CHAPTER 4

EFFICACY OF WATER SOLUBLE POTASSIUM SILICATE AGAINST PHYTOPHTHORA ROOT ROT OF AVOCADO UNDER FIELD CONDITIONS

4.1 ABSTRACT

Phytophthora root rot is the most important disease of avocados worldwide. *P. cinnamomi* causes rot of the feeder roots and depending on root rot severity, may lead to tree death. Although cultural practices, biological control and resistant cultivars play an important role in suppression of the disease, the avocado industry relies almost solely on phosphonate fungicides for control of root rot. The possibility of development of resistance against this group of fungicides is a concern and to this end silicon was investigated as a possible alternative treatment. An orchard of thirteen year old 'Hass' avocado trees on 'Duke7' seedling rootstocks was selected. This orchard was naturally infested with *P. cinnamomi*. Potassium silicate was applied as either a soil drench or a trunk injection. Three silicon (Si x 3) soil drench applications resulted in significantly higher root densities compared to the control and potassium phosphonate (Avoguard®) treatments. Significant differences in root density were obtained during March 2005 between Si x 3 (5.54%) and Si x 2 (4.45%), compared to the potassium phosphonate treatment (2.16%) and untreated control (2.35%). These differences were negated during drier periods (May 2005) with no significant differences occurring between treatments. However, from November 2005 to July 2006, Si x 3 soil drench treatments resulted in significantly higher root densities compared to the untreated control and potassium phosphonate treatments. These results correlated with tree canopy ratings. All potassium silicate soil drench treatments resulted in lower disease ratings (canopy condition) over the 18 month period of data collection, with significant differences obtained at all data collection dates, except July 2006, when potassium silicate soil drench treatments (viz. Si x 1 = 2.55, Si x 2 = 2.4 and Si x 3 = 2.55) resulted in similar disease ratings as those observed in the control (3.15) and potassium phosphonate treatments (2.95). This indicates that potassium silicate soil drench treatments reduced drought stress, apart from reducing disease stress. The effect of a potassium silicate stem injections did not result in differences in tree root densities or canopy ratings. Silicon x 3 also significantly increased total yield per tree as well as the number of fruit per tree in comparison to the untreated control. No clear effect of silicon on post harvest diseases was observed.

4.2 INTRODUCTION

Avocados (*Persea americana* Mill.) are widely distributed throughout South Africa, with the most important cultivars being 'Fuerte' and 'Hass' (Knight, 2002). True to the phenological model, avocado roots display rhythmic growth (termed flushes), which alternate with quiescent periods (Wolstenholme, 1981). Consequently, the balance between root and shoot mass must always be maintained. Wolstenholme (1987) described the avocado tree root system as relatively inefficient, although feeder roots may reach as deep as 1m (Whiley, 1994). The majority of these white, unsuberized feeder roots are, however, found in the upper 0.6m of soil (Pegg *et al*., 2002). Tree performance is ultimately reflected in yield and quality, and these factors are governed by the condition of the root system, and the severity of pathogen attack on avocado roots.

Phytophthora root rot, caused by the fungus *Phytophthora cinnamomi* Rands, is the most important and destructive disease of avocados worldwide (Pegg *et al*., 2002). Phytophthora root rot has been the main factor limiting successful economic avocado production in countries such as Australia, South Africa and the USA (Coffey, 1987). It attacks trees of all ages, and may kill both nursery and large bearing trees. *Phytophthora cinnamomi* causes rot of feeder roots (Anon, 2004), although invasion of larger roots has also been reported (Pegg *et al*., 2002; Anon, 2004). A moderate tolerance is often observed in avocado trees which do not show degradation of canopy condition (Ploetz and Parrado, 1988). However, symptoms normally manifest in the canopy, resulting in foliage becoming wilted and chlorotic, leaves abscising and branches rapidly dying back. Occurrence of these symptoms depends on root rot severity. In infected trees new leaf growth is minimal, and if leaves do form, they are small and pale green. Fruit set is usually low in root rot affected trees, and fruits are small. Because roots are unable to control salt uptake, chloride accumulates in leaves and may reach toxic levels, resulting in scorching of leaf margins and tips (Whiley *et al*., 1987). The effect of Phytophthora root rot on photosynthate accumulation and storage is of major importance, as infection leads to lower water potential, reduced stomatal openings, and reduced water and nutrient uptake (Sterne *et al.,* 1977, 1978; Whiley *et al.,* 1986).

Prevention of Phytophthora root rot is difficult, and control measures are mostly limited to cultural practices, including the selection of virgin sites and clean plant material (Ohr and Zentmyer, 1991). The use of biological methods to control *P. cinnamomi* has been investigated by numerous authors (Pegg, 1977; Casale, 1990; Duvenhage and Kotze, 1993), and McLeod *et al.* (1995) reported a reduction in *P. cinnamomi* populations of more than 50% with application of *Trichoderma* isolates. To date, host resistance is the best

preventative method for reducing Phytophthora root rot (Coffey 1987). Some rootstocks express tolerance to root rot through the rapid regeneration of active feeder roots while in others the progress of infection in the root is inhibited (Phillips *et al.,* 1987). Avocado rootstocks bred for resistance include Dusa™ and Duke 7 (Kremer-Köhne and Duvenhage, 2000).

Chemical control however remains the most important control measure, and to this end, phosphate-based fungicides play a major role. Phosphonate fungicides, including fosetyl-Al (Aliette®) and its breakdown product phosphorous acid, are highly mobile in plants (Guest *et al.,* 1995) and are believed to control *Phytophthora* spp. by a combination of direct fungitoxic activity and stimulation of host defence mechanisms (Guest *et al*., 1995; Hardy *et al.,* 2001).

Duvenhage (1994) reported that isolates of *P. cinnamomi* obtained from trees treated with fosetyl-Al or H_3PO_3 were less sensitive to these compounds *in vitro*, compared to isolates obtained from untreated trees. He concluded that the possibility of resistance does exist (Duvenhage, 1999), which would pose a serious threat to the avocado industry.

In an attempt to find a viable alternative treatment for Phytophthora root rot of avocado, studies have been conducted to determine the effect of potassium silicate application on *P. cinnamomi* root rot development in both avocado nursery trees and trees in the field. The suppressive effects of silicon on plant diseases have previously been reported (Epstein, 1999; Ma and Takahashi, 2002). Methods of disease suppression by silicon include increased mechanical barriers (Datnoff *et al.,* 1997) and the production of plant enzymes (Samuels *et al.,* 1993) and fungitoxic compounds (Fawe *et al.,* 1998).

The aim of this study was therefore to determine whether the application of soluble silicon in the form of potassium silicate to *P. cinnamomi* infected trees would suppress the disease.

4.3 MATERIALS AND METHODS

4.3.1 Chemicals

Silicon was obtained from Ineos Silicas (Pty) Ltd and potassium phosphonate (Avoguard®) from Ocean Agriculture, Johannesburg, South Africa.

4.3.2 Experimental Layout

An avocado orchard at an altitude of 847m in the Tzaneen area, South Africa (latitude 23° 43’ 60S; longitude 30°10’0E), was selected. Trees consisted of thirteen year old ‘Hass’ on

'Duke7' rootstocks planted at a density of 204 trees.ha^{-1} (7 x 7m spacing). Trees were on a southern facing slope. The presence of *Phytophthora cinnamomi* in the soil was confirmed by means of the citrus leaf baiting technique (Matheron and Tatejka, 1991). Virulent *P. cinnamomi* fungal isolates were obtained from avocado roots plated out on PARPH medium (Jeffers and Martin, 1986) and tested for pathogenicity before the trial was started in November 2004.

Temperature was measured every 30min from January 2005 to July 2006 using a HOBO® H8 data logger (Onset Computer Corporations, Bourne, MA, USA). The data logger was place inside a tree canopy that formed part of the experimental data group, 1.5m above soil level. Rainfall data was obtained from a rain gauge situated in the orchard. Mean bimonthly temperatures and rainfall are presented in Figure 4.1.

The soil drench trial (Experiment 1) consisted of 50 plants with 10 plants per treatment in a completely randomized block design (Appendix B). The trial where potassium silicate was applied as a trunk injection (Experiment 2) consisted of 20 plants with 5 plants per treatment organised in a completely randomised block design (Appendix B).

4.3.3 Standard Management Practices in the Orchard

Soil moisture content was determined by means of tensiometers at 0.3 and 0.6m below the soil surface and water was applied with drip irrigation when tensiometers readings dropped below -40kPa. Chemical fungicides as well as fertilisers were applied at critical periods (Appendix C) during the season according to nutritional requirements, as indicated by soil and leaf analyses. Weeds were managed by regular mechanical slashing between rows.

4.3.4 Treatments

4.3.4.1 Experiment 1

Silicon treatments consisted of trees drenched with a 20l solution of 20ml.l^{-1} soluble potassium silicate (20.7% silicon dioxide) (Bekker *et al.,* 2006) per tree either once, twice or three times in a growing season. Trees injected with potassium phosphonate (Avoguard®) were incorporated as a standard fungicide treatment. Untreated trees served as a control.

4.3.4.2 Experiment 2

Silicon treatments consisted of trees injected with either 20ml of 0.74ml.l^{-1} (200ppm; pH 10.35) or 20ml.l^{-1} (5405ppm; pH 11.46) potassium silicate (20.7% silicon dioxide), or with 20ml of a KOH solution (pH 10.35). These treatments were timed to correspond with the potassium phosphonate (Avoguard®) injections (Appendix C).

4.3.5 Root and Leaf Sample and Photographic Data Collection

For Experiment 1 data was collected from January 2005 to July 2006, and Experiment 2 from March 2005 to July 2006. Digital photographs (described hereafter) and root and leaf samples were taken every second month on the northern side of the tree, and fruit samples were taken at harvest. Trees were harvested in July 2005 and 2006, and fruit count size and total tree yield were determined for each tree.

4.3.6 Assessment of Tree Canopy Condition

The canopy condition was rated according to a Ciba Geigy (Darvas *et al.,* 1984; Bezuidenhout *et al.,* 1987) avocado tree rating scale from 0 to 10 where 0 = healthy looking tree and 10 = dead tree (Appendix D). Ratings were done every second month independently by two parties, as well as from digital photographs taken in the field.

