WHAT, WHEN, WHERE AND HOW MUCH MULCH SHOULD BE APPLIED TO 'HASS' AVOCADO TREES IN THE WESTERN BAY OF PLENTY

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ABSTRACT

In New Zealand, mulch under avocado trees is considered to be important for obtaining good yields. The disadvantages of mulch are cost, availability and the labour needed for application. Increasingly available, greenwaste could meet the need for mulch in avocado orchards. The benefits of mulch on yield have not been quantified under New Zealand conditions. Four experiments examining the composition, time of application, bandwidth and thickness of mulch were repeated across a number of orchards to define best practice for application of mulch on yield and root growth. A total of 592 trees in 19 orchards were used with the common controls of: minimal mulch (removal of leaf litter under trees), leaf litter (natural build up of plant material) and post peelings *(Pinus radiata)*. The type of mulch, time of application, amount of mulch and location of mulch did not affect yield or growth of the trees compared to the minimal mulch and leaf litter treatments. Post peelings mulch can increase the number of avocado feeder roots and may help improve root health where feeder roots are under stress in the first two years after application. Other mulches did not increase root coverage at the soil mulch interface. The soil under mulches containing compost had significantly higher levels of phosphorous and potassium than the soil under the minimal mulch, leaf litter and peelings mulch treatments. Weed coverage was reduced in the first year after application of mulch. Soil moisture matrix potential at 30cm or 60cm depth was similar in all mulch treatments. Yield was not affected by mulch, implying that mulch alone is not limiting 'Hass' avocado tree productivity in the Western Bay of Plenty. In the New Zealand avocado orchards the soil organic matter content was between 12.5% and 7.4%. These levels of organic matter are greater than in some other countries where the organic matter is typically 1% organic matter with very rapid rates of decomposition. The results from applying mulch in other countries should not be extrapolated to New Zealand avocado orchards. There was no difference between mulches in the rate of decrease in thickness over the three years of the project. The percentage of roots at the soil mulch interface was increased the most by application of peelings mulch at a depth of 100mm or greater and a width of greater than 1.0m.

Keywords: *yield, growth, roots, shoots, trunk, nutrients, decay, greenwaste, compost*

INTRODUCTION

The area of land planted in avocados has increased rapidly in the past decade with total current plantings in New Zealand estimated to be 5,200 ha (New Zealand Avocado Growers' Association Annual Report, 2007). Along with increased plantings of avocados the total industry production has increased. Individual orchard yields, however, have been erratic with many orchards having strong alternate bearing patterns. Application of mulch under avocado trees is considered to be important to obtaining good yields (Wolstenholme *et al.*, 1996). About one third of avocado orchards are expected to apply new mulch each year representing a potential demand of over 69,000 tonnes of mulch material each year.

Mulching is the application of any layer of plant material or other suitable material to the surface of soil without incorporation into the soil (Wolstenholme *et al.*, 1996). In contrast, compost includes any organic material that has undergone managed, aerobic microbial degradation at elevated temperatures, resulting in significant microbial, physical and chemical changes to the original material (Wallace *et al.*, 2004). Mulches differ from compost in that mulches are not intended as a growth medium or to contribute to soil fertility. Mulch composts slowly and at lower temperatures than compost and through the activity of soil fauna, in particular earthworms, is slowly incorporated into the soil 'A' horizon.

Mulches in many crops, and in general, are thought to confer improved growth and productivity of plants through stimulation of root growth and health by: improved water conservation, reduced weed cover and growth, increased soil organic matter allowing for deeper root growth, lower ground water contamination of heavy metals and nitrates, maintaining a constant soil temperature (Gregoriou and Rajkumar, 1985), adding to the nutrient content of the soil and suppression of soil borne diseases by increasing microbe activity (Wolstenholme *et al.*, 1996). In New Zealand, the soil under two 'Hass' avocado trees on seedling 'Zutano' rootstocks established in large planting holes (2m x 2m x 2m deep) with 0.33m^3 of compost had large numbers of feeder roots down to at least 1m depth (Dixon and Sher, 2003). In South Africa, feeder root flushes occur for longer and produce more roots under mulched trees (Moore-Gordon *et al.*, 1996). The stimulation of root activity may improve nutrient uptake with consequent improvements in yield. In South Africa, in a study in one orchard on six trees mulched with composted pine bark, calculated yields were between 18 to 42% greater on the mulched trees compared to un-mulched trees (Moore-Gordon and Wolstenholme, 1996).

Soil mulches are often claimed to increase the efficiency of water use on the orchard by reducing evaporation from the soil surface reducing total water demand (Turney and Menge, 1994). Consequently, the soil is assumed to remain moist during the driest times of the year.

The carbon to nitrogen (C:N) ratio is determined by the composition of the organic material in the mulch. The C:N ratio determines the nitrogen usage during decomposition (Wolstenholme *et al.*, 1996). Reduction of nitrogen from the soil due to microbial activity when the carbon to nitrogen ratio is above 100 to 1 can cause the leaves to yellow through nitrogen deficiency. Mulches composed of small particles should be avoided as these can absorb a lot of nitrogen from the soil creating a deficit of nitrogen. Mulches that decompose rapidly can also cause problems in that the extra nutrients released may upset the vegetative-reproductive balance of the tree. Wolstenholme *et al*., (1996) proposed that the ideal mulch on avocado orchards in South Africa should have the following properties: a C:N ratio of between 25 to 1 and 100 to 1 and be composed of fibrous materials with a moderate rate of breakdown and composted chunky pine bark. These recommendations are re-interpreted in the New Zealand situation to mean the ideal mulch should have chunks of bark and wood that breakdown slowly.

The greatest disadvantages of mulch are cost, availability and the need to apply under trees. Transport costs of mulch can be high as mulch is bulky and application requires the use of specialised machinery or a lot of labour. Many New Zealand avocado orchards utilize mulch from many different sources, for example: shelter belt trimmings, prunings, and avocado trees removed as part of a thinning programme. Often the amount of material available for mulch from an orchard is insufficient to adequately cover the area under trees. Many orchards buy in mulch that is commonly sourced from the waste from sawmills. Green waste mulch could also supply the need for mulch in avocado orchards. In many regions of New Zealand greenwaste is increasingly available.

As the application of mulch can be a major orchard cost, the benefits of using mulch on yield and the costs of production require quantification under New Zealand conditions. To achieve the benefits of mulching reported outside of New Zealand the best time to apply mulch at the right thickness and bandwidth under trees was determined. The project was divided into four experiments repeated across a number of orchards that sought to answer a separate question which related specifically to defining best practice for application of mulch.

The questions were:
What should the mulch be made of?
Mulches available ranged from compost to material composed mainly of bark and wood. A study was conducted to determine the effect of mulches composed of compost, green waste material and wood on growth and productivity of 'Hass' avocado trees in the Western Bay of Plenty.

When should the mulch be applied?
Mulch is generally recommended to be applied when soil moisture levels are high at times of the year when root flushes are occurring. A study was conducted to determine the effect of applying mulch to the soil around 'Hass' avocado trees at different times of the year on root growth and tree productivity in the Western Bay of Plenty.

