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ORCHARD MULCHING EFFECTS ON AVOCADO FRUITING

B.N. Wolstenholme, C.S. Moore-Gordon & A.K. Cowan
Department of Horticultural Science, University of Natal, Pietermaritzburg, South Africa

Abstract

The "subtropical" avocado tree evolved in a cool, mesic highland rainforest with a decomposing litter layer, in which its feeder roots proliferate. We reasoned that under more stressful orchard conditions it should benefit from mulching with suitable materials to reinforce the natural dead leaf layer. We also hypothesized that the resultant improved root health and growth would partly ameliorate the 'Hass' small fruit syndrome, which is associated with "stress". An ongoing mulching trial with composted pine bark in the cool, mesic summer rainfall mistbelt of KwaZulu-Natal has led to an average increase form mulching (over 3 seasons) of 7% in fruit size, 15% in fruit number and 23% in yield. Mulching reduced measured components of tree stress, including a lowering of leaf canopy temperature, photoinhibition of photosynthesis, premature seed coat abortion and pedicel ringneck. Phenotypically small fruits were higher in flesh abscisic acid and lower in cytokinins. However mulching amelioration of stress does not explain all aspects of the small fruit phenotype. Mulching with suitable materials has additional benefits in most orchard situations, but pros and cons (including availability, cost, C:N ratio, rapidity of decomposition) must be understood and tailored to particular orchard environments and conditions.

Introduction

The South African avocado industry exports about 60% of the crop annually, mainly to France and the UK but also to many other mainly European markets. Record exports amounted to over 45 000 t, and in the absence of drought and other climatic hazards the potential exports from existing plantings may reach 55 000 t in the next season or two. 'Hass' has overtaken 'Fuerte' as the main cultivar, and is well received overseas provided quality parameters are met. However, up to 50% of the Hass crop may be undersize (less than 200g fruit weight, or with counts of 20 or more fruits per standard 4,5 kg export carton)(Köhne, 1992). In the 1994 season this "small fruit problem" was estimated to have cost the industry R30 million in lost export revenue (Moore-Gordon and Wolstenholme, 1996).

The 'Hass' small fruit problem is not restricted to diseased, unhealthy or old trees. Even healthy trees produce 5-25% of small fruit (Kremer-Köhne, Köhne, 1995). Whiley and Schaffer (1994) . noted that there is anecdotal evidence that the problem is aggravated by high mean temperatures during fruit growth specifically that 'Hass' fruit were 30%

smaller in a warm subtropical coastal Queensland environment as compared to a cool subtropical highland environment (mean max./min. temperatures for the 4 months preceding fruit maturity 28.6/19.0°C and 21.4/13.6°C respectively). More recently, it was noted that mean fruit size over 4 years was 195.0±6.5g vs 227.9±3.6g for these two localities, representing a ca. 17% increase at the cooler site (Whiley *et al,* 1996).

[1]In South Africa it is accepted that fruit from hotter, drier localities is smaller on average than that from cooler, moister (more mesic or "soft") environments. This may be partly explained by the relatively high respiration rate of 'Hass' fruit compared to 'Fuerte (Blanke and Whiley, 1995), especially at higher temperatures. Other factors affecting 'Hass' fruit size are cross-vs self-pollination, crop load, tree size and age. In general, heavy crop load (lower leaf to fruit ratio), larger tree size and older trees all reduce average fruit size. The major cause of course is genetic.

The above discussion relates to the more obvious environmental and horticultural causes of the 'Hass' small fruit syndrome. However, it is known that premature/early seed coat (Steyn *et al,* 1993) senescence is strongly associated with the small fruit phenotype. A key paper in this regard is that of Blumenfeld *&* Gazit (1974), the first detailed study of seeded vs seedless ("cukes") avocado fruit. Early studies in Israel also noted that the avocado seed coat is rich in growth hormones (Blumenfeld and Gazit, 1970; 1972; Gazit and Blumenfeld, 1972). These studies were extended by Cutting *et* a/.(1986) and Cutting (1993). It was also noted that there was a correlation between the appearance of pedicel "ringneck", which has been associated with environmental/physiological "stress" (Whiley *et al.,* 1986; Whiley and Schaffer, 1994), and both premature seed coat death and small fruit.