4.3.7 Root Density Assessment

Ten sheets of newspaper were placed on top of one another, within the drip line of each tree, on the soil surface to cover a 0.5m^2 area, and covered with leaf mulch. Newspaper acted as a barrier to ensure avocado feeder roots do not grow into the mulch, but grow in a two-dimensional fashion on top of the soil surface. After two months, the mulch was carefully raked away, and the newspaper was removed. A digital photograph of the exposed feeder roots was taken at a set height of 75cm above the soil surface with a Konika Minolta Dimage Z5 camera (5 megapixel, 35-420mm lens). The newspaper was replaced every second month with new sheets and covered with mulch.

Photographs were analysed using the computer software ImageJ 1.33u (Wayne Rasband, National Institutes of Health, USA). The photos were converted from a RGB colour type photo to an 8-bit image. A threshold (upper threshold 255, lower threshold level 170-195) was assigned to the foreground colour (the yellow/white avocado feeder roots) and the remaining pixels to the background colour (soil surface), whereafter the photo was converted

to a black and white picture. Pixels not related to roots, including leaf material and mulch litter (background noise) in the photo were deleted from the picture (Figure 4.2). The picture was then computer analysed, an area fraction determined and recorded as a percentage root density.

4.3.8 Yield Data

In both experiments avocado fruit were harvested, packed into lug boxes, labelled and transported to the packhouse. Fruit size distribution was determined gravimetrically for individual trees using the international fruit count system. The count number equals the amount of fruit of a certain size that will fit into a 4kg carton (count 10 = 366 to 450g; count 12 = 306 to 465g; count 14 = 266 to 305g; count 16 = 236 to 265g; count 18 = 211 to 235g; count 20 = 191 to 210g; count 22 = 171 to 190g; and count 24 and smaller = < 170g. Yield data for Experiment 2 was not collected during July 2005.

4.3.9 Post-Harvest Disease Rating

The influence of silicon application during the growth season on the incidence of post-harvest diseases on fruit was monitored for two years. As part of the standard spray program in the orchard, fruit received two applications of copper oxychloride (Demildex®) during the 2004/2005 season and one application during the following season (Appendix C). Subsamples of two 4kg cartons of counts 16 (236 - 265g), 18 (211 - 235g) or 20 (191 - 210g) 'Hass' fruit from each tree were taken from the packhouse. Fruit was stored at 5.5°C for 28 days to simulate export conditions. Thereafter fruit was removed from cold storage and stored at 20°C in a temperature controlled room and allowed to ripen.

When fruit reached a firmness of 55 – 65pa, measured with a densimeter, it was cut open and rated according to the method described by Bezuidenhout and Kuschke (1982). Fruit were evaluated externally and internally for post-harvest diseases (anthracnose, stem end rot) and physiological disorders (pulp spot, grey pulp, bruising, vascular browning, cold damage, and lenticel damage). A rating scale of 0 – 3 was used where 0 = healthy fruit and 3 = 100% diseased.

Representative lesions of the different type of post-harvest diseases were selected for pathogen isolations. Fruit was surface sterilized by dipping it into 96% ethanol and left to dry on a work bench. This was repeated twice. Isolations were made by cutting small pieces of fruit pulp from the discoloured tissue on the fringes of lesions. Five pieces were taken from each lesion and plated onto PDA supplemented with 0.01% chloramphenicol. Plates were

incubated at room temperature until sporulation was visible. Representative colonies which developed from the avocado tissue were pure-cultured for identification. Cultures were identified microscopically.

4.3.10 Nutrient Analysis

Leaf and soil samples were taken during July for both 2005 and 2006. Analyses of avocado tissue and soil from the avocado orchard were done by Central Agricultural Laboratories (CAL), Pelindaba, South Africa. Four replicates of the plant material were analysed per treatment. Soil samples were pooled and analysed as a singular sample, and therefore no statistical analysis were done on soil samples.

4.4 RESULTS AND DISCUSSION

4.4.1 Root Health and Canopy Condition

Application of potassium silicate (20.7% silicon dioxide) as a soil drench to control Phytophthora root rot, affected root density positively (Figure 4.3). Higher root densities were recorded throughout the trial period in trees treated with potassium silicate application compared to that of potassium phosphonate (Avoguard®) injections. Significant differences were obtained during March 2005 between Si x 3 (5.54%) and Si x 2 (4.45%) compared to the potassium phosphonate (2.16%) and untreated control treatments (2.35) (Figure 4.4). These differences were negated during drier periods resulting in no significant differences between treatments (May 2005). However, from November 2005 to July 2006, Si x 3 resulted in significantly higher root densities compared to both the untreated control and potassium phosphonate treatments. One (Si x 1) silicon application per season resulted in significantly higher root densities compared to the control treatment except for March 2005 (2.3 vs. 2.35), May 2005 (2.52 vs. 1.39) and March 2006 (7.32 vs. 6.37). Two (Si x 2) silicon applications per season resulted in significantly higher root densities compared to the control during March 2005 (4.45) and for the period of January to July 2006. Differences in root density between treatments correlated with the availability of soil moisture, i.e. rainfall received throughout the season, although seasonal growth flushes and timing of silicon application also played a role. Soil water dissolves the applied potassium silicate. Adequate rainfall therefore ensures optimal quantities of silicon to be available for plant uptake. It has been reported that soluble silicon polymerizes rapidly, resulting in insoluble silicon compounds, while diseases are effectively suppressed only if silicon is present in soluble

form (Bowen *et al*., 1992). To provide maximum protection, and therefore minimize disease development, Bowen *et al.* (1992) suggested silicon to be applied continuously. Results from the current study concur with this, as three applications of silicon resulted in the best disease suppression and stimulation of new root growth. These results (root density) (Figures 4.3 & 4.4), were confirmed by tree canopy ratings (Figure 4.6) as trees that received silicon frequently, showed better canopy conditions compared to the control treatments.

The effect of potassium silicate as a stem injection to control *Phytophthora cinnamomi* severity was not significant in terms of differences in tree feeder root densities (Figure 4.5). Root densities of both potassium silicate injected trees and trees receiving potassium silicate as a soil drench increased under conditions of optimal rainfall. No significant trend could, however, be observed while the trial was conducted. Potassium phosphonate injected trees (12.4%) had significantly higher root densities compared to that of potassium silicate (8.16%) only during July 2006. Potassium hydroxide injections did not induce higher root densities during the summer months, but resulted in higher root densities compared to potassium silicate injected trees during May (KOH = 9.95% vs. 20ml.l^{-1} Si = 7.95%) and July 2006 (KOH = 10.86% vs. 0.74ml.l^{-1} Si = 11.3%). According to Kaiser (1993), a root flush occurs in avocado trees from autumn to early spring. The applied potassium in the form of potassium hydroxide may be translocated to the roots where it is incorporated into newly formed root tissue, explaining the higher root densities. The potassium applied as potassium silicate will not be freely transported to the root system as silicon in not easily translocated, and will therefore not have a similar effect.

Phenological cycling, rather than rainfall, was the determining factor in canopy condition. However, canopy condition followed similar trends to that of root density over the period of data collection. Under conditions of limited drought stress, tree canopies showed less symptoms of disease stress. During dry conditions, canopy condition deteriorated dramatically. This was nullified when rainfall resumed during Dec 2005 (Figure 4.6). All potassium silicate soil drench treatments resulted in lower canopy ratings over the 18 month period of data collection compared to the control. Significant differences were obtained at all data collection dates, except March and July 2006, when potassium silicate soil drench treatments had similar canopy ratings than those observed in the control (3.15 and 3.15) and potassium phosphonate treatments (2.90 and 2.95). This indicates that potassium silicate soil drench treatments reduced drought stress, concomitantly with reducing disease stress.

When potassium silicate was applied as a stem injection to avocado trees infected with *P. cinnamomi* and compared with KOH and potassium phosphonate (Avoguard®) injections,

potassium hydroxide resulted in the lowest disease rating over the period of data collection (Figure 4.7) except for March 2005. Results of potassium silicate injections did not show any clear trends. Anderson *et al*. (2004) injected avocado trees with a disease rating of 5.5 with a 200ppm (0.74ml potassium silicate) solution. They reported stimulation of epicormic buds, with "an eventual significant increase in canopy density", and a 31% mean tree health improvement. In the current study, no epicormic bud bursts were observed, and no simultaneous increase in canopy density was detected. No mention is made as to when epicormic bud burst was observed in relation to phenological cycling. and thus it could possibly be that the cycling observed by Anderson *et al*. (2004) was as a result of normal tree phenology.

If excess water is lost during transpiration, stomata close and a decrease in photosynthetic rate occurs. Transpiration mainly occurs through the stomata and partly through the cuticle. If Si is present in the plant, it is deposited beneath the cuticle forming a double layer (Si-cuticle), which limits transpiration through the cuticle. This can be a great advantage in plants with thin cuticles (Ma and Takahashi, 2002). Gong *et al*. (2005) reported that silicon improved the water status of drought stressed wheat plants with regard to leaf water potential and water content, compared to untreated plants. This also seems to be the case in silicon treated avocado plants. Whiley *et al*. (1986) reported fosetyl-Al foliar sprays or metalaxyl soil applications resulted in higher xylem water potentials and treated plants showed fasted and more complete recovery from water stress due to Phytophthora root rot compared to uninfected trees. A similar situation may be occurring in silicon-treated avocado trees. However, in our study, the overriding influence of silicon seems to be its effect on disease suppression, and therefore canopy condition as an indicator of disease severity. Chérif *et al.* (1994) reported that although silicon had no effect on phenolic concentrations of plants in the absence of pathogen infection, significant differences can, however, be seen in inoculated plants compared to uninoculated control cucumber plants. Concentrations of phenolic compounds in inoculated plants were reported to be double that of uninoculated plants six days after inoculation. The differences seen in avocado canopy condition in our study can therefore possibly be attributed to disease suppression by silicon, and not other external factors influencing tree health.

