

Healthy Soils in Macadamia orchards

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Abstract

NSW Agriculture and its collaborators have committed significant resources to the benchmarking of soil health on macadamia farms in NSW, and in the development of rehabilitation techniques for degraded areas. Results have demonstrated significant declines in soil health indicators including carbon content, bulk density, microbial activity, biomass carbon and earthworm numbers and biomass. The oldest property in the study generally had the lowest microbial activity, biomass C and total C, indicating that over time, soil health continues to decline under the current management system. High bulk densities were correlated to significant declines in biomass carbon and microbial activity. Low soil pH did not have a major impact on soil health at the macadamia farms studied, most likely due to the high organic carbon content present (3.4-7.2%). The farm under organic management had the greatest biomass carbon and microbial activity, and the organic carbon (7.2% in 0-5cm profile underneath trees) was also significantly greater. The macadamia orchards had fewer earthworms (40 m²) than their control plots (ca. 135 m²) or other sub-tropical production systems sampled. Trials using composted macadamia husk and chicken litter have shown improvements in microbial activity and water holding capacity in degraded macadamia soils.

It was hypothesised that soil erosion, reduced organic carbon and compaction in macadamia orchards are the primary causes for declines in soil health indicators, and work is continuing to better understand the influence of soil health on the economic and environmental sustainability of the macadamia industry.

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Introduction

Interest in soil health has escalated in Australia and internationally over the past few years. The concern about soil health is motivated by present and future interest in both agricultural productivity and profitability. Drivers in the promotion of soil health have come from both natural resource managers and agricultural industries.

Many prominent research groups have defined soil health, however the following definition is often used for describing soil health in agricultural systems.

"Soil health is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health." Doran and Zeiss, 2000 (USDA)

In order to achieve sustainable agriculture, Sherwood and Uphoff (2000) argue that efforts are needed to better link multi-disciplinary research with practice and political actions. The achievement of sustainable agriculture was "let down" in the 20th Century as research was strongly focused on soil chemical and physical factors, with comparative neglect of biological factors. In the definition of soil health by Doran and Zeiss (2000), soil is referred to as a "living" entity. The knowledge that soils contain many living organisms, including bacteria, fungi, protozoa, algae and earthworms is not new; but what is emerging is an understanding of how these soil organisms can be utilised in agricultural systems to improve soil health.

Many factors can have negative impacts upon soil health. These factors include; loss of organic carbon (Islam and Weil, 2000), compaction (Singleton and Addison, 1999), disruption of soil macroaggregates (Islam and Weil, 2000), pesticides (Mitra and Raghu, 1998; Tu, 1991) and pesticide breakdown products (Cernakova and Zemanovicova, 1998), inorganic pollution arising through fertilisers, fungicides and sludge application (Merry *et al.* 1986; Gong *et al.* 1997), the use of fertilisers (Stamatiadis *et al.* 1999) and non-pesticide organic pollution including surfactants (Wilke, 1997). Other causes of reduced soil health can arise through water and wind

erosion (Garcia *et al.* 1997), loss of organic matter due to fire, deforestation and tillage (Islam and Weil, 2000).

Benchmarking macadamia soil health in NSW

Sampling

Five macadamia properties were selected in north-eastern NSW to benchmark soil health in 1999-2000. These were located in the Richmond and Tweed Catchment areas. One of the macadamia properties (Farm 5) is a certified organic producer. Each farm had four sampling sites and two control sites. Control sites were areas that comprised a similar soil type and similar microclimate, but were not influenced by recent agricultural practices. Often, control sites consisted of natural vegetation. Two sampling sites on the macadamia farms were located beneath the trees, and two sampling sites were between rows (inter-row space). At each sampling site, four soil cores were taken and each sub-divided into 0-5cm and 5-20cm samples. Separate bulk density cores of the 0-5cm profile and 5-10cm profile were taken at each sampling site.