These observations led to the hypothesis that reduction of stress and promotion of root health should lead to a reduced proportion of phenotypically small 'Hass' fruit. Part of the reasoning was that ecologically the avocado tree evolved in a rainforest environment with a decomposing litter layer, and in that it is essentially a rather shallow-rooted "litter feeder", adapted to a mesic environment (i.e. the "sub-tropical" as opposed to "tropical" avocado). Bergh (1992) believes that three aspects of evolution shaped avocado roots: frequent good rains; rapidly draining soils (exemplified by the high oxygen requirement of roots), and the rich surface organic mulch layer, in which healthy feeder roots proliferate. Accordingly, Cutting initiated a mulching trial in KwaZulu-Natal as a short-term solution to ameliorate the small fruit problem, before re-locating to New Zealand.

Subsequently, much has been learned about the physiology of avocado fruit growth. Cowan (1997) and Cowan *et al.* (1997b) have defined the small fruit problem, and noted that a long-term solution depends on a better understanding of the physiology and molecular biology of fruit growth. Recent publications, generated from the mulching trial in the first instance, cover both horticultural aspects (Moore-Gordon *et al.,* 1995, 1996, 1997; Moore-Gordon *&* Wolstenholme, 1996), as well as physiology (Cowan, 1997, Cowan *et al.,* 1997a). This paper will focus more on the horticultural aspects of mulching, and three season's data generated by the mulching trial. Wolstenholme *et al.* (1996) summarized the pros and cons of mulching avocado orchards. An important

[1] J.G.M. Cutting, New Zealand Avocado Industry Council

general reference on mulching is Handreck *&* Black's (1994) book on growing media. Mention must also be made of the pioneering work on *Phytophthora* "suppressive" soils (Broadbent *&* Baker, 1974; Pegg *et al,* 1982), which popularized reinforced mulching in avocado orchards as a root-rot control strategy before the advent of effective chemical control using phosphonate (Pegg *et al,* 1985).

Materials and methods

A mulching trial was initiated in February 1993 on 6 year old 'Hass' trees on clonal 'Duke 7' rootstock, spaced 7 x 7m, at Everdon Estate near Howick in the KwaZulu-Natal mist-belt (30°16E, 29°27'S). Mean max./min. temperatures range from 26.1/15.0°C in January to 19.4/6.7°C in July. The altitude is ca 1080m, and with a summer-maximum rainfall mean of 1052mm, the climate is cool to cold subtropical and conducive to high 'Hass' yields. The soil is an oxisol of the Hutton form, dystrophic, with a subsoil clay content of ca. 50%. The orchard received excellent management care including fertilization and microjet irrigation.

A commercial composted pine bark mulch (coarse potting mix) supplied by Gromed Organics was applied to a depth of ca 15cm, under the drip of six trees (total of 1,5m^3), with six adjacent unmulched trees as control. This mulch was chosen because of its good physical properties, and its long half-life of ca 5 years implied that the high initial cost could be amortized over a number of years.

The mulching trial has run for four consecutive seasons, during which data were collected on the major phenological events, fruit growth, and fruit number and size at harvest. In two seasons, records were kept of the incidence of pedicel "ringneck" in relation to seed coat health and fruit size at harvest. Fruit samples were taken for anatomy and physiology studies. For 20 months, infrared thermometry sensors were used to monitor canopy temperatures, as a measure of water stress. Regular trunk bark samples were taken to determine fluctuations in starch reserves on a seasonal basis. A plant stress meter was also used to monitor chlorophyll fluorescence as a measure of photo synthetic efficiency and photoinhibition of photosynthesis.

To determine mulching effects on fruit size distribution, fruits were classified into three categories, viz. highly suitable for export: counts 14-18 (per 4.5 kg carton); suitable: counts 10-12 and 20-22; and unsuitable: counts >24.