4.4.2 Post-harvest Disease Rating

No significant differences were seen over a two-year period with regards to black cold damage between treatments. Although this was true for brown cold during 2006, significant differences were observed during 2005 (Table 4.1). Cold damage is a physiological disorder resulting from fruit being subjected to too low temperatures during storage. Woolf *et al*. (2003) reported that external cold damage occurs at storage temperatures below 3 °C. These temperatures cause dark, irregular, but clearly outlined patches on the fruit skin to appear after a few days. Severity is directly proportional to the degree of low temperatures experienced, and the length of time the fruit was subjected to these low temperatures (Swarts, 1984). In the current study, differences between treatments were most likely due to bad circulation in the cold storage room, and not to treatment factors implemented in the orchard. Stomata prominent in young avocado fruit regenerate due to lenticel formation, producing white or grey specks on the fruit rind surface. These become corky and rough, with the epidermis rupturing, causing lenticel damage (Scora *et al.,* 2002). During 2005, treatments receiving the least silicon resulted in the lowest lenticel damage rating with Si x 1 (0.507), Si x 2 (0.714) and control (0.721) differing significantly from the Si x 3 (1.021) soil drench, and the 0.74ml.l^{-1} (0.984) and 20ml.l^{-1} (1.021) potassium silicate injection treatments. During 2006 however, the 20ml (0.138) injection treatment resulted in the lowest rating of lenticell damage compared to all other treatments. Although significant differences were observed, no clear trends could be seen over the two-year period between treatments.

Anthracnose symptoms may develop either before or after harvest, although symptoms appearing after harvest only commence when fruit are ripened. Lesions initially appear as small, light brown circular lesions. As lesions enlarge they, however, become slightly sunken in the centre and change colour to dark brown or black. Symptoms are difficult to see on ripe 'Hass' fruit due to its' dark skin colour (Pegg *et al*., 2002) as a result of increased anthocyanin and decreased chlorophyll a and b levels in the fruit skin (Cox *et al*., 2004). The following fungi were isolated from lesions of 'Hass' avocado fruit in the current study: *Mucor pucillus*, *Botrytis cinerea*, *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl., and *Colletotrichum gloeosporioides* Penzig [telomorph *Glomerella cingulata* (Stonem.) Spauld & Schreck]. During the 2004/2005 season, significant differences in anthracnose ratings were observed between all treatments compared to the control treatment. Fruit from trees injected with 0.74ml.l^{-1} potassium silicate showed the lowest rating of anthracnose with an average rating of 0.143 per box of fruit. This was followed by fruit from potassium phosphonate (Avoguard®) treated trees (0.293), fruit from trees receiving three silicon applications (Si x 3;

0.279) and fruit from trees injected with 20ml.l^{-1} potassium silicate (0.3). No differences were recorded during the 2005/2006 season with regards to anthracnose rating. Anderson *et al.* (2004) injected four year old 'Hass' trees on clonal Velvic rootstocks using 1000ppm potassium silicate (equal to 37ml of a 20.7% silicon dioxide solution). Fruit from injected trees were harvested on three consecutive days, one month apart. Fruit harvested two weeks after injection did not differ significantly from fruit harvested from uninjected trees. However, fruit harvested six and 10 weeks after injection had significantly lower anthracnose ratings compared to uninjected trees. Their findings confirm results of the current study, indicating silicon injection may be a possible preventative measure to control anthracnose incidence and severity in avocado fruit. Anderson *et al.* (2005), however, stated that if silicon was mixed with phosphorous acid (80:20 v/v; pH 6.3), no control of anthracnose occurred. They propose that because silicon solubility was lower at a lower pH, silicon was unavailable to plants at such a low pH.

Stem end rot starts from the pedicel end of fruit and advances internally, causing rot of fruit flesh (Darvas, 1982). Externally, infection lesions turn brown to black coinciding with infectious advancement internally. Internal symptoms include flesh rot, leading to mycelial filled cavities, and are often associated with vascular discolouration (Darvas, 1982). The following fungi were isolated from lesions on the stem end of 'Hass' avocado fruit in the current study: *Phomopsis perseae* Zerova, *Rhizopus stolonifer* (Ehrenb. Ex Fr.) Vuill., *Botrytis cinerea*, *Lasiodiplodia theobromae*, *Alternaria alternata* (Fr:Fr.) Kiesl. and *Colletotrichum gloeosporioides* (telomorph *Glomerella cingulata*). During the 2004/2005 season, Si x 2 application resulted in the lowest average stem end rot rating of 0.4 per box of fruit (Table 4.1). Potassium phosphonate (Avoguard®) (0.7) and Si x 1 (0.757) applications had the highest rating of stem end rot. Surprisingly, Si x 3 (0.679) did not differ significantly from either the potassium phosphonate or Si x 1 treatments. During the 2005/2006 season, the Si x 1 (0.095) and the control (0.06) treatments had significantly higher ratings of stem end rot compared to all other treatments. Anderson *et al.* (2005) reported that injecting trees with silicon had no significant effect on stem end rot incidence and severity thereof.

Fruit harvested in 2005 from trees injected with potassium silicate (viz. ratings of 0.74ml.l^{-1} = 0.135 and 20ml.l^{-1} = 0.1) had significantly lower levels of bruising compared to other treatments (Table 4.1). No trend could be seen between soil drench applications of silicon and the control and potassium phosphonate treatments. No difference was seen between treatments during the 2005/2006 season, and no conclusive deductions can be made at this stage.

Darvas (1982) stated that stem end rot can frequently be associated with the browning of vascular tracts in infected fruit. In the current study, ratings of vascular browning in fruit harvested during 2005 showed a correlation with stem end rot ratings in the same fruit. Si x 2 (0.086) and Si x 3 (0.143) had lower ratings of vascular browning compared to potassium phosphonate (0.357), Si x 1 (0.4) and control (0.379) treatments (Table 4.1). During 2006, fruit from trees injected with 0.74ml.l^{-1} (0.1035) had significantly higher rating of vascular browning compared to silicon at 20ml.l^{-1} (0.0615) and potassium phosphonate (0.0575) treatments.

There was very low incidence of pulp spot over the two seasons and as a result there were no significant differences between treatments (Table 4.1).

There was no incidence of grey pulp in 2005, and even though the incidence was very low in 2006 there were some significant differences between treatments (Table 4.1). Fruit from trees receiving potassium silicate soil drenches showed a higher rating of grey pulp, with Si x 3 (0.0947) and Si x 2 (0.065) differing significantly from potassium phosphonate (0.01) and control (0.04) treatments.

4.4.3 Yield and Fruit Size

Total yield per tree of only Si x 2 (39kg.tree^{-1}) differed significantly from the control treatment (64kg.tree^{-1}) during 2005 (Table 4.2). During 2006, Si x 3 (158kg.tree^{-1}) was significantly different compared to all treatments with regards to the fruit yield per tree, followed by Si x 1 (111kg.tree^{-1}) and Si x 2 (104kg.tree^{-1}) differing significantly from potassium phosphonate (Avoguard®) (74kg.tree^{-1}) and the control treatment (16kg.tree^{-1}). There is, notwithstanding differences between treatments, a significant difference between total yields of 2005 and 2006. This is indicative of the occurrence of bi-annual (alternate) bearing prevalent in avocado orchards. Whiley (1994) reported that flower or fruit pruning to be an effective method to control alternate bearing. He stated that during a heavy crop set, this pruning may be effective to increase fruit size, but during a light bearing year, little differences could be seen in tree yield or fruit size. However, in the present trial no pruning occurred, resulting in a heavy crop set during 2006. The reason why Si x 1 (135kg.tree^{-1}) and Si x 2 (146.9kg.tree^{-1}) had lower yields compared to the control treatments (166kg.tree^{-1}) and potassium phosphonate (Avoguard®) (176kg.tree^{-1}) during 2006 are unclear. It is possible that the third silicon application was applied at a critical time in fruit development or tree

phenological cycle, and that this could have induced bigger-sized fruit, or reduced fruit drop during the second phenological fruit drop.

During 2005 the number of fruits from Si x 1 (222.6 fruits.tree^{-1}) and Si x 2 (189.7 fruits.tree^{-1}) treated trees were significantly lower compared to that of potassium phosphonate (Avoguard®) (294 fruits.tree^{-1}) treated trees and the control (348.1 fruits.tree^{-1}). During 2006, Si x 3 (780.5fruits.tree^{-1}) treated trees resulted in a significantly higher fruit number per tree compared to all other treatments, except for potassium phosphonate (Avoguard®) treated trees. Again, Si x 1 (648.3 fruits.tree^{-1}) and Si x 2 (700 fruits.tree^{-1}) had fewer fruit compared to the potassium phosphonate (Avoguard®) (840.8fruits.tree^{-1}) and control (780.5fruits.tree^{-1}) treatments.

Results from both total yield per tree and the number of fruit per tree indicate that Si x 3 is effective in, if not increasing yield and fruit number, sustaining tree health to a productive level. It should, however, be determined whether the amount of silicon applied, or the timing at which the third application was employed with regard to the tree phenological model, is the determining factor in increasing yield and number of fruit per tree.

No significant differences were seen between treatments over the two harvesting seasons with regards to fruit size in the 10 to 24 count size distribution. However, during 2005, the control treatment (28.52kg.tree^{-1}) showed higher yields in the fruit count increment smaller than 24. Hofman *et al.* (2002) reported fruit from 'Hass' trees with high fruit yields to be generally smaller, and to have a lower rating of anthracnose. This was reiterated in the current study within the fruits smaller that count 24. However, no differences were seen in lower fruit counts, and higher yields were only due to an increase in counts smaller than 24. Fruit size, especially in 'Hass' fruit, remains a problem. Marketing has moved towards 'ripe and ready' fruit, resulting in a niche market for smaller fruit. Producers, however, still aim to obtain maximum yields per unit area, and therefore larger fruit sizes to maximize their profit (Geldenhuis, Pers. com, Tzaneen). Although silicon increases the number of small fruit in 'Hass', especially with three applications timed correctly, this creates scope for other market explorations, or greater freedom during flower or fruit pruning.

In the silicon injection trial no differences were seen in terms of yield, the number of fruit or fruit count size (Table 4.3). This could be due to too low silicon concentrations in the injection solutions. Although Anderson *et al.* (2004) applied a 200ppm solution; they increased their solution concentration to 1000 – 2000ppm (Anderson *et al.,* 2005) during the consecutive experiment. Although their aim was to study the effect of silicon on anthracnose

incidence and severity, higher concentrations have a higher pH, rendering silicon more soluble, mobile, and therefore more efficient in plant tissue.

