Recycled Organics Unit

Recycled Organics Products in Intensive Agriculture

Volume 3 – Fruit and Orchard Production

A review of recycled organics products application field trials in fruit and orchard production in Australia

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Second Edition

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Acknowledgement

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Many persons and organisations across Australia have made their published and unpublished information and reports to be included in this review are graciously thanked for their contributions.

Executive summary

Background

The potential benefits of recycled organics (RO) products in fruit and orchard production have been studied in Australia over the last five years using a range of compost products. However, most of this research has not been peer reviewed or published, and is not readily accessible. Therefore the objectives of this report are to obtain and review relevant project reports, publications, presentations, and articles in fruit and orchard production to:

- Establish baseline performance data for the use of RO products for fruit and orchard production applications within the context of environmental factors and farm management systems;
- Review the methodology of previous trials, document key experimental design issues for applied field trials and to prioritise relevant monitoring parameters for the purpose of establishing the performance benefits and cost-benefit advantages of the application of RO products;
- Identify gaps in available data, thereby informing and prioritising future applied product application trials, and
- Inform the future development of performance-based RO product standards and application guidelines for the Fruit and orchard production market segment.

Opportunities for inclusion of RO products into fruit and orchard production

Fruits are grown throughout NSW. The total land area occupied in NSW under orchards excluding viticulture was 74,981 hectares (ABS, 1997). Sydney statistical division covered 5,266 hectares under orchards. The main area where fruits are grown in NSW outside Sydney and within 300-400 km radius of Sydney are the Hunter, Central Coast and Central West. The Hunter statistical division occupied 854 hectares and Central-West occupied 6,479 hectares (ABS, 1997).

The main types of fruit crops grown in NSW include: citrus; stone fruits; pome fruits; strawberries; nuts; tropical fruits; and other orchard fruits. The greater Sydney basin is considered as the fruit and salad bowl of NSW. Main fruits grown in the Sydney basin are peaches, nectarines, and strawberries. Stone fruits and apples are grown in the Blue Mountains area. Southern Sydney grows similar fruits as the Sydney basin. There are small holdings of stone fruits in Camden and the Picton/Appin area to Sydney's south and south west. In the Central West of NSW around Orange and Bathurst common fruits grown are apples and pears. The NSW Central Coast is famous for growing citrus, stone fruits, avocados, strawberries and kiwi fruits.

Intensive working of land used for fruit production as discussed in Volume 1, Section 3.2 (ROU, 2003), like other intensive agriculture production systems, causes loss of soil organic matter (SOM). This loss can result in soil structure decline, land degradation and loss of soil productivity. Recycled organics products when applied to the soil surface as mulch reduce the growth of weeds, and water evaporation from the soil surface and increase soil moisture. Recycled organics products also contain organic matter and nutrients, and when applied to the surface of the soil (surface mulch) or incorporated into the soil (soil conditioner), organic matter decomposes slowly over time and integrates with the mineral component of the soil improving soil conditions. Consequently soil productivity and crop production is maintained and land degradation is prevented. The nutrients present in RO products are released steadily over time and become available for crop use. The use of RO products in fruit and orchard production therefore provides opportunity to address the following agricultural and environmental issues:

- Weed suppression resulting in the reduction or avoidance of herbicides,
- Reduced evaporation of water from the soil surface. Increased soil moisture may lead to reduced use of irrigation water for irrigated conditions and water conservation in non-irrigated conditions,
- Sustained and long term release of nutrients for growth of fruit crops reduces use and manufacturing of chemical fertilisers,
- Reduced fluctuation of soil temperature and soil moisture results in reduced crop stress,
- Increasing soil organic matter leads to improved soil health and productivity, and prevention of land degradation, and
- Assistance with conversion to organic production systems and/or achievement of environmental certification and labelling.

Conclusions

The main conclusion from the review of field trials conducted across Australia using RO products in fruit and orchard production is that application of RO products has demonstrated a range of performance benefits. The performance benefits of RO products used as surface mulches and soil conditioners in fruit and orchard production from the review of 14 field trials carried out across Australia have been summarised in Table 1 and are discussed below.

<u>Soil moisture</u>

Application of RO products increased soil moisture from 10 to 80% when applied as surface mulches. Thick mulches (10 cm deep and higher) produced the greatest increase in soil moisture. It is not known whether, or to what extent this increase in soil moisture has impacted on the capacity of the soil to retain moisture available for plant use. Increased soil moisture does not relate directly to increased plant available water in the soil. It is the increase in soil moisture that can be extracted by plants, known as plant available water, that directly reduces plant stress and reduces requirement for irrigation. An increase in soil moisture that relates to reduced irrigation water requirements carries great importance for growers in rainfed as well as in irrigated conditions (properly managed irrigation systems). This has not been evaluated in any of the scientific trials. Soil water is a limiting factor in agricultural production. Water deficit can result in increased plant stress, significant reduction in yield or even crop failure. With implementation of the NSW Government's water reforms, growers are under tremendous pressure to pay water prices based on volume of water extracted for irrigated agriculture. If mulch application demonstrates reduced water requirement in irrigated agriculture (in properly managed irrigation systems) and/or moisture conservation in dryland (rainfed) conditions, this can reduce growers water bills and/or reduce the risk of crop stress/failure, thereby providing significant incentives for incorporating RO products into farm management practices.

Table 1 Brief summary of performance outcomes of RO products used in fruit and orchard production.

Performance categories	**Performance outcomes**	**RO products as surface mulches**	**RO products as soil conditioners**	**Comments**
Reduced risk to crop failure	Incidence of pest and diseases	Not investigated.	Less susceptible to fungal diseases. (1)	
	Frost risk in cooler climates	Not investigated.	Not investigated.	
	Crop stress in hot climate	Not investigated.	Not investigated	
Increased revenue	Tree growth (establishment of juvenile plantings)	Tree growth increased in all cases (20-360%) (~10).	Tree growth increased in all cases and ranged 5- 63% (6).	Lower mulching depths & soil conditioner rates have produced higher yields, however varying compost maturity may account for this trend. Increased fruit size attracts higher price in the market.
	Fruit yield	Fruit yield varied and when it increased, the increase ranged 20-400% for various crops. Fruit size has been reported to increase in some cases. (4)	Yield has increased up to 48% (1)	
	Fruit quality	Unaffected mainly, but increased greenness of peaches (where excess N was applied) which continued even when fruit was fully ripe. (1)	Unaffected. (1)	Addition of larger amounts of N than required for fruit crops deteriorates fruit quality.
	Time to market	Not investigated	Not investigated	
Reduced farm maintenance costs	Weed suppression	Confirmed weed suppression from 85-100% (3)	Not investigated. Generally do not suppress weeds.	Deeper mulches were more effective in weed suppression but has the potential to cause other deleterious effects depending upon product maturity, particle size and nutrient content.
	Reduced irrigation water usage	Confirmed increases in soil moisture (10-80%). Available water capacity did not change. Highest increase was found within surface to topsoil layer (5).	Not investigated.	Deeper mulches were more effective to increase soil moisture but may cause other detrimental effects (see above). No data to support irrigation saving claims.
	Reduced fertiliser application	Not investigated.	Slow release compared to mineral fertiliser. (1)	Rates of mulches and soil conditioners should not exceed nutrient requirements of fruit crops. Absence of data relating to nutrient release and availability over time.
Increased farm capital value	Increased soil health (soil biological, physical and chemical properties)	Increased microbial and enzyme activity and increase was highest in the topsoil. Tendency to increase SOM, N, Ca, Ca:Mg, infiltration (4).	Not investigated.	Long term application would eventually improve soil health

Note: the figures in brackets are number of trials that have measured/investigated that performance outcome out of total 14 field trials reviewed for this report.

