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INTEGRATED MANAGEMENT OF PHYTOPHTHORA ROOT ROT
THE "PEGG WHEEL" UPDATED

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Introduction

Phytophthora cinnamomi (*P.c.*) root rot, even today remains the number one enemy of avocado trees virtually everywhere they are grown. The South African industry was in deep trouble until the mid-1970's, when the first effective chemical was registered (Ridomil®). This was followed soon after by the very effective phosphonate-based Aliette-Ca®, pioneered by Dr Joe Darvas with stem-injection technology adapted from the citrus industry. In Queensland, Australia, pathologist Ken Pegg and horticulturist Tony Whiley were able to overcome patent restrictions and register potassium phosphonate (active ingredient phosphorous acid, H_3PO_3, or more particularly the phosphite ion PO_3^-) for control of avocado root rot. These advances literally saved the avocado industry in humid, subtropical countries. One has only to look at old orchard photographs before effective chemicals became available to appreciate how devastating *P.c.* root rot was. "Organic" growers, forced to rely on updated 1970s chemical-less technology, will vouch for this – they rely entirely on **biological** control.

In 1979, the senior author (BNW) after visiting Queensland, Israel and the USA, was very impressed with the "Pegg-Whiley" approach of "living with" *P.c.,* just as Ridomil® became available and Aliette-Ca® was being researched. He coined the term "Pegg Wheel" for the **integrated** approach to managing *P.c.*. This was based on a diagram in one of Ken Pegg's early papers, with six spokes summarizing management imperatives for healthy, productive avocado trees. Naming it after Ken Pegg was this author's tribute to this highly regarded plant pathologist. Ken himself is far too modest for self-aggrandisement.

With the registration of phosphonate-based fungicidal products, the other five (non-fungicidal) spokes did not become any less important – all are still necessary for effective *P.c.* management, in a package deal that combines chemical and other management practices, i.e. **integrated** rather than purely **biological** control. The Pegg Wheel became widely known in our industry, and was taught to many generations of horticulture students at the University of Natal. It has undergone subtle modification since 1979, but the basics remain sound.

Ken Pegg and his team, including Jay Anderson, Lindy Coates, Elizabeth Dann, Luke Smith in more recent years, have continued *P.c.* research for over 30 years, on avocados and pineapples – both "blue sky" basic as well as practical research, with

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Whiley's horticultural input. Ken was asked by Colin Partridge, ex SAAGA director now with Southern Produce (previously TeamHort) in New Zealand, to address growers on his life's work on *P.c.* in June 2010. The basis of this talk was kindly made available to BNW, with Ken's permission to "spread the word" on the Australian approach.

This article summarizes the six basic components of managing *P.c.* in orchards, as recommended by Pegg and co-workers in Australia, but including South African recommendations and other research results. We believe that there is much that is of interest, and in some respects new, for the South African grower. Our objective is not to upset the local apple (avocado) cart, or to suggest wholesale uncritical adoption of Australian technology without prior experimentation and adaptation. We do point out however that their *P.c.* research leads the world in many respects, and in BNW's experience their orchards appear healthier, on average, than many of ours. Their growers are also extremely lucky to have a root analysis service for phosphite (PO_3^-), with well established target concentrations refined by research.