4.4.4 Nutrient Analysis

Nitrogen levels in all avocado leaf tissue were classified as deficient during 2005 according to standards set by Embleton and Jones (1964), Lahav and Kadman (1980) and Whiley *et al.* (1996a) (Table 4.4), except that of 0.74 ml Si (1.95%) and Si x 3 (1.58%) which were on the border of 1.6%, which is defined as being deficient. There were nonetheless no significant differences between treatments. This deficiency was nullified during the 2006 season by effective fertilizer applications (Appendix B), when all treatments, except Si x 3, were above the minimum level of deficiency. Phosphorous levels in leaf tissue of all treatments were below the deficiency level, indicating possible phosphorous stress. This is of interest as potassium phosphonate (Avoguard®) injections into tree stems leads to rapid translocation of this phosphorous product to photosynthetically active plant material, i.e. leaves. Schutte *et al.* (1988), however, reported that phosphite concentrations in avocado leaves peak three days after injections, and thereafter decrease steadily. The degree to which this decrease occurs is, however, not known. Si x 3 (0.13%) and 0.74ml.l^{-1} (0.12%) Si led to significantly higher phosphorous levels in leaf tissue during 2005 compared to all other treatments (0.1%). This effect of silicon was, however, not carried over to 2006, when no significant differences were observed between treatments.

Numerous authors (Boshoff *et al.*, 1996; Schoeman and Manicom, 2002) have reported on the beneficial effects of copper sprays on post-harvest disease incidence, *Colletotrichum gloeosporioides* in particular. Copper (Demildex) was therefore included into the spray program to inhibit post-harvest disease development. However, this leads to a build-up of copper in, not only soils, but avocado tissue, possibly leading to toxic levels in plants.

Significant differences between treatments were seen during 2005 with regards to boron concentrations in avocado leaf tissue. Si x 3 (39.25mg.kg^{-1} boron) was significantly different from all other treatments. Potassium phosphonate (Avoguard®), (34.75 mg.kg^{-1}), 0.74ml.l^{-1} Si (36 mg.kg^{-1}) and 20ml.l^{-1} Si (36 mg.kg^{-1}) were statistically similar, but still differed significantly from the control (29.75 mg.kg^{-1}). Although all treatments were within the recommended concentration, it does appear that silicon application increases the boron uptake. Although no significant differences were obtained with regards to boron concentration in avocado leaves during 2006, the same trend was observed. Whiley *et al.*

(1996b) reported that boron application may increase fruit set and quality. If silicon application increase boron uptake, this may result in additional benefits of silicon to the avocado plant.

Contrary to the expected outcome, silicon concentrations were not the highest in silicon treated avocado tissue. During 2005, Si x 3 (0.10%) had the lowest silicon concentration, and was statically different to both the potassium phosphonate (Avoguard®) (0.18%) and control (0.23%) treatments. During 2006 however, no significant differences were observed between the Si x 3 (0.30%), potassium phosphonate (Avoguard®) (0.15%) or the control (0.24%) treatments. These levels were however statistically different from the silicon injected treatments.

During 2005 potassium phosphonate (Avoguard®) (1.4%; 0.27%) and Si x 3 (1.4%; 0.3%) had significantly higher nitrogen and phosphorous concentrations in root tissue compared to the control treatment (1.1%; 0.13%)(Table 4.5). Schutte *et al*. (1988) reported the phosphite concentration in avocado roots to peak 21 days after potassium phosphonate (Avoguard®) injections, where after it decreases steadily. This may therefore explain the higher levels in root tissue treated with potassium phosphonate (Avoguard®). Silicon application may aid in phosphorous uptake by plant roots. There were, however, no significant differences between treatments during 2006 with regard to nitrogen or phosphorous concentrations in avocado root tissue.

No differences were obtained for copper concentrations between treatments over the two year period. Potassium phosphonate (Avoguard®) (188mg.kg^{-1}) and Si x 3 (155 mg.kg^{-1}) had significantly higher sodium concentrations in avocado root tissue compared to the control treatment (86mg.kg^{-1}). This effect was however not carried over to 2006. Roots from Si x 3 (2005 = 9110 mg.kg^{-1}; 2006 = 9090 mg.kg^{-1}) had significantly higher iron concentrations compared to all other treatments.

Roots from potassium phosphonate (Avoguard®) treated trees had significantly higher boron levels (108mg.kg^{-1}) compared to both that of the control (90mg.kg^{-1}) and Si x 3 treatments. This effect was again nullified during 2006. There was, however, no significant difference between treatments with regard to root zinc concentrations during 2006. During 2005, potassium phosphonate (Avoguard®) (3.35%) and Si x 3 (3.6%) had significantly higher silicon levels in the root tissue compared to the control (2.45%). This was the case for 2006 as well, where Si x 3 (4.75%) differed significantly from the potassium phosphonate (Avoguard®) (3.18%) and control (3.75%). This indicates that silicon is absorbed by avocado roots, but not effectively translocated in the plant to leaf tissue.

Due to the fact that no statistical analysis was done on soil samples (Table 4.6), only trends will be discussed. The pH of the potassium silicate used is 12.7 (Bekker *et al.,* 2006). This seems to have an effect on soil pH, as Si x 3 treated soil increased the pH from pH 4.73 during November 2004 to pH 5.28 during 2006. As expected, the silicon concentration of the soil receiving three treatments per year increased from 8.19% during 2004 to 18.2% during 2006.

Silicon appears to have an alleviating effect on not only biotic, but also abiotic stress (Bowen *et al*., 1995). This suggests the possibility that the effect of Si on plant growth and performance are only evident when plants are under some form of stress. The effect of silicon on plant growth and disease development in plants is related to the interaction of silicon with other essential and non-essential plant growth elements. Application of silicate fertilizers increased levels of P, Si, Ca, and Cu, and reduce N, K, Mg, Fe, Mn and Zn levels in sugarcane leaves (Elawad *et al*., 1982). Silicate materials also increased pH, Si, P, Ca and Mg in the soil (Sistani *et al.,* 1998).

Wutscher (1989) reported a strong correlation between silicon levels and that of S, P, Fe, Mg, Mn, Cu, Zn and Mo, especially in tree bark, leaves and feeder roots of Valencia oranges (*Citrus sinensis* L.). Korndörfer *et al*. (1999) reported the alleviation of Fe toxicity symptoms by silicon application. It is known that Si reduces Fe and Mn toxicity, and it is thought that Si increases the 'oxidising power' of roots making Mn and Fe less soluble (Ma, 1990). Silicon may alleviate this toxicity not only because it reduces absorption, but also increases the internal tolerance level of the plant to an excess of these elements in the tissue.

Toxicity of these elements depends on the availability of it to the plant for uptake, and this availability is determined primarily by soil pH. Increase in soil pH, as found in the current study, deems these metals insoluble, and therefore limits the uptake thereof (Ma, 1990).

4.5 CONCLUSION

The application of potassium silicate to *P. cinnamomi* infected trees resulted in higher feeder root densities than the control method currently implemented to inhibit the effect of *Phytophthora* infection on avocado trees. Differences in root density between treatments were however affected by the availability of soil moisture, although seasonal growth flushes and timing of silicon application also played a role. This was reiterated in tree canopy ratings, as trees that received silicon frequently had better canopy conditions compared to the control treatments. Results indicate that three silicon applications were the most effective to suppress

the disease and stimulate new root growth. Silicon application should however be timed according to the phenological model with the first application during the period of flowering and fruit set (September); the second to occur before the fruit drop (November); and the third application to be applied before the root flush during February to March (Kaiser, 1993).

Potassium silicate stem injections to inhibit *P. cinnamomi* disease severity were not effective in increasing feeder root densities. Potassium silicate injections did not show any significant trends throughout the trial period, and it is proposed that potassium silicate stem injections are not a viable method to inhibit Phytophthora root rot of avocado trees.

The application of potassium silicate to avocado trees to suppress the infection and spread of Phytophthora root rot seems to be most effective when applied as a soil drench. The possibility of physical barrier formation in roots will be limited as silicon is not actively transported in avocado tissue, and the expression of phenolic and other fungitoxic compounds were confined to plant parts receiving silicon.

Anthracnose severity during the 2004/2005 season was lower in fruit from trees treated with silicon. No significant differences were seen during the 2005/2006 season with regards to anthracnose incidence between treatments. Although some level of inhibition of stem end rot was observed in fruit from trees receiving silicon as a soil drench, results were not consistent, and fruit from silicon injected trees did not differ significantly from the control.

The application of potassium silicate to trees as a soil drench led to higher yields compared to the control treatment. It is possible that increased tree health due to a lower root rot disease severity led to a lower flower/fruit drop, resulting in higher yields compared to the control treatment. Results from both total yield per tree and the number of fruit per tree indicate that Si x 3 is effective in, if not increasing yield and fruit number, sustaining tree health to a productive level.

Three silicon applications resulted in higher boron concentrations in leaves compared to all other treatments and it appears that silicon application increases the boron uptake of avocado plants. Silicon application to avocado trees as a soil drench does not increase silicon translocation to avocado leaves. This indicates that silicon is absorbed by avocado roots, but not effectively translocated in the plant to leaf tissue.

Potassium silicate application to avocado trees as a soil drench leads to an increase in soil pH. This is an especially important additional benefit of silicon application as it is known that most avocado producing areas of South Africa have acidic pHs partly due to the high rainfall and low CEC (cation exchange capacity) of the soil in which avocados are cultivated.

