INHIBITION OF *Phytophthora* ROOT ROT OF AVOCADO WITH POTASSIUM SILICATE APPLICATION

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Phytophthora cinnamomi (Pc) causes avocado root rot which in severe cases leads to tree death. An alternative was sought to the use of phosphonate fungicides to control the disease. In greenhouse experiments, root rot in trees drenched three times with soluble potassium silicate was similar to that of uninoculated control trees. Silicate treatment of *Pc* inoculated trees rendered a better suppression of *Phytophthora* root rot than potassium phosphonate treatment, and silicate treated trees yielded the highest root mass. In field experiments done with Hass on Duke 7 trees in a *Pc* infested orchard, three soil drench applications of potassium silicate resulted in higher root densities than the untreated control as well as the potassium phosphonate (PA) treatment. Better results were obtained as regards root rot control during the drier periods (May 2005). Improved root densities were recorded for silicate treatments from Nov 2005 to July 2006. Furthermore, the data indicated that a single application of silicate was not effective. These results indicate that repeated application of potassium silicate as a soil drench has potential as an alternative control measure for avocado root rot.

Keywords: Avocado, *Persea americana, Phytophthora cinnamomi*, Root rot, silicon, Potassium silicate

INHIBICIÓN DE LA PODREDUMBRE DE LA RAIZ DEL PALTO CAUSADA POR *Phytophthora* CON LA APLICACIÓN DE SILICATO POTÁSICO

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Phytophthora cinnamomi (Pc) causa la pudrición de la raíz del aguacate que en casos graves resulta en la muerte del árbol. Para controlar la enfermedad, se buscó una alternativa al uso de fungicidas en base a fosfonatos. En los experimentos de invernadero, la pudrición de raíces en árboles rociados tres veces con sillicato de potasio soluble era similar al de árboles testigos no inoculados. El tratamiento en base a silicato contra Pc fue más eficiente en suprimir la pudrición de raíces causada por Phytophthora que el tratamiento en base a fosfonato de potasio; mientras que el tratamiento en base a silicato produjo la mayor masa radical. En los experimentos de campo hechos con Hass sobre árboles de Duke 7 en un huerto infestado con Pc, tres aplicaciones de abundante silicato de potasio sobre el suelo, lograron una mayor densidad radicular con respecto al testigo no tratado al igual que el tratamiento en base a fosfonato de potasio (PA).

Los mejores resultados con respecto al control de pudrición de raíces fueron obtenidos durante períodos más secos (mayo 2005). Las mejores densidades de raíces fueron logradas en los tratamientos de silicato desde noviembre de 2005 a julio de 2006. Además, los datos indicaron que una sola aplicación de silicato no era eficaz. Estos resultados demuestran que aplicaciones repetidas abundantes de silicato de potasio sobre el suelo son una potencial alternativa como medida de control de la pudrición de raíces del palto.

Palabras claves: Aguacate, *Persea americana*, *Phytophthora cinnamomi*, putrefacción de la raíz, silicio, silicato del potasio.

Introduction

Phytophthora root rot, caused by the fungus *Phytophthora cinnamomi* Rands, is the most important and destructive disease of avocados worldwide and causes root rot of the white, unsuberized feeder found in the top 600mm of soil (Pegg *et al*., 2002). *Phytophthora* root rot has been the main economic factor limiting successful avocado production in countries such as Australia, South Africa and the USA (Coffey, 1987).

Prevention of *Phytophthora* root rot is difficult, and prevention measures are mostly limited to cultural practices (Ohr and Zentmyer, 1991). To date, host resistance is the best preventative method for reducing *Phytophthora* root rot (Hardy *et al.,* 2001).

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).

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) as well as 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.

Material and Methods

Four replicate greenhouse experiments were conducted over a period of two years to determine the efficacy of potassium silicate in inhibiting *Phytophthora* root rot in avocado nursery trees. Avocado nursery trees grown in composted pine-bark medium were replanted in 5l plastic pots in steam-sterilized soil and allowed to re-establish before the experiment was initiated. Treatments consisted of a) *P. cinnamomi* inoculated trees drenched with $20ml.l^{-1}$ soluble potassium silicate (20.7% silicon dioxide) at the rate of one litre per tree as a once of application; or b) multiple applications of potassium silicate (20.7% silicon dioxide) before and after inoculation (Bekker *et al*., 2006); c) trees treated with potassium silicate and not inoculated; d) inoculated trees treated with potassium phosphonate (Avoguard®); e) trees inoculated and untreated; f) and trees uninoculated and untreated. Ten replicate trees were assigned to each treatment and pots were placed randomly on the greenhouse benches to ensure even growth. Trees were grown in controlled environment greenhouses and watered manually every second day with 300ml water per pot. Trees were inoculated by applying 80ml of *P. cinnamomi* colonized millet seed inoculum into four holes in the soil around the stem of each tree (Bekker, 2007). At harvest, tree root condition was assessed according to a root rot rating scale of 1 to 5 (1 = roots completely rotten, with no root ball present; 5 = no root rot, with a healthy intact root ball) Fresh and dry mass was determined gravimetrically for both roots and shoots of each plant.