Where should mulch be applied?
Mulch is considered to encourage the growth of a large number of feeder roots. By placing mulch outside of the drip line of avocado trees it may be possible to increase the feeder root mass under an avocado tree. A study was conducted to determine the effect on root growth and tree productivity of applying mulch beyond the drip line of 'Hass' avocado trees.

How much mulch should be applied?
The thickness of mulch may be important in determining how easily water and nutrients can move through the mulch to the soil. The rate at which the mulch decomposes over time will determine how often the mulch needs to be re-applied. A study was conducted to determine the effect on avocado roots and tree productivity of applying mulch at different thicknesses.

MATERIALS AND METHODS

General experimental set up
Avocado trees, 'Hass' grafted onto seedling 'Zutano' rootstock, from 19 orchards in the Western Bay of Plenty, New Zealand, were selected for mulching treatments. When the mulch treatments were initially applied the age of trees was typically between 5 to 7 years, unless otherwise stated. Mulch treatments were applied to trees that did not have mulch applied for at least 3 years previously. When treatments were applied, the old mulch layer was typically thin to very thin (<10mm thickness) under the trees. Pest and disease control was within current New Zealand avocado industry norms. The orchards in the study all followed commonly accepted fertilizer programmes with variations from orchard to orchard according to the results of soil and leaf mineral analysis tests and previous cropping history. Where appropriate, the trees were injected with phosphorus acid at recommended label rates for control of *Phytophthora cinnamomi* root rot. At the time of applying the first mulch treatments no trees showed symptoms of Phytophthora infection nor did trees develop symptoms of Phytophthora infection during the 3 years of evaluation. There were 3 mulching treatments applied to trees in all the orchards in the project: minimal mulch, leaf litter and post peelings. These treatments acted as internal controls within each orchard and allowed comparison between orchards.

Experiments

Experiment 1. What should the mulch be made of?
5 trees per treatment (total 35 trees) on each of five orchards were randomly selected for mulch treatments as follows:

- Controls
  - Minimal mulch (removal of leaf litter under trees)
  - Leaf litter (natural build up of plant material)
  - Post peelings *(Pinus radiata)* typical mulch material available to avocado orchards

- Treatments
  - Granulated bark/chips *(Pinus radiata)* plus 20% compost
  - 10 day old green waste (un-composted green waste)
  - Compost (fully composted and screened green waste)
  - Compost tailings (oversize fraction of compost)

All mulches were applied in a 1m band centred on the drip line at 100mm thickness. Additional mulch was added for the treatments 10 day old green waste, compost and compost tailings once the mulch thickness had reduced by about 50%.

Experiment 2. When should the mulch be applied?
Five trees per treatment (total 25 trees) on each of 5 orchards were randomly selected for mulch treatments as follows:

- Controls
  - Minimal mulch (regular removal of leaf litter under trees)
  - Leaf litter (natural build up of plant material)
- Treatment
  - Post peelings *(Pinus radiata)* applied in:
    - Spring/Summer (November – December 2002)
    - Autumn (March – April 2003)
    - Winter (May – June 2003)

All mulches were applied in a 1m band centred on the drip line at 100mm thickness.

Experiment 3. Where should mulch be applied?
Five trees per treatment (total 30 trees) on each of 4 orchards were randomly selected for mulch treatments as follows:

- Controls
  - Minimal mulch (regular removal of leaf litter under trees)
  - Leaf litter (natural build up of plant material)
- Treatments
  - Post peelings *(Pinus radiata)* applied to:
    - 0.5m either side of the drip line (1m band)
    - 1.0m either side of the drip line (2m band)
    - 1.5m either side of the drip line (3m band)
    - 2.0m either side of the drip line (4m band)

All mulches were applied at 100mm thickness.

Experiment 4. How much mulch should be applied?
Five trees per treatment (total 35 trees) on each of 5 orchards were randomly selected for mulch treatments as follows:

- Controls
  - Minimal mulch (regular removal of leaf litter under trees)
  - Leaf litter (natural build up of plant material)
- Treatment
  - Post peelings *(Pinus radiata)* applied at:
    - 50mm thickness of mulch
    - 100mm thickness of mulch
    - 200mm thickness of mulch
  - 10 day old green waste applied at:
    - 50mm thickness of mulch
    - 100mm thickness of mulch

All mulches were applied in a 1m band centred on the drip line of the tree. Additional mulch was added for the 10 day old green waste treatment once the mulch thickness had reduced by about 50%.

Mulching treatments
Minimal mulch: organic material was raked away to the soil mulch interface from 0.5m around the drip line of the tree each time a measurement was made (about 4 to 5 times a year).
Leaf litter: organic material was allowed to accumulate from leaf fall and tree prunings and no additional mulch material was added.

Post peelings: *Pinus radiata* wood shavings about 25mm wide, 100-150mm long and 2-3mm thick were sourced from a sawmill and applied in a standard manner of a 1m band centred on the drip line at a thickness of 100mm.

Granulated bark chips plus 20% compost: Partly composted bark chips about 25mm by 25mm (a propriety product Forest Floor mulch, Attwood's compost) mixed with 20% compost made from green waste and chicken manure (Te Manga, Tauranga composting plant).

10 day old green waste: Partly processed green waste material blended from Living Earth Ltd and Revital Fertilisers composting operations. The material was pasteurised and minimally processed before placement under trees. The mulch decayed rapidly once applied. The wood fraction was about 25% with the remaining 75% leafy type material.

Compost: Fully processed green waste into compost. The compost was accelerated with chicken manure and sieved to a fine particle size.

Compost tailings: The oversize fraction remaining after sieving compost consisting of woody twigs, branches and some compost material. There was also a considerable fraction of household rubbish in the tailings mainly consisting of pieces of plastic.

The nutrient composition of the different mulch material is given in the following tables.

Table 1. Organic matter, chemical and nutrient levels of each type of mulch placed under trees in 2002, sampled 3/12/2002.

Mulch Nutrients and Characteristics	Peelings	Compost	Compost tailings	Bark+ Compost	10 Day green waste
Total Carbon (%)	46.8	21.5	32.2	36.3	39.5
Total Nitrogen (%)	0.24	1.66	1.75	0.86	0.98
Carbon to Nitrogen ratio	195.0	13.0	18.4	42.2	40.3
Organic Matter (%)	80.7	37.1	55.4	62.6	68.0
Dry Matter (%)	64.3	70.0	53.8	62.8	57.3
Total Phosphorus (mg/kg)	166	4750	6100	3080	1170
Total Sulphur (mg/kg)	213	3170	3510	1550	1070
Total Potassium (mg/kg)	1970	9530	14100	8330	6150
Total Calcium (mg/kg)	1580	29100	26500	22100	12800
Total Magnesium (mg/kg)	500	3710	3280	2060	2080
Total Sodium (mg/kg)	2	2040	3240	1600	1100
Total Iron (mg/kg)	361	12200	4690	4250	4760
Total Manganese (mg/kg)	52.4	430	393	301	196
Total Zinc (mg/kg)	22.1	203	171	122	113
Total Copper (mg/kg)	2.8	64.6	40.0	26.8	22.0
Total Boron (mg/kg)	7.2	32.9	29.0	16.5	17.3
Total Aluminium at pH 3.0 (mg/kg)	672	6700	5600	4620	3930

Table 2. Organic matter, chemical and nutrient levels of each type of mulch placed under trees in 2003 to replenish depleted mulch layers, sampled 19/11/2003.