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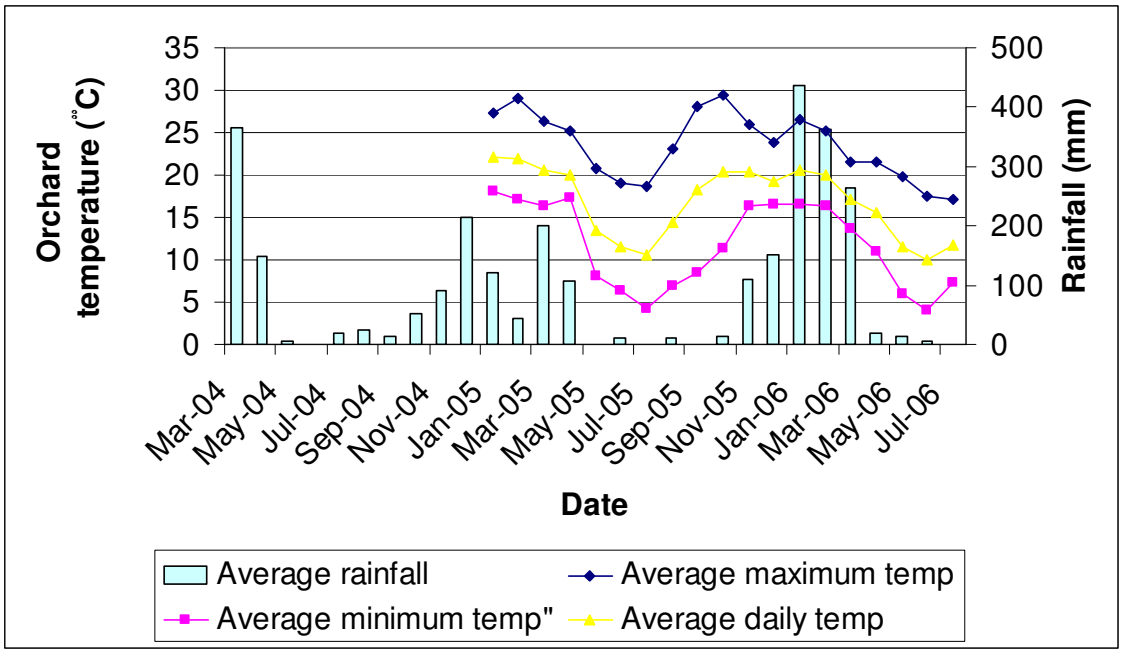


Figure 4.1: Mean bimonthly rainfall data for February 2004 to July 2006, and average maximum, minimum and mean temperatures for January 2005 to July 2006, measured in the orchard in the Tzaneen area, South Africa (latitude 23° 43’ 60S; longitude 30°10’0E).

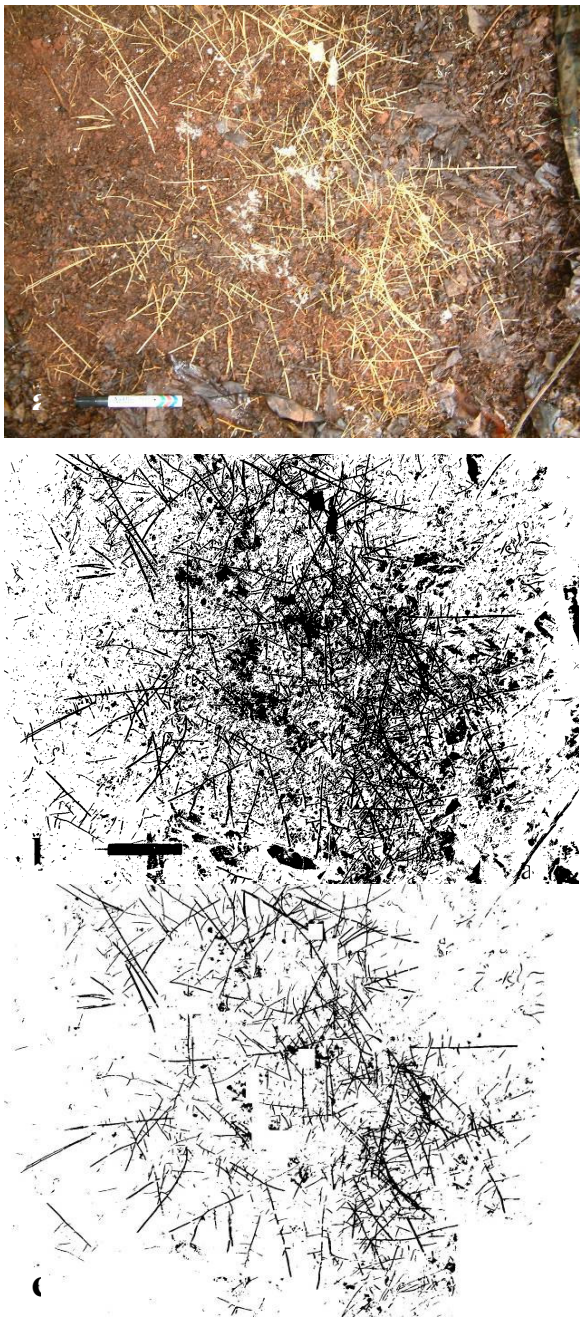


Figure 4.2: Representative photograph preparation for avocado root density determination by means of digital images analysed using ImageJ 1.33u software.

a) Normal photo of avocado roots on soil surface
b) Photo converted to black and white image
c) Pixels not related to roots (including leaf material and mulch litter) removed

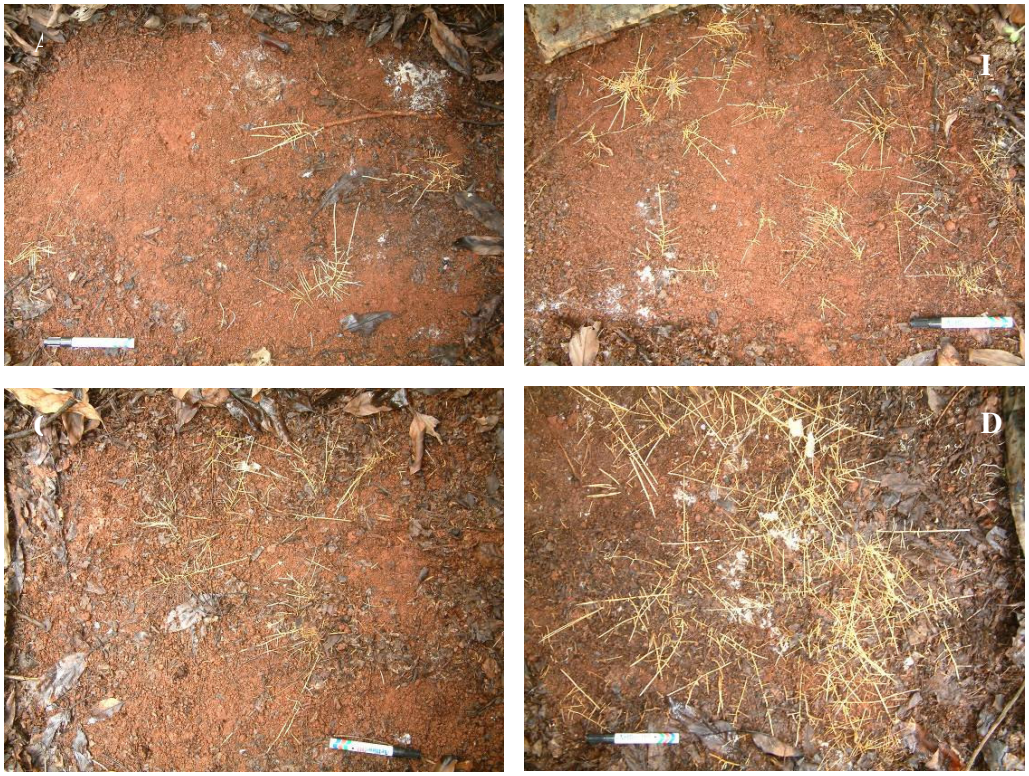
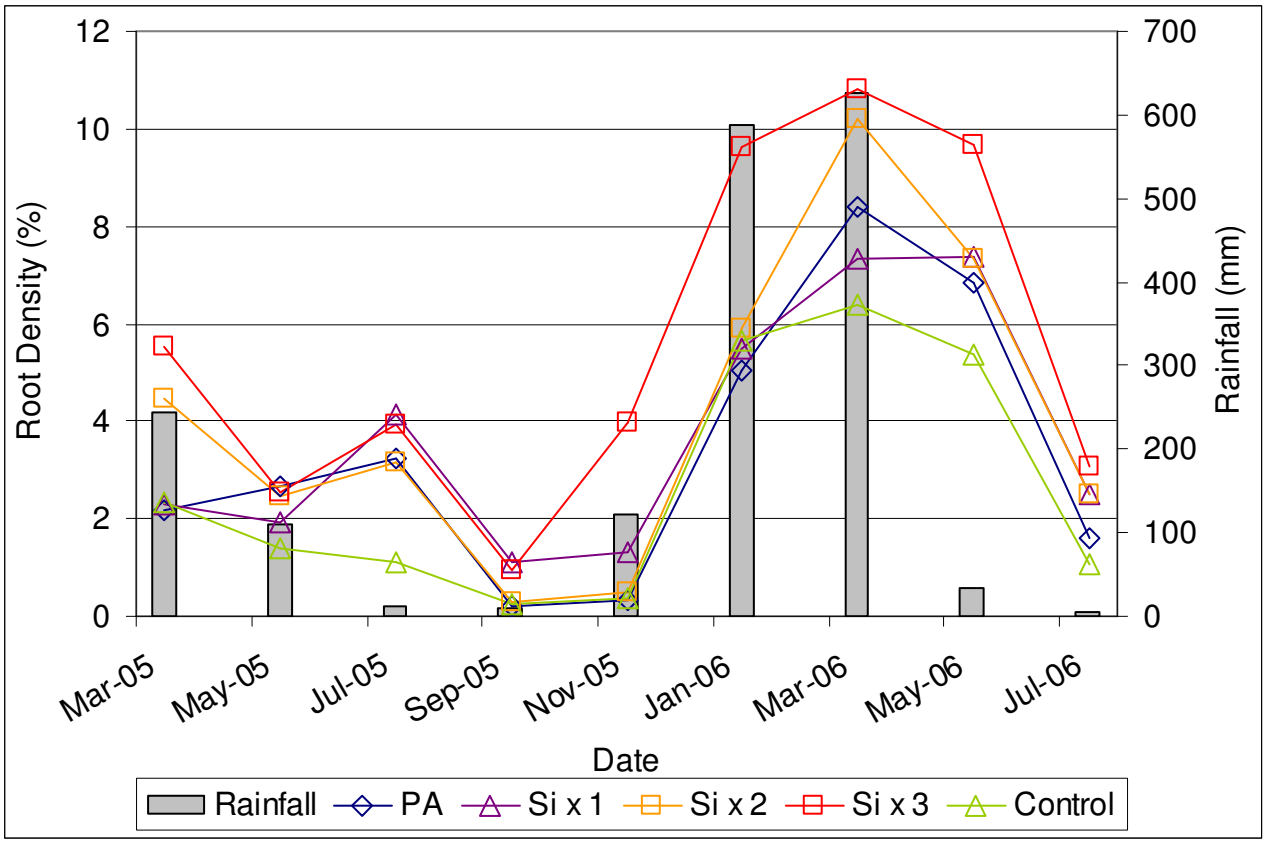
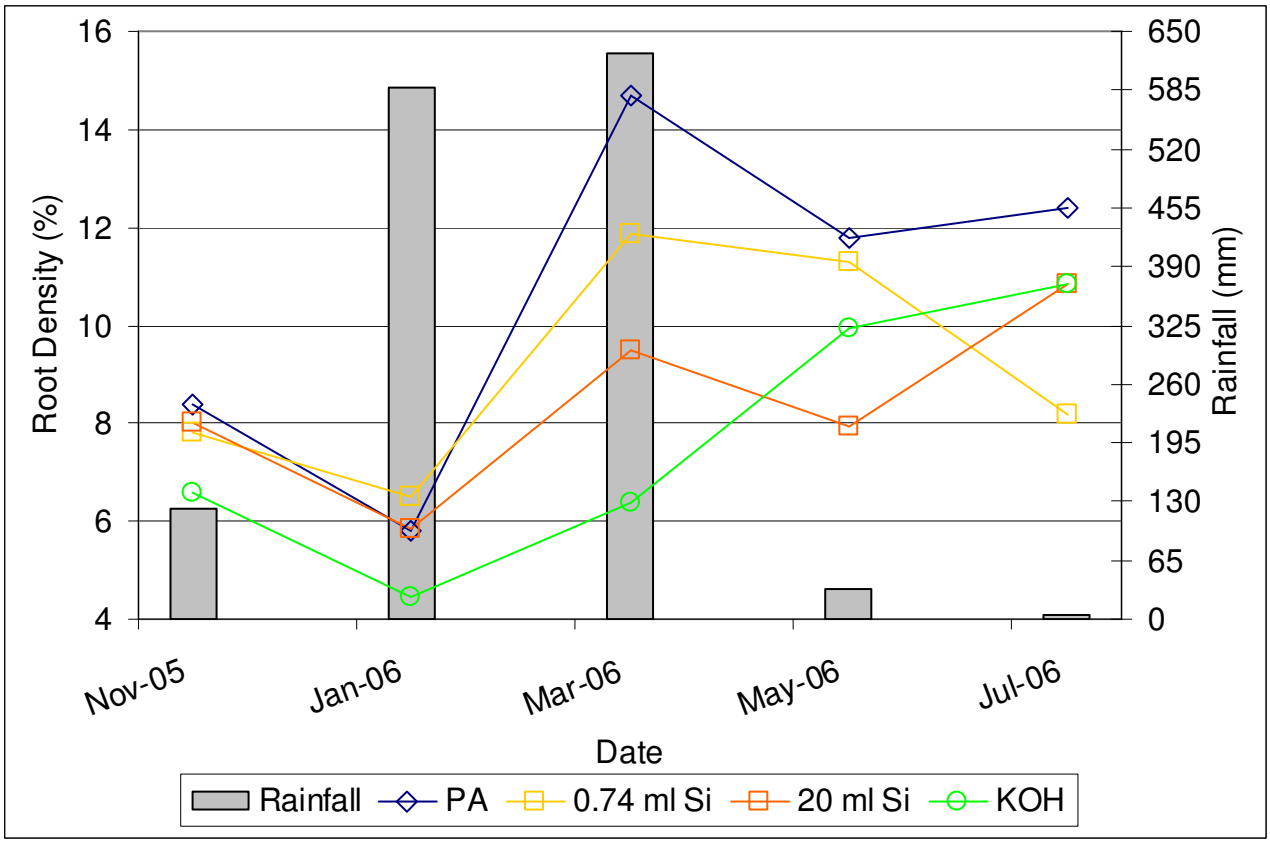