Results

<u>Yield and fruit size</u>

Results for three consecutive seasons are summarized in Table 1. The first and third seasons were "on" years with control trees averaging 101 kg and 151 kg per tree respectively, while the second season was an "off' year (47 kg $tree^{-1}$). However, in all three seasons mulching significantly increased yields, by 18.5% and 18.9% in the "on" years, 42.2% in the "off' year, and by 22.6% overall (the latter representing 22.0± 1.2 kg per tree). It is noteworthy that mulching benefits on yield were proportionally greatest during the "off" year. Three year mean yields were equivalent to 20.41 ha^{-1} and 24.91

ha^{-1} in unmulched and mulched trees respectively.

Mean fruit weight, surprisingly, was lowest in the "off" year and highest in the year of heaviest cropping. Mulched tree fruit weight was significantly heavier in the first two seasons (in both cases by 11.8%) but not in the third season of very high yield. Consequently the three season average increase in fruit mass was only 6.6% ($P<0.01$), but this was achieved despite a significant 14.7% increase in fruit number. Only in the first season, when the mulch had only been applied a few months before fruit set, was there no significant difference in fruit number (Table 1).

Table 1 **Summary of the effects of pinebark mulching on 'Hass' avocado productivity. Figures are means of six trees. ★★ denotes a significant ($p \leq 0.01$) increase in response to mulching**

	Control	Mulch	Percentage increase
1993/1994			
Mean fruit mass (g)	198.0	221.3	11.8**
Fruit number / tree	509	540	6.1
Yield (kg / tree)	101	119	18.5**
1994/1995			
Mean fruit mass (g)	178.2	199.2	11.8**
Fruit number / tree	262	333	27.2**
Yield (kg / tree)	47	67	42.2**
1995/1996			
Mean fruit mass (g)	216.1	220.4	2.0
Fruit number / tree	698	814	16.6**
Yield (kg / tree)	151	179	18.9**
Overall			
Mean fruit mass (g)	203.1	216.5	6.6**
Fruit number / tree	509	540	14.7**
Yield (kg / tree)	100	122	22.6**

Figure 1 shows fruit count size distributions for the three seasons, and the total number of fruits in each count. It is obvious that in all seasons, mulching shifted fruits into smaller counts, i.e. larger fruit sizes. The numbers of fruits in the "small" counts of 22-26, plus factory grade, were greatly reduced relative to unmulched trees. Overall, mulching resulted in a 14.3±1.2g increase in fruit mass, representing a shift of one count size in favour of larger fruit.