Soil Health Tests

Numerous tests were conducted at the NSW Agriculture laboratories to assess soil health indicators. These included microbial activity, biomass C, total carbon and nitrogen, pH, bulk density and water holding capacity. Soil pH (CaCl_2), moisture, water holding capacity and bulk density were determined using the methods described by Alef and Nannipieri (1998). Soil microbial activity was determined in duplicate for each sample using the hydrolysis of fluorescein diacetate (FDA) method, using a modified method described by Zelles *et al.* (1991), Fontvieille *et al.* (1991) and Schnurer and Rosswall (1982). Fluorescein was detected by a UV spectrophotometer, or by a multilabel plate reader in fluorescence mode. Biomass carbon was analysed by methods described by Islam and Weil (1998), and utilised TOC analysis of soil extracts to determine total organic microbial carbon and inorganic carbon. Total C and N analyses were performed using Leco.

Results and Discussion

Soil pH

The macadamia farms in the current study were all located on acid soils, as indicated by Table 1. The use of lime had increased pH at a number of sites, whilst farms 2 and 4 have pH values lower than the control sites. Acosta-Martinez and Tabatabai, (2000) have demonstrated that soil pH can influence the activity of soil organisms. Liming was able to increase the activity of a range of enzymes – however, another study showed an increase in protease activity and decrease in N-mineralisation with long term lime application (Lorenz *et al.* 2001). Vimpany (2001) discusses the importance of humus, or soil organic carbon in buffering against fluctuations in pH, and in reducing aluminium toxicity in soils. The influence of pH on soil microbial activity is considered later in this manuscript.

Farm	Depth	control pH (CaCl₂)	row pH (CaCl₂)	inter-row pH (CaCl₂)
1	0-5cm	4.9	5.8**	5.6
	5-20cm	4.7	5.0	5.0
2	0-5cm	5.7	4.1*	5.0
	5-20cm	5.3	4.1*	4.7
3	0-5cm	4.4	4.6	5.5**
	5-20cm	4.3	4.7	5.0
4	0-5cm	4.6	4.1	4.9
	5-20cm	4.6	4.1	4.4
5 (organic)	0-5cm	3.9	4.5	4.6
	5-20cm	3.6	4.6**	4.2

Table 1: Mean pH (CaCl₂) levels at each site, depth and farm. Average standard error of the means is 0.2 units. Average least significant difference was 0.8 units. (* indicates a significant decrease from the control site; ** indicates a significant increase from the control).

Bulk Density

Bulk density (Table 2) in the macadamia soils was significantly increased over control sites on all conventional properties, indicating farm management practices have increased the level of soil compaction. Farm 3 had the greatest bulk density, with values of 2.00 and 2.04g/cm³ recorded for inter-row areas. Factors which may have resulted in this increased bulk density include use of farm machinery on wet or bare soils, soil erosion, reduction in organic carbon and biomass carbon, and reduced microbial and earthworm activity. It was demonstrated that the farm under organic management did not have any statistically significant increases in bulk density.

Farm	Depth	control g/cm³	row g/cm³	inter-row g/cm³
1	0-5cm	1.18	1.22	1.59**
	5-20cm	1.34	1.81**	1.81**
2	0-5cm	1.00	1.73**	1.51**
	5-20cm	1.22	1.41	1.39
3	0-5cm	1.61	1.67	2.00**
	5-20cm	1.63	1.91	2.04**
4	0-5cm	1.04	1.61**	1.85**
	5-20cm	1.16	1.51**	1.77**
5 (organic)	0-5cm	1.49	1.65	1.53
	5-20cm	1.59	1.61	1.79

Table 2: Mean Bulk Density levels at each site, depth and farm. Average standard error of the means is 0.18 units. Average least significant difference was 0.39 units. (** indicates a significant increase from the control).

Total Carbon

Soil organic carbon influences the physical, chemical and biological aspects of soil health (Chan, 2001). The carbon in soils comes mainly from decomposed plant and animal material, however a portion is composed of soil organisms and plant roots.