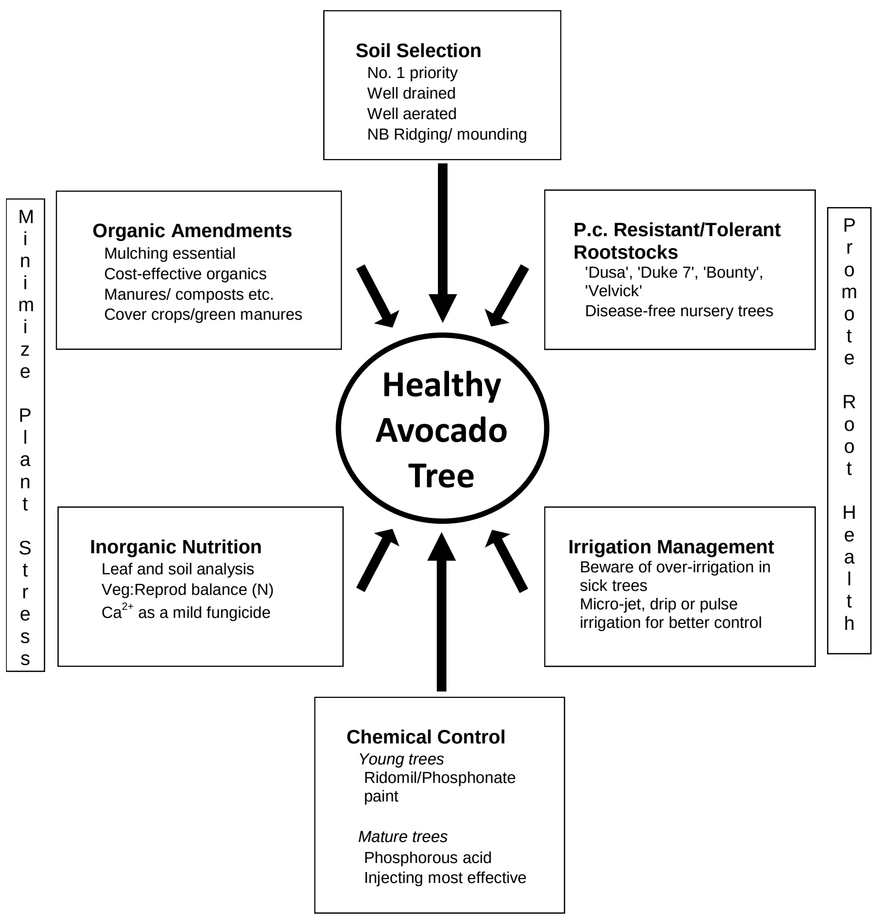

Figure 1: Integrated management of *P.c.* through avocado root health. Based on Pegg (2010) and modified from Wolstenholme (1979).

The Updated Pegg Wheel

We suggest, mainly from Pegg's (2010) talk, an updated summary of the Pegg Wheel for 2010 (Fig.1). The underlying themes remain the promotion of "root health" (a well established concept, but currently, a very much in vogue bandwagon and "flavour of the month"); and the minimization of tree stress. Each of the six spokes will be discussed in the light of research advances and present-day recommendations to Australian and local growers. The greater the *P.c.* risk, the greater the importance of adopting the entire package of recommendations. The humid, high (summer) rainfall subtropics with heavy clay soils (and occasional cyclonic storms) are particularly at risk.

1. Soil Selection

Most advisers on the recommendations for reducing *P.c.* risk would list soil selection as the top priority. The greater the risk and the higher the rainfall, the more important it is to plant on very well-drained soils. If the area is subject to periodic cyclones, tropical storms or cut-off lows, delivering 300 – 500+ mm in a few days, even the best drained soils can become temporarily saturated, causing devastating *P.c.* root rot and tree decline or death. This is where proper ridging can save the day by quickly shedding surplus water (into well-grassed waterways) and preventing saturation in the main root zone. There is a school of thought that any avocado soil with more than 15% clay should be ridged before planting. Ridging also increases soil depth (Fig. 2). Ridges must have sufficient slope, must be broad-based to reduce erosion, preferably run N-S, and be mulched to reduce drying out.

Figure 2. Large ridges under construction for a new avocado planting.