Mulch Nutrients and Characteristics	Peelings	Compost	Compost tailings	Bark+ Compost	10 Day green waste
Total Carbon (%)	46.6	19.8	26.9	24.9	28.4
Total Nitrogen (%)	0.15	1.39	1.65	1.30	1.28
Carbon to Nitrogen ratio	310.7	14.2	16.3	19.2	22.2
Organic Matter (%)	80.3	34.1	46.5	42.9	48.9
Dry Matter (%)	39.3	56.3	47.2	57.9	54.2
Total Phosphorus (mg/kg)	83	5610	6630	2190	2010
Total Sulphur (mg/kg)	70	2550	3920	1870	1860
Total Potassium (mg/kg)	281	3570	5370	1760	1850
Total Calcium (mg/kg)	551	38500	27400	25200	16800
Total Magnesium (mg/kg)	194	4060	3610	3100	4130
Total Sodium (mg/kg)	<1	343	148	56	641
Total Iron (mg/kg)	433	9410	7920	4220	10700
Total Manganese (mg/kg)	43.7	482	561	294	424
Total Zinc (mg/kg)	8.37	253	354	273	232
Total Copper (mg/kg)	5.68	86.0	108	85.5	76.1
Total Boron (mg/kg)	0.28	18.1	30.4	29.5	19.5
Total Aluminium (mg/kg)	462	7460	6970	4400	9740

Measurements

Tree phenology

Shoot growth – the length of two shoots from the tip to the bud ring of current growth on the north facing side of the tree were measured to the nearest mm. One shoot was 'long' with an initial length of between 500 to 600mm and the other shoot 'short' with an initial length of between 200 to 300mm. The different shoot lengths represented the range of shoot vigour typically found within an avocado tree.

Trunk circumference – a metal washer was glued about 300 to 400mm above the graft to mark the position for measuring trunk circumference to the nearest mm.

Root mass – mulch was raked away to reveal the soil-mulch interface at a point randomly selected under the drip line of each tree. The percentage cover by roots of the soil surface was recorded in a 0.5m^2 area. Roots present were rated for the percentage of fine roots (<3mm width), thick roots (>3mm width); the roots present were further rated as the percentage of black roots or roots with white tips the remainder of roots were apparently healthy but turning brown.

Root mass – at the end of the project the roots under trees in Experiment 1 on the south and north side of each tree were collected from soil plugs using a hand auger 150mm diameter and 150mm deep. Two plugs of soil were taken from the same hole, 0 to 150mm and 150 to 300mm deep. The soil was sieved and the avocado roots collected weighed to the nearest 1/100th of a gram. Roots were dried for 24 hours at 65°C to determine dry weight.

Leaf nutrient status – once each year in April through to May, 25 leaves were collected once from each tree for each mulch treatment in Experiment 1. The leaves were bulked together for analysis at a commercial testing laboratory (Hill Laboratories Ltd, Hamilton, New Zealand). For the other Experiments leaves were collected from each tree in the minimal mulch treatment only. This sampling protocol was not the standard method for sampling a block of trees.

Soil characteristics

Water status – the general soil moisture was measured as soil moisture matrix potential using tensiometers (Irrometer, USA) installed at depths of 30cm and 60cm. In Experiment 1 a pair of tensiometers was installed under one tree in each treatment for a total of seven pairs of tensiometers in each orchard. In the other Experiments one pair of 30cm and 60cm tensiometers were installed under one tree in the minimal mulch treatment.

Nutrient status – at the same time as a leaf sample was collected for nutrient analysis soil samples were collected after brushing aside the mulch to test for soil nutrients as described by Hill Laboratories soil sampling protocol. The soil tests were conducted by Hill Laboratories Ltd in Hamilton, New Zealand.

Soil A horizon – at the end of the project the soil 'A' horizon under trees in Experiment 1 was measured to the nearest mm.

Biological activity – the number of earthworms in the soil plugs taken to measure root mass were recorded.

Mulch breakdown

Change in mulch thickness was used to measure mulch breakdown, a combination of settling, decay and mixing with the soil 'A' horizon. Small wooden stakes about 400mm long and 5mm wide were pushed through the mulch into the soil. The length of the stake from the mulch surface to the top of the stake was measured to the nearest mm. The change in the stake length was used to calculate the change in mulch thickness.

Tree productivity

Yield – Individual fruit were weighed to the nearest gram from each tree by a commercial fruit grading system or electronic scales.

Quality – 100 fruit per tree from two orchards from the treatments leaf litter, compost and post peelings in Experiment 1 were placed into cool storage at 4°C ± 0.5°C, 85% RH for 28 days before ripening at 20°C ± 1.0°C, 65% RH. The fruit were analysed for disorders as described in the New Zealand Avocado Fruit Assessment Manual 2003 (AIC, 2003).

Alternate bearing index – was calculated for the two year period 2004 to 2005 using the following formula: ABI = (2004 yield – 2005 yield)/(2004 yield + 2005 yield).

Statistical Design
Each experiment on each orchard was established as a complete randomised block design with repeated measures. Treatments were randomly assigned to individual trees within each orchard selected as being healthy and typical of the trees in the orchard. Care was taken to ensure the trees were not located in areas that may bias their performance. For each orchard there were 5 tree replicates per treatment and each experiment was initially established in 5 orchards. There was only one experiment per orchard. Data analysis was conducted using MINITAB version 13.31 and where appropriate values were transformed to meet the assumption of normal distribution for analysis of variance. Untransformed means are presented in the tables.

RESULTS

Yield
The application of peelings mulch did not significantly increase yield in 2004 or 2005 compared to the minimal mulch and leaf litter treatments (Table 3). Trees in the peelings mulch treatment tended to have the greatest yield in 2004 and the lowest yield in 2005. The cumulative yields in each treatment for 2004 and 2005 were similar (Table 3). The type of mulch, time of application, amount of mulch and location of mulch did not alter the total amount of fruit produced per tree compared to the minimal mulch and leaf litter treatments (Table 4). There were large differences in individual tree yields between orchards (Table 4). The distribution of fruit sizes was not affected by the mulch treatments (Table 5).

Table 3. Average yield (kg) per tree for all trees in the minimal mulch, leaf litter and peelings mulch applied at 100mm thickness and 1.0m bandwidth treatments, across all trials.