Weed suppression

Addition of RO products as surface mulches under fruit trees can reduce the growth of weeds from 80 to 100% in the first season after mulch application. Soil conditioners did not suppress weeds. Higher mulching rates (10 and 15 cm deep) were more effective in weed suppression.

Disease suppression

Soils amended with particular RO products under some circumstances have been found less susceptible to fungal diseases.

Yield and quality

All trials have found increased growth of young fruit trees (10-300%) due to application of mulches and soil conditioners when compared to juvenile trees established without composts. Combination of lowest rates of soil conditioners (25 to 50 t ha^{-1}) and surface mulch (2.5 to 5 cm deep) produced highest growth of young fruit trees. A small number of field trials that have measured fruit yield found varying results. Reported increases in fruit yield have varied widely from 20-400%.

The most attractive finding for growers was that the total number of large fruit size has been found to increase (in two field trials with peaches and cherries) when fruits were graded according to size. Larger fruit size attracts premium price at the market, and can provide significant incentive to growers for including RO products in farm management practices.

Application of RO products as surface mulch did not change most of the fruit quality parameters of peaches, apples and cherries (based on results of two trials only) with the exception that Brix levels of apples, peaches and cherries increased. In one trial, peaches developed a green area even when fruit was fully matured. Formation of green calyx/area is an undesirable effect and was the result of application of excess N (via mulches) than that required by peach trees. This negative highlights the importance of considering nutrient budgeting when selecting and applying RO products and supplimentary fertiliser regime to match the nutrient requirements of the crop.

Nutrient availability

One field trial studied the release of nitrates after application of soil conditioners and found a relatively slow release of nitrogen compared to chemical N fertilisers. Recycled organics products release nutrients variably and slowly over 3-5 years after the decomposition of organic matter present in the RO products. Release and availability of plant nutrients from RO products under various Australian environmental and farm management conditions are have not known and not been specifically evaluated in any of these trials. This information is critical for estimating RO product application rates and nutrient contribution to meet specific crop requirements without having any detrimental impact on crop yield and quality as well as on the environment.

Soil health

Application of mulches had a varying effect on soil health over the short term. In some cases there was improvement in soil properties such as infiltration, increased soil microbial and enzyme activity, increased levels of SOM, Ca, nitrogen, and Ca:Mg ratio. Application of RO products over time eventually increases SOM, consequently improving all soil properties, and resulting in increased soil productivity and reduced land degradation.

Application rate

Application of thick mulches (greater than 10 cm) were found to be effective in weed suppression and increasing soil moisture, however, thick mulches or higher rates of soil conditioners with high nutrient content can supply excess nutrients to plant requirements, promoting vegetative growth which can result in a reduction of fruit yield and quality, or cause other deleterious effects. Selection of optimum mulching depth and particle size that provides maximum benefit in terms of weed suppression and soil moisture increase without any detrimental impact on crop productivity is necessary. A relatively low nutrient composted mulch that can be applied at a higher application rate may be preferred in this regard. Nutrient budgeting is a necessary consideration when specifying products and application rates for particular crops.

Longevity of benefit

Mulches maintained the effect of soil moisture increase over a long time (3-5 years), while weed suppression effect decreases over time (after 6-12 months). Reapplication time of mulches should take into account these issues to maximise benefits of mulch application to fruit and orchard production.

Recommendations

Use of RO products as surface mulches have demonstrated significant reduction in weed growth, reduced water evaporation from soil surface, and increased percentage of large fruit size. All these performance benefits would assist growers to maintain long term land and crop productivity, whilst potentially reducing the irrigation water and the use of farm chemicals and hence reducing production costs.

Due to the short term funding of these projects, most performance benefits have been measured over one season. Many specific performance benefits have been studied in only a small number of field trials, and over short term duration (Table 1). In addition, results have in some instances not been statistically analysed. As a result, the use of such performance data must be quantified with associated limitations. A number of important performance benefits have not been studied at all in these trials (Table 1).

Long term and statistically significant data is required to demonstrate and quantify predictable performance benefits that can demonstrate cost-benefit advantage and support increased demand. It is reccommended that a comprehensive, multisite, long term strategically designed R & D program be conducted that specifically targets vital performance benefits and covers the key gaps identified in Section 5. This program should use RO products of suitable and known specifications, to provide reliable performance data to inform valid cost-benefit analysis. Such a program may be supported by deliberately complementary demonstration trials and other strategies, which may be conducted concurrently on growers properties in the fruit production regions. The results of these trials and strategies will inform integration of RO products into farm management practices and will provide complementary data (particularly with regard to yield and quality) to accelerate RO product uptake in fruit and orchard production.

This study provides generic specifications of composted mulches and composted soil conditioners (Section 7.1) that can be used in fruit and orchard production to maximise benefits of RO products. This study also provides a structure for the consideration of a number of standard performance categories and monitoring parameters for consideration in designing recycled organics product application field trials to inform cost-benefit analysis and environmental impacts (Section 7.2, Table 7.3). The provision of the Table 7.3 (Section 7.2) does not mean that all performance benefits should be studied in a single trial, nor does it mean all performance benefits needs to be studied in future trials. However, it is highly recommended that future trials should be designed in a way that specific performance benefit/s is/are studied thoroughly and over the long term (3-6 years) to reach conclusive results. Based on the knowledge gathered from this review, the following monitoring parameters have been identified to be given priority consideration in future R & D programs:

- Trials should be of relevant duration and soils, climatic conditions, characteristics of recycled organics products, and farm management practices are known and documented. Recycled organics products selected are of optimum characteristics to maximise agricultural performance and cost-benefit advantage.
- Reduced irrigation water usage - Quantification of the increase in soil moisture arising as a result of application of composted mulches and composted soil conditioners and evaluation of the relationship between increase in soil moisture and irrigation water savings in properly managed irrigation systems.
- Reduced fertiliser application – Quantification of the release and availability of major nutrients (N, P and K) for plant use through application of composted mulches and composted soil conditioners.
- Duration of weed suppression – Quantification of weed suppression over time from different depths of composted mulches.

Section 1 How to Use the Report

1.1 Objectives of the report

The NSW Waste Boards market study carried out in 1999 identified a significant potential for recycled organics (RO) product use in and around the Greater Sydney Region for fruit and orchard production applications. About 10% of fruits and orchard producers are estimated to currently use RO products and the remaining 90% potential is yet to be realised. Creation of demand in this market segment requires knowledge of performance benefits of RO products for this application. The development of a product specification designed to consistently meet the specific needs of this market segment and to maximise the cost/benefit advantage to growers, will provide market confidence and contribute to overcoming affordability barriers (Recycled Organics Unit, 2002).

The potential benefits of RO products in fruit and orchard production have been studied in Australia over the last five years using various compost products. However, most of this research has not been peer reviewed or published, and is not readily accessible. Therefore the objectives of this report are to obtain and review relevant project reports, publications, presentations, and articles in fruit and orchard production to:

- Establish baseline performance data for the use of RO products for fruit and orchard production applications within the context of environmental factors and farm management systems;
- Review the methodology of previous trials, document key experimental design issues for applied field trials and to prioritise relevant monitoring parameters for the purpose of establishing the performance benefits and cost-benefit advantages of application of RO products;
- Identify gaps in available data, thereby informing and prioritising future applied product application trials, and
- Inform the future development of performance-based RO product standards and application guidelines for the fruit and orchard production market segment.

1.2 Scope

The report reviews relevant project reports, publications, presentations and articles on RO product application in fruit and orchard production. Information reviewed will include (but not be limited to) studies conducted by NSW Agriculture Organic Waste Recycling Unit (OWRU), Agriculture Victoria (Institute for Horticultural Development), Agriculture WA, CSIRO Land and Water, and SA EPA.

