1 **Soil amendments and suppression of *Phytophthora* root rot in avocado (*Persea indica*)**

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9 **Short title** Suppression of *Phytophthora* root rot by soil amendments

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12

Abstract

The ability of microbial or mineral-based soil additives to suppress root rot caused by *Phytophthora cinnamomi* was assessed. Phosphite and metalaxyl treatments for the control of disease, and glyphosate for weed control were also assessed. A treatment simulating avocado orchard conditions had chicken manure, wood mulch, and mulch from beneath trees in an avocado orchard added to the pots. Soil treatments (three probiotic and two mineral-based) were applied to 9-month-old saplings growing in containers in a glasshouse. After one-month, half of the plants of each treatment were inoculated with the pathogen. Three months after inoculation, plants were harvested and plant growth and root damage were measured. In the first experiment infestation with *P. cinnamomi* significantly reduced fine root dry weight in all plants except those in soil treated with one silicon-based mineral mulch. Visible root damage was higher in plants treated with probiotics. In this experiment, and in a repeat experiment the reduction of fine root damage achieved by spraying plants with phosphite or addition of a silica based mineral mulch was similar. Phosphite was preferable to metalaxyl as a chemical treatment, as the latter reduced shoot and root growth of non-infected plants. Glyphosate treatment of wheat seedlings growing in the pots with the avocados reduced shoot and fine root growth of both non-infected and infected plants. These observations need to be confirmed under field conditions.

32 **Introduction**

33 Phytophthora root rot caused by the oomycete *Phytophthora cinnamomi* is one of the
 34 worst avocado diseases worldwide. This pathogen attacks the feeder roots of avocado
 35 trees, and if left untreated can result in the death of trees and high economic losses
 36 (Reeksting et al. 2016; Ramirez-Gil et al. 2017). Management strategies include
 37 controlling movement of people, livestock and vehicles, the use of chemicals, soil
 38 additives and development of *P. cinnamomi*-tolerant cultivars or rootstocks (D'Souza et al.
 39 2005). The most robust and environmentally benign methods are integrated management
 40 approaches (Pegg and Whaley 1987; Wolstenholme and Sheard 2010) including selection
 41 of tolerant varieties, application of organic fertilizers and mulches, addition of cultured
 42 microbial antagonistic agents, inorganic nutrition and liming, irrigation management and
 43 fungicide application (Wolstenholme and Sheard 2010; Pegg 2010). Phosphite is the most
 44 commonly used chemical for control of *Phytophthora* root rot caused by *P. cinnamomi* in
 45 agricultural, forestry, horticultural and natural ecosystems worldwide (Pegg et al. 1987;
 46 Hardy et al. 2001; Shearer and Fairman 2007; King et al. 2010; Scott et al. 2015; Ramírez-
 47 Gil et al. 2017; Masikane et al. 2020). It is the only chemical effective against this disease
 48 as it acts directly on the pathogen as well as increasing the plants' resistance to the
 49 pathogen (King et al. 2010). However, prolonged use of phosphite increases the potential
 50 for development of phosphite resistance in the pathogen (Dobrowolski et al. 2008).
 51 Moreover, use of agrochemicals may have a negative effect on environment through
 52 detrimental effects on beneficial soil microbes, and disruption of soil ecology (Hardy et al.
 53 2001; Gill and Garg 2014; Xi et al. 2020).

54 Commercial microbial soil probiotic additives/conditioners comprising proprietary
 55 mixtures of microbial species are receiving increasing attention with the global demand for
 56 these products growing at 10% each year (Berg 2009; Song et al. 2012). The most

57 promising biocontrol beneficial microbial organisms, effective against several foliar and
58 soil-borne diseases are the Proteobacteria (*Bacillus* spp.), actinobacteria (*Streptomyces*
59 spp.), the fluorescent pseudomonads (e.g. *Firmicutes*), and fungi (e.g. non-pathogenic
60 *Fusarium* spp. and *Trichoderma* spp.) (Raaijmakers et al. 2009; Bhattacharjee and Dey
61 2014).