Analysis of total carbon was performed on farms 3, 4 and 5. As discussed previously, organic matter status of soil is critical for moisture retention, CEC, soil structure and as food for soil organisms. Hence soil C status is a key soil health indicator. Spain *et al.* (1983) estimates that 75% of Australian soils contain under 1% organic carbon, and this level of C is reducing with agriculture and many farm management practices. Table 3 shows that all farms in the current study have relatively high carbon content (ranging from 3.41% in farm 3 to 7.22% in the organic farm). However, when compared with control sites, there is evidence that the organic carbon content is being depleted within the orchards. Variation of 1.66 units indicates significant differences in C content, hence statistical evidence exists for declined C underneath trees. This was particularly evident with farms 3 and 4, where soils in both the 0-5cm and 5-20cm horizons had significantly reduced C. It was concluded that soil erosion and management practices maintaining bare earth under trees is responsible for this decline in organic carbon. Farm 4, although having greatly reduced C compared to the controls, did not have this effect of reduced C in row. The control sites for farm 4 had very high levels of carbon. The organic property had comparable C contents in the controls, and in soils inter-row and in row. In general, the organic property had the highest level of C.

Farm	Depth	Control C%	row C%	inter-row C%
3	0-5cm	7.00	4.31	7.18
	5-20cm	5.48	3.41	4.31
4	0-5cm	23.07	5.94	6.59
	5-20cm	9.44	4.62	4.97
5 (organic)	0-5cm	9.57	7.22	6.73
	5-20cm	5.22	4.72	4.64

Table 3: Total Carbon levels at each farm. Average least significant difference was 1.66 units.

Total Nitrogen

The total nitrogen content of soil is an indication of soil fertility, and it is influenced principally by the storage potential of nitrate as well as by total nitrogen inputs. Table 4 shows that Farm 3 has significantly reduced total N in row at both soil depths, however, inter-row N content did not vary significantly from the control. The N content of the control site for farm 4 had abnormally high N concentrations, thus making a valid comparison to the farms difficult. However, levels of N inter-row and in row do not vary significantly, indicating the effect seen in farm 3 (depleted N in-row) was absent. No significant differences were seen at the organic farm. It is likely that N has migrated from soil in-row at farm 3, either due to leaching or surface run-off (either with soil or in water). Best practice and organic farming systems have been shown to have significantly lower off site migration of N (Dougherty and Wells, 2001).

Farm	Depth	Control N%	row N%	inter-row N%
3	0-5cm	0.58	0.42	0.63
	5-20cm	0.49	0.35	0.44
4	0-5cm	1.70	0.54	0.57
	5-20cm	0.77	0.43	0.47
5 (organic)	0-5cm	0.74	0.65	0.62
	5-20cm	0.49	0.46	0.47

Table 4: Total Nitrogen levels at each farm. Average least significant difference was 0.15 units.

Microbial Activity

Microbial activity was determined in the macadamia soils using the hydrolysis of fluorescein diacetate. This method has been described as an effective measure of the activity of decomposer organisms in soil, and the technique has been correlated to

respiration (Schnurer and Rosswall, 1982). FDA hydrolysis has been described as a measure of the microbial component that plays a central role in the ecology of soils (Dick, 1994). Results in Table 5 demonstrate that farms 3 and 4 (both inter-row and row) had significantly lower levels of microbial activity than the comparable control site. Farm 2 and the organic property had significantly lower levels underneath the trees but not inter-row. The organic macadamia property (property 5) had the highest level of microbial activity, being statistically greater than farms 2, 3 and 4.