1.3 Who is the report for?

This report firstly is for government policy makers who have involvement in the development of programs and initiatives to support the development of the recycled organics industry. Government support in this context aims to assist industry in maximising the diversion of compostable organic materials from the waste stream and recovering these resources for higher resource value applications.

This report is also useful for manufacturers of RO products who are seeking customers in fruit and orchard production, and who invest in the development of RO products for the needs of specific customers or markets.

In particular, the report has been written for:

- Department of Environment and Conservation (NSW);
- Manufacturers and/or blenders of RO products;
- Marketers of recycled organics products;
- Waste educators;
- Industry consultants and contract researchers;
- Agriculture and Natural Resource departments of various State Governments; and
- Other relevant NSW, interstate and Commonwealth Government agencies.

1.4 How to use the report

The report is organised in ten sections. The first section lists the objectives of the report, who this report is for, how to use the report, terminology and how to cite the report.

The second section begins with a brief description of fruit and orchard production as a farm management system, provides information on costs involved, best and common management practices and brief introduction on opportunities of RO product application in fruit and orchard production.

The third and fourth sections of the report provide an assessment of the context of field trials in fruit and orchard production using mulches and soil conditioners. These sections report on spectfic variables affecting performance such as climate, soil types, irrigation/non-irrigation, irrigation water quality, RO product type, RO product qualities, RO application rate and method and experimental design for product application trials. Performance outcomes arising from the use of RO products are grouped under the following four categories: reduced risk of crop loss, increased revenue due to increased yield, reduced costs in farm management; and increased farm capital value.

The fifth and sixth sections identify the gaps and limitations of the existing studies, provide conclusions and recommendations including R & D priorities and suggested methodology for product application trials. The seventh section provides basic product characteristics as recommended for fruit and orchard production on the basis of current knowledge.

The eigth and ninth sections include the references and glossary.

1.5 Terminology

Terms used throughout this report have been officially adopted by the Waste Boards (now NSW Department of Environment and Conservation) in July 2000 in the form of the nationally reviewed RO Dictionary and Thesaurus: Standard terminology for the recycled organics industry (Recycled Organics Unit, 2002a). This document is freely downloadable from http://www.rolibrary.com

Where possible, nationally accepted terms have been used in this report. Key terms and definitions are provided in the Glossary (Section 9).

1.6 How to cite the report

This report should be cited in the following manner:

Recycled Organics Unit (2002). *The Recycled Organics In Intensive Agriculture Volume 3-Fruit and Orchard Production. A Review of Recycled Organics Product Application Field Trials in Fruit and Orchard Production in Australia.* Recycled Organics Unit, internet publication: www.recycledorganics.com

Section 2 Introduction to fruit and orchard production

Fruits are grown throughout NSW. Total land area occupied in NSW under orchards excluding viticulture was 74,981 hectares (ABS, 1997). Sydney statistical division covered 5,266 hectares under orchards. The main areas where fruits are grown in NSW outside Sydney and within 300-400 km radius of Sydney are the Hunter, Central Coast and Central West. The Hunter statistical division occupied 854 hectares and Central-West occupied 6,479 hectares (ABS, 1997). The Illawara region is not considered to be major fruit growing region and land occupied by orchards in this statistical division was 342 hectares (ABS, 1997). Please note latest statistical data (2001) collected by ABS was not yet available at the time of writing this report.

The main types of fruit crops grown in NSW include:

- Citrus (oranges, lemons, limes and mandarins),
- Stone fruits (apricot, nectarines, olives, cherries, peaches, plums and prunes),
- Pome Fruits (apple, pear, and nashi),
- Blueberries,
- Strawberries,
- Nuts (macadamias),
- Tropical fruits (bananas, pineapples, pawpaws), and
- Other orchard fruits (avocados).

The greater Sydney basin is considered as the fruit and salad bowl of NSW. Main fruits grown in Sydney basin are peaches, nectarines, and strawberries. Stone fruits and apples are grown in the Blue Mountains area. Southern Sydney grows similar fruits as the Sydney basin. There are small holdings of stone fruits in Camden and the Picton/Appin area to Sydney's south and south west. In the Central West of NSW around Orange and Bathurst common fruits grown are apples and pears. The NSW Central Coast is famous for growing citrus, stone fruits, avocados, strawberries and kiwi fruits.

2.1 Brief description of fruit and orchard production as a farm management system

Like vineyards, the establishment of fruits and orchard growing farms requires a whole farm plan that considers the farm's physical, financial and personnel requirements for now and the future (NSW Agriculture, 2002). Farms should be planned and designed to protect the environment, allow for maximum agricultural use and profitability, and to ensure that farming practices have minimal impact on on-farm and off-farm natural resources.

NSW Agriculture has developed the best practice guidelines for *Horticulture In The Sydney Drinking Water Catchment* (2002a). Site selection is important for all horticultural crops. Slopes to the north-east are preferred for maximum sunlight, warmth and protection from wind. To prevent erosion on steep slopes, plantings are best positioned on a contour and trees are planted across the slope to minimize any soil erosion. Water flow following heavy rainfall should be diverted into dams and grassed areas. Buffer zones (areas of vegetated land) need to be established or left in place to protect sensitive environmental areas. Wind protection and screening of the whole farm and of individual large paddocks is recommended. The better soil types are deep, well drained sands, sandy loams and loams. Heavy clays are less suitable as they drain poorly and waterlog easily.

A range of fruit crops are included in the fruit and orchard production market segment, information on each specific fruit crop and how it is managed at farm level is not provided here. Most fruit crops are grown on rows. Number of trees per hectare vary for each fruit crop. The stages of growth, maturity and time of first fruit harvest will also vary for each fruit crop.

2.2 Costs involved

The costs involved in establishing and running a fruit orchard will vary from propeerty to property, type and variety of fruit trees and management systems and are as follows:

- capital costs of establishing a orchard,
- production costs, and
- overhead costs.

The capital costs of a fruit orchard will be similar to a vineyard (discussed in Volume 2, Section 2.2) and include costs of land, irrigation system and irrigation headworks, purchasing fruit trees and provision of machinery and windbreaks. A budget of up to $345,000/ha have been estimated could be required to establish a 10 ha vineyard up to the first crop in the third season (Hedberg and Doyle, 1996).

Farm budgets have been prepared for various citrus fruit types, varieties and for different regions of NSW (NSW Agriculture, 1997) and the total production costs have been summarised in Table 2.1. The production costs in these budgets include costs for herbcides, irrigation, fertilisers, fungicides, insecticides, bait sprays, pruning, tractor, and harvesting (NSW Agriculture, 1997). The main diffrences in production costs (Table 2.1) are mainly due to costs of harvesting and some in irrigation water requirements for different types of irrigation systems and fruit types. The yield and quality of fruit trees vary with regions, variety and management practices.

Table 2.1 Production costs of citrus enterprise per hectare for different regions of NSW.