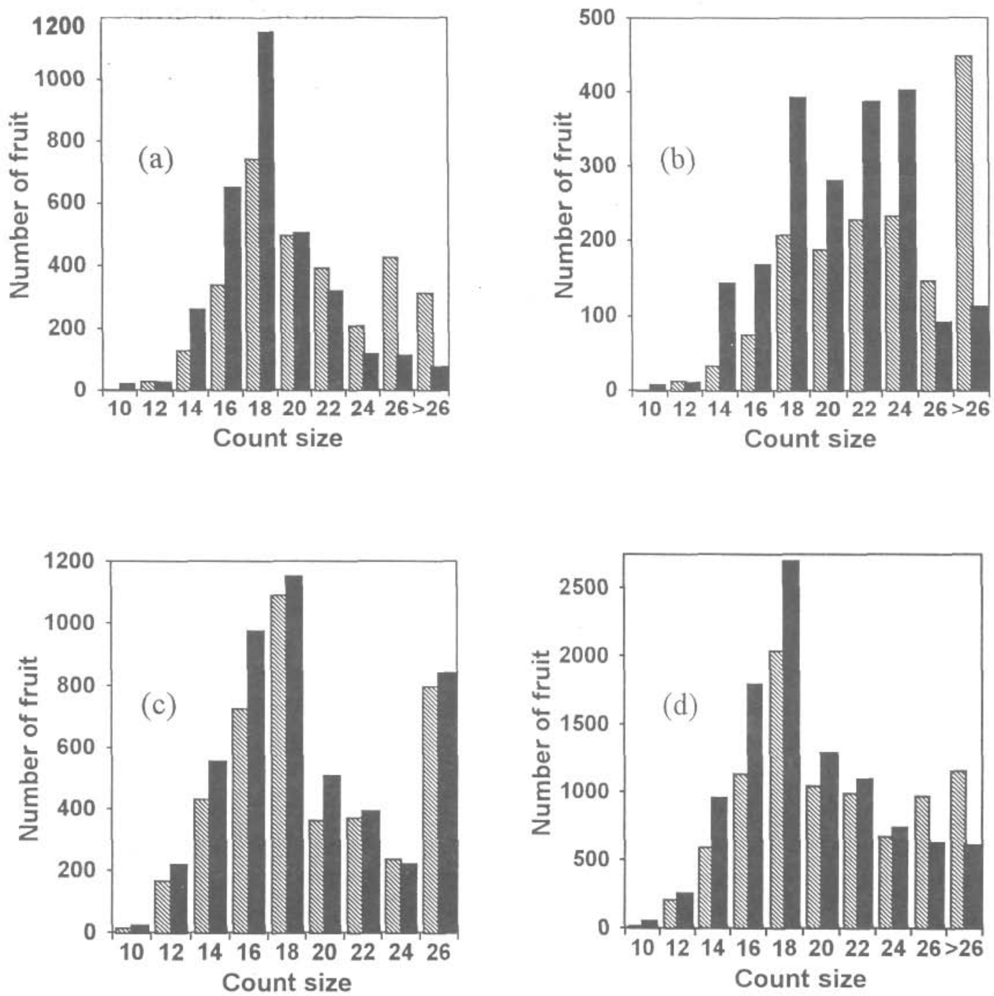

Figure 1 **'Hass' fruit size distributions for the 1993/94 (a), 1994/95 (b) and 1995/96 (c) seasons, and a total for all three seasons (d). Solid histograms represent the mulch treatment and striped histograms represent the control.**

In terms of suitability for export, results in Table 2 show that mulched trees produced 45% more fruits in the "highly suitable for export" category (3 season average), and in the "acceptable" category by 20.0%. The number of "unsuitable" fruits was reduced by 29.0%. A partial economic analysis, based only on the costs of the particular mulch used, showed that the initial cost was offset in the second season. Four-and-a-half years later, there has been no need to replenish the mulch (which has an estimated half-life of 5 years).

Table 2 **Summary of the effects of pinebark mulching on export potential related to fruit size. Counts 14 - 18 were considered to be highly suitable for export; counts 10 - 12 and 20 -22 were considered to be acceptable for export; and counts ≥ 24 were considered to be not suitable for export. Figures are mean numbers of fruits per category per tree**

	Control	Mulch	Percentage difference†
1993/1994			
Suitable	200	344	+ 72.0
Acceptable	152	145	- 4.6
Not suitable	157	51	- 67.5
1994/1995			
Suitable	53	117	+ 120.8
Acceptable	71	114	+ 60.6
Not suitable	138	102	- 26.1
1995/1996			
Suitable	374	447	+ 19.5
Acceptable	152	190	+ 25.0
Not suitable	172	177	+ 2.9
Overall			
Suitable	209	303	+ 45.0
Acceptable	125	150	+ 20.0
Not suitable	155	110	- 29.0

†Figures preceded by a positive sign indicate an increase by mulching, and figures preceded by a negative sign indicate a decrease by mulching

Phenology

No marked differences were found for the time of shoot flushing, with the spring flush being more vigorous than the summer flush in all trees. Mulched trees had slightly more vigorous flushes. However, flushing of surface feeder roots, measured under a newspaper mat, was always more pronounced in mulched than unmulched trees (Fig. 2). Root growth ratings showed the expected spring/early summer (lower) and late summer/autumn (higher) peaks. Unmulched tree ratings were mostly scored in the "poor" category, only rating "medium" during the summer/autumn flush. In contrast, mulched trees rated mostly in the "medium" category, with "good" ratings during the second flush. The onset and duration of root flushes was both earlier and more prolonged in mulched trees, where root proliferation within the mulch was prominent.