62 Mineral soil conditioners, particularly silicon-based mulches, have also shown
63 encouraging outcomes for plant disease control and growth in agricultural crops (Pozza et
64 al. 2015; Tubana et al. 2016). They have been effective for the control of anthracnose
65 (*Colletotrichum lindemuthianum*) (Moraes et al. 2009) and powdery mildew
66 (*Sphaerotheca fuliginea*) (Samuels et al. 1991; Menzies et al. 1992; Belanger et al. 2003).
67 Silica is known to impact on a wide range of plant metabolic processes, and also to affect
68 the soil microbiota, though less is known about the latter (Rajput et al. 2021).

69 No information is currently available on the comparative effectiveness of soil probiotics
70 developed commercially for management of *Phytophthora* in avocado. This study presents
71 information on the effectiveness spraying with phosphite, compared with use of organic
72 mulches, commercial soil probiotics and silicon-based mineral mulches on root damage in
73 avocado caused by *P. cinnamomi*. It also investigates whether a commonly used herbicide,
74 glyphosate may exacerbate *Phytophthora* root damage.

75 **Methods**

76 **Plant Material**

77 Avocados (cv. Reed) were grown from seed, initially in potting mix (Richgro Garden
78 Products, Australia). Nine-month-old plants were transplanted into 220 x 330 mm (15 L)

79 free-draining polybags (Garden City Plastics, Forrestfield, Western Australia) for the first
80 experiment, and for second experiment 150 x 380 mm (7 L) polybags were used.

81 **Soil and growing conditions**

82 In experiment 1 Channybearup yellow brown clay loam soil was sourced from Manjimup
83 Western Australia (WA). It is moderately well draining and has a high-water holding
84 capacity. It was used in a 1:4 ratio of soil: coarse perlite (Perlite and Vermiculite
85 Company, Myaree, WA). For the repeat experiment, a clay loamy soil was collected from
86 Carabooda, Western Australia (WA). It was moderately well drained with good porosity
87 which was mixed with river sand in ratio of 1:1. Both soils are known to be conducive to
88 *Phytophthora* as native vegetation or avocado orchards on these soils suffer from
89 phytophthora dieback but both soils were determined to be free of *P. cinnamomi* through
90 standard baiting of the soil (Aghighi et al. 2016; Simamora et al. 2018). Two inoculation
91 tubes (25 mm dia x 20 cm long) were placed in each bag when plants were potted to
92 minimise the chance of damaging roots during the insertion of the inoculation plugs. Plants
93 were watered daily to container capacity. Plants were placed on benches in a completely
94 randomized design in evaporative cooled glasshouse maintained at 25-27 °C. All had
95 weekly applications of liquid Thrive for fruits (Yates, Australia), (4gm/L, 300-400ml/pot)
96 and 5ml/L Eco oil (Organic crop protectant Pty. Ltd., NSW, Australia) was sprayed on
97 foliage and the soil surface when required for insect control.

98 **Treatments**

99 There were eleven treatments in Experiment 1, and treatments 1, 3, 4, 7, 8,10 were
100 repeated in experiment 2.

101 Treatment 1 had no additives.

102 Treatments 2-11 had 50 g of well decomposed chicken manure applied monthly and 200
103 g/pot jarrah (*Eucalyptus marginata*) wood mulch placed on the surface at the time of
104 transplanting. In experiment 2, in the smaller pots, half these amounts were applied.

105 Treatments 3-11 had 150 g of avocado mulch added at the time of transplanting for
106 experiment 1, (75g was applied in experiment 2). Avocado orchard mulch was collected
107 from a 20-year-old orchard in which *P. cinnamomi* is controlled by phosphite spray
108 (Delroy Orchards, Pemberton, WA), application of decomposed wood mulch, chicken
109 manure, fertigation with standard fertilisers and fish emulsion. The jarrah wood mulch and
110 the avocado orchard mulch were determined to be free of *P. cinnamomi* through baiting.

111 Treatment 4 had weekly application of a 25% concentration of a microbial soil conditioner
112 known to include *Lactobacillus*, *Bacillus*, *Saccharomyces*, *Acetobacter* and *Azotobacter*.