Farm	Depth	control mg/fluor./ g/45min	inter-row mg/fluor./ g/45min	row mg/fluor./ g/45min
1	0-5cm	26.9	24.3	21.4
	5-20cm	27.0	25.1	22.9
2	0-5cm	18.9	19.8	12.1*
	5-20cm	16.6	16.9	16.9
3	0-5cm	19.6	12.3*	11.2*
	5-20cm	24.2	11.8*	10.6*
4	0-5cm	41.6	17.67*	17.8*
	5-20cm	41.1	22.78*	21.9*
5 (organic)	0-5cm	28.4	27.2	23.7
	5-20cm	31.1	27.7	23.8*

Table 5: Mean FDA levels (mg fluorescein produced/g soil/45 min) at each site, depth and farm. Average standard error of the means is 3.5 units. Average Least significant difference is 6.7 units. (* indicates a significant decrease from the control site)

There was some evidence that a correlation existed between FDA and bulk density. In Figure 1, it can be seen that on farm 4 where a wide range of bulk densities was recorded, increasing bulk density led to a decrease in microbial activity. A similar trend is discussed later with biomass C. No correlations were detected between microbial activity and soil pH.

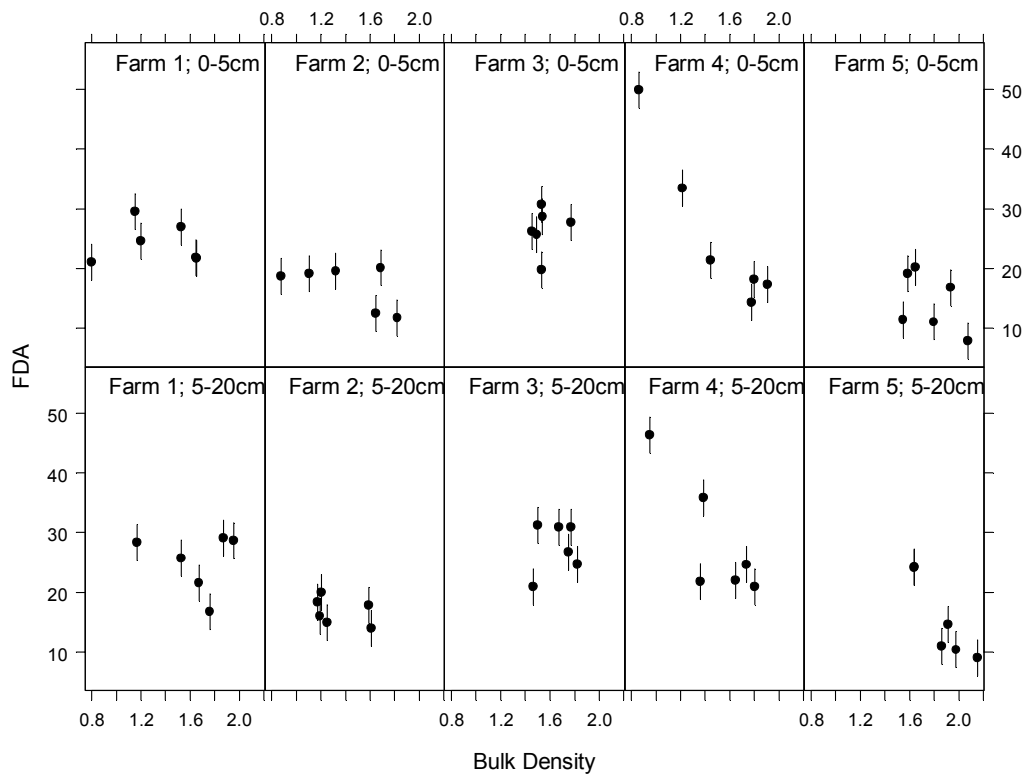


Figure 1: Average FDA levels for samples grouped by the degree of bulk density within each plot. Vertical bars indicate approximate 95% confidence limits about each average.

Biomass Carbon

Various indicators of soil quality have been proposed, but measurements of microbial biomass are most commonly used (Webster *et al.* 2001). Biomass carbon analyses were performed on farms 3, 4 and 5. The least significant difference value for the data was 0.78. Figure 2 shows the 5-20cm soil profile at all farms had significantly lower biomass C than the 5-20cm profiles in the respective controls. Farm 3 had significantly lower in-row biomass C in the 0-5cm profile than either the control or inter-row sites on the same farm.