Year	Mulch Treatment	Yield (kg/tree)
2004	Minimal mulch	38.0
	Leaf litter	38.7
	Peelings	55.3
2005	Minimal mulch	120.2
	Leaf litter	122.7
	Peelings	107.9

Table 4. Average cumulative yield (kg) per tree for each mulch treatment from each orchard for the harvest seasons starting in 2004 and 2005.

Experiment	Orchard	Minimal mulch	Leaf litter	Peelings[1]	Compost	Compost tailings	Bark + compost	10 day Green waste
What should the mulch mulch be made of?	A	230.2	132.2	127.2	171.7	111.8	140.1	132.6
	B	0	0	0	0	0	0	0
	C	161.1	153.1	165.2	158.9	150.5	166.9	160.2
	D	14.3	22.0	31.7	6.6	13.5	13.8	8.1
	E	727.6	657.8	678.7	698.8	-[2]	611.0	462.8
Time of year				**Autumn**	**Winter**	**Spring**		
When should the mulch be applied?	F	0	0	0	0	0		
	G[3]	75.8	63.0	66.4	91.0	61.8		
	H	117.2	170.1	121.0	101.8	170.1		
	I	28.6	19.8	66.6	28.8	52.0		
	J	0	0	0	0	0		
Bandwidth				**0.5m**	**1.0m**	**1.5m**	**2.0m**	
Where should mulch be applied?	K	90.2	85.4	120.9	78.2	87.2	122.9	
	L	57.8	28.1	45.6	46.1	62.2	71.1	
	M	22.3	19.7	12.7	15.9	14.3	10.5	
	N	118.0	115.0	155.5	87.2	111.4	193.6	
	Thickness		**Peelings**	**100mm**	**50mm**	**200mm**	**GW 50[4]**	**GW 100[5]**
How much mulch should be applied?	O	23.6	61.7	44.6	39.7	32.6	25.5	26.8
	P	118.3	182.4	171.8	130.9	183.2	143.7	113.3
	Q	100.7	104.7	173.1	75.2	125.4	74.0	127.5
	R	154.8	136.8	109.7	125.2	134.5	127.7	120.9
	S	82.7	116.3	87.7	91.3	84.8	80.3	85.2

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2]Not applied; [3]Harvest in 2004 only; [4]10 day old green waste 50mm thickness; [5]10 day old green gaste 100mm thickness.

Table 5. Percentage of cumulative fruit numbers in each fruit size category for orchards A, B, C and D in Experiment 1 for the years 2004 to 2005.

Treatment	Fruit count[1] 16	18	20	23	25	28	32	>32
Minimal mulch	7.0	14.1	21.6	19.3	15.3	8.1	9.6	5.1
Leaf litter	4.2	10.2	23.1	20.0	16.2	8.5	10.9	6.8
Peelings	5.1	12.3	22.4	19.6	15.5	9.4	10.1	5.7
Compost	5.8	11.3	23.3	20.8	15.9	8.4	9.9	4.7
Compost tailings	5.7	9.5	23.7	19.1	16.7	8.6	11.7	5.0
Bark & compost	4.7	11.0	22.4	19.3	17.6	8.3	10.0	6.6
10 day green waste	6.4	14.6	23.0	19.7	16.4	6.5	9.2	4.2
Average	5.6	11.9	22.8	19.7	16.2	8.3	10.2	5.4

[1]Fruit counts are based on the AIC quality manual fruit mass ranges for avocados packed for export.

Thirteen of the orchards used in this study were alternate bearing with an average ABI of 0.59 (Table 6). Four of these orchards had severe alternate bearing with an ABI of 1.0. None of the trees on 3 of the orchards produced fruit in 2004 and 2005. In addition, a number of trees within some orchards did not produce fruit in 2004 and 2005 while adjacent trees in the same orchard produced fruit in at least one of the years 2004 and 2005 (Table 6).

Tree growth

There was no significant difference between mulch treatments in tree growth as measured by the percentage increase in trunk circumference (Table 7) or shoot extension (Table 8) of trees within an orchard. The type of mulch, time of application, amount and location of mulch did not alter the growth of the trees (Tables 7 and 8).

Table 6. Cropping characteristics of 'Hass' avocado trees used to evaluate mulch treatments in the years 2004 and 2005.

Experiment	Orchard	ABI[1]	% trees with no crop		% trees with no crop both years
			2004	2005	
What should the mulch be made of?	A	0.91	65.7	5.7	2.9
	B	-	100.0	100.0	100.0
	C	0.66	0.0	0.0	0.0
	D	1.00	100.0	11.4	11.4
	E	0.82	6.7	3.3	0.0
When should the mulch be applied?	F	-	100.0	100.0	100.0
	G[2]	-		0.0	
	H	0.60	0.0	0.0	0.0
	I	1.00	100.0	0.0	0.0
	J	-	100.0	100.0	100.0
Where should mulch be applied?	K	0.45	3.3	3.3	0.0
	L	0.82	0.0	46.4	0.0
	M	0.77	20.0	6.7	0.0
	N	1.00	100.0	0.0	0.0
How much mulch should be applied?	O	0.83	25.7	8.6	2.9
	P	0.59	2.9	14.3	2.9
	Q	1.00	2.9	100.0	2.9
	R	0.88	31.4	2.9	2.9
	S	0.27	0.0	0.0	0.0

[1]*Alternate Bearing Index;* [2]*Harvest in 2004 only.*

Table 7. Average percentage increase in trunk circumference per tree for each mulch treatment from each orchard from 2003 to 2005.

Experiment	Orchard	Minimal mulch	Leaf litter	Peelings[1]	Compost	Compost tailings	Bark + compost	10 day green waste
What should the mulch be made of?	A	28.2	37.2	31.9	35.3	24.3	42.3	42.7
	B	37.8	44.9	43.2	40.3	38.2	41.8	41.6
	C	52.0	48.7	55.9	49.6	53.9	52.2	48.9
	D	25.1	26.7	25.6	29.3	37.8	37.0	28.2
	E	13.8bc[6]	25.2a	13.1bc	15.8abc	-[2]	12.5c	16.1abc
Time of year				**Autumn**	**Winter**	**Spring**		
When should the mulch be applied?	F	30.8	25.6	25.1	30.7	24.1		
	G[3]	47.9	31.3	41.3	37.9	45.5		
	H	27.1	28.3	30.3	29.0	27.8		
	I	32.7	33.0	35.0	39.6	33.5		
	J	35.2	32.1	31.3	32.9	33.4		
Bandwidth			**0.5m**	**1.0m**	**1.5m**	**2.0m**		
Where should the mulch be applied?	K	26.5	19.5	38.0	25.2	22.1	32.1	
	L	20.4	39.4	25.6	21.2	41.2	25.2	
	M	28.6	31.9	27.0	30.5	33.3	31.2	
	N	22.8	25.3	22.8	21.6	23.5	19.9	
Thickness			**Peelings**	**100mm**	**50mm**	**200mm**	**GW 50[4]**	**GW 100[5]**
How much mulch should be applied?	O	26.8	23.9	23.4	23.9	25.2	21.5	30.4
	P	12.1	10.2	7.2	13.6	10.6	10.2	14.5
	Q	8.7	8.5	10.0	10.2	7.0	10.5	6.0
	R	10.4	11.7	12.9	11.7	15.0	8.6	14.7
	S	19.9	11.1	14.1	13.4	19.4	23.3	22.7

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2]Not applied; [3]Harvest in 2004 only; [4]10 day old green waste 50mm thickness; [5]10 day old green waste 100mm thickness; [6] Means across a row for each treatment followed by the same letter are not different according to a One Way ANOVA using Tukey's pairwise comparisons at the 5% level.