Soil selection guidelines for avocado are well known, emphasizing good drainage, good aeration, and low bulk density (realistically 1.0 – 1.5 $g \cdot cm^{-3}$ ($t\ m^{-3}$)) in subtropical highly weathered soils (Wolstenholme, 2002). In comparison, a cricket pitch has a bulk density of about 1.8 $g \cdot cm^{-3}$ after repeated rolling and compaction. Fast internal drainage to at least 1.5 m in high rainfall areas (>900 mm p.a.) is needed, and no obstruction such as solid rock or compacted layers, allowing an even a temporary rise of the water table into the rooting zone. There is no substitute for digging soil pits down the slope, and mapping the soil form and family. Wet spots, and any signs of wetness, e.g. concretions, or mottling in the soil profile are warning signs. Slopes are not necessarily well drained, especially if unweathered bedrock occurs close to the surface. Clay content often tends to increase with depth (luvic soils) and down the slope. Internal drainage water reaches the surface at the foot-slope seep line near the drainage channel – where conditions are totally unsuitable for avocados. Soils can vary widely over short distances.

Ken Pegg, after a lifetime of *P.c.* research, confirms in a letter to BNW (Pegg, 2010, personal communication) that he considers proper soil selection as the number one priority for avocado orchards. South African growers will welcome Martin Fey's new book "Soils of South Africa" (2010) for a better understanding of our soils.

2. *P.c. T*olerant Rootstocks and Disease-free Nursery Trees

The range of proven "resistant" (actually "tolerant" at best) rootstocks has increased since 1979, when the Mexican race 'Duke 7' was the most widely used clonal rootstock in California and South Africa. Since then, the 'Martin Grande' series, with good *P.c.* tolerance but excessive vigour, has fallen from grace, and 'Duke 6' was discarded in South Africa due to a stem pitting virus. In Australia, 'Velvick' (West Indian X Guatemalan hybrid) seedlings have proved reliable in *P.c.* situations, and Whiley's rootstock selection research is throwing up a few promising candidates. In South Africa, 'Dusa' and 'Bounty' have been added to 'Duke 7'and have been widely planted in recent years. The Australian industry is still seedling rootstock based, with a large pool for selection of "escape tree" rootstocks, mainly of Guatemalan race (subspecies) parentage, with its greater tolerance to *P.c.* trunk canker (Dann *et al*., 2009/2010).

Since 1979, planting of disease-free ("certified" or "accredited") nursery trees has become standard practice in progressive avocado industries, and is non-negotiable. All trees in South Africa should only be purchased from Avocado Nurserymen Association (ANA) *accredited* nurseries (NB. not just ANA *members*). It is the grower's responsibility to prevent *P.c.* infection from the time the trees leave the nursery until planting. The first two years in the orchard are the most critical, and fungicidal treatment is justified as an insurance policy in the non-bearing years.

Some seedling e.g. 'Zutano', 'Mexicola', 'Lula' rootstocks used in Australia, New Zealand and elsewhere are associated with scion (e.g.'Hass') trunk overgrowth in relation to the rootstock trunk, easily seen at the graft union. Tony Whiley (2003) has pointed out that this invariably leads to some root starvation due to partial incompatibility, and aggravates alternate bearing. An excessively heavy "on" crop then places the tree under stress, especially in summer and autumn, and can aggravate *P.c.*

root rot and reduce summer shoot flushing. The authors have noted some scion overgrowth in trees on certain clonal rootstocks, e.g. ‘Bounty’, suggesting that management of alternate bearing will be especially important on this promising rootstock (Fig. 3).

Figure 3. Scion overgrowth on a 6-year old ‘Hass’ tree.

3. Organic Amendments

Until effective *P.c.* fungicides became available in the 1970s, the addition of organic matter through mulching and organic fertilizers was the grower’s primary tool in “living with” *P.c.* root rot. For “organic” growers, little has changed and once *P.c.* becomes established (usually the result of high rainfall, heavy soils and heavy bearing) the task becomes daunting. Conventional growers at least have the additional powerful tool of phosphorous acid. Organic growers rely heavily on boosting soil organic matter, which may not be sufficient under heavy rainfall conditions in bearing orchards.