Location	Description	Enterprise	Costs involved (dollars)
Riverina	Furrow with herbicide/sod culture	Oranges-Valencia	3,510.71
Riverina	Furrow with herbicide/sod culture	Oranges Early Navel	3,796.61
Riverina	Furrow with herbicide/sod culture	Oranges Washington Navel	4,418.51
Riverina	Furrow with herbicide/sod culture	Oranges Late Navel	3,535.36
Riverina	Microspray, pressurised water delivery/sod culture	Mandarins-Clementine	6,788.16
Sunraysia	Microspray, pressurised water delivery/sod culture	Oranges-Valencia	3,916.97
Sunraysia	Microspray, pressurised water delivery/sod culture	Oranges- Washington Navel	4,515.87
Sunraysia	Microspray, pressurised water delivery/sod culture	Oranges Late Navel	3,975.79
Sunraysia	Microspray, pressurised water delivery/sod culture	Mandarins-Imperial	6,753.27
Central Cost	Microjet (supplementary irrigation only)/sod culture	Oranges-Valencia	4,263.50
Central Cost	Microjet (supplementary irrigation only)/sod culture	Oranges-Washington Navel	4,721.47
Central Cost	Microjet (supplementary irrigation only)/sod culture	Lemons (Standard Density Planting)	2,890.30
Central Cost	Microjet (supplementary irrigation only)/sod culture	Lemons (Double Density Planting)	6,958.51

2.3 Best management practices

NSW Agriculture (2002a) has developed *Best Practice Guidelines for Horticulture in the Sydney Drinking Water Catchment*, relevant issues are discussed below. The best practice soil and weed management includes maintaining a wide weed-free strip under the trees, and the use of cover crops. Legume based cover crops are preferred because these crops fix atmospheric nitrogen (N) in their roots which through the soil becomes available to fruit trees. Application of fertilisers based on soil and/or leaf tissue analysis, and irrigation requirement determined by soil moisture conditions are considered best practice. The integrated pest and disease management (IPM) is considered the best to protect environment and human health. Integrated disease and pest management includes combined use of chemicals, cultural, mechanical and biological means such as crop rotation, good hygiene practices, crop monitoring, using beneficial organisms (biological pest management) and protecting naturally occurring beneficial organisms and having breaks in crop production (fallow practices). Softer insecticides such as petroleum spray oils and soaps that minimise impact on beneficial organisms and negate spray residue problems are also recommended.

The best practce irrigation method is the *deficit irrigation strategy*. This strategy aims to apply water only to the rooting depth of the crop and the soil is never watered beyond field capacity. Deficit irrigation, which takes into consideration evapotranspiration (i.e. both water evaporation from the soil and transpiration from plants), applies less water than that indicated by soil moisture monitoring without causing detrimental effect on plant growth.

2.4 Common management practices

Common management practices vary for different regions depending upon horticultural crops, yields, climatic and environmental conditions. For example in high rainfall areas, management practices will be focused mainly on reducing weeds, pests and diseases and less on irrigation. Higher yield areas such as Grifiths will require to focus on fertiliser and irrigation management to sustain higher yields. As a result, performance objectives may be prioritised differently by growers in different regions, which in turn may impact upon RO product specifications required for different regions, even for same crop type.

2.5 Opportunities for inclusion of RO products into fruit and orchard production systems

As discussed in Volume 1, Section 3.2 (ROU, 2003) the intensive working of land used for fruit production, like other intensive agriculture production systems, causes loss of soil organic matter (SOM) resulting into soil structure decline, land degradation and loss of soil productivity. Recycled organics products when applied to the soil surface as mulch reduce the growth of weeds, and water evaporation from the soil surface and increase soil moisture. Recycled organics products also contain organic matter and nutrients, and when applied to the surface of the soil (surface mulch) or incorporated into the soil (soil conditioner), organic matter decomposes slowly over time and integrates with soil's mineral component improving soil conditions. Consequently soil productivity and crop production is maintained and land degradation is prevented. The nutrients present in RO products are released steadily over time and become available for crop use. The use of RO products in fruit and orchard production therefore provides opportunity to address the following agricultural and environmental issues:

- Weed suppression resulting in reduced or avoiding use of herbicides,
- Reduced evaporation of water from the soil surface. Increased soil moisture may lead to reduced use of irrigation water for irrigated conditions and water conservation in non-irrigated conditions,
- Sustained and long term release of nutrients for growth of fruit crops reduces use and manufacturing of chemical fertilisers,
- Reduced fluctuation of soil temperature and soil moisture results in reduced crop stress,
- Increasing soil organic matter leads to improved soil health and productivity, and prevention of land degradation, and
- Assist with conversion to organic production systems and/or achievement of environmental certification and labelling.

Section 3 Mulch application to fruit and orchard production

3.1 Description of field trials

This section provides information about known performance outcomes arising from the use of RO products as surface mulch in fruit and orchard production. Mulch is defined as any composted and/or pasteurised product that is used as surface application around plants, and is not incorporated into the soil. Mulch has at least 70% by mass of its particles with a minimum size of equal or greater than 16 mm, as defined in the Australian Standard for composts, soil conditioners and mulches (AS 4454, 2003).

A total of 14 relevant field trials have been carried out across Australia over the past decade. These trials have studied the benefits/effects of using RO products as surface mulch in fruit and orchard production. Information on these trials is available as mentioned below:

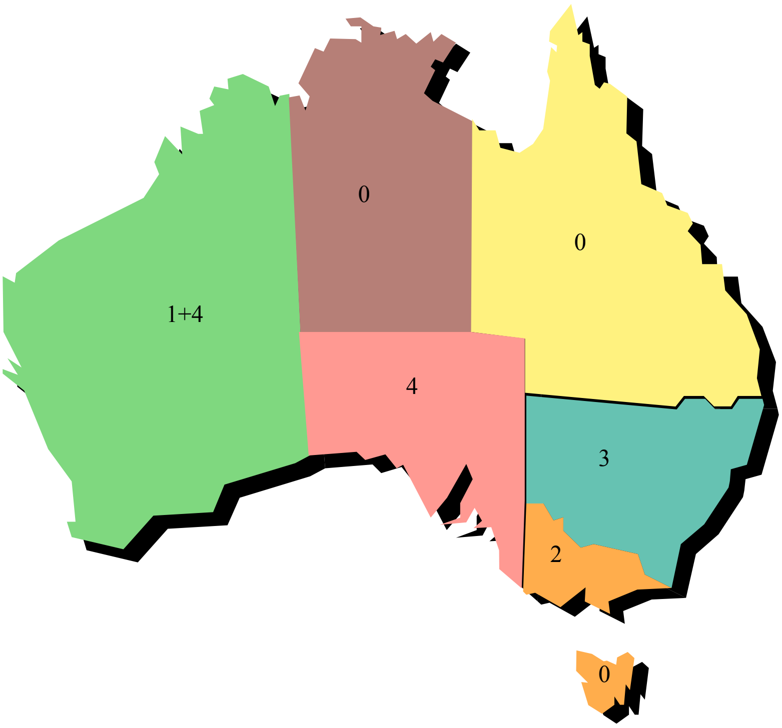
- The scope and location of these trials is identified in Table 3.1 and Figure 3.1;
- The documented performances outcomes are summarised in Table 3.2;
- A detailed description of each trial is provided as Appendix 1; and
- Specific and detailed performance outcomes are documented in Appendix 4.

This review focuses on the scientific trials that offer more reliable data, but also provides a description of demonstration trials that have been conducted.

Table 3.1 State-wise identification of field trials conducted across Australia using recycled organics products as surface mulches in fruit and orchard production.

Name of state	Number of trials	Recycled Organics Products used	Fruit crops tested
Victoria	2	Composted mulches produced from garden organics and from garden organics and yard cow manure, Straw, Wool scour	Cherry
Western Australia	1 (surface mulch) 4 (soil conditioners +surface mulch)	Composted mulches made from garden organics, land clearing based plant material, grower produced composted mulch	Citrus (oranges), Avacado, Apple
South Auistralia	4	Composted mulches from garden organics, almond husk	Pears, almond, cherries and oranges
New South Vales	3	Composted mulches produced from macadamia husks and boiler chicken manure with sawdust; from garden organics and biosolids; and from garden organics only.	Macadamia, Apples, Peaches

Figure 3.1 Number of field trials conducted in fruit and orchard production in various states across Australia.