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 $204 trees.ha^{-1}$. The trial consisted of 50 trees with 10 trees per treatment in a completely randomized block design. 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. Data was collected from January 2005 to July 2006, 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. Ratings were done every second month independently by two parties. Root density was determined every second month by digital analysis of avocado feeder roots photographs according to the method described by Bekker *et al.* (2006).

Results and Discussion

Silicon treated trees (Table 1) showed no root rot, similar to uninoculated untreated control trees, and these trees had similar or higher levels of root regeneration. Soluble silicon polymerizes rapidly, resulting in insoluble silicon compounds (Epstein, 2001). For effective disease suppression silicon must therefore be applied continuously (Bowen *et al*., 1995). This seems to be confirmed by results from the present study, as trees receiving one silicon application one day before inoculation did not exhibit improved resistance to *Phytophthora* root rot.

Phosphonate fungicides are currently the preferred option of control of *Phytophthora* root rot in avocados (Hardy *et al.,* 2001). In the current study silicon application inhibited *Phytophthora* root rot to levels similar to, or better than those obtained by potassium phosphonate applications. Wutscher (1989) reported that in young orange trees, silicon accumulates in young leaves and feeder roots, leading to protection of plant roots from infection. Root rot data in the present study however tends to reiterate the findings of Chérif *et al*. (1994) who stated that silicon deposited on the surface of roots makes plant cells less susceptible to enzymatic degradation by fungal pathogens. These findings are of paramount importance to the avocado industry as it implies that potassium silicate may be proposed as a possible alternative control for *P. cinnamomi* root rot on avocado nursery trees.
Because pathogens affect physiological processes including photosynthesis, it is likely that changes in the amount of biomass and nutrients accumulated might also occur (Ishiguro, 2001). Fresh root masses of uninoculated, untreated trees; inoculated, potassium phosphonate treated trees; trees treated with silicon one day before inoculation; and silicon treated trees were statistically similar to each other, but differed significantly from the inoculated, silicon treated trees with regards to fresh root mass, the latter having the highest average fresh root mass (Table 2). This implies that silicon either stimulates growth or imparts some form of protection to avocado roots if applied prior to *P. cinnamomi* inoculation. This protection has long been thought to be that of a physical barrier due to strengthening of the cell wall (Nicholson and Hammerschmidt, 1992).

Application of potassium silicate (20.7% silicon dioxide) as a soil drench to control *Phytophthora cinnamomi* root rot, affected root density of field-grown trees dramatically. 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 1). 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). 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. 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 3 & 4) were confirmed by tree canopy ratings as trees that received silicon frequently, showed better canopy conditions compared to the control treatments.

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 2). 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 reducing disease stress.

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 that fosetyl-Al foliar sprays or metalaxyl soil applications resulted in higher xylem water potentials and treated plants showed faster 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.

CONCLUSION

Potassium silicate application to *Phytophthora cinnamomi* infected nursery trees resulted in effective inhibition of root rot, similar to levels obtained by commercial application of potassium phosphonate (Avoguard®). Potassium silicate application imparts protection to roots under infection pressure, and induces new root growth. The beneficial effect of potassium silicate is however dependant on reapplication, as these beneficial effects is lost if control is reliant on only one application. The timing of reapplication will be determined by, amongst other factors, the growth medium characteristics, as silicon leaches easily in media with low cation exchange capacity, rendering the applied silicon as unavailable for plant uptake. Sandy soil will therefore necessitate more regular applications of silicon to maintain the level of disease suppression reached in the host plant.

Root rot of inoculated trees treated with silicon were either statistically comparable to, or better than root rot in inoculated trees treated with potassium phosphonate, the standard commercial fungicide, implying that silicon does induce some form of resistance in the plant suppressing fungal penetration and infection. These findings are of paramount importance as this implies that

potassium silicate may be an alternative control to inhibit *P. cinnamomi* root rot on avocado trees.
Silicon treated trees had the highest fresh and dry root mass compared to all other treatments. This implies that silicon either stimulates growth or imparts some form of protection to avocado roots if applied prior to *P. cinnamomi* inoculation. Leaf fresh mass of inoculated, silicon treated trees were similar to that of uninoculated, untreated trees. For experiments grown in sandy soils, inoculated, potassium phosphonate treated trees resulted in the lowest leaf dry mass compared to all the other treatments.

The application of potassium silicate to *P. cinnamomi* infected trees under field conditions resulted in higher feeder root densities than those treated with potassium phosphonate. 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 is 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 is the most effective to suppress the disease and stimulate new root growth.