Biomass C responds to the quality and quantity of C present in soil (Webster *et al.* 2001) and also to other influences such as pH, bulk density and the presence of toxic

compounds. A weak negative correlation was found between biomass C and bulk density (slope = -0.72, r^2 12%). This indicated as the bulk density increased, the biomass decreased. No such correlation was found with biomass C and pH, even though many reports in the literature describe pH as a major influence on soil biomass. All sites studied had relatively high organic carbon concentrations, which are likely to have buffered against the effects of pH.

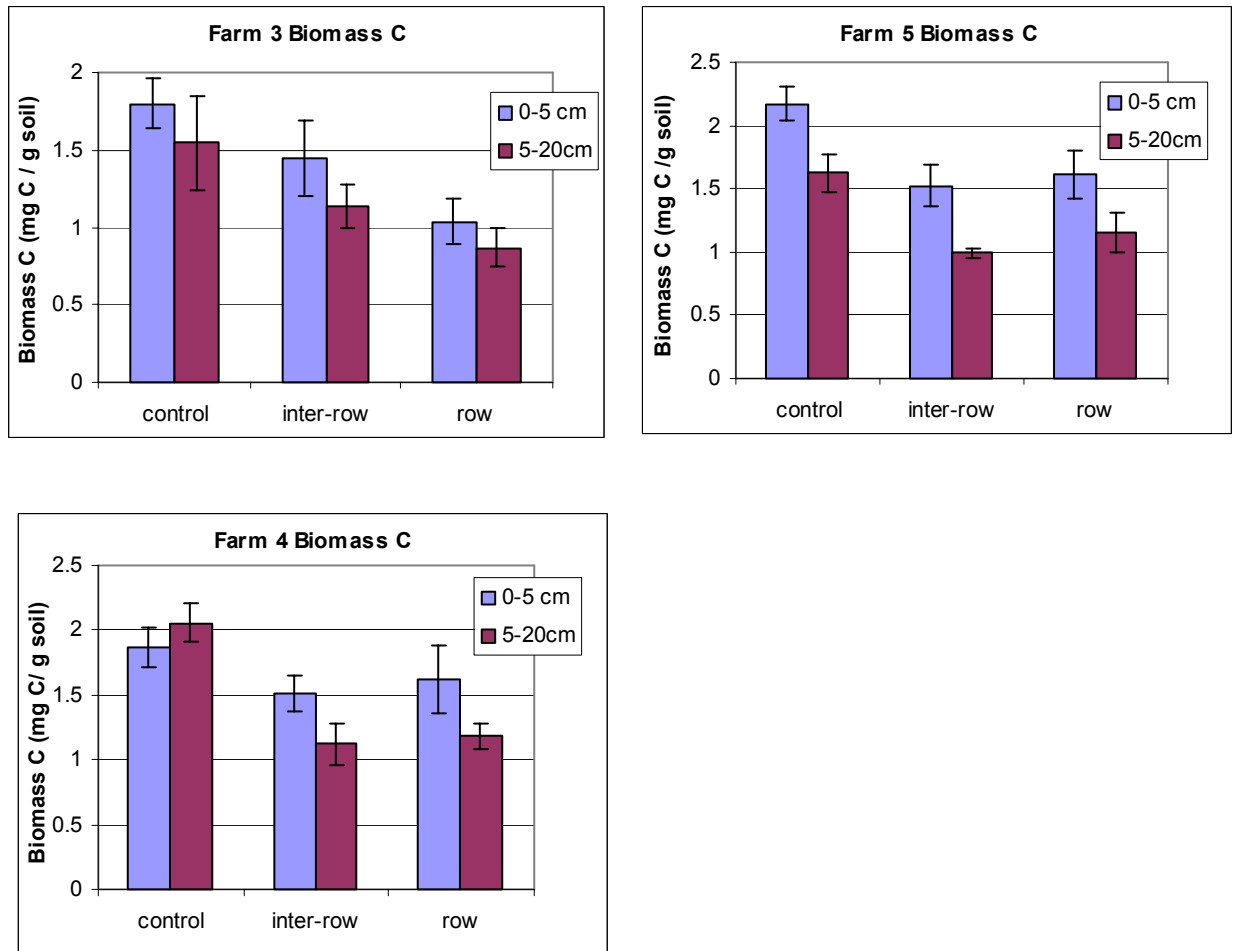


Figure 2: Biomass carbon at farms 3,4 and 5. (Least significance difference = 0.78)