Figure 4.3: Digital images of avocado tree root densities after *P. cinnamomi* infected trees were subjected to the following treatments: A - Control, B - Si x 1 soil drench; C - Potassium phosphonate (Avoguard®) stem injection and D - Si x 3 soil drench.



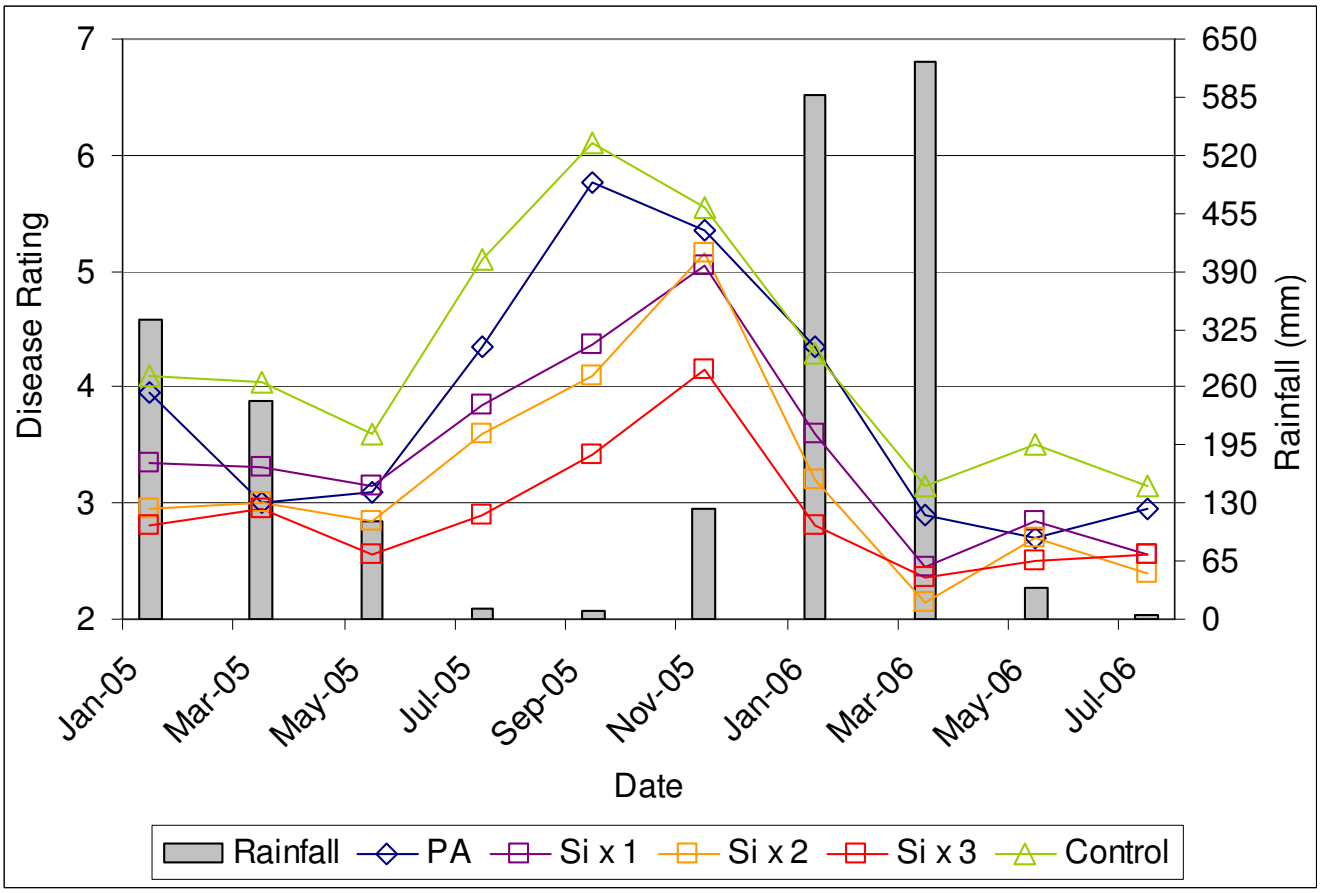
	Mar-05	May-05	Jul-05	Sep-05	Nov-05	Jan-06	Mar-06	May-06	Jul-06
PA	2.16a	2.65a	3.22b	0.20a	0.31a	5.04a	8.38b	6.85ab	1.60a
Si x 1	2.30a	1.93a	4.12b	1.09b	1.30b	5.49b	7.32ab	7.39b	2.48b
Si x 2	4.45b	2.46a	3.16ab	0.28a	0.48a	5.90b	10.18c	7.33b	2.49b
Si x 3	5.54b	2.52a	3.93b	0.93ab	3.98c	9.62c	10.82c	9.65c	3.06b
Control	2.35a	1.39a	1.12a	0.26a	0.38a	5.66a	6.37a	5.38a	1.06a
Rainfall (mm)	244	109	11	10	123	588	625	34	5

Figure 4.4: Avocado tree root density recorded over a period of 18 months to determine whether potassium silicate application as a soil drench to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity and improve root density. Treatments consisted of either one (Si x 1), two (Si x 2) or tree (Si x 3) potassium silicate soil drench applications per year; trees injected with potassium phosphonate (Avoguard®) (PA) and trees receiving no treatment (control). Values in each column followed by different symbols indicate significant differences at a 95% level of significance.