The soil where RO products are applied represents a biologically active system. Soils vary greatly, react differently under different environmental conditions and agricultural management systems, and undergo changes over time. Therefore the performance of mulches in agriculture production systems vary and is mainly controlled by the following factors:

- RO product characteristics (chemical, physical and biological characteristics),
- Environmental conditions (temperature, rainfall, soil types), and
- Farm management systems (crop variety and age, RO application method and rate, irrigation/non irrigation, irrigation water quality, use of fertilisers, herbicides and insecticides)

Given that performance of RO products in agricultural production systems is influenced by all these factors, information of these factors is essential in interpretation of the performance results of RO product applications. The characteristics of RO products, environmental conditions and farm management systems used in fruit and orchard production field trials reviewed for this report are discussed below.

3.1.1 RO product type and quality

Traditionally RO products as surface mulches have been used in agriculture to reduce water evaporation from the soil surface, to suppress growth of weeds and to reduce temperature fluctuations at the soil surface. These benefits are determined by the type, quantity and quality of RO products applied. The successful establishment and management of a fruit orchard are critical for the viability of fruit industry, therefore reliable and suitable RO product quality is an important element in realising the demand potential in fruit industry.

Type and quality of mulches depends mainly upon input materials (raw materials), and on the compost processing technology and management practices. The raw materials from which compost are produced can greatly affect the quality of mulches. For example mulches produced from animal manure, biosolids or garden organics will have higher nutrient content compared to products produced from woody or timber materials. Mulches produced from biosolids or Municipal Solid Waste (MSW) will tend to have higher heavy metal contents compared to garden organics or food organics. Mature composted mulches will contain high levels of stable organic humic compounds compared to pasteurised mulches, which will have low levels of stable organic humic compounds and potentially phytotoxicity risks. Poorly managed composts may not provide reliable pasteurisation of materials and are much more likely to contain weeds and pathogens.

The quality of mulches particularly the particle size; organic matter and moisture contents; toxicity; maturity; nutrient value; nitrogen drawdown index (NDI), heavy metals, and impurities (plant propogules, pathogens, stones, glass, plastics, etc.); are all important for fruit and orchard production. For example mulches with high impurities and heavy metal contents will not be suitable for the production of fruit crops. Particle size and nutrient value in particular are also very relevant to application depth of mulch.

Australian Standard for composts, soil conditioners and mulches (AS 4454, 2003) defines characteristics and qualities of various RO products. New South Wales EPA guidelines (1997) for *Use and Disposal of Biosolids Products* documents permissible units with regards to the heavy metals for various land applications.

The RO products used as surface mulches in field trials reviewed for this report were mainly:

- composted mulches produced from garden organics; land clearing derived waste; and timber residuals from timber processing and clearing (Western Australia),
- composted mulches produced from garden organics (garden waste), garden organics plus biosolids, macadamia husk plus boiler chicken manure with sawdust (New South Wales); and
- composted mulches produced from garden organics and other organic materials (Victoria).

The chemical and physical characteristics of mulches provided in Western Australian, Victorian and New South Wales project reports are presented in Appendix 2, some meet the requirements of composted mulches as per Australian Standard AS 4454 (2003). The exception being some mulches used in Western Australian and New South Wales trials which did not meet the requirements of Australian Standard AS 4454 (2003). Unfortunately many studies did not provide chemical and physical characteristics of mulches which is fundamental for interpretation of results. Information on basic characteristics such as particle size is undocumented in the vast majority of studies.

Composted mulch H produced from land clearing derived plant materials used in Western Australian Trial 14 had higher toxicity levels (<1% root length relative to control mix) than that required for composted mulches (>60%) as per requirements of AS 4454 (2003). The toxicity levels in grower's (on-farm produced) composted mulch derived from chipped apple tree wood and chicken manure that was applied in Western Australian Trial 12 were also high (<1%) compared to that required for composted mulches (>60%). Grower's composted mulch also had slightly higher pH of 8. Generally lower rates of mulch application are recommended for mulches having toxicity levels beneath the 60% minimum threshold level specified for mature composts (AS 4454, 2003). The contents of heavy metals and boron (B) were not provided for mulches used in Western Australian trials.

The composted mulches produced from garden organics, and from garden organics plus biosolids used in NSW trial with apples and peaches had the levels of copper (Cu) slightly higher (120 and 160 mg kg^{-1}) than contaminant Grade A product (100 mg kg^{-1} dry weight basis) but were within the limits of contaminant Grade B product (375 mg kg^{-1} dry weight basis) according to *NSW EPA Guidelines for Use and Disposal of Biosolids Products* (NSW EPA, 1997). The contaminant grade B products are suitable for agricultural land application. The levels of zinc (Zn) in composted mulch produced from garden organics plus biosolids were slightly higher (232 mg kg^{-1}) than that required in contaminant Grade A (200 mg kg^{-1}) as per *NSW EPA Guidelines for Use and Disposal of Biosolids Products* (NSW EPA, 1997). If RO products with heavy metal contents higher than contaminate grade A are applied to orchards, soils, plants and fruits should be monitored to ensure concentration of those heavy metals do not exceed maximum permissible concentrations. The mulches used in NSW trial were not tested for organic matter, B, moisture content, or toxicity levels.

It is not possible to extend the performance data from specific (and unknown) products to mulches in general. This places significant limitations on the use of existing data for reliable cost benefit analysis or performance claims.

3.1.2 Environmental conditions

The variation in environmental conditions such as climate (rainfall and temperature), soil types and properties will have varying effect on the performance outcomes of mulches used in fruit crops. Therefore this information is important to accurately interpret the results of performance outcomes of RO products from field trials. For example Dala and Chan (2001) has reported more rapid decomposition of SOC in tropical regions than in more temerate regions suggesting RO products (which are source of organic carbon/organic matter) will follow similar trend i.e decompose faster in warmer than in cooler climate hence the effect of RO products applied at same rate may last longer in cool compared to warm climates. Evaporation is also normally higher in hotter, drier areas, where the benefits of mulch may be more pronounced. In relation to soils, the application of mulches on clayey soils with restricted drainage has the potential to cause prolonged waterlogging due to reduced water evaporation from the soil surface (Biala, 2001), therefore we should assume that the application of mulch is always and necessarily beneficial.

Some reports have provided reasonable information on environmental conditions that were specific to the trials undertaken (Appendix 1). New South Wales trial with macadamia was located at NSW North Coast on ferrosol acidic soils and had sub-tropical climate with summer dominant annual rainfall. New South Wales trial with apples and peaches was located at Bathurst on podzolic duplex type soils which experiences winter frost periods. Western Australian reports did not provide information on climate and soils were mainly sandy in texture. There was no information available on climate and soils for South Australian and Victorian trials.

The data available on environmental conditions from this review suggests that mulches have been tested in a range of climatic conditions and on varying soil types. This range of information will be beneficial in the future development of performance based product specifications and application guidelines for fruit orchards.

3.1.3 Agricultural management practices

Different fruit crops and their varieties show varying response to mulch treatments as do the fruit trees of different age. The studies have covered a range of fruit crops such as cherries, strawberries, macadamia, oranges, avocados, apples, almonds, pears, and peaches. Application of mulches has been tested on establishing as well as established fruit trees.

The characteristics of each individual fruit tree such as growth, maturity and production, diseases, etc. varies among varieties. The main fruit crops grown in the greater Sydney metropolitan region and surrounding 300-400 km areas are apples, pears, peaches, oranges, avocados, strawberries, raspberries, and nectarines (pers. comm. Mr Antony Somers, District Horticulturist, NSW Agriculture, Tocal and Sandra Hardy, Gosford, NSW Agriculture).