The rationale for mulching avocado trees is well known (Pegg and Whiley, 1987). Mulching helps maintain high organic matter content in the feeder root zone, and coarse mulches provide an oxygen-rich root environment. In particular, mulches improve soil health by *inter alia* increasing microbial activity, and therefore making topsoils more suppressive to *P.c.* – thereby reducing *P.c.* “inoculum”. Pegg (2010) notes that adding laboratory cultured microbial antagonists, such as *Trichoderma/Gliocladium* to avocado soils, at great expense will give little additional benefit if large populations of antagonists are already present. Crowley (2008) gives further reasons why such artificial manipulations are unlikely to succeed.

The pros and cons of avocado orchard mulching were discussed by Turney and Menge (1992), and by Wolstenholme *et al*. (1996) arising from PhD research by Clive Moore-Gordon using composted pine bark. Many other studies have been conducted locally and world-wide. In summary, Pegg (2010) recommends mulches with a C:N ratio of preferably between 25:1 and 100:1. Avocado prunings and trimmings, chipped to a suitable size, have been very successful. Aged hardwood, e.g. eucalypts, aged or composted pine bark, and straw from stalky grasses (e.g. Rhodes grass used widely in Australia)(Fig. 4) are also suitable. Care is needed to compensate for any nitrogen "drawdown" from any high C:N ratio mulches (leaf analysis), while sawdust is too compact and too low in N (severe N negative period). Natural avocado leaf fall is helpful, but woody mulches are better. Do not remove pruned branches, but rather chip and leave them in the orchard.

Figure 4. Grass mulch on young (left) and bearing (right) avocado orchards.

Mulches are used as a food (energy) source by beneficial fungi, which use the enzyme cellulase to break down cellulose including the cellulose cell walls of *P.c.* (Pegg, 2010). Properly used mulches should be regarded as standard "best practice" in avocado orchards. Ken Pegg is adamant – mulching is essential (Pegg, 2010, pers. comm.).

4. Inorganic Nutrition and Liming

Conventional avocado growers, happily, can still use "synthetic" man-made inorganic fertilizers. They can thus take advantage of the tremendous advances in technology since the difficult days when manures (animal and sometimes human), bones, bone meal and cover crops had to be relied on for additional nutrient elements. Responsible, knowledgeable growers use soil and leaf analysis to guide supplemental nutrient needs, are aware of the dangers of over-fertilisation, and welcome the use of organic supplements to maintain soil health. They should stick with mainstream, scientifically researched soil and leaf analysis methodology and interpretations to remedy deficiencies (e.g. K, Zn and B in our leached soils) and toxicities (Al and Mn most likely under our conditions, and Na and Cl in arid climates). Remember also that *P.c.* infected trees give different leaf analysis results for some elements.

Nitrogen (N) is an important manipulator element which has a major role in maintaining the desired vegetative:reproductive balance. Too much N leads to fruit quality problems (especially 'Fuerte' and 'Pinkerton'), aggravates alternate bearing, promotes excessive shoot growth, and pollutes ground water and rivers/dams. South African soils derived from diabase (or dolerite), which are high in organic matter (especially with humic A horizons), can mineralize high amounts of N (and other elements) each year, and may not need supplemental N in some years. Targeted urea (LB) sprays can be helpful (with pruning) in promoting the summer shoot flush which is important for providing fruiting sites for the following season.

Liming will usually be necessary on leached, acid soils in our high rainfall avocado areas. The prime objective is not so much to raise the pH value (virtually impossible without over-liming on some heavily buffered soils in Kwa-Zulu Natal, for example), but to reduce or eliminate aluminium (Al) toxicity. In some imperfectly drained soils (at depth), manganese can go in and out of solution (along with iron, Fe) in a zone of fluctuating water table, and cause Mn toxicity. The latter is best avoided by soil selection and/or improved drainage, but liming is also helpful. Guidelines are available for type of lime (agricultural, dolomitic, gypsum, calmasil) and quantity to apply.

From a *P.c.* viewpoint, it is well known that calcium, specifically in the ionic form Ca^{2+}, most easily obtained from the ionization of gypsum ($CaSO_4$) or calcium nitrate ($CaNO_3$) but also from liming materials, is a mild fungicide. Pegg (2010) therefore recommends gypsum applications after new plantings, and especially for replants. Some Australian growers regularly apply microgypsum (finer particles, more soluble) through fertigation. Most regard an annual application of gypsum of *ca*. 0.5t/ha as necessary for improving soil structure and aeration, as well as for its anti- *P.c.* fungicidal effect.