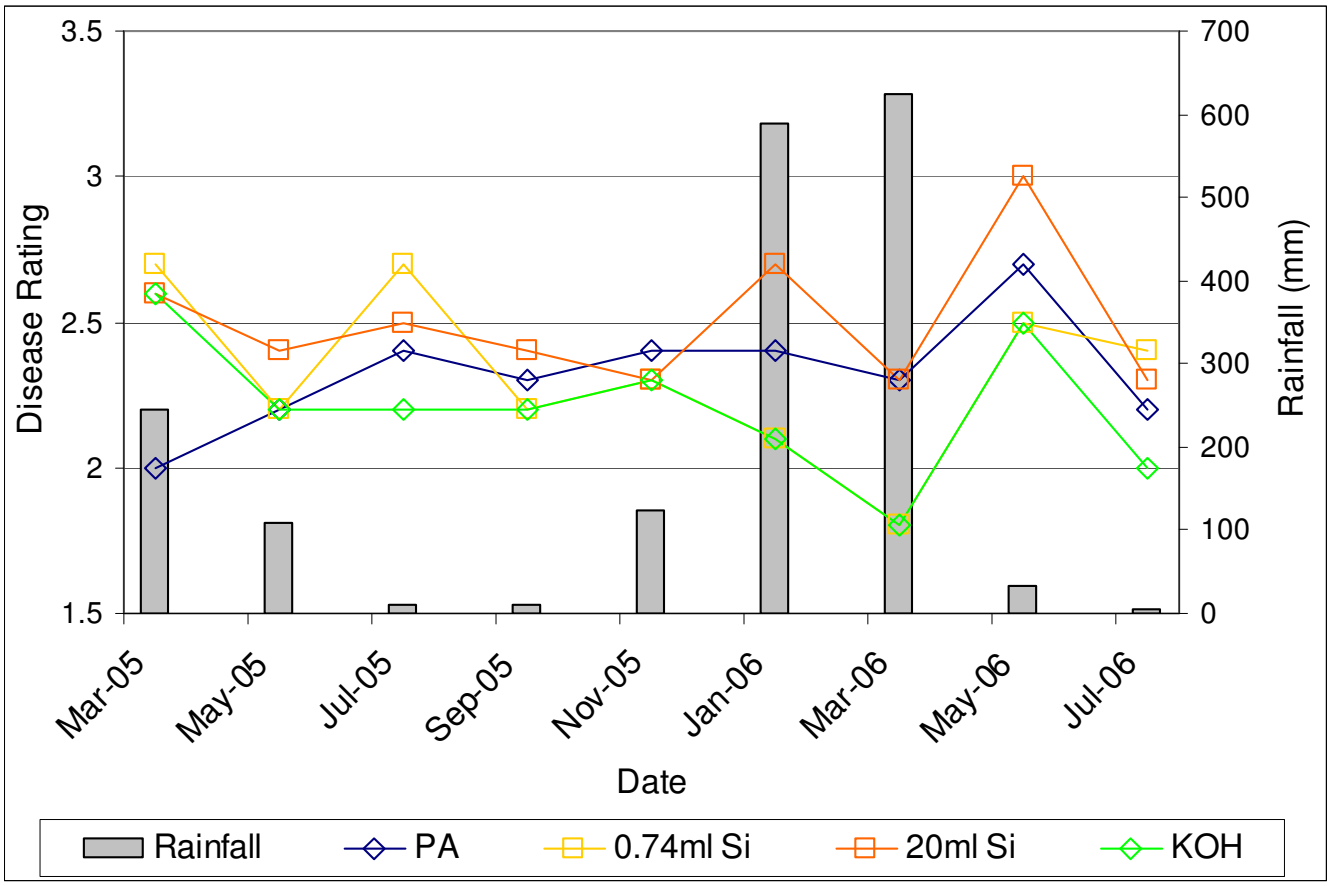
	Nov-05	Jan-06	Mar-06	May-06	Jul-06
PA	8.38b	5.80b	14.68c	11.80c	12.40c
0.74 ml.l^{-1} Si	7.82ab	6.48c	11.88bc	11.30bc	8.16a
20 ml.l^{-1} Si	8.00b	5.86b	9.50b	7.95a	10.86b
KOH	6.56a	4.46a	6.36a	9.95b	10.86b
Rainfall (mm)	123	588	625	34	5

Figure 4.5: Avocado tree root density over a period of 10 months to determine whether potassium silicate applied as a stem injection to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity and improve root density. Treatments consisted of biannual injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate solutions (20.7% silicon dioxide); a KOH solution at pH 10.35 or potassium phosphonate (Avoguard®) (PA). Values in each column followed by different symbols indicate significant differences at a 95% level of significance.



	Jan-05	Mar-05	May-05	Jul-05	Sep-05	Nov-05	Jan-06	Mar-06	May-06	Jul-06
PA	3.90b	3.00a	3.10ab	4.35c	4.35b	5.35b	4.35c	2.90b	2.70a	2.95ab
Si x 1	3.35ab	3.30a	3.15ab	3.85bc	3.85b	5.05b	3.60b	2.45ab	2.85ab	2.55ab
Si x 2	2.95a	3.00a	2.85ab	3.60b	3.60ab	5.15b	3.20ab	2.15a	2.70a	2.40a
Si x 3	2.80a	2.95a	2.55a	2.90a	3.00a	4.15a	2.80a	2.35ab	2.50a	2.55ab
Control	4.10b	4.05b	3.50b	5.10d	5.10c	5.55b	4.30c	3.15b	3.50b	3.15b
Rainfall (mm)	355	244	109	11	10	123	588	625	34	5

Figure 4.6: Avocado canopy condition according to the Ciba Geigy disease rating scale, recorded over a period of 18 months to determine whether potassium silicate application as a soil drench to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity. Treatments consisted of either one (Si x 1), two (Si x 2) or tree (Si x 3) potassium silicate soil drench applications; trees injected with potassium phosphonate (Avoguard®) (PA) and trees receiving no treatment (control). Values in each column followed by different symbols indicate significant differences at a 95% level of significance.



	Mar-05	May-05	Jul-05	Sep-05	Nov-05	Jan-06	Mar-06	May-06	Jul-06
PA	2.0a	2.2a	2.4b	2.3ab	2.4b	2.4b	2.3b	2.7b	2.2b
0.74ml.l^{-1} Si	2.7b	2.2a	2.7c	2.2a	2.3a	2.1a	1.8a	2.5a	2.4c
20ml.l^{-1} Si	2.6b	2.4b	2.5b	2.4b	2.3a	2.7c	2.3b	3.0c	2.3bc
KOH	2.6b	2.2a	2.2a	2.2a	2.3a	2.1a	1.8a	2.5a	2.0a
Rainfall	244	109	11	10	123	588	625	34	5

Figure 4.7: Avocado canopy condition according to the Ciba Geigy disease rating scale recorded over a period of 16 months to determine whether potassium silicate applied as a stem injection to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity. Treatments consisted of biannual injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate solutions; a KOH solution at pH 10.35 or Potassium phosphonate (Avoguard®) (PA). Values in each column followed by different symbols indicate significant differences at a 95% level of significance.

Table 4.1: Post-harvest disease rating in avocado fruit harvested from trees that were used in a study to determine the efficacy of soluble potassium silicate application to avocado trees on *Phytophthora cinnamomi* disease severity. Treatments consisted of injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate solutions (20.7% silicon dioxide); a KOH solution at pH 10.35, one (Si x 1), two (Si x 2) or tree (Si x 3) potassium silicate soil drench applications; trees receiving no treatment (control), or potassium phosphonate (Avoguard®) injected trees (PA). Fruit were stored at 5.5°C for 28 days, left to ripen and rated using a scale where 0 = no incidence of the disease to 3 = a severely infected fruit. Values followed by different symbols within each column for each experiment indicate significant differences at a 95% level of significance.

Treatment	**Disease or Physiological Disorder**								
	Black Cold Damage	Brown Cold Damage	Lenticel Damage	Anthracnose	Stem End Rot	Bruising	Vascular Browning	Pulp spot	Grey Pulp
2005									
PA	0a	1a	0.814bc	0.293b	0.7d	0.214b	0.357d	0a	0a
Si x 1[a]	0a	1.386b	0.507a	0.35c	0.757d	0.357c	0.4d	0a	0a
Si x 2[a]	0a	1.971d	0.714b	0.414c	0.4a	0.486d	0.086a	0a	0a
Si x 3[a]	0a	1.686c	1.021c	0.279b	0.679cd	0.393c	0.143ab	0a	0a
Control	0a	1.6bc	0.721b	0.464d	0.579bc	0.386c	0.379d	0a	0a
0.74ml.l^{-1} [b]	0a	0.843a	0.984c	0.143a	0.484b	0.135a	0.175b	0a	0a
20ml.l^{-1} [b]	0a	1.871cd	1.021c	0.3b	0.593c	0.1a	0.25c	0a	0a
2006									
PA	0.0075a	0.02a	0.195b	0.0275a	0.03a	0.0025a	0.0575a	0a	0.01a
Si x 1[a]	0a	0.01a	0.1675ab	0.0375a	0.095b	0.0225a	0.0925ab	0.0025a	0.055b
Si x 2[a]	0.0075a	0.03a	0.18b	0.025a	0.05a	0.0125a	0.0925ab	0.0025a	0.065bc
Si x 3[a]	0.0158a	0.0368a	0.2b	0.0368a	0.0316a	0a	0.0711ab	0.0026a	0.0947c
Control	0.005a	0.0025a	0.2175b	0.025a	0.06ab	0.0225a	0.075ab	0a	0.04ab
0.74ml.l^{-1} [b]	0a	0a	0.1965b	0.011a	0.032a	0.022a	0.1035b	0a	0.022ab
20 ml.l^{-1} [b]	0a	0.011a	0.138a	0.036a	0.029a	0.012a	0.0615a	0a	0.031ab

[a] Trees treated with a soil drench of potassium silicate

[b] Trees receiving a trunk injection of potassium silicate

Table 4.2: Yield data from avocado trees treated with soluble potassium silicate soil drenches to inhibit *Phytophthora cinnamomi* disease severity. Treatments consisted of one (Si x 1), two (Si x 2) or three (Si x 3) potassium silicate soil drench applications per season, trees receiving no treatment as a control treatment, or potassium phosphonate (Avoguard®) injected trees (PA). Each tree was harvested individually, and fruit sent through a pack line to sort according to size. Values within a column in the table with different symbols indicate significant differences at a 95% level of significance.