113 Treatment 5 had an additive (conc. 1:500) sprayed to foliage to run-off and applied to soil
114 to field capacity (immediately after potting, and after inoculation). This additive contained
115 humates and an organic chemical.

116 Treatment 6 had applications of two additives that contained a mixture of *Bacillus* species.
117 One was applied at 50 g/pot at the time of transplanting, and the second at 2.5 ml/pot every
118 6 weeks.

119 Treatments 7 had 200 g/pot for experiment 1 and 100 g/pot for experiment 2 of 'Mineral
120 Mulch', a mulch containing calcium, silicon (www.mineralmulch.com)

121 Treatment 8 had applications of mineral based additives containing silica and sulphur. At
122 the time of transplanting 2 g/pot of Dolomite (calcium magnesium carbonate) and 1.5
123 g/pot of Humus 400' (derived from lignite; for inorganic analysis available:

ecogrowth.com.au/products/humus400) was added. Then every fortnight 5 g/pot of ‘Eco-prime’ (chemical analysis available: ecogrowth.com.au/products/eco-prime-avocado) and 0.5 ml of ‘Eco X’ (containing silica, calcium and sulphur) was added for both experiments.

Treatment 9 had wheat seeds planted at the time of transplanting. When four weeks old the wheat seedlings were sprayed with ‘Roundup’ (active ingredients: 7.2g/L glyphosphate and 21g/L Nonanoic acid manufactured by Evergreen Garden Care Australia Pty. Ltd., NSW, Australia) to run-off) (the stems of the avocados were protected with aluminium foil). In avocado orchards glyphosate is routinely used to control weeds (Nartvaranant et al. 2004).

Treatments 10 had plants sprayed with fungicide for *P. cinnamomi* control: Agri-Fos 600 (active ingredient: 600g/L phosphorus acid manufactured by Nufarm Australia Ltd, Western Australia) sprayed according to manufacturer manual on the avocado plants to runoff. Phosphite was applied after transplanting and repeated after a further 10 days.

Treatment 11 was also a fungicide treatment: Ridomil Gold (active ingredient: 25g/kg Metalaxyl-M; Syngenta Australia Pty Ltd, NSW, Australia) was applied as a soil drench at the recommended rate. Metalaxyl was applied 2 weeks before plants were inoculated with *Phytophthora*, then 6 weeks after inoculation.

Inoculum production and inoculation

Branches of live tagasaste (*Chamaecytisus palmensis*) (1-2 cm dia.) were cut into approximately 2 cm pieces. Two hundred plugs were placed in each of ten 2 L conical flasks. The plugs were soaked in distilled water overnight, then rinsed. Distilled water (approx. 50-70 mL, sufficient to cover the bottom of the flask) was added, the flask was

147 plugged with a non-absorbent cotton plug and autoclaved at 121 °C for 30 min, then
 148 allowed to cool to room temperature and the process was repeated after 24 h. Two Petri
 149 plates of *P. cinnamomi* (isolate MP 94-48 from the Centre for Phytophthora Science and
 150 Management culture collection, Genbank Accession number for ITS gene region is
 151 JX113294), cultured on a V8 (vegetable juice) agar medium for 7 days at 25 °C in the
 152 dark, were cut into 1 cm squares and aseptically added to the conical flasks. The flasks
 153 were shaken to evenly distribute the agar plugs and incubated at 25 °C in the dark. Flasks
 154 were incubated for 4 weeks and shaken weekly to obtain uniform colonisation of the
 155 inoculum plugs.

156 All treatments consisted of 10 non-inoculated controls and 10 infested plants inoculated
 157 with *P. cinnamomi*. Plants were inoculated by insertion of two *P. cinnamomi* colonised
 158 plugs to a depth of 10 cm into each of the two holes created after removal of the
 159 inoculation tubes. Similarly, for the control plants, non-colonised plugs were inserted to
 160 the same depth in the holes after removal of tubes in non-inoculated pots. Three weeks
 161 after inoculation, all the plant containers were flooded for 24 h to stimulate the release of
 162 zoospores.