Table 8. Average cumulative increase in shoot length (mm) per tree for each mulch treatment from each orchard from 2003 to 2005.

Experiment	Orchard	Minimal mulch	Leaf litter	Peelings[1]	Compost	Compost tailings	Bark + compost	10 day green waste
What should the mulch be made of?	A	1094	1236	1135.2	938.2	770.4	871.8	1246.2
	B	1365.8	1257.6	1330.4	1010	759.4	902.8	859.4
	C	1810	1583	1093	1560	1194.4	1981	1615.8
	D	745.8	857	853.4	965	709.6	683	844.8
	E	1369.6	1034.6	1130.6	918.8	-[2]	1402.8	1140
Time of year				**Autumn**	**Winter**	**Spring**		
When should the mulch be applied?	F	1101.8	918.2	1259.6	1255.8	741		
	G[3]	1074	1127.2	1438.6	1246	1571.6		
	H	1409.8	1208	1356.2	1230	1117		
	I	1775.4	1585.6	1730	2401	1461.8		
	J	588.6	943	762.4	923	1012.2		
Bandwidth				**0.5m**	**1.0m**	**1.5m**	**2.0m**	
Where should the mulch be applied?	K	1214.4	909.1	1207.8	803	1267.6	1027.2	
	L	761.4	1158.6	1057	1061.2	995.8	938	
	M	1413.2	1053.6	1038	1171.8	1601.6	1218	
	N	1889	1586	1495.2	1446.2	1810.6	1827.2	
Thickness			**Peelings**	**100mm**	**50mm**	**200mm**	**GW 50[4]**	**GW 100[5]**
How much mulch should be applied?	O	1254.2	1282.2	997	1074.4	1087.2	1456.4	1328
	P	1026	1079.8	852.8	617.6	676.2	611.8	675.4
	Q	1529	1753.4	1522	1595	1950.8	1444.2	1556.4
	R	1156.8	1082.4	1542.4	1543.2	1483.8	1383.6	1303.4
	S	1227	950.8	1236.6	1371.6	1645.4	1262.4	1087.4

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2]Not applied; [3]Harvest in 2004 only; [4]10 day old green waste 50mm thickness; [5]10 day old green waste 100mm thickness.

Root coverage

In general, the application of peelings mulch increased the number of feeder roots at the soil-mulch interface compared to the minimal mulch and leaf litter treatments (Table 9). Of the roots present the proportion of thick and thin roots under the peelings mulch were not different to the minimal mulch or leaf litter treatments. The proportion of roots present with white tips was similar for each mulch treatment. Roots under the peelings mulch tended to have a lesser proportion of black roots than the roots under minimal mulch and leaf litter. The coverage of feeder roots was greatest in the first year after application of mulch and declined each year thereafter but was still greater in the peelings mulch treatment three years after application.

Mulches other than peelings, used in Experiment 1, did not have different root coverage at the soil mulch interface (Table 10). The time of year, bandwidth or thickness of peelings mulch when applied did not increase feeder root coverage compared to the leaf litter treatment (Table 10). The coverage of roots at the soil mulch interface was not affected by the thickness of the 10 day old green waste mulch (Table 10). There was trend for the thinner (50mm application thickness) 10 day old green waste treatment to have more roots at the soil mulch interface than the thicker (100mm) 10 day old green waste treatment.

Table 9. Average percentage coverage of feeder roots, thick or thin feeder roots, and feeder roots with white tips or that had turned black covering a 0.5m^2 area of soil mulch interface per tree for all trees in the minimal mulch, leaf litter and peelings mulch treatments across all trials.

Measurement	Mulch Treatment	2003	2004	2005
Coverage of roots	Minimal mulch	11.3b[1]	2.5c	1.3c
	Leaf litter	14.5b	5.6b	6.1b
	Peelings	23.4a	15.5a	9.3a
% of roots >3mm thick	Minimal mulch	47.3	46.5	50.4
	Leaf litter	40.6	41.3	43.8
	Peelings	45.7	48.0	46.5
% of roots <3mm thick	Minimal mulch	52.7b	53.5	49.6
	Leaf litter	59.4a	58.7	56.2
	Peelings	54.3b	52.0	53.5
% of roots with white tips	Minimal mulch	28.7	16.0	35.0
	Leaf litter	29.6	16.8	37.3
	Peelings	36.6	20.8	26.4
% of roots black	Minimal mulch	11.1	21.7a	26.4
	Leaf litter	11.3	15.5ab	17.1
	Peelings	7.1	8.8b	16.6

[1]Means within a column for each type of measurement followed by the same letter are not different according to a One Way ANOVA using Tukey's pairwise comparisons at the 5% level.

Table 10. Average percentage of roots covering a 0.5m^2 area at the soil-mulch interface for 2005.

Experiment	Orchard	Minimal mulch	Leaf litter	Peelings[1]	Compost	Compost tailings	Bark + compost	10 day green waste
What should the mulch be made of?	A	0.2b	2.8ab	7.1a	3.5ab	14.4a	2.9ab	1.4ab
	B	1.3b	2.0b	25.5a	3.4b	2.8b	7.0ab	4.0ab
	C	0.0	1.2	2.1	1.8	0.3	1.0	2.3
	D	1.1b	4.7ab	7.0a	4.4ab	5.4a	3.4b	3.6ab
	E	2.5	0.5	2.4	1.6	-	0.8	1.0
	Average	**1.2b**	**7.2b**	**18.2a**	**6.3ab**	**12.3ab**	**4.9b**	**4.8b**
	Time of year			**Autumn**	**Winter**	**Spring**		
When should the mulch be applied?	F	0.1c	5.9abc	1.8bc	9.3ab	22.3a		
	G[3]	0.2c	1.4bc	7.9a	3.5bab	1.4bc		
	H	0.1	4.1	7.4	8.4	7.4		
	I	1.8	22.0	17.9	14.5	11.3		
	J	0.0b	1.1ab	9.0a	6.9ab	2.5ab		
	Average	**0.4b**	**7.2a**	**8.0a**	**8.5a**	**8.4a**		
	Bandwidth			**0.5m**	**1.0m**	**1.5m**	**2.0m**	
Where should the mulch be applied?	K	0.5	0.7	0.6	0.7	1.1	0.4	
	L	0.6	1.0	5.8	1.1	3.0	0.7	
	M	0.0	0.7	1.2	4.2	4.5	0.7	
	N	1.4b	9.1ab	9.1ab	7.9ab	19.2a	13.5ab	
	Average	**0.6b**	**3.0ab**	**4.1ab**	**3.5ab**	**7.0a**	**3.8ab**	
	Thickness		**Peelings**	**100mm**	**50mm**	**200mm**	**GW 50[4]**	**GW 100[5]**
How much mulch should be applied?	O	1.4b	1.0b	11.6a	0.5b	8.4ab	2.1ab	2.2b
	P	0.7	0.5	5.6	14.1	8.6	1.9	2.6
	Q	0.6	2.0	2.9	1.4	2.5	4.2	1.7
	R	11.0	27.4	6.4	26.4	24.0	11.4	4.8
	S	0.0	1.2	2.1	0.6	0.4	1.1	3.3
Average	**2.7b**	**6.4ab**	**5.7ab**	**8.4ab**	**8.8a**	**4.2ab**	**2.9ab**	

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2] Means within a row followed by the same letter are not significantly different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%; [3]Not applied; [4]Harvest in 2004 only; [5]10 day old green waste 50mm thickness; [6]10 day old green waste 100mm thickness.