Significance of earthworms in the macadamia industry

A survey of earthworms in macadamia and other orchards (avocados, coffee, bananas and blueberries) was conducted in the Northern Rivers region of New South Wales in March 2001. One macadamia farm under organic management was included. Where

available, adjacent areas of grassland, either grazed or mown were also sampled as 'controls'. Ten 20 cm cubes of samples, were taken from within the tree rows and also from the inter-row areas. The soil was broken up and the earthworms were removed, preserved and later identified, counted and weighed. Weights were converted to grams biomass per square metre surface area.

Macadamia orchards were found to support comparatively low populations (Figure 3) and biomass (Figure 4) of earthworms. Mean body weight of individuals was greater in macadamias than for the other horticultural crops examined. Within macadamia orchards there were only minor differences between row and inter-row areas, for all three measures. Interestingly, varieties of earthworms native to the region were found more frequently in macadamia orchards than in other crops. These tended to be larger than the overseas species prevalent in the other orchards. We can only speculate that this represents a special association with the only orchard tree native to Australia.

Other potentially relevant differences between macadamia orchards and those with higher earthworm biomass (notably coffee, blueberries and bananas) include:

- Ground cover plants grew more densely and covered a greater proportion of the inter-row area in crops (especially coffee, blueberries and bananas) having less spreading and shady canopies. This has obvious implications for root density, resistance to erosion and for organic matter production at ground level.
- Orchard floor management in macadamias, notably sweeping for pre-harvest clean-up and the blowing of nuts from the rows during harvest, inhibits establishment of an organic horizon and thus provides a poor environment and reduced source of nutriment for earthworms.
- Some macadamia orchard soils had raised soil copper levels, a feature that has been found to inhibit earthworm occupation of the soil. This factor is less evident than in some other horticultural crops, notably avocados, where greater quantities of copper fungicides are applied and soil levels are as a result greater.

As a consequence of these factors, poor soil aggregation has been observed in the majority of macadamia orchards investigated. If confirmed by appropriate methodology, this issue would be cause for great concern.

These interrelationships are the subject of further study by our research group with a view to capturing the benefits to soil structure and nutrient cycling that are potentially available from these organisms. This will involve learning which earthworm species are best suited to macadamia orchard floor conditions and establishing and applying earthworm-compatible management.

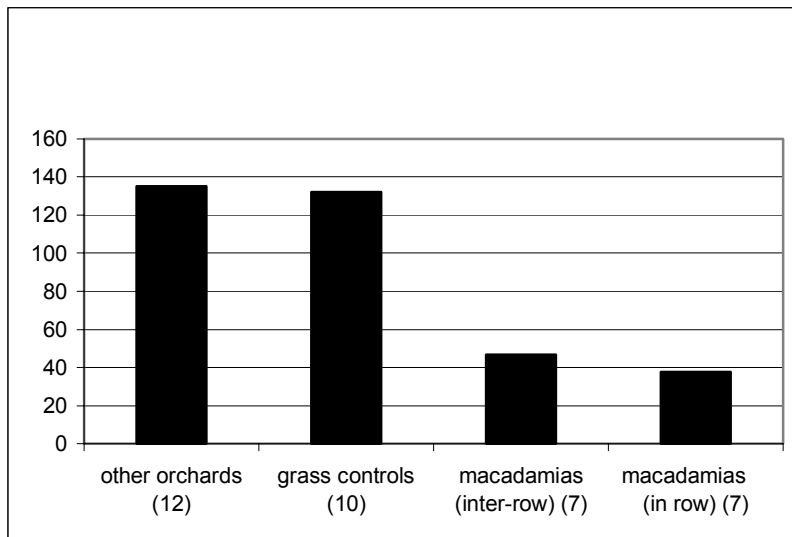


Figure 3: Earthworm numbers in macadamia orchards compared with other orchards and grass