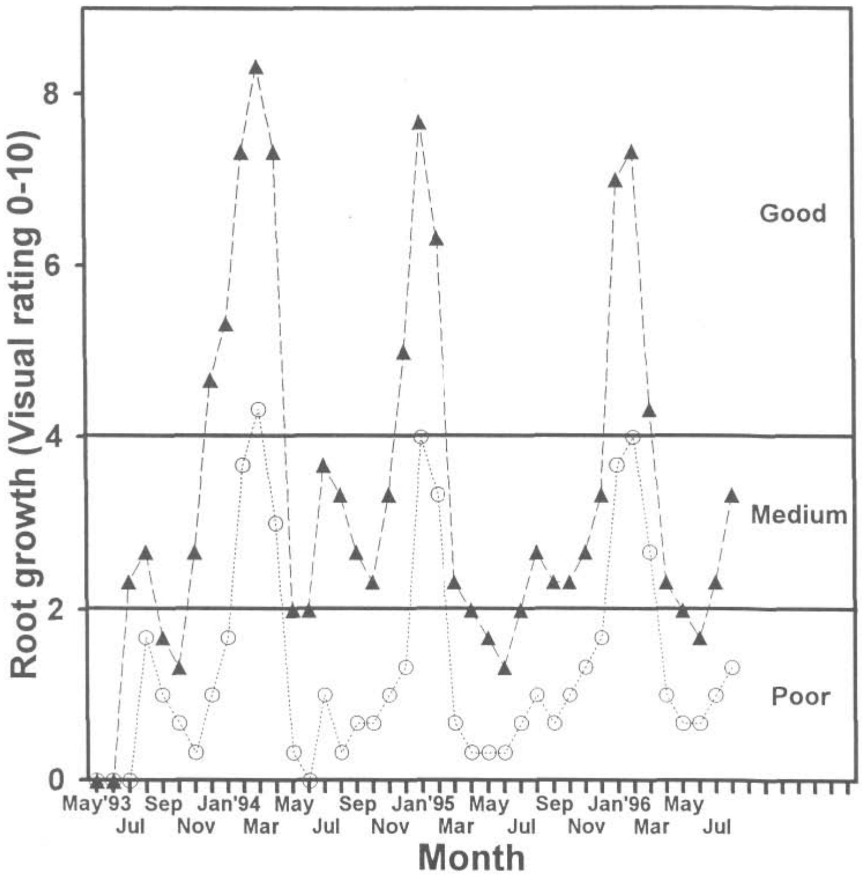

Figure 2 Root flushes for the mulch (Δ) and control (○) treatments as determined by a visual rating where there is no root growth for a rating of 0 and extensive root growth for a rating of 10. Values are the mean of 6 measurements per treatment

No differences between treatments were found in periods or intensity of flowering. In the second two seasons, following colder winters, peak flowering was delayed by ca. 1 month.

<u>Carbohydrate cycling</u>

The bark starch concentration showed typical seasonal variations, in the range from ca. 2%-3% in late summer to 7-9% in late winter just before flowering. The low yield season of 1994/5 followed a relatively low starch peak during winter 1994, while the very high yields of 1995/6 followed a high starch peak in winter 1995. There was a tendency for peak concentrations (but not troughs) to be higher in mulched trees (Fig. 3). The same trend was noted for trunk bark sugar concentrations (data not shown).