Soil 'A' horizon, roots and worms

There was no effect of mulch treatment on the fresh or dry weight of feeder roots in the soil down to 300mm depth (Table 11). The numbers of worms and the 'A' soil horizon was not different between treatments (Table 11).

Table 11. Average soil 'A' horizon, number of worms in the top 15cm of soil under mulch and feeder root fresh mass at the end of the trial in 2005, the average percentage of black roots in the soil under mulch during the trial in 2005.

Treatment	Soil 'A' horizon depth (mm)	Number of worms	Feeder roots (g)	
			0-15cm	15-30cm
Minimal mulch	184.0	3.3	16.2	9.3
Leaf litter	196.8	3.2	15.5	6.5
Peelings	199.5	2.9	14.5	5.8
Compost	228.5	6.4	10.9	9.1
Tailings	219.0	4.8	14.9	7.2
Bark	218.0	3.4	11.2	4.2
10 day green waste	218.6	5.3	13.8	5.6

Soil mineral content

The soil under mulches containing compost had significantly higher levels of phosphorous and potassium than the soil under the minimal mulch, leaf litter and peelings mulch treatments (Table 12). While not significant, soil magnesium, boron in 2004 and calcium tended to be greater under the compost containing mulches than the minimal mulch, leaf litter and peelings mulch treatments. The zinc soil levels in 2005 tended to be lower in the soil under the compost containing mulches than the other mulch treatments.

Table 12. Average levels of selected soil nutrients for the orchards in Experiment 1.

Mineral	Mulch Year	Contains Compost	10 day green waste	Minimal mulch	Leaf litter	Peelings
Phosphorous	2004	51.9a[1]	40.8ab	32.2ab	30.4b	30.2b
Olsen P mg/L	2005	47.9a	37.0b	31.4b	33.8b	34.4b
Potassium	2004	2.1a	1.7a	0.8b	0.9b	0.9b
me/100g	2005	1.9a	1.6ab	0.9b	1.0b	0.9b
Magnesium	2004	3.6	3.6	2.4	2.7	2.6
me/100g	2005	3.9	3.9	2.7	2.9	2.9
Boron	2004	4.1	4.7	3.6	2.9	3.4
mg/L	2005	4.8	5.1	4.9	4.7	5.6
Zinc	2004	29.1	30.3	31.0	25.1	36.3
mg/L	2005	24.6	29.0	36.4	33.6	31.2
Calcium	2004	22.5	22.9	18.4	18.6	20.4
me/100g	2005	22.9	23.2	19.1	19.1	19.3

[1] *Means within a row followed by the same letter are not significantly different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%.*

Change in mulch thickness

Overall, there was no statistically significant difference between treatments or orchards in the decrease of mulch thickness during the trial (Table 13). There was a trend for the peelings mulch applied at 200mm thickness as well as 10 day green waste applied at 100mm thickness to have the greatest reduction in thickness.

Table 13. Average decrease in mulch thickness (mm) per tree for each mulch treatment from each orchard from 2003 to 2005.

Experiment	Orchard	Peelings[1]	Compost	Compost tailings	Bark compost	10 day green waste
What should the mulch be made of?	A	73.6	40.6	83.3	30.7	59.2
	B	89.1a[2]	11.4b	16.7ab	64.6ab	62.5ab
	C	37.3	30.1	64.0	19.4	50.4
	D	33.3	51.4	56.2	48.8	4.6
	E	16.1	-28.0	-[3]	-1.9	16.0
	Average	**49.9**	**21.1**	**55.1**	**32.3**	**39.0**
	Time of year	**Autumn**	**Winter**	**Spring**		
When should the mulch be applied?	F	11.0	3.6	45.1		
	G[4]	21.8	-4.2	2.1		
	H	28.4	25.4	14.9		
	I	9.1	2.6	-4.3		
	J	21.9b	104.0a	15.1b		
	Average	**18.4**	**26.3**	**13.3**		
	Bandwidth	**0.5m**	**1.0m**	**1.5m**	**2.0m**	
Where should mulch be applied?	K	-16.2	-3.3	7.5	-8.0	
	L	13.0	26.3	-0.9	7.9	
	M	6.1	47.3	11.0	25.5	
	N	29.3	3.8	24.0	5.4	
	Average	**7.8**	**18.5**	**10.4**	**7.7**	
	Thickness	**100mm**	**50mm**	**200mm**	**GW 50[5]**	**GW 100[6]**
How much mulch should be applied?	O	-0.8ab	18.7ab	56.9b	-23.6a	23.9ab
	P	9.1	-27.4	-5.9	4.2	14.9
	Q	38.3	29.5	32.6	20.1	41.1
	R	13.0	46.4	50.7	45.6	37.8
	S	7.4	-14.7	63.6	5.4	21.3
	Average	**13.4**	**10.5**	**39.6**	**10.3**	**27.8**

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2] Means within a row followed by the same letter are not significantly different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%; [3]Not applied; [4]Harvest in 2004 only; [5]10 day old green waste 50mm thickness; [6]10 day old green waste 100mm thickness.

Coverage of weeds

In general, the peelings mulch reduced coverage of weeds in the first year after application (Table 14). In the following years weed coverage increased to where in 2005 weed coverage was, apart from the 1.5m bandwidth peelings mulch treatment, not statistically different between the mulch treatments and the minimal treatment.

Table 14. Average maximum percentage of weeds covering a $0.5m^2$ area at the soil-mulch interface each year.