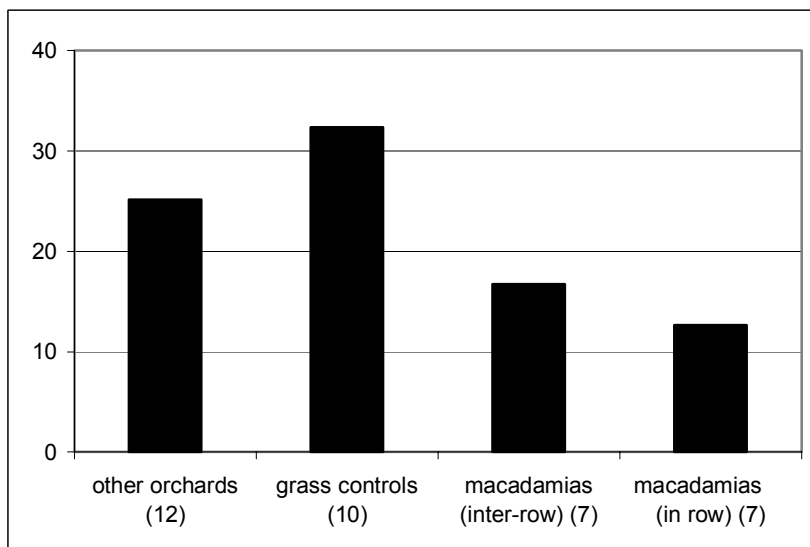


Figure 4: Earthworm biomass (g worm/m) in macadamia orchards compared with other orchards and grass

Application of composted husk to improve soil health

Rehabilitation technologies to improve microbial activity and soil health are not new. These may include the addition of manures, fertilisers, lime and gypsum, and organic materials to soil; and the use of crop rotations, green manures and fallows. In fact, most farmers, both organic and conventional are currently practising some form of soil rehabilitation. What is lacking, however, is a thorough understanding of how these processes benefit the soil biology, to promote soil health. For example, in an Australian vegetable cropping trial which received high inputs of compost, improvements including higher organic carbon content, greater microbial activity and biomass, greater exchangeable nutrient cations, and greater water holding capacity and aggregate stability were observed (Wells *et al.* 2000).

A composting process was developed in collaboration with farmers from Tuckombil Landcare to convert farm wastes, including macadamia husk and chicken litter, into a soil conditioner. A pilot system was initially set up according to Van Zwieten *et al.* (1997). Following this, a field scale demonstration was established at a commercial macadamia farm with degraded soil health. The farm had evidence of erosion and decline in soil physical properties, and reductions in biological activity and biomass were measured. Here, 40m³ of chicken litter was composted with 60m³ of macadamia husk. The compost remained thermophilic for more than eight weeks, and the pile was turned three times in this period. Water had to be added to the compost pile, as the moisture level dropped below 50% w/w on a number of occasions. The final compost was spread on an area of the farm that was prone to erosion, and where obvious soil loss had exposed surface roots. The addition of the compost did not affect the farm's standard management practices, as neither sweepers nor nut harvesters were hindered by the presence of the 100mm thick compost layer.

More recently, the composted farm waste described above and commercial compost sourced from Coffs Harbour have also been applied to areas within a five year old macadamia orchard at Tropical Fruit Research Station, Alstonville to further evaluate organic matter addition and improvements in soil health. Some treatments had coconut fibre matting placed on top of them to act as a weed mat, to further reduce the risk of soil erosion. Results from this trial will be made available in the future.

The addition of compost on the commercial macadamia farm gave promising results with improvements in water holding capacity (results not shown) as well as quite dramatic increases in microbial activity, measured by the hydrolysis of fluorescein diacetate (Figure 5). The data show the level of microbial activity before the application of compost in November 2000, and the increase in microbial activity by

March 2001. Compost addition was beginning to influence microbial activity deeper in the soil profile. The compost layer had a very high level of activity, which is likely to decrease as the organic matter becomes incorporated into the soil. Other plots near the area with no compost addition showed very little variation in the levels of microbial activity at the two sampling times. Sampling at both this site and the Alstonville site is continuing.