163 **Harvest**

164 Twelve weeks after inoculation with *P. cinnamomi* the plants were harvested. In both
 165 experiments, shoots were excised then dried in an oven at 60 °C to constant dry weight.
 166 Roots were washed free of soil and the visual damage caused by the pathogen scored using
 167 the rankings 1= healthy roots, 2= 1-25% damage, 3= 26-50% damage, 4= 51-75% damage
 168 and 5= 76-100% damage. Fine roots were separated, and the dry weight of fine and coarse
 169 roots recorded. Total root dry weights were calculated by adding fine and coarse root dry

170 weights. Re-isolation of *P. cinnamomi* was undertaken using a randomly chosen plant in
171 each treatment to confirm that the inoculation caused disease.

172

173 **Data analysis**

174 To check the effect of different treatments on the control of damage caused by *P.*
 175 *cinnamomi*, data for shoot dry weight, total root dry weight and fine root dry weight, these
 176 data were analysed using a linear model with terms for treatment, + and - *P. cinnamomi*,
 177 and their interactions. Homoscedasticity was assessed by plotting residuals vs fitted values
 178 and normality of residuals were assessed using q-q plots. Duncan multiples range test was
 179 used to assess the significance between all pairs of treatments /+,- *P. cinnamomi*
 180 combinations. The qualitative data on root damage for each treatment was assessed
 181 separately using Chi square tests. All the data analyses were conducted and bar graphs
 182 were generated in R software.

183 **Results**

184 **Shoot dry weight**

185 In both experiments all seedlings were alive at the time of harvest and there was no
 186 evidence of wilt associated with the presence of *Phytophthora*. The first experiment for
 187 non-infested plants highest total shoot dry weight was recorded for plants receiving
 188 phosphite (T10) and this was statistically significantly higher than values for treatments
 189 with metalaxyl (T11) or glyphosate (T9) (Fig 2a). Following infestation with *Phytophthora*
 190 only plants treated with phosphite showed a significant fall in shoot dry weight (Fig 2a).

191 When selected treatments were repeated, there was no significant difference in shoot dry
 192 weight of treatments not infested with *Phytophthora*, while in infested plants shoot dry
 193 weight was highest for plants treated with mineral mulch 1 (T7) or phosphite (T10), but
 194 there was no statistical difference between these weights and the other treatments (Fig 2b).

195 There was a significant reduction of shoot dry weight following infection in the treatments
196 with probiotic 1 (T4) or mineral mulch 2 (T8) (Fig 2a).

197 **Total root dry weight**

198 In the first experiment for non- infested plants highest total root weight was recorded for
199 plants receiving mineral mulch 2 (T8) but this was only statistically significantly higher
200 than values for treatments with mineral mulch 1 (T7) metalaxyl (T11) or glyphosate (T9)
201 (Fig 3a). In the repeat experiment total root dry weight in non-infested plants was
202 significantly higher in treatments with probiotic 1 (T4), mineral mulch 1 (T7) and
203 phosphite (T10) than in the treatment with avocado mulch or with no additives (Fig 3b).
204 When soil was infested with *Phytophthora* in the first experiment there was a significant
205 drop in total root weight for the treatment with no additives or with only chicken manure,
206 but no significant reduction in the other treatments (Fig 3a).

207 In repeat experiment, in both non-infested, and infested soil, probiotic 1, mineral mulch
208 and phosphite showed more root growth with greatest growth being observed in plants
209 from the mineral mulch 1 and phosphite treatments. However, the reduction in root dry
210 weight after infection was significant in all treatments (Fig 3b).

211 **Fine root dry weight**

212 For the non- infested treatments, fine root dry weight was not significantly increased by
213 the additional of any soil additives (T4-T8) above that of adding avocado orchard mulch
214 alone (T3) (Fig. 4a). For non-infested plants, phosphite (T10) also had no impact on the
215 fine root dry weight, however, metalaxyl (T11) and glyphosate (T9) both resulted in a
216 significant reduction in the fine root dry weight (Fig 4a). The fine root dry weight was
217 reduced by infection with *P. cinnamomi* in all treatments except T7 (mineral mulch1) (Fig.