Experiment	Year	Minimal mulch	Leaf litter	Peelings[1] tailings	Compost	Compost	Bark + compost	10 day green waste
What should	2003	43.6a	43.6a	7.3b	29.4ab	24.1ab	33.2ab	27.8ab
the mulch be	2004	56.0	57.4	37.8	48.2	37.9	50.4	46.7
made of?	2005	50.2	49.2	44.6	54.7	45.3	47.8	46.0
	Average	**49.9a**	**50.0a**	**29.9b**	**44.1ab**	**35.6ab**	**43.8a**	**40.2ab**
	Time of year			**Autumn**	**Winter**	**Spring**		
When should	2003	22.2	19.2	11.0	4.4	20.1		
the mulch be	2004	36.4	31.6	22.0	27.8	25.3		
applied?	2005	24.9	23.0	22.0	23.1	15.3		
	Average	**27.8**	**24.6**	**18.3**	**18.4**	**20.2**		
	Bandwidth			**0.5m**	**1.0m**	**1.5m**	**2.0m**	
Where should	2003	49.5a	59.5a	23.0b	10.1b	13.1b	12.1b	
mulch be	2004	54.8a	50.5ab	39.0ab	33.5ab	26.3b	24.3b	
applied?	2005	62.8a	56.1ab	41.8ab	49.5ab	33.6b	44.4ab	
	Average	**55.7a**	**55.4a**	**34.6b**	**31.0b**	**24.3b**	**26.9b**	
	Thickness		**Peelings**	**100mm**	**50mm**	**200mm**	**GW 50[4]**	**GW 100[5]**
How much	2003	54.3a	46.3ab	33.5ab	42.2ab	16.9b	45.4ab	42.0ab
mulch should	2004	63.1a	49.4ab	42.4ab	56.8ab	30.8b	52.8ab	39.6ab
be applied?	2005	62.0	51.4	52.2	55.0	49.4	56.7	51.0
Average	59.8a	49.0a	42.7bc	51.3ac	32.4b	51.5a	44.2ab	

[1]Mulch applied spring/summer 0.5m either side of the drip line at 100mm thickness; [2] Means within a row followed by the same letter are not significantly different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%; [3]Not applied; [4]Harvest in 2004 only; [5]10 day old green waste 50mm thickness; [6]10 day old green waste 100mm thickness.

Soil moisture
There was no difference between mulch treatments or between orchards of soil matrix water potential at 30cm or 60cm depth (Table 15).

Table 15. Average soil moisture matrix potential (kPa) of 30cm and 60cm tensiometers installed under one tree in each mulch treatment in Experiment 1 for the duration of the experiment.

Depth	Minimal mulch	Leaf litter	Peelings[1]	Compost	Compost tailings	Bark + compost	10 day green waste
30cm	-27.8	-24.9	-28.3	-27.4	-24.5	-26.7	-26.6
60cm	-26.2	-23.3	-19.6	-25.9	-25.5	-23.9	-27.8

Fruit quality
There was no effect of mulch on the incidence and severity of ripe rots for fruit from orchards A and E (Table 16).

Table 16. Average severity and incidence of ripe rots of fruit harvested from trees in two orchards in Experiment 1 in 2005.

Treatment	Stem end rot[1]		Brown patches[1]	
	Severity (%)	Incidence (%)	Severity (%)	Incidence (%)
Leaf litter	0.2	8.5	0.5	4.5
Peelings	0.5	10.5	0.6	7.5
Compost	0.3	17.5	0.6	7.5

DISCUSSION

Yield
Yield did not increase after application of mulch. This was a surprising result given the almost immediate increases in yield reported in South Africa following application of mulch (Moore-Gordon *et al.*, 1997). However, the South African trial on mulching examined only 12 trees (six mulched trees and six un-mulched trees) on one orchard. The mulching project reported here covers 19 orchards (one orchard dropped out of the project after it changed owners during the project) and can be considered to represent the typical range of orchard management practices in the Western Bay of Plenty, New Zealand. Five trees per mulch treatment for a total of 592 trees overall were measured. Each individual experiment was conducted as a complete experiment within each orchard thereby replicating the same experiment across a number of orchards. It is possible that the results obtained from the trial in South Africa was specific to the orchard used rather than reflecting the effect of mulch on the

'average' tree in South Africa. To be sure that any effect of mulch application on yield would occur on a typical New Zealand orchard the number of orchards used in each trial was increased from one to five for each Experiment. A much larger number of trees have been measured in this project than in the South African experiment. The increased replication of experiments on the effect of mulch application on yield should increase the confidence that the results obtained accurately describe the effect of using mulch under avocado trees in New Zealand. That yield was not affected by mulch application implies that mulching alone is not limiting 'Hass' avocado tree productivity in the Western Bay of Plenty.

Mulch treatments were applied at the end of 2002 and beginning of 2003. It is unlikely that mulch applied shortly before harvest influenced the 2003 crop. Therefore, the effect of mulch treatments on yield was analysed for the 2004 and 2005 harvests only. When the yield for 2004 or 2005 of all trees in the minimal mulch, leaf litter and peelings at 100mm thickness and 1.0m width treatments are combined across all orchards and compared (a total of 95 trees per treatment) there was no statistically significant difference in yield (Table 1). Such a result also implies that other factors influence yield other than application of mulch. Despite the very quick response of trees to mulch application in South Africa the effect of mulch under New Zealand avocado trees may not be apparent for several years after application as the effect of mulch on the soil could be expected to develop over time. Two years may be insufficient time to allow differences to develop between trees with mulch and un-mulched trees. Therefore the lack of a yield response to application of mulch may not be obvious for several years after application. In New Zealand avocado orchards mulch could have a limited effect on yield each year.

The different response to mulching by avocado trees in South Africa and New Zealand may be explained by the different soil composition in the two countries. The soil of orchards in Experiment 1 had organic matter content between 12.5% and 7.4%. These levels of organic matter are greater than in the orchard in the South African study and South African soils in general. Most soils in South Africa are granitic or doleritic in origin, highly leached, acid and infertile with high clay content but well drained (Wolstenholme, 1999). By contrast, the soils in the Western Bay of Plenty are of recent volcanic origin with low clay content, are poorly weathered and highly leached. The South African soil is typically 1% organic matter (Wolstenholme, 2001) with very rapid rates of decomposition in the warm, wet summer. The soil in South Africa could be considered to be deficient in organic matter compared to the New Zealand avocado orchard soils in the Western Bay of Plenty. Therefore, adding mulch to a soil containing high amounts of organic matter is unlikely to affect soil characteristics that may favour increased avocado productivity.

The soil 'A' horizon is recognised as an organic matter rich top layer of soil. Changes to the depth of the 'A' horizon could indicate changes to the organic matter content of the soil. There was a non-significant trend for the depth of the organic matter rich soil 'A' horizon to be the least in the minimal mulch treatment in Experiment 1 (Table 9). This project was terminated after three years but the decrease in the soil 'A' horizon for the minimal mulch treatment if continued may have declined to reach low levels. However, the soil 'A' horizon under the leaf litter treatment was similar to the peelings mulch treatment. This may indicate that the rate of organic matter incorporation into the soil was similar to the natural accumulation of leaf litter under the trees and that the 'natural' soil organic matter levels are similar to those measured in this project. This further suggested that the New Zealand avocado orchard soils in the Western Bay of Plenty are fundamentally different to the South African soils with respect to the turnover and accumulation of organic matter. Organic matter has important influences in the soil affecting mineralization rates, water holding capacity, soil flora and fauna and temperature buffering (Wolstenholme, 2002). The difference in soil type and composition between South Africa and New

Zealand would indicate that results on the effect of applying mulch obtained in South African avocado orchards should not be extrapolated to New Zealand avocado orchards.