Treatment		**Yield (Kg/ tree)**	**Fruits/ tree**	**Fruit Count (Kg/ tree)**								
				< 24	24	22	20	18	16	14	12	10
2005	**PA**	57.2ab	294b	13.41a	10.98a	11.03a	8.97a	12.17a	5.17a	3.57a	0.88a	0a
	Si x 1	42.5ab	222.6a	6.86a	8.58a	5.83a	4.37a	8.11a	4.45a	2.87a	0.47a	0a
	Si x 2	39.6a	189.7a	9.61a	3.72a	6.38a	5.06a	7.43a	4.56a	3.93a	0.84a	0a
	Si x 3	45.2ab	253.8ab	10.55a	9.35a	5.47a	5.57a	7.8a	4.51a	4.27a	1.35a	0.05a
	Control	64.4b	348.1b	28.52b	7.11a	7.45a	7.78a	8.3a	5.64a	4.91a	1.39a	0.05a
2006	**PA**	176b	840.8bc	74.45b	12.49a	13.83a	13.44a	7.05a	1.96a	0.46a	0.04a	0a
	Si x 1	135a	648.3a	111c	10.91a	10.56a	7.22a	3.81a	0.42a	0.09a	0a	0a
	Si x 2	146.9a	700a	104.25c	8.04a	13.64a	12.64a	6.04a	4.93a	0.37a	0a	0a
	Si x 3	202.2c	989.2c	158.25d	16.64a	18.11a	17.37a	8.55a	1.85a	0.37a	0.07a	0a
	Control	166.8b	780.5b	16.8a	13.26a	12.33a	11.68a	5.31a	1.3a	0.4a	0.07a	0a

Table 4.3: Yield data from avocado trees treated with soluble potassium silicate as a stem injection to inhibit *Phytophthora cinnamomi* disease severity. Treatments consisted of biannual injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate injection solutions (20.7% silicon dioxide); a KOH solution at pH 10.35, or potassium phosphonate (Avoguard®) injections (PA). Each tree was harvested individually, and fruit sent through a pack line to sort according to size. Values within a column in the table with different symbols indicate significant differences at a 95% level of significance.

Treatment	**Yield (Kg/ tree)**	**Fruits/ tree**	**Fruit Count (Kg/ tree)**								
			< 24	24	22	20	18	16	14	12	10
PA	176.058a	846.4a	126a	14.79a	14.74a	14.32a	4.93a	0.9a	0.37a	0a	0a
KOH	184.841a	877.8a	135a	11.22a	13.45a	13.02a	7.52a	3.76a	0.79a	0.07a	0a
0.74 ml.l^{-1} Si	214.578a	1030.2a	159a	45.23a	21.13a	12.39a	5.78a	0.74a	0.3a	0a	0a
20 ml.l^{-1} Si	197.009a	940.8a	150a	14.31a	13.76a	9.74a	7a	1.64a	0.55a	0a	0a

Table 4.4: Avocado leaf nutrient concentrations sampled during July of two consecutive years from avocado trees treated with soluble potassium silicate to inhibit *Phytophthora cinnamomi* disease severity. Treatments analysed consisted of three (Si x 3) potassium silicate soil drench applications per season, biannual injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate (20.7% silicon dioxide) injection solutions, trees receiving no treatment as a control, or potassium phosphonate (Avoguard®) injected trees (PA). Standards for nutrient content of avocado tissue were taken from Embleton and Jones (1964), Lahav and Kadman (1980) and Whiley *et al*. (1996a). Values within a column in the table with different symbols indicate significant differences at a 95% level of significance.

LEAF	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**S**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**Mo**	**Si**
	%	**%**	**%**	**%**	**%**	**mg/kg**	**%**	**mg/kg**	**Mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**%**
Control July 2005	1.55a	0.10a	0.41a	1.13a	0.83a	18.75a	0.21a	86.25a	200.75a	824.75a	36.25a	29.75a	0.80a	0.23b
PA July 2005	1.45a	0.10a	0.39a	0.94a	0.73a	13.50a	0.21a	73.75a	142.25a	681.75a	31.00a	34.75b	1.47a	0.18b
Si x 3 July 2005[a]	1.58a	0.13b	0.44a	1.04a	0.84a	10.75a	0.24a	125.50a	121.75a	670.50a	33.50a	39.25c	2.30a	0.10a
0.74 ml.l^{-1} Si July 2005[b]	1.95a	0.12b	0.49a	0.92a	0.78a	12.25a	0.24a	115.50a	124.25a	676.50a	32.25a	36b	1.68a	0.11ab
20 ml.l^{-1} Si July 2005[b]	1.53a	0.10a	0.41a	0.92a	0.78a	10.50a	0.22a	95.00a	113.00a	694.75a	35.00a	36b	1.79a	0.15ab
Control July 2006	1.75a	0.12a	0.50a	0.97a	0.75a	18.50a	0.23a	164.50a	134.00a	716.75a	34.00a	33.25a	1.88a	0.24b
PA July 2006	1.80a	0.11a	0.44a	0.99a	0.76a	7.00a	0.25a	116.25a	172.50a	663.25a	33.25a	37.25a	2.77a	0.15ab
Si x 3 July 2006[a]	1.58a	0.13a	0.44a	1.04a	0.84a	10.75a	0.24a	125.50a	121.75a	670.50a	33.00a	39.25a	2.31a	0.30b
0.74 ml.l^{-1} Si July 2006[b]	1.95a	0.12a	0.49a	0.92a	0.78a	12.25a	0.24a	115.50a	124.25a	676.50a	32.25a	36.00a	1.68a	0.12a
20 ml.l^{-1} Si July 2006[b]	1.73a	0.11a	0.45a	1.07a	0.82a	7.50a	0.23a	174.00a	112.75a	81.25a	33.75a	35.25a	1.94a	0.13a
	N	**P**	**K**	**Ca**	**Mg**	**Na**	**S**	**Cu**	**Fe**	**Mn**	**Zn**	**B**		
Deficient	1.60	0.08	0.4	0.50	0.15		0.05	2-3	20-40	10-15	10-15	10-20		
Commercial Range	1.6-2.8	0.08-0.2	0.75-1.5	1-3	0.25-0.8		0.2-0.6	5-15	50-200	30-500	40-80	40-60		
Excess	3.00	0.30	3.00	4.00	1.00	0.25-0.5	1.00	25.0		1000	100	100		

[a] Trees treated with a soil drench of potassium silicate

[b] Trees receiving a trunk injection of potassium silicate

Table 4.5: Avocado root nutrient concentrations for two consecutive years sampled during July from trees used in a study to determine the efficacy of soluble potassium silicate application to avocado trees on *Phytophthora cinnamomi* disease severity. Treatments analysed consisted of three (Si x 3) potassium silicate soil drench applications per season, biannual injections of either 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate injection solutions (20.7% silicon dioxide), trees receiving no treatment as a control, or potassium phosphonate (Avoguard®) injected trees (PA). Data for 0.74ml.l^{-1} or 20ml.l^{-1} potassium silicate injections in 2005 are not available due to lack of samples taken. Values within a column in the table with different symbols indicate significant differences at a 95% level of significance.

ROOTS	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**S**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**Mo**	**Si**
	%	**%**	**%**	%	%	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	**%**
Control July 2005	1.1a	0.13a	0.29a	0.62a	0.21a	86a	0.11a	1360a	7800a	593a	204ab	90a	6.53b	2.45a
PA July 2005	1.4b	0.27b	0.31a	1.37a	0.4c	188b	0.17a	2170a	7810a	848b	168a	108b	2.52a	3.35b
Si x 3 July 2005[a]	1.4b	0.3c	0.43b	0.96a	0.31b	155b	0.14a	1460a	9110b	569a	253b	85a	3.14a	3.60b
Control July 2006	1.28a	0.19a	0.29a	0.99a	0.34a	161a	0.14a	1680a	7768a	815c	255.5a	147a	1.52a	4.75b
PA July 2006	1.30a	0.21a	0.33a	0.98a	0.32a	145a	0.15a	1768a	7758a	685a	328a	138a	3.8a	3.18a
Si x 3 July 2006[a]	1.20a	0.18a	0.24a	0.83a	0.29a	159a	0.13a	1693a	9090b	793bc	185a	115a	3.26a	4.75b
0.74 ml.l^{-1} Si July 2006[b]	1.15a	0.15a	0.22a	0.95a	0.26a	94.75a	0.13a	1326a	8073a	653a	211.5a	133a	2.93a	4.69ab
20 ml.l^{-1} Si July 2006[b]	1.28a	0.17a	0.3a	1.13a	0.32a	100.3a	0.15a	1555a	7775a	749b	214.5a	138a	3.49a	4.33ab

[a] Trees treated with a soil drench of potassium silicate

[b] Trees receiving a trunk injection of potassium silicate

Table 4.6: Soil nutrient analysis from an avocado orchard treated with soluble potassium silicate as a soil drench to inhibit *Phytophthora cinnamomi* disease severity. Soil samples analysed were taken from three (Si x 3) potassium silicate soil drench applications per season and trees receiving no treatment (control).

	pH (KCl)	**K**	**Mg**	**Na**	**Resistance**	**Ca**	**Mg**	**Na**	**Ca:Mg**
		mg/kg	mg/kg	mg/kg	Ohms	%	%	%	
November 2004	4.73	250	172	19	3500	36.59	41.94	2.46	0.87
Control July 2005	4.67	100	259	15	3000	62.1	32.92	1.01	1.89
Control July 2006	5.04	108	267	16	1500	62.03	32.79	1.04	1.89
Si x 3 July 2005	5.03	105	210	11	4000	69.37	25.87	0.72	2.68
Si x 3 July 2006	5.28	175	315	12	1500	52.82	39.53	0.8	1.34
	Ca+Mg)/K	**Mg:K**	**S-Value**	**Zn**	**Cu**	**Mn**	**Fe**	**Si**	
			cmol(+)/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	
November 2004	4.13	2.2	3.36	18	34	100	5	8.19	
Control July 2005	23.96	8.3	6.45	42	34	75	5	10.94	
Control July 2006	22.91	7.92	6.67	23	39	87	6	12.33	
Si x 3 July 2005	23.6	6.41	6.65	27	27	53	5	12.89	
Si x 3 July 2006	13.48	5.77	6.53	34	34	68	5.8	18.2	