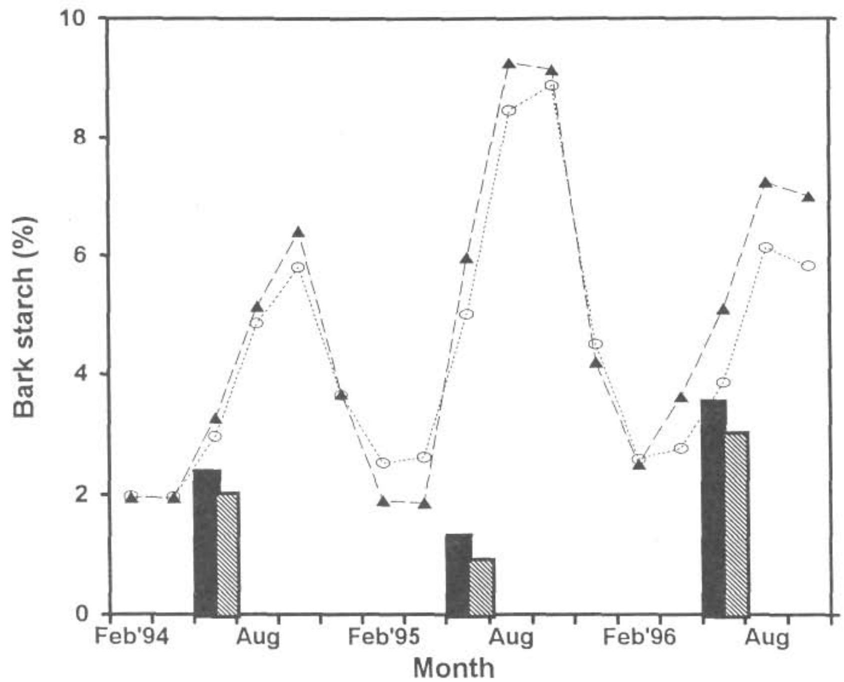

Figure 3 **Bark starch cycling in trees on the mulch (Δ) and control (O) treatments. Histograms show relative yields for the mulch (solid) and control (striped) treatments each season. SE (diff) = 0.25**

Physiological disorders

Mulched trees had an average of 38.6% ($P<0.05$) reduced incidence of dead seed coats at harvest maturity in the two seasons (Table 4) when this parameter was measured. The low incidence of below 20% in 1995/6 (NS) contrasted with a 55,7% ($P<0.01$) reduction in seed coat death in 1994/5. For pedicel "ringneck", an average of 13.4% of control fruits contrasted with 7.1% in mulched fruits, an average 47.0% ($P<0.01$) reduction (Table 3). The relatively low figure is indicative of the comparatively non-stressful, mesic environment.

Canopy temperature and photoinhibition

Two seasons' data (1994/5 and 1995/6) indicated that canopy temperature exceeded air temperature by between 0.5°C and 6°C in unmulched trees. A dramatic rise in leaf canopy temperature relative to air temperature occurred from February through April or May. At midday during this "stress period", leaf temperature of unmulched trees was up to 3°C higher than in mulched trees (data not shown). The Fv/Fm ratio, a measure of chlorophyll fluorescence, was typically also lower at midday in unmulched trees than mulched trees. Both these parameters indicate less stressed mulched trees, with more open stomates (faster transpiration rates) and less photoinhibited leaves.

Table 3 Effect of mulching on the incidence of pedicel ring-neck and seed coat abortion

		1993/94	1994/95	1995/96	Overall
	Control	17.5±2.2	13.3±2.7	9.4±1.6	13.4±2.4
Pedicel ring neck	Mulch	7.5±2.4	7.2±1.9	6.7±1.3	7.1±1.8
	% decrease	57.1**	45.9**	28.7^{NS}	47.0**
	Control	ND	31.4±4.2	19.4±3.2	25.4±3.7
Degenerate seed coat	Mulch	ND	13.9±2.4	17.3±3.0	15.6±2.8
	% decrease	ND	55.7**	10.8^{NS}	38.6*

NS denotes not significantly different; ★ denotes a significant decrease ($P \leq 0.05$); ★★ denotes a significant decrease ($P \leq 0.01$). (ND = not determined)

Discussion and conclusions

Yield and fruit size in avocado are under the control of many interacting factors, including genetic make-up, climatic extremes, poor flowering and poor pollination, and vegetative-reproductive competition. Furthermore, a host of as yet poorly understood physiological events impact on the critical early and main periods of fruit growth when size is determined in particular the time at which seed coat deterioration sets in.

Our studies have clearly shown that from a horticultural viewpoint there is much to be gained by reinforcing the natural dead litter mulch under healthy avocado trees. In two out of three seasons we obtained meaningful increases in fruit size despite fairly substantial yield increases, and even in a very heavy cropping season (32 and 361 ha^{-1} in unmulched and mulched trees) mean fruit size was maintained at ca 220 g by mulching. Overall, average increases over three seasons of 7% in fruit size, 15% in fruit number and 23% in yield in mulched trees are dramatic, especially in a well-managed orchard in a relatively mesic, non-stressful environment. When fruit size distributions in desirable export counts are compared, mulching benefits were even more obvious.