The ammonium ion NH_4^+, and ammonia (NH_3) are also toxic to *P.c.*. The original Pegg Wheel (1979) suggested using ammonium sources of N fertilizer (LAN, urea etc) rather than nitrates. We now unfortunately know that NH_3 is also toxic to avocado feeder roots. Pegg (2010) suggests that any form of ammonia applied in a mulch must be used sparingly. However, before planting and especially in a replant situation, fungicidal effects of ammonia can be used by applying *fresh* cattle or poultry manure in the planting hole *six months* before planting, mixing with soil and covering with straw. The amount of *P.c.* inoculum will thereby be greatly reduced, with lowered NH_3 levels by the time the trees are planted.

5. Irrigation Management

Too few growers make adjustments to irrigation of individual trees or orchards. Obviously sick trees need less water as their feeder roots have rotted – reduce the number or output of micro-sprinklers or drippers to avoid over-irrigation (which aggravates the problem). For a sick orchard, reduce both sprinklers and duration of irrigation. Be guided by tensiometers or preferably electronic soil moisture probes.

Pegg (2010) points out that both over-irrigation and under-irrigation (stressed trees) and salinity promote *P.c.* infection of feeder roots. Mulches also retain water, especially finegrained and recently applied mulches. They are best applied in autumn, so that microbial activity is high during the critical spring period, and some decomposition has occurred before the onset of heavy summer rains.

6. Use of Chemicals – Fungicides as an Essential Aid

Cultural practices rarely give complete control of *P.c.* root rot and chemicals are required to reduce disease severity and improve tree health. The effective management of *P.c.* root rot is achieved by the use of phosphonates (phosphorous acid, H_3PO_3), without which the avocado industry would almost certainly fail. Fungicides should thus always be used in an integrated program incorporating the previously discussed cultural practices.

Two groups of fungicides, metalaxyl (Ridomil®) and phosphonates (phosphorous acid/potassium phosphonate e.g. Aliette®, Rootmaster®, Avoguard 500SL®) have been found to be the most effective chemicals for *P.c.* root rot control in avocados.

Metalaxyl is directly toxic to Phytophthora and will suppress the pathogen populations in the soil. Commercial use in established orchards is almost non-existent due to rapid biodegradation by soil microorganisms. It is currently recommended for new/re-plant trees where it should be applied to the soil surface or lightly incorporated at a rate of 40-60g/m^2 at planting. Ridomil Gold 25G® (granular) is no longer available on the SA market, so Ridomil Gold 480EC® should be used as a soil drench at a rate of 2.1ml product in 200ml water/m^2 tree drip area.

Phosphonates do not reduce *P.c.* populations in the soil but have a dual action in the plant. At high root mass concentrations (>25 mg/kg phosphite), they provide direct *P.c.* control while at lower concentrations, they have been shown to activate the plant's defense responses. Whiley *et al.* (1992) showed that, following trunk injections, phosphonates move rapidly to the leaves (within 24hrs and peak after 10 days) where they become phloem-mobile. Its movement in the tree is related to photo-assimilate/carbohydrate partitioning which varies with the activity of competing sinks (i.e. roots, leaves, fruit). The roots only become relatively "strong" metabolic sinks following leaf maturity (hardening off) in late spring (October/November) and late summer (March/April) so injections should be timed to coincide with these periods.