218 4a). This reduction was significant in the treatments with no mulch, chicken manure (T2),
 219 organic mulch (T3), T4 (probiotic conditioner 1) and T5 (probiotic conditioner 2) (Fig 4a).
 220 The result was not significant for any of the other treatment pairs suggesting that the other
 221 additives (T6, T7 and T8, T9, T10, T11) reduced the impact of *Phytophthora* on the loss of
 222 fine roots. This was most striking for mineral mulch 1 (T7), where the fine root weight of
 223 infested and non-infested seedlings was the same (Fig. 4a).

224 In the repeat experiment in non-infested soil, application of mineral mulch 1 (T7) or
 225 phosphite (T10) gave the highest fine root dry weight. For plants grown in infested soil,
 226 treatment with mineral mulch 1(T7) or probiotic conditioner 1(T4) gave results equivalent
 227 to treatment with phosphite with the highest fine root weight being recorded for plants
 228 treatment with mineral mulch 1 (T7) (Fig 4b). However, after infection significant
 229 reduction in fine root dry weight was observed in all other treatments except no mulch
 230 (T1) (Fig 4b).

231 **Root damage**

232 There was no significant difference in the root damage rating between treatments for non-
 233 infested plants but significantly ($P < 0.05$) more root damage in all treatments infested with
 234 *P. cinnamomi* compared to their respective non-infested controls (Chi square test) in both
 235 experiments (Figs. 5a, b). In experiment 1 for infested plants there was greater root
 236 damage in treatments with probiotic conditioners (T4, 5, 6) and the glyphosate treatment.
 237 Infested plants given T8 (Ecoprime, a silicon-based mineral conditioner) had less damage
 238 than those in T3 (avocado orchard mulch) while in mineral mulch (T7) damage of infested
 239 plants was similar to that seen in avocado orchard mulch (T3). Amongst the pesticide
 240 treatments, glyphosate application (T9) resulted in more root damage of infested plants
 241 than infested plants treated with phosphite (T10) and metalaxyl (T11). Application of

242 avocado mulch (T3), or mineral mulch (T7, T8) resulted in resulted in similar or less
243 damage than that seen on plants sprayed with phosphite (T10) (Fig 5a).

244 In the second experiment overall root damage was higher in both non infested and infested
245 treatments than in experiment 1. In infested soil the least root damage was in plants with
246 mineral mulch 1 or phosphite. This reduction was significantly less compared to plants
247 with no mulch (T1), avocado orchard much (T3) or mineral mulch 2 (T8) (Fig 5 b).

248 **Discussion**

249 In these experiments although fine root weight was reduced by up to 50% in infested
250 plants in some treatments, and 51-75% of the roots showed visible damage, shoots were
251 healthy and no wilting was observed. This is probably because plants were grown under
252 glasshouse conditions with adequate daily watering. Under field conditions, similar root
253 damage could be expected to have much greater impact on total dry weight. In addition, if
254 the glasshouse experiment had utilized younger plants with less woody roots
255 (Rodriguez-Molina et al. 2002), or if the plants had been allowed to grow for longer after
256 inoculation (Faber et al. 2000), there may have been a greater impact of *P. cinnamomi* on
257 total dry weights and more divergence in effectiveness of the different treatments as
258 assessed by total dry weight. As *P. cinnamomi* has its initial impact on fine roots, it is
259 considered that the most accurate assessment of the effectiveness of the treatments applied
260 here is seen through the data on total root dry weight, fine root dry weight and root
261 damage.

262

263 **Effect of treatments on plants in soil infested with *P. cinnamomi***

264 The addition of avocado orchard mulch (T3) resulted in a small improvement in root dry
265 weight compared to those without (T1 and T2) in experiment 1 but not in the repeat

experiment. Treatment 3 is the closest equivalent to conditions in an avocado orchard in these pot experiments. No consistent beneficial effects of other soil additives on total root dry weight, fine root dry weight and root damage were seen. A possible exception is mineral mulch (T7), for which total root dry weight and fine root dry weight was not reduced by *P. cinnamomi* and there was less visible root damage than in other treatments. In the second experiment avocado mulch gave no improvement, but addition of probiotic 1 (T4), mineral mulch (T7) or phosphite (T10) increased both root total weight and fine root weight. Visible root damage was increased by addition of treatments to the avocado mulch (T3) treatment except for mineral mulch (T7). In experiment 2 mineral mulch (T7) showed the lowest damage. Mineral mulch 1 (T7) contains silicon, which is known to improve root growth and increase defence mechanisms of roots when infected with *Phytophthora* (Bekker et al. 2006; Bekker et al. 2007; Bekker 2011; Dann and Le 2017).