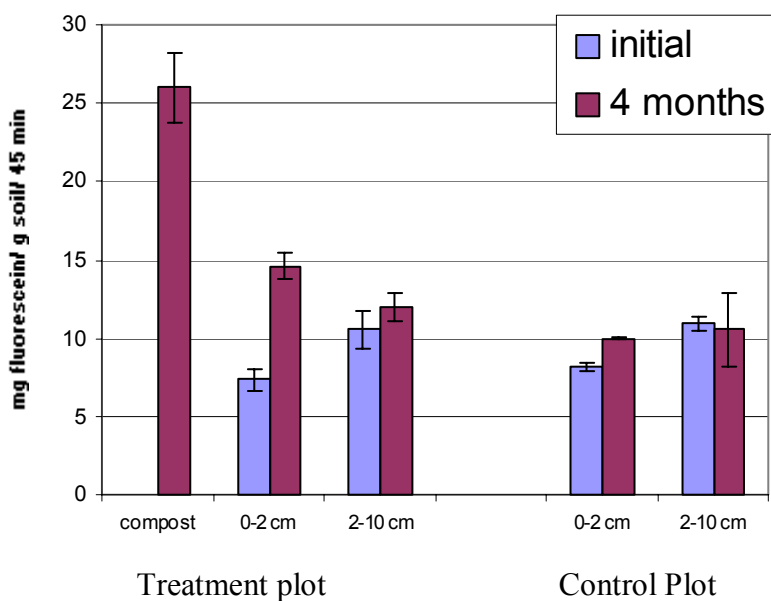


Figure 5: Influence of composted farm waste on soil microbial activity

Potential benefits of healthy soil in the macadamia industry

Soil health is fundamental for agricultural sustainability, but it is still undergoing significant degradation in many agricultural systems. It has been discussed that if soil is improved, the whole agricultural system's health is improved (Pretty *et al.* 2002). The benefits of having healthy soils are numerous. For example, soil microorganisms produce polysaccharides that act as gums to bind and stabilise soil aggregates, hence influence soil structure (Stirling, 2001a). Microorganisms and earthworms in healthy soils play a major role in nutrient cycling, making many nutrients available to plants. Healthy soils are also able to buffer against soil-borne diseases and nematodes (Stirling, 2001b), thus improving the health of crops.

Agricultural sustainability starts with the soil by seeking to reduce erosion, and to make improvements to soil physical structure, organic matter content, water holding capacity and nutrient balance (Pretty *et al.* 2002).

This project has demonstrated a decline in soil health at all of the macadamia properties studied, however, properties 1 and 5 (organic) were shown to be least affected. Property 3, which was the oldest property in the study, generally had the lowest microbial activity, biomass C and total C, indicating that over time, soil health continues to decline under the current management system. Degradation of soil quality can result from increased disruption of macroaggregates, reductions in microbial biomass, and loss of organic matter due to fire, deforestation, tillage and accelerated erosion (Islam and Weil, 2000). For the macadamia industry, factors most likely to have led to this decline include soil erosion and compaction by machinery. These factors are accentuated by management practices creating bare earth underneath trees. This study has shown that the relatively high levels of organic carbon in the macadamia soils are reducing the impacts of other potentially damaging effects to soil health such as low pH and high bulk density. Thus, the protection of the remaining organic carbon source is vital for maintaining soil health in the longer term.

As for the future, multi-disciplinary research teams need to further assess the soil biology, along with soil chemistry and soil physics to better understand soil health. The facilities at Wollongbar Agricultural Institute are well situated to undertake analyses of soil health for the macadamia industry, and continuing research projects are developing management systems to improve soil health, ensuring the economic and environmental sustainability of the industry on the NSW north coast.

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