Lateral translocation of phosphonate is limited so injection sites must be evenly spaced around the tree. Bearing trees should be injected using a 20% phosphonate (phosphorous acid) solution, except Avoguard, which is applied undiluted (i.e. 0.4 g Phosphorous acid per m^2 canopy). The current Australian recommendation is to inject 15 mL per meter of canopy diameter, using 20% phosphonate and 20 mL per syringe. It should be noted that reducing the number of injection sites and using higher concentrations (40 – 60% phosphonate) may cause long-term damage to tissues around the injection site, leaf burn (phytotoxicity) and delay root flushes. Healthy trees should be injected annually when the spring growth flush has hardened off to maintain tree health. Heavy bearing and unhealthy trees should be injected twice a year at the completion of each growth flush when leaves have matured. Applications should cease at least 6 weeks before flowering.

Foliar (0.5 – 0.6% phosphonate, tank mix buffered to pH 7.2) and bark (20% phosphonate plus 2% bark penetrant) sprays have been tested by the Australian industry on bearing trees. They currently use 3 to 5 foliar sprays per season to maintain productivity in mature trees with a healthy canopy. Summer foliar sprays of Aliette (30ml/10L) are recommended by SAAGA for controlling root rot in young, newly planted trees. Bark paints or sprays are very effective on young trees but should not be used for managing root rot on older trees. As mentioned previously, Ca^{2+} has a mild fungicidal effect vs *P.c.* and Ken Pegg advises growers in Australia to apply microgyp at a rate of $7 g/m^2$ monthly or gypsum applied at $20 g/m^2$ every 2 months.

With the high levels of *P.c*. root rot noted in many avocado orchards, it would be advisable to use an integrated approach to tackle the Phytophthora problem. With correct soil selection and land preparation, use of disease-free nursery trees on *P.c*. tolerant rootstocks, mulching, nutrition, irrigation management and chemical control, growers should be able to grow healthy, productive avocado trees. A commercial root analysis service for phosphite testing to determine if roots are getting enough protection (>25 mg/kg or >25 ppm PO_3^-), would be beneficial to the industry.

References/Literature Cited

Crowley, D. 2008. Managing soils for avocado production and root health. *Calif. Avo. Soc. Yrbk* 90, 107 -130.

Dann, E., Smith, L. & Pegg, K.G. 2009. *Phythopthora* trunk canker. *Talking Avocados* 20(4), 26 – 27.

Dann, E., Smith, L., Pegg, K.G and Whiley, A. 2009. Managing *Phytophthora cinnamomi. 4th Aus. & NZ Avo. Grs' Conf*., Cairns, Australia.

Fey, M. 2010. *Soils of South Africa*. Cape Town: Cambridge Univ. Press. Pp 287

Pegg, K.G. 2010. Pathology challenges in avocado: Phytophthora management. Talk to Southern Produce Avocado Conference, New Zealand, June 2010.

Pegg, K.G. and Whiley, A.W. 1987. Phythopthora control in Australia. *S. Afr. Avo. Grs'. Assoc. Yrbk.* 10, 94-96

Turney, J. & Menge, J. 1994. Root health: mulching to control diseases in avocado and citrus. Univ. Calif. Riverside, Circ. CAS 94/2.

Whiley, A.W. 2003. Rootstock incompatibility- does it affect tree performance? *Talking Avocados* 14(2), 13 -15.

Whiley, A.W., Saranah, J.B., Langdon, P.W., Hargreaves, P.A., Pegg, K.G. and Ruddle, L.J. 1992. Timing of phosphonate trunk injections for *Phytophthora* root rot control in avocado trees. *Proc. of 2nd World Avo. Cong*, pp. 75 – 78.

Wolstenholme, B.N. 1979. Prospects for integrated and biological control of avocado root rot – some overseas impressions. *S.Afr. Avo. Grs'. Assoc.* 3, 17 – 20.

Wolstenholme, B.N. 2002. Ecology: Climate and the edaphic environment. In: A.W. Whiley, B. Schaffer & B.N. Wolstenholme (eds). Avocado: Botany, Production and Uses, CABI Publishing, Wallingford, UK.

Wolstenholme, B.N., Moore-Gordon, C. & Ansermino, C.D. 1996. Some pros and cons of mulching avocado orchards. *S. Afr. Avo. Grs'. Assoc. Yrbk*. 19, 87 – 94.