Effect of the treatments on roots of non-infected plants

In experiment 1 no treatment significantly affected total root dry weight, fine root dry weight, or visible rot damage in any non-infested treatment. In the second experiment total root dry weight and fine root dry weight was increased by application of probiotic (T4), mineral mulch (T7 & T8), or spraying plants with phosphite (T10). Visible root damage was similar in all treatments. The soils were very similar in the two experiments but use of smaller pots, and sand rather than perlite in the mix for experiment 2, resulted in a greater root mass in the non-infested control treatment with no additives (T1) than in experiment 1, and conditions more conducive for *Phytophthora* as seen by the higher level of fine root damage. In experiment 2 the conditions were more suitable for detection of the effects of additional soil additives on root growth and reduction of *Phytophthora* root damage. The addition of mineral mulch and phosphite had positive effect on the growth of non-infected plants and improved the root biomass. The silicon-based mineral mulch may act

291 as fertilizer and improve the availability of micronutrients and cation exchange activity,
292 and reduce the excess uptake of Fe, Mn and Al (Etesami and Jeong 2018; Etesami 2018)
293 and thus improve growth of shoots and roots (Al-Garni et al. 2019). Phosphite may also
294 act as fertilizer and stimulate the root growth (Ramirez-Gil et al. 2017).

295 **The effect of fungicides and an herbicide**

296 In the current experiment it appeared that glyphosate use may worsen disease symptoms.
297 (T11). Although no glyphosate was sprayed directly on the avocado plants, (it was used to
298 kill a lawn of wheat growing in the pots) it reduced both total and fine root dry weight and
299 there was a high level of root damage when *P. cinnamomi* was present (T11). The use of
300 glyphosate in orchards may be damaging to avocado trees, possibly as it may result in
301 mineral deficiencies which in turn increase disease susceptibility (Kremer et al. 2009;
302 Zobiolo et al. 2010; Zobiolo et al. 2011). It may also be detrimental to beneficial
303 rhizosphere microbes (Zobiolo et al. 2011).

304 Control of *P. cinnamomi* by phosphite spray was no greater than the control seen in plants
305 treated only with avocado orchard mulch. Metalaxyl had a greater detrimental effect on
306 overall growth specially shoot growth of non-inoculated plants than phosphite. It has been
307 observed that the ability of avocado trees to resist *P. cinnamomi* may increase with the age
308 of an orchard (Develey-Riviere and Galiana 2007), and with the build-up of soil organic
309 matter from leaf litter (Schadler et al. 2010). Leaf litter together with organic matter in
310 particular well decomposed chick manure raised microbial activity and soil pH which in
311 return significantly reduced the *P. cinnamomi* survival (Aryantha et al. 2000; Konam and
312 Guest 2002). As soil microflora were not studied, it is possible that the proprietary
313 microbial soil additives increased soil microflora populations, but they had no effect on *P.*
314 *cinnamomi* beyond those provided by avocado orchard mulch. The avocado orchard mulch

315 may either contain beneficial microbial consortia, and/or possess properties that enhance
316 their growth.

317 **Conclusions**

318 Although the experiment attempted to simulate the conditions of an orchard, it is difficult
319 to exactly replicate orchard conditions in a container trial in glasshouse, and to be sure that
320 the soil additives will have similar effects in the field. Temperature regimes, water
321 retention, aeration, and surface evaporation are factors that might have different effects on
322 abiotic conditions and thus microbiota in pots and in the field (Poorter et al. 2016). In
323 particular, the microbes included in the probiotics may not multiply and persist as well
324 under container conditions as in the field.