There are few studies other than the South African study that report on the effects of mulch on avocado yield. In Spain, sugarcane bagasse mulch was applied up to year 9 after planting where there was a trend for mulched trees to have a greater yield compared to cultivation or clean soil through herbicide application (Hermoso *et al.*, 1995). Mulch applied to avocado trees in Israel in a trial that ran over 10 years resulted in a 23% increase in cumulative yield of applying manure (compost at a rate of $20m^3$ per acre each year) compared to ammonium nitrate for 'Fuerte' avocado trees (Ben-Ya'acov, 1995). The compost was applied to a light soil with poor water holding capacity and low fertility. Raw yard trimmings (probably equivalent to the 10 day green waste used in this project) were applied to newly planted avocado trees at two sites in California (Downer *et al.*, 1999). Yield was increased by 13% in one site but was decreased by 39% at the other site. The differences in yield were attributed to poor irrigation practice at the site where yields were depressed. The common thread with each of these studies is that the avocados were being grown on soils that compared to the soils typically found in the Western Bay of Plenty would be considered to be very low in organic matter. For example, soil organic matter in the Californian study was 2-3% (Menge *et al.*, 1999). Therefore application of mulch to these soils deficient in organic matter would be expected to greatly increase the feeder root mass under the trees. The soils overseas are more similar to the very sandy soils found in the Far North region of New Zealand which have very low organic matter compared to Western Bay of Plenty soils. Therefore applying mulch to Western Bay of Plenty soils is unlikely to have a similar effect as reported in the literature.

Roots and Nutrition

There was a generally consistent increase in feeder roots under the peelings mulch across all trials and demonstrates that mulch can increase the number of avocado feeder roots. Of the roots present, the ratio of thick roots to thin roots was about the same over the three years of the project in all treatments. Application of mulch did not appear to alter the type of feeder roots growing at the soil-mulch interface. Why there should be relatively large numbers of thin feeder roots is unknown. The characteristics of thin feeder roots with respect to water and nutrient uptake compared to thick feeder roots would be a useful area to research. Root health was probably better under peelings mulch as the roots present tended to have more white tips and fewer black roots than the other mulch treatments. Application of peelings mulch could assist with increasing root coverage and help improve root health where feeder roots are under stress. Improved root coverage and health appears to be temporary lasting about two years after application. Where an improvement in root health is desired application of fresh mulch every two years could be required.

Peelings mulch gave the greatest amount of root growth. This was contrary to expectations that mulches containing compost or green waste that decomposes after application would have the greatest root coverage. This expectation was due to the reported increase in root numbers under well composted mulch compared to no mulch (Downer *et al.*, 1999). Peelings mulch was low in nutrients and had the highest C:N ratio and suggests that if increased root numbers are a desired outcome the mulch applied to avocado trees should consist of woody material with a low nutrient value.

Mulches with compost added did not have, at least, the same root coverage at the soil mulch interface as the peelings mulch. This may have been due to the compost containing mulches forming a crust and becoming sodden after rain. The air content of water logged mulch has less air than more coarse mulch. Avocado feeder roots have high oxygen requirements (Wolstenholme, 2002) and feeder root growth is favoured in conditions that are moist with high air content. The compost used in this project was sieved to fine particle size before application leading to the mulch settling into a compact mass. The compost tailings mulch initially had a better air content with coarse material retained more than compost only. The tailings mulch separated soon after application into small particles at the soil surface and coarse material above. The small particles concentrated at the soil mulch interface could have formed a compact mass as for the compost only mulch. Despite these observations the fresh and dry mass of roots in the soil under the different mulch treatments was similar to the minimal mulch and leaf litter treatments at the end of the project. Earlier sampling of feeder roots below the soil-mulch interface in the first year after application may have revealed a greater difference in root mass under the different mulch treatments than was observed three years after application.

The 10 day green waste mulch decayed rapidly after application as it contained green material (mostly leaves) as well as woody material. Considerable numbers of fungal fruiting bodies of many types were observed growing from the 10 day green waste once it started to decay. From this observation it is reasonable to expect an increase in the soil biodiversity under the green waste mulch. Earthworm numbers in the soil under the mulch were not significantly different but tended to be highest in the soil under the compost based mulches and may reflect higher soil biodiversity. The apparent increase in soil flora and fauna did not increase yield or promote greater numbers of feeder roots.

During the project, mineral fertilisers were added to the mulch under the trees that may have interacted with the mulch to create imbalances in the proportions of nutrients available to the trees. The microbes rotting the organic material can use all available nitrogen (Valenzuela-Solano and Crohn, 2006). Further, rapidly decaying organic material can release excessive amounts of nutrients that do not suit the nutritional needs of the avocado trees. The minerals: phosphorous and potassium were greater in the soil under the compost containing mulches; magnesium and boron in 2004 tended to be greater in the soil underneath the compost based mulches compared to the soil underneath the peelings, leaf litter and minimal mulch treatments. This finding implies that for compost containing mulches the fertiliser programme may need to alter fertiliser inputs as some minerals will be present in greater amounts from the mulch.

The nitrogen cycle is important in determining the availability of nitrogen to the trees and is likely to vary considerably from orchard to orchard as it depends on the soil type, soil microbiology and chemistry and nitrogen inputs (Wolstenholme, 2004). The use of compost may change the nitrogen cycle and the need for mineral nitrogen through changes to the soil organic matter and microbiology (Wolstenholme, 2004). The peelings mulch that had a very high C:N ratio and would be expected to remove nitrogen from the soil to allow decay of the woody material and subsequently reduce the leaf nitrogen percentage. That there was no statistical difference in the leaf nitrogen percentage between mulch treatments (data not shown) would suggest that nitrogen inputs in the orchards in this project were high enough to compensate for the nitrogen used by decay of mulch.

CONCLUSIONS

Applying mulch to soils that are already rich in organic matter and have a good 'A' horizon under avocado trees in the Western Bay of Plenty does not increase yield. Mulch alone does not affect: tree growth (trunk circumference and shoot growth), root mass in the soil under mulch, soil 'A' horizon depth, soil mineral content and physical characteristics, leaf nutrient content, soil moisture matrix potential, fruit size and post harvest fruit quality. There was no difference between mulches in the rate of decrease in thickness over the three years of the project. The percentage of roots at the soil mulch interface was increased the most by application of peelings mulch at a depth of 100mm or greater and a width of greater than 1.0m.

ACKNOWLEDGEMENTS

The AIC wishes to thank all the avocado growers, packers, and packers' staff in the Western Bay of Plenty that generously participated in the project. Thanks also to the staff of Revital Fertilizers Ltd, and Living Earth Ltd for mulch material and advice without whom the project would not have run smoothly. The AIC also wishes to thank the Sustainable Farming Fund for the funding of this project as grant number: 02/070.

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