Our results from the phenological and physiological parameters studied provide much evidence that alleviation of physiological stress through improved root growth is at least part of the explanation of mulching benefits. Root growth was greatly improved by mulching; there was evidence of more prolonged seed coat viability and reduced ringneck; somewhat higher storage starch peaks; cooler (less stressed) canopies in summer and autumn, and less photoinhibited (photosynthetically more efficient) leaves.

More detailed anatomical studies not described detail in this paper have furthermore shown that growth of phenotypically small fruit is limited by cell number and not cell size. In addition, small fruits can be chemically induced by injecting ABA (abscisic acid, a growth inhibiting hormone) and mevastatin (an inhibitor of isoprenoid biosynthesis) (Cowan *et al.,* 1997b) into the fruit stalk during fruit development. Co-treatment with a growth promoting cytokinin hormone negated the effect of both ABA and mevastatin. Small fruits have increased flesh concentrations of ABA and reduced levels of the enzyme affected by mevastatin, viz. HMGR. FDVIGR catalyses the formation of mevalonic acid, the precursor to all isoprenoid compounds including ABA and cytokinins (Cowan, 1997a). While a discussion of these physiological aspects is beyond the scope of this paper, the results suggest that the cytokinin/ABA ratio is a key to fruit size, with small fruits low in cytokinin (a cell division factor) and high in ABA (related to water stress). We also have increasing evidence that carbohydrate flux in small fruit is compromised, and that the sucrose:hexose ratio may modulate plant hormone metabolism.

The above evidence for a role for "stress" in the small fruit syndrome is convincing, but only part of the story. We draw attention to the many other benefits of mulching, summarized by Turney and Menge (1994) and Wolstenholme *et al.* (1996). These include water conservation, improved root growth and reduced physiological stress, and a more mesic edaphic environment; promotion of "suppressive soils" for reduction of root diseases; provision of minerals for improved root growth (P, Ca, B) and tree growth; and they may improve weed control. Smith *et al.* (1995) found that soil boron applications in deficient Queensland soils improved 'Hass' fruit size by 11-15%. Our pine bark mulch is believed to have supplied added boron during decomposition, and improved feeder root growth increases foraging efficiency. This mulch had a C:N ratio of 37:1 and a N content of 1.1%, so there was no danger of a nitrogen "draw-down" (Handreck & Black, 1994; Turney & Menge, 1994: Wolstenholme *et al.,* 1996). We have initiated another trial comparing pinebark with filter-press cake from sugarcane mills, at Cooling Farm near Wartburg.

The composted pine bark mulch used in our trial was a relatively expensive but long-term product with excellent physical properties. The choice of mulching material for avocado orchards will be affected by many factors, not least availability (e.g. filter-press cake from sugarcane in KwaZulu-Natal), C:N ratio (ideally between 25:1 and 100:1) and rapidity of decomposition. For more rapidly decomposed mulches, time of application is important (winter/early spring) so that potential soil wetness problems in heavy summer rains are not aggravated. The contribution of mulches to nutrition must be taken into account and monitored by soil and leaf analysis. There are both pros and cons to mulching, and mulches must be used correctly.

In conclusion, the evolutionary history of the avocado tree suggests that it will, in most orchard circumstances, be responsive to mulching. We present evidence from an ongoing mulching trial that substantial yield increases, made possible by both increased fruit number and fruit size, can be achieved even in a relatively non-stressful summer rainfall environment. Improved tree performance was partly due to alleviation of stress, but probably also due to an improved root environment and improved nutrient uptake. Careful choice of type of mulch is necessary, and ultimately mulching is an economic decision. The use of *inter alia* orchard prunings as mulch material is common sense. Awareness of the pros and cons of mulching relative to the particular orchard situation, and monitoring of water relations and mineral nutrition, is fundamental to success.

Acknowledgments

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