325 Control methods that reduce the use of chemicals or avoid the build-up of resistance to
326 phosphite or fungicides are highly desirable for commercial horticulture. In the current
327 study, the application of a number of soil additives to containerised avocado plants under
328 glasshouse conditions indicated that avocado orchard mulch was beneficial in reducing
329 *Phytophthora* root damage. Further control may be possible through the application of a
330 silicon based mineral mulch. Probiotic conditioners did not improve disease control. The
331 silicon content of the mineral mulch may enhance the plants defence mechanisms against
332 the pathogen. Future experiments will investigate the effect of these treatments on the soil
333 microbiome. It was also shown that application of glyphosate for weed control damages
334 avocado roots. If chemical control of *Phytophthora* is necessary, phosphite is better if
335 applied at recommended rates (Gilardi et al. 2020) than metalaxyl as it has less detrimental
336 effects on overall plant growth. *Phytophthora* resistant isolates developed faster in
337 metalaxyl than in phosphite treated plants, as the former chemical has a targeted mode of
338 action (Browne and Viveros 2005), whilst phosphite does not (McDonald et al. 2001;

339 Browne and Viveros 2005). Under glasshouse conditions, none of the soil additives
340 improved growth of potted avocado plants, or were more effective against *P. cinnamomi*
341 than treatments simulating current silvicultural methods (application of chicken manure,
342 wood mulch and retention of leaf litter) used by avocado growers in their orchards.
343 However, it is important to conduct follow up trials by using these products in the field to
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352

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 519

520 **Figure captions**

521 **Fig1** Examples of root damage of avocado roots after inoculation with *Phytophthora*
522 *cinnamomi*. Whole root systems were rated visually for *Phytophthora* root rot on the bases
523 of scale 1-5 (left to right) 1 = healthy roots, 2 = 1-25% damage, 3 = 26-50% damage, 4 =
524 51-75% damage 5 = 76-100% damage.

525 **Fig. 2** a) The effect of eleven soil treatments (T1-T11, see Table 1) on shoot dry weight of
526 non-infested avocado plants (grey bars) and those infested with *Phytophthora cinnamomi*
527 (black bars). b) The effect of soil treatments (T1, T3, T4, T7, T8, T10, see Table 1) on
528 shoot dry weight of non-infested avocado plants (grey bars) and those infested with
529 *Phytophthora cinnamomi* (black bars). Vertical lines indicate SE and letters indicate
530 significant difference ($p < 0.05$).

531 **Fig. 3** a) The effect of eleven soil treatments (T1-T11, see Table 1) on total root dry weight
532 of non-infested avocado plants (grey bars) and those infested with *Phytophthora*
533 *cinnamomi* (black bars). b) The effect of soil treatments (T1, T3, T4, T7, T8, T10, see
534 Table 1) on total root dry weight of non-infested avocado plants (grey bars) and those
535 infested with *Phytophthora cinnamomi* (black bars). Vertical lines indicate SE and letters
536 indicate significant difference ($p < 0.05$).

537 **Fig. 4a** The effect of eleven soil treatments (T1-T11, see Table 1) on fine root dry weight
538 of non-infested avocado plants (grey bars) and those infested with *Phytophthora*
539 *cinnamomi* (black bars). b) The effect of soil treatments (T1, T3, T4, T7, T8, T10, see
540 Table 1) on fine root dry weight of non-infested avocado plants (grey bars) and those
541 infested with *Phytophthora cinnamomi* (black bars). Vertical lines indicate SE and letters
542 indicate significant difference ($p < 0.05$).

543 **Fig. 5a)** The effect of eleven soil treatments (T1-T11, see Table 1) on root damage of non-
 544 infested avocado plants (grey bars) and those infested with *Phytophthora cinnamomi*
 545 (black bars). b) The effect of soil treatments (T1, T3, T4, T7, T8, T10, see Table 1) on root
 546 damage of non-infested avocado plants (grey bars) and those infested with *Phytophthora*
 547 *cinnamomi* (black bars). Vertical lines indicate SE and letters indicate significant
 548 difference ($\alpha < 0.05$).

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Root Damage Score