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Table 1: Effect of treatments with potassium silicate and potassium phosphonate on root rot of *Phytophthora cinnamomi* inoculated avocado nursery trees in the greenhouse. Values in each column followed by the same letter do not differ significantly at 5% confidence interval. Root rot assessed according to a rating scale of 1 to 5 (1 = roots completely rotten; and 5 = no root rot).
Tabla 1: El efecto de tratamientos con el phosphonate del silicato del potasio y del potasio en la putrefacción de la raíz del *Phytophthora cinnamomi* inoculó árboles del cuarto de niños del aguacate en el invernadero. Los valores en cada columna seguida por la misma letra no diferencian perceptiblemente en el intervalo de la confianza del 5%. Arraigue la putrefacción determinada según una escala de grado de 1 a 5 (1 = arraiga totalmente putrefacto; y 5 = ninguna putrefacción de la raíz).

Treatment	**Root rot**
Silicon 1day before inoculation	2.28a
Uninoculated, untreated control	3.96c
Inoculated, untreated control	2a
Inoculated & potassium phosphonate	2.74ab
Silicon	3.7c
Inoculated & Silicon	3.12bc

Table 2: Effect of treatments with potassium silicate and potassium phosphonate on root and shoot fresh (FM) and dry (DM) mass (g) of *Phytophthora cinnamomi* inoculated avocado nursery trees in the greenhouse. Values followed by the same letter do not differ significantly at 5% confidence interval.

Tabla 2: El efecto de tratamientos (en cuatro réplicas) con el phosphonate del silicato del potasio y del potasio en raíz y el lanzamiento fresco (FM) y seca (DM) (g) total del *Phytophthora cinnamomi* los árboles inoculados del cuarto de niños del aguacate en el invernadero. Los valores seguidos por la misma letra no diferencian perceptiblemente en el intervalo de la confianza del 5%.

	Experiment 1		**Experiment 2**				**Experiment 3**				**Experiment 4**			
	Root	Leaf	Root		Leaf		Root		Leaf		Root		Leaf	
	DM	DM	FM	DM	FM	DM	FM	DM	FM	DM	FM	DM	FM	DM
Silicon 1day before inoculated	11.50a	15.28c	43.42b	14.00a	47.16a	18.15a	77.34a	23.33a	42.47ab	17.99a	118.84a	49.67a	173.54ab	66.61a
Uninoculated, untreated control	11.61a	8.96a	39.58b	17.89a	45.12a	18.32a	99.09a	27.75a	55.62b	20.52a	150.34a	64.29a	214.40b	88.39b
Inoculated, untreated control	9.78a	8.53a	24.08a	10.71a	46.69a	18.70a	65.24a	19.18a	50.16b	22.59a	113.60a	48.25a	172.23a	72.19ab
Inoculated & potassium phosphonate	11.85a	12.61b	40.98b	14.41a	54.61a	22.24a	59.46a	17.50a	29.27a	15.33a	135.16a	56.40a	160.56a	64.43a
Uninoculated, Silicon treated	12.10a	11.26ab	39.59b	15.22a	43.34a	18.56a	82.71a	21.16a	44.09b	17.80a	128.07a	50.59a	163.35a	68.27ab
Inoculated & Silicon	12.83a	13.46bc	58.11c	17.95a	55.30a	22.59a	107.56a	28.06a	43.59b	17.69a	172.29a	69.75a	204.25b	78.63b

