 26.7%, intermediate between and statistically indistinguishable from AgSil or the non treated (Table 20). Both AgSil 27™ and Stand SKH™ treatments had statistically significantly (*P* = 0.023) lower severity of rots than the non treated at this time. The predominant fungi associated with rots were *Sclerotinia sclerotiorum*, *Fusarium* spp. and *Penicillium* spp.

Table 18. Effect of potassium silicate on yield and quality of pumpkin.

	Non treated	**AgSil 27™**	**Stand SKH™**	***P* =**	**LSD**
Number of pumpkins/ha in following categories:					
Marketable	23,542 b[1]	27,333 ab	29,236 a	0.03	4,318
Blemished	903	583	347	ns[2]	-
Immature	1,319	1,333	417	ns	-
Rots	1,667	1,833	1,944	ns	-
Total	27,431	31,083	31,944	ns	-
Yield (t/ha) of pumpkins in following categories:					
Marketable	23.58 c	26.21 b	28.11 a	0.048	1.73
Blemished	1.11	0.67	0.37	ns	-
Immature	0.69	0.89	0.42	ns	-
Rots	0.54	0.77	0.90	ns	-
Total	25.92	28.54	29.81	ns	-

[1] Means within rows followed by the same letter are not statistically significantly different.
[2]Not statistically significantly different.

Table 19. Cost benefit of potassium silicate treatments on pumpkin.

	Non treated	Potassium silicate
Marketable yield (t/ha)	23.58	26.21 – 28.11
Gross return ($/ha)	$7,074	$7,863 - $8433
Cost of potassium silicate (8 applications at 6 L/ha each) ($/ha)	-	$390
Cost of tractor operation (8 applications at $41 each) ($/ha)	-	$328
Net benefit over non treated ($/ha)	-	$71 - $641

Table 20. Incidence and severity of fungal rots on pumpkin in cool storage.

	Non treated	AgSil	Stand SKH	*P* =	LSD
30th June					
Mean incidence (%)[1]	27.1 a	8.3 b[3]	11.7 b	0.025	12.8
Mean severity (%)[2]	1.8	1.4	0.4	ns[4]	-
13th July					
Mean incidence (%)[1]	41.4 a	13.3 b	26.7 ab	0.020	17.1
Mean severity (%)[2]	6.8 a	3.0 b	1.5 b	0.023	3.5

[1] Percentage of pumpkins with fungal rots (*n* = 20).
[2] Percentage of pumpkin surface covered with mycelium.
[3] Means within rows followed by the same letter are not significantly different.
[4]Not statistically significantly different.

4.6.3 Conclusion

Potassium silicate treatment had no effect on total yield of pumpkin but significantly increased the yield of marketable pumpkins with a positive net benefit of $71 to $641/ha.

In addition, there was a residual effect of potassium silicate which conferred resistance to storage rots in cold storage. This effect was potentially of commercial significance, and should be investigated further. Silicon may also have application as a postharvest dip for control of pathogens on fruit and vegetables. Guo *et al.* (2007) demonstrated that dipping cantaloupe in silicon oxide or sodium silicate could control postharvest rot of Chinese cantaloupe caused by *Trichothecium roseum*.

5. Silicon analysis of vegetable cropping soils in Tasmania.

5.1 Materials and methods

Soil samples were collected from 23 fields used for intensive vegetable production in Tasmania. Soils were air dried and sent to CSBP Laboratories for analysis.

5.2 Results and conclusion

The average concentration of silicon in Tasmanian cropping soils was 36.4 mg/kg Si, with a minimum of 4.6 and a maximum of 73.9 mg/kg Si (Table 21). Berthelsen *et al*. (2003) considered fields with <10 mg/kg Si (extracted with 0.01 M $CaCl_2$) and those with 10-20 mg/kg Si to be 'sub-optimal' and 'marginal' respectively for sugarcane growth. Due to the lesser accumulation of silicon by many vegetable crops in comparison to sugarcane, it is difficult to speculate whether the amounts of silicon present in the soils tested are sufficient for optimum growth of vegetable crops. However, our results in section 4 have suggested that some improvement to yield can be conferred by the application of potassium silicate to crops grown in soils with these concentrations of silicon.

Table 21. Texture, colour and silicon content of 23 soils used for vegetable cropping in Tasmania.