Application of mulches at different rates (low or high) will have considerably varying effect on the performance of fruit trees. As discussed previously that the main role of mulches is to suppress weeds and to retain soil moisture, and mulches can also provide nutrients. Higher rates of mulches may have greater effect on weed suppression and soil moisture retention but at same time excessively thick mulch layer may provide an ideal microenvironment for diseases, restrict further fertilizer side dressings, and N may be lost from the soil by denitrification if the soil is too wet beneath the mulch. Deeper mulches, paricularly those containing a proportion of fine particles can “suffocate” soil by inhibiting gaseous exchange, and may even reduce water penetration by absorbing moisture before it can reach the soil.

The field trials reviewed for this volume of the report have used mulches at various depths and widths. Depths of mulches in these field trials ranged from 0.5, 1, 2, 2.5, 5, 7.5 and 10 cm (Appendix 1). Mulch application width in various experiments ranged from 1, 1.5 and 2 m (Appendix 1). In one of the Western Australian trial mulch was applied on volume basis at the rate of 2, 5 and 10 litres per m^2 per tree. Application of mulch at varying depth and width means that total volume of mulch added per hectare will vary depending upon effective area covered by mulch application which in turn depends on number of trees per hectare and distance between trees in a row or number of rows in a hectare of a particular fruit tree and the width of a tree row. For example application of mulch to 10 cm depth and 50 cm width to a vineyard will be equal to about 150 m^3 per hectare (Appendix 3). Conversion of mulch application depth and width to volume of mulch applied per hectare is provided in Appendix 3.

The standard farming practices can mask the effects of mulch application to an agricultural system. For example application of herbicides prior to the application of mulches must be documented where this occurs, as knowledge of this will help in interpretation of results. In relation to plant nutrition, same fertiliser regime can continue to be applied to mulched treatments without regard to the nutrient contribution of the mulch effectively producing distorted results which relate to additional fertiliser application rather than to benefits from the actual mulch. Treatments must maintain equal conditions for trees in terms of nutrient availability so as to isolate the performance benefits of the mulch.

The standard farming practices including use of insecticides or herbicides were unchanged in most trials. The standard fertiliser practices varied in some trials. It appears that most trials were irrigated and only few were non-irrigated. The quality and source of irrigation water was not provided in any report.

3.1.4 Experimental methodology

A long term R & D program, including experimental design and monitoring requirements is essential to quantify performance benefits of RO products in intensive agriculture. The statistically significant performance benefits from research trials based on appropriate experimental design (replicated, randomised and having control for comparison) and comprehenssive monitoring requirements provide strong scientific base to validate the results.

All scientific trials reviewed for this volume incorporated key elements of appropriate experimental design including replication, randomisation and control. Most field trials used replicated randomised complete block experimental design, some have used Latin Square and Split Plot as well. However, the monitoring parameters and methods of trials varied significantly, and have been compromised in many cases. The majority of trials have monitored performance benefits such as crop growth, fruit yield, soil moisture and weed suppression but in most cases results have been derived from monitoring a single growing season only, which is not sufficient for reaching scientific conclusions, particularly in relation to performance and cost/benefit data in agricultural production systems using RO products. Many performance benefits were measured as one of the parameters or as a side issue in these trials. The results of trials that are planned and designed to study specific performance benefit/s provide accurate and valuable information on performance benefits.

Very few field trials have monitored fruit quality, nutrient availability, frost risk and soil health parameters (such as soil biological, physical and chemical properties). The potential performance benefits such as disease suppression, crop stress, time of crop growth stages and maturity, and fruit storage quality were not monitored in these field trials.

This is not necessarily a critisism of the researchers involved. Trials are planned and implemented within the context of client objectives, budgetary constraints and ideally industry stakeholder consultation and/or direct participation. All stakeholders share responsibility for poorly planned trials. The recommendations in Section 7 provide suggestions and tools for the specification of clear objectives, monitoring parametrs and trial duration.

3.2 Documented performance outcomes

The results of 14 field trials conducted throughout Australia have been reviewed for fruit and orchard production. The detailed results of performance benefits of RO products as surface mulches have been provided in Appendix 4 and summary of these results are presented in Table 3.2. The performance outcomes have been presented under the following four performance categories:

- Reduced risk of crop failure,
- Increased revenue (from increased yield, improved produce quality and time to market),
- Reduced costs in farm management (reduced water usage, fertilizer application, farm chemicals), and
- Increased farm capital value (soil health).

Please note throughout this report effort has been made to present performance benefits in relation to the different fruit types such as stone, pome, citrus, berries, nuts, tropical, and others particularly for fruit yield and quality.

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
VIC-KW-2000 Cherries C-Control (bare ground) S10-Straw 10 cm layer applied as surface mulch CM5-Fine composted mulch applied 5 cm deep as surface mulch CM10-Coarse composted mulch applied 10 cm deep as surface mulch		Cheery yield (1998). No increase after first season monitoring as mulch was applied two months prior. Summit variety (1999) (kg/tree)-Yield significantly higher (84-104%) for composted mulches for 2nd season monitoring. Lower rates had higher yields. Stella variety also had higher yields but not significantly higher.	Weed growth (1998) - Percentage weeds per m^2 decreased 87-98% for composted mulches.	Water pooling under irrigation drippers (1999)- Occurred less frequently under composted mulches by 12-18%.
VIC-GCR-1999 Cherries Demonstration trial CM10-Composted mulch applied 10 cm deep and 1.8 m wide as surface mulch S10-Straw applied 10 cm deep as surface mulch WS10- Woolscour applied 10 deep as surface mulch		Stem growth- measurements were conducted on a monthly basis. Growth of mulched trees was better. Some root growth has occurred under greenchip compost resulting from moisture retention under thick mulch. Greenchip mulch held leaves for 10 days longer than other composts.		
NSW-JC-2002 a & b Demonstration trial, not replicated C-Control (No compost) CM-Composted mulch applied to 10 cm depth			Water holding capacity of the soil after 4, 8 and 12 months of mulch application. Higher at 0-2 cm layer No change at 2-10 cm layer Water holding capacity of the soil (%)- No change after 4 and 8 months of mulch application. Initial Increased by 10% at 0-2 cm and decreased by 40% at 2-10 cm soil depths for CM After 4 months Increased- 45 and 10 % at 0-2 and 2-10 cm soil depths for CM After 8 months.	**Soil microbial activity**- (FDA activity mg FDA/g soil/45 min) Measured microbial breakdown of the FDA molecule, which is fluorescent. Average over 12 months period Decreased by 50% in compost from 4th month onwards to 8 and 12 months. Initial- Hardly any change at 0-2 and 2-10 cm soil depths. After 4 months- Increased– 45 and 14% at 0-2 and 2-10 cm soil depths for CM After 8 months- Increased 50% at 0-2 cm and decreased 38% at 2-10 cm soil depths for CM

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	**Reduced risk of crop failure**	**Increased revenue (yield, time to market, produce quality)**	**Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals**	**Increased farm capital value (soil health)**
NSW-JC-2002 a & b (Contd) Demonstration trial, not replicated C-Control (No compost) CM-Composted mulch applied to 10 cm depth			Decreased- 30% at 0-2 cm and increased 5% at 2-10 cm soil depths for CM	After 12 months- No change at both depths. **Enzyme activity** (alkaline phosphatase ug AP/g soil/hr) Decreased by 48% from 4th months onwards to 8 month in compost. Initial- Increased 15 and 6% at 0-2 and 2-10 cm soil depths for CM. After 4 months- Decreased 10 and 38% at 0-2 and 2-10 cm soil depths for CM After 8 months- Decreased 43% at 0-2 cm soil depth and no change at 2-10 cm soil depth. **Soil total carbon (%)** Decreased by 15% from 4th months onwards to 8 months in compost. Initial-Hardly any change at both depths After 4 months- Increased 31 and 18% at 0-2 and 2-10 cm soil depths for CM. After 8 months-Hardly any change at both depths **Soil total nitrogen (%)** Decreased 14% from 4th months onwards to 8 months in compost. Initial-Hardly any change at both depths After 4 months-Increased 47 and 16% at 0-2 and 2-10 cm soil depths for CM. After 8 months- No change **Soil chemical properties-** Measured soil pH, bulk density, carbon, nitrogen and organic matter – Slight improvements

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	**Reduced risk of crop failure**	**Increased revenue (yield, time to market, produce quality)**	**Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals**	**Increased farm capital value (soil health)**
NSW-JC-2001 Site 2 C-Control (bare ground) CMMH10--Composted mulch from macadamia husk applied 10 cm deep and 1.5 m wide each side as surface mulch CMGO10-Composted mulch from garden organics applied 10 cm deep and 1.5 m wide each side as surface mulch				Soil microbial activity- (FDA activity mg FDA/g soil/45 min) Measured microbial breakdown of the FDA molecule, which is fluorescent. Microbial activity of mulches decreased 47 and 68% for macadamia and garden organics compost after 3 months. Initial- No change at 0-2 cm soil depth for both mulches Increased 15-20% for both mulches at 2-10 cm soil depth After 3 months- Increased 94% for CMMH10 and 22% CMGO10 at 0-2 cm soil depth and 35-40% for both mulches at 2-10 cm soil depth.
NSW-PW-2001 Peaches C-Control (no mulch+standard fertiliser program) GL-F-Green Life composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH-F-Nitrohumus composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH+F-Nitrohumus composted mulch applied 10 cm deep as surface mulch with standard fertiliser program		Tree and canopy growth Increment in butt circumference (cm) 1998- Increased significantly (40-60%) for all mulched treatments 1999- Decreased for all mulched treatments but staistically not significant. Butt area (cm^2)-Unaffected in1998 & 1999 Yield per tree fresh weight basis (kg)-Unaffected in 1998 & 1999 Tree efficiency (kg/cm^2)-Unaffected in 1998 & 1999 Pruning Winter 1998 Weight of pruning (g/plot)-Increased significantly (20-30%) for all mulched treatments Number of laterals/plot-Increased significantly (22%) for both Nitrohumus treatments only.	Weed assessment- Total number of weeds reduced significantly in composted mulch compared to control Total weeds-Decrea sed statistically significantly (80-85%) in all mulched treatments Total grass weeds-Decreased statistically significantly (95-97%) in all mulched treatments Soil moisture-Soil moisture was measured with neutron probe. Soil moisture content under peach trees fluctuated to a similar extent with rainfall and irrigation events and soil moisture was similar for all mulched treatments. Volumetric soil moisture (%) in the soil under mulched trees was consistently higher (ranged 28-37%) than that under the unmulched control (ranged 18-30%).	Soil physical properties Soil infiltration, bulk density and available water capacity measured from control (no biosolids, no compost) and Green Life composted treatment (with and without removing mulch) The control plot had zero infiltration rate (no infiltration). The initial infiltration and five minutes average infiltration for mulched treatment increased to measurable amounts but was slow to very slow 0.5 cm/hr. Bulk density did not change with mulch application. Soil chemical properties Measured at 0-10 cm soil depth 2 years after mulch application. Most properties did not change except pH, SOC, Ca, and Ca:Mg ratio.

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
NSW-PW-2001 (Contd) Peaches C-Control (no mulch+standard fertiliser program) GL-F-Green Life composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH-F-Nitrohumus composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH+F-Nitrohumus composted mulch applied 10 cm deep as surface mulch with standard fertiliser program		Pruning Summer (g/plot) 1998- Increased significantly (40-70%) for all mulched treatments, highest for GL 1999-Increased significantly (30-50%) for GL and NH-F treatments. **Fruit yield** fresh weight basis (kg/plot)-Unaffected in 1998 & 1999 Number of total fruits per plot 1998-Decreased significantly for NH-F (12%). Number of large size fruits increased significantly (85-117%) for all mulched treatments. Number of medium size fruits decreased significantly (20%) for NH-F treatment only in 1998 and was unaffected in 1999. **Fruit quality** for 1998 &1999 Total soluble solids (%) 1998-Increased significantly (6%) for both nitrohumus treatments only. 1999-Unaffected Unaffected Firmness (kg pressure)-Unaffected 1998 & 1999 Red skin colouration (1 to 10)-Unaffected 1998 & 1999. Background yellow skin colour (rating 1 to 6)-Decaresed significantly for NH+F in 1998 and was unaffected in 1999. Green Calyx (% of sample)-1998-Increased highly significantly (1000%) for all mulched treatments. 1999- Increased highly significantly (350-500%) for all mulched treatments. **Elemental composition of fruit for 1998 and 1999** Nitrogen (% dry weight)-Increased significantly (20-30%) for both nitrohumus treatments in 1998 and was unaffected in 1999. P, K, Ca & S (% dry weight)-Unaffceted in 1998 & 1999 Cd, Cu, Ni, Zn, Fe (mg/kg dry weight)-Unaffected Manganese (mg/kg dry weight)-Increased significantly for both nitrohumus treatments (15-25%) in 1998.	Available water capacity (cm^3/cm^3) – Measured 2 years after mulch application. AWC did not change with mulch application. AWC was measured after clearing mulch. Use of total irrigation water per hectare 1997-98 Litres per tree 5018 Mega litres per hectare 3.31 1998-99 Litres per tree 3796 Mega litres per hectare 2.81	Soil pH ($CaCl_2$)- Increased significantly in both nitrohumus treatments from 5.2 to 5.8. Soil EC (dS/m)-Increased significantly in both nitrohumus treatments from 0.06 to 0.07 Total organic carbon (%)-Increased significantly (27%) for NH+F. Total soil nitrogen (%)- Unaffected Bray phosphorus (mg/kg)-Unaffected Exchangeable cations in the topsoil Exchangeable Mg & Na (cmol(+)/kg-Unaffected Exchangeable Ca (cmol(+)/kg-Increased significantly in NH+F (34%). Exchangeable K (cmol(+)/kg Increased significantly in NH+F (34%) Cation exchange capacity-Unaffected Soil Ca:Mg ratio- Increased significantly (30-40%) in all mulched treatments. Concentration of heavy metals (Cu, Zn, Cd and Ni) (mg/kg)- Unaffected.

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
NSW-PW-2001 (Contd) Peaches C-Control (no mulch+standard fertiliser program) GL-F-Green Life composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH-F-Nitrohumus composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH+F-Nitrohumus composted mulch applied 10 cm deep as surface mulch with standard fertiliser program		**Elemental composition of peach leaves for 1998 nad 1999** Nitrogen (% dry weight))-Increased significantly (10%) for all mulched treatments in 1998 and was unaffected in 1999. Phosphorus (% dry weight)-Decreased significantly for NH+F in 1998 and was unaffected in 1999 Potassium (% dry weight)-Increased significanly (15-25%) in all mulched treatments in 1998 & 1999. Calcium (% dry weight) Decreased significantly (15-25%) for all mulched treatments in 1998 and was unaffected in 1999 Magnesium (% dry weight) Decreased significantly (18-27%) for all mulched treatments in 1998 and only NH+F (16%) in 1999 Sulphur (% dry weight)-Increased significantly (10%) for both nitrohumus treatments in 1998 and was unaffected in 1999 Cd, Ni and Zn (mg/kg dry weight)- Unaffcted Copper (mg/kg dry weight)-Increased significantly (12-13%) for all mulched treatments in 1998 and was unchanged in 1999. Iron (mg/kg dry weight)-Increased significantly for GL and NH+F (15-18%) in 1998 and NH+F (30%) only in 1999. Manganese (mg/kg dry weight)-Increased significantly for both nitrohumus treatments (60%) in 1998 and was unaffected in 1999.		
NSW-PW-2001, Apples C-Control (no mulch+standard fertiliser program) GL+F-Green Life composted mulch applied 10 cm deep as surface mulch without standard fertiliser program NH-F-Nitrohumus composted mulch applied 10 cm deep as surface mulch without standard		Tree and canopy growth Increment in butt circumference (cm)-Unaffected in 1998 & 1999 Butt area (cm^2)-Unaffected in 1998 and 1999 Yield fresh weight basis per tree (kg)-Unaffected in 1998 & 1999 Tree efficiency (kg/cm^2)-Unaffected in 1998 & 1999 Total Winter Pruning 1998 and 1999 Unaffected.	Weed assessment- Total number of weeds reduced significantly in mulched treatments compared to control Total weeds in plots Reduced significantly (70-88%) in all mulched treatments Total grass weeds in plots Reduced significantly (82-99%) in all mulched treatments.	

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

fertiliser program				
Trial code and treatments	**Reduced risk of crop failure**	**Increased revenue (yield, time to market, produce quality)**	**Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals**	**Increased farm capital value (soil health)**
NH+F-Nitrohumus composted mulch applied 10 cm deep as surface mulch with standard fertiliser program		Fruit yield fresh weight basis (kg/plot)- Unaffected Number of total fruits per plot-Reduced significantly (19%) for NH+F Average weight of a fruit (g)-Unaffected Fruit quality was measured during March/April, June/July and Sept/Oct. Total soluble solids (%)-Unaffected in 1998 for all periods and increased significantly (4-5%) from March to July in NH-F in 1999. Pressure (kg)- Unaffected for all periods in 1998 and increased significantly (7%) for GL during June/July period in 1999. Acidity (meq NaOH)-Unaffected for all periods in 1998 and increased significantly (15%) in March/April in 1999 for all mulched treatments. Starch (mg/kg)- Unaffected for all periods in 1998 & 1999. Elemental composition of fruit for 1998 and 1999 P, K, Ca, Cu and Zn (mg/kg dry weight)- Unaffceted in 1998 & 1999 Sulphur (mg/kg dry weight) Increased significantly (27%) for GL in 1998 and unaffected for all treatments in 1999. Magnesium (mg/kg dry weight) Increased significantly (14%) for GL in 1998 and unaffected in all treatments in 1999. Elemental composition of apple leaves for 1999 P, K, S, Ca and Mg (% dry weight)- Unaffected Sodium (ppm dry weight) Increased significantly (25%) for NH+F. Cu, Fe, Ni and Zn (mg/kg dry weight)- Unaffected Manganese (mg/kg dry weight) Increased significantly (55%) for NH+F.	Soil moisture content under apple trees also fluctuated to a similar extent with rainfall and irrigation events and soil moisture was similar for all mulched treatments. Volumetric soil moisture (%) in the soil under mulched apple trees was consistently higher (ranged 32-37%) than that under the unmulched control (ranged 23-32%). Use of total irrigation water per hectare 1997-98 Litres per tree 3042 Mega litres per hectare 2.25 1998-99 Litres per tree 1638 Mega litres per hectare 1.21	

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
WA-BP-2001 Citrus establishment trial (Trial 10) C-Control CSCA2-Compost A @ 2 lt/hole as soil conditioner in the planting hole CSCA5-Compost A @ 5 lt/hole as soil conditioner in the planting hole CSCA10-Compost A @ 10 lt/hole as soil conditioner in the planting hole CSCF2-Compost F @ 2 lt/hole as soil conditioner in the planting hole CSCF5-Compost F @ 5 lt/hole as soil conditioner in the planting hole CSCF10-Compost F @ 10 lt/hole as soil conditioner in the planting hole CMG2-Composted mulch G @ 2 lt to $1m^2$ area around each tree as surface mulch. CMG5-Composted mulch G @ 5 lt to $1m^2$ area around each tree as surface mulch. CMG10-Composted mulch G @ 10 lt to $1m^2$ area around each tree as surface mulch. Raw Polutry Manure-Applied about 30 m^3/ha		Tree growth - Application of mulches increased tree growth although statistically not significant during initial 12 months of tree growth. Average tree growth increase (%)-Increased about 16-34% for all treatments. Highest increase was obtained for highest mulching rate and raw polutry manure.		
WA-BP-2001 Citrus trials (Trial 11) C-Control (no mulch) CMG0.5-Compost G applied 0.5 cm deep to a 1.5 wide strip centred on tree row as surface mulch CMG1-Compost G applied 1 cm deep to a 1.5 wide strip centred on tree row as surface mulch CMG2-Compost G applied 2 cm deep to a 1.5 wide strip centred on tree row as surface mulch		Initial trunk circumference measurements were made in October 1998, however, the trees were subsequently removed and replaced before the next set of measurements could be made.		

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
WA-BP-2001 Avocado establishment trial (Trial 12) 1. C-Control (growers practice) 2. C+CMG5-Control+ Compost G applied 5 cm deep as surface mulch 3. CSCA25-Compost A @ 25 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth 4. CSCA25+CMG5-Treatment 3+ Compost G applied 5 cm deep as surface mulch 5. CSCA50-Compost A @ 50 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth 6. CSCA50+CMG5-Treatment 5+ Compost G applied 5 cm deep as surface mulch 7. CSCA100-Compost A @ 100 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth 8. CSCA100+CMG5-Treatment 7+ Compost G applied 5 cm deep as surface mulch 9. CSCA200-Compost A @ 200 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth 10. CSCA200+CMG5-Treatment 9+ Compost G applied 5 cm deep as surface mulch.		Tree growth increase (%) Treatments had variable rates of soil conditioners ranging from 25 t/ha to 200 t/ha and composted mulch G to the depth of 5 cm. Tree growth after 12 months of treatment increased 30-95%. Highest tree growth was obtained from lowest rate of soil conditioner plus mulch.		

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
WA-BP-2001 Apple establishment trial (Trial 13) Control (no treatment) CSCE50-Composted soil conditioner @ 50 m3/ha applied to a 2 m wide strip centred on planting row rotary hoed to 20 cm depth CSCE50+CMI5-Treatment 2+ Compost I applied as surface mulch to 5 cm depth to a 1 m wide strip after two weeks of planting CMI5-Compost I applied as surface mulch to 5 cm depth to a 1 m wide strip after two weeks of planting		Tree growth– Improved Trunk diameter (mm)- Increased highest (42%) for soil conditioner plus mulch treatment compared to the control. Mulched treatment only increased about 21% tree growth.		
WA-BP-2001 Apple trial post plant apple tree establishment (Trial 14) C-Control (growers practice) C+CSCA30-Control (growers practice)+ Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row CSCA30+CMH2.5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 2.5 cm depth CMH2.5-Compost H applied as surface mulch to 2.5 cm depth CSCA30+CMH5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 5 cm depth CMH5-Compost H applied as surface mulch to 5 cm depth		Tree growth (mm) Trunk diameter (mm)- Increased in 9 months from 20-360% for various treatments. Highest increase was obtained for lowest composted mulch rate. Soil conditioners plus highest rate of mulches and growers composted mulch were not effective.		

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
WA-BP-200, Trial 14 (Contd) CSCA30+CMH7.5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 7.