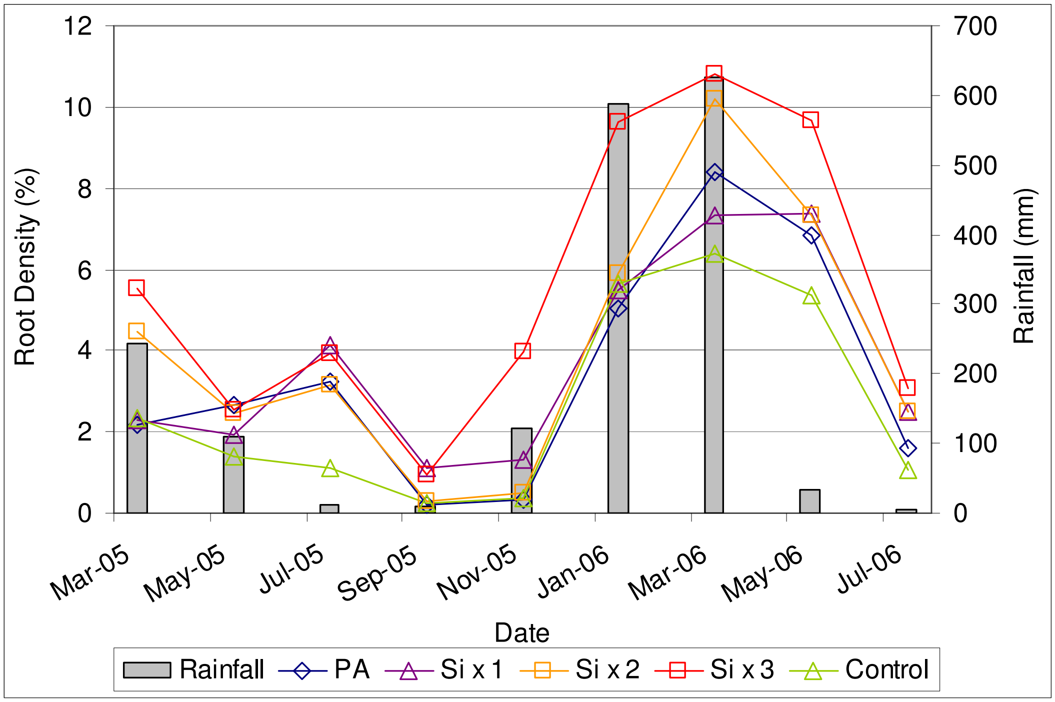

Figure 1: Avocado tree root density recorded over a period of 18 months to determine whether potassium silicate application as a soil drench to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity and improve root density. Treatments consisted of either one (Si x 1), two (Si 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.

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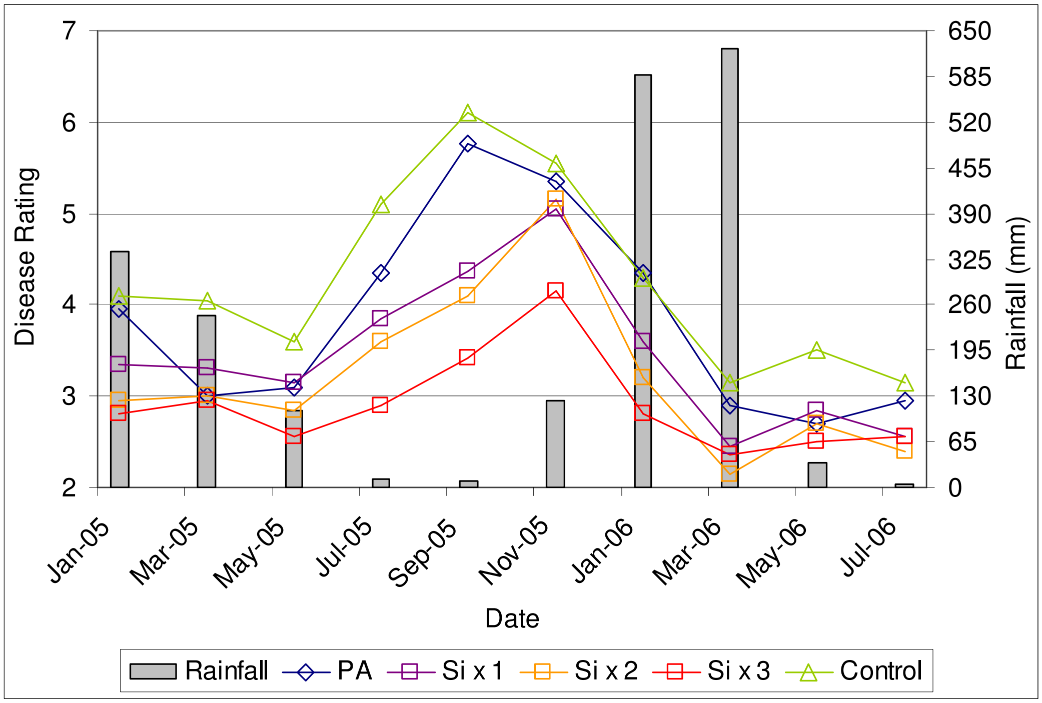

Figure 2: Avocado canopy condition according to the Ciba Geigy disease rating scale, recorded over a period of 18 months to determine whether potassium silicate application as a soil drench to diseased avocado trees, could suppress *Phytophthora cinnamomi* disease severity. Treatments consisted of either 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.

Cuadro 2: Condición del pabellón del aguacate según la escala de grado de la enfermedad del Ciba Geigy, registrada durante 18 meses para determinarse si el uso del silicato del potasio como tratamiento del suelo a los aguacates enfermos, podría suprimir severidad de la enfermedad del cinnamomi de Phytophthora. Los tratamientos consistieron en uno (el silicio x 1), dos (el silicio x 2) o árbol (usos del tratamiento del suelo del silicato del potasio del silicio x 3); árboles inyectados con el phosphonate del potasio (Avoguard®) (PA) y árboles que no reciben ningún tratamiento (control). Los valores en cada columna siguieron por diversos símbolos indican diferencias significativas en un nivel del 95% de la significación.