Location	Silicon (mg/kg)[1]	Texture	Colour
Latrobe	4.62	sandy clay loam	brown
Devonport	8.47	medium clay (rocky)	dark greyish brown
Melrose	19.66	sandy clay loam	dark brown
Rocky Cape	22.21	sandy clay loam	dark yellowish brown
Barrington	22.70	sandy clay loam	dark brown
Kindred	24.46	sandy clay loam	dark brown
Sassafrass	26.30	sandy clay loam	dark reddish brown
Barrington	27.36	sandy clay loam	dark reddish brown
Kimberley	27.46	sandy loam/ medium clay	dark greyish brown
Kindred	28.33	sandy clay loam	dark reddish brown
Cressy	28.95	light clay	greyish brown
Bracknell	32.02	clay loam/light clay	n/a[2]
Cressy	36.34	sandy clay loam	greyish brown
Mersey Lea	43.31	sandy clay loam	dark brown
Mersey Lea	49.47	light clay	dark brown
Squeaking Point	50.19	sandy clay loam	dark yellowish brown
Hagley	51.71	light/medium clay	dark greyish brown
Cressy	56.00	sandy clay loam	n/a[2]
Sassafrass	57.49	sandy clay loam	dark brown
Latrobe	59.04	sandy clay loam	n/a[2]
Hagley	66.31	sandy clay loam	dark greyish brown
Bracknell	73.93	sandy clay loam	dark reddish brown
Penguin	20.30	sandy clay loam	dark reddish brown

[1]Extraction with $CaCl_2$

[2]not assessed.

6. General conclusion

This project was demonstrated that potassium silicate has fungicidal activity *in vitro* against a range of fungal plant pathogens, in agreement with the recent findings of Kaiser *et al.* (2005) and Bekker *et al*. (2006a). Furthermore potassium silicate was able to inhibit spore germination and should therefore act in a similar manner to a protectant fungicide when applied to plants. However, it is not known how long this residual activity might last on the plant surface, and it is likely that applications would be required at regular intervals to maintain disease control. In our trials potassium silicate was demonstrated to have bactericidal activity *in vitro* against the plant pathogen *Xanthomonas campestris*. This was an interesting finding given that there are few chemical options for the control of bacterial plant pathogens in crops. In other studies, potassium silicate has also been shown to increase chemicals associated with host plant resistance and reduce disease, even in plants such as pea (Dann and Muir 2002) which are relatively poor accumulators of silicon in comparison to other crops such as rice and sugarcane.

A series of field trials in a range of crops was undertaken as part of this project, however low disease pressure prevented a full assessment of the ability of potassium silicate to reduce disease in vegetable crops. Despite this, some benefits of potassium silicate application were noted. Potassium silicate application gave increased yield in three of seven trials with pea, with a borderline statistical response in a further two trials. Potassium silicate increased the percentage of marketable carrots and reduced split/cracked and misshapen carrots. Potassium silicate also increased the marketable yield of pumpkin and had a residual effect for several weeks after harvest in terms of reducing the incidence and severity of rots in storage. Potassium silicate had no effect on bean, corn or broccoli in our study.

This project indicated that there are likely to be benefits from the use of silicate in vegetable crops, even though many vegetables are not considered to be accumulators of silicon.

Further work is necessary to understand the plant response to silicon to enable a more consistent effect to be realised.

7. Recommendations

The following are suggestions for future work

- There is very little literature on the relative ability of various vegetable crops to take up silicon. A study should be undertaken to determine concentrations of silicon in various vegetable crops, and determine whether concentrations in soils which are heavily cropped are 'sufficient' for optimum growth.
- The ability of silicon to induce a host plant resistance response should be assessed in various vegetable crops to determine which crops are most likely to benefit from silicon application in terms of disease control.
- The fungicidal and bactericidal activity of silicon needs to be more clearly assessed in field trials under moderate to high disease pressure. Given that silicon is taken up in the transpiration stream there is potential for control of fungal and bacterial wilts through soil drenches.
- Some of the physiological responses noted in this project need to be assessed further. The finding that silicon could significantly reduce misshapen carrots and carrot splitting in one trial in our study could be of commercial significance and needs further assessment. Similarly the ability of silicon applied as a foliar spray during the season to reduce rots of pumpkins in storage some weeks afterward could also be of commercial significance, for a range of vegetable and fruit crops.

8. Technology transfer

Technology transfer during the life of the project has been limited due to the low disease pressure and lack of positive results over the first two years of the project. The following updates have been provided.

'Management of vegetable diseases with silicon'. Presentation at the 10th Annual Research Development and Extension Day, Ulverstone, Tasmania, 1 August 2007. Potato and Vegetable Agricultural Research and Advisory Committee.

Annual updates were provided as part of the HAL Annual Vegetable Industry Reports for 2007, 2008 and 2009.

9. Acknowledgements

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Appendix 1. Assessment scale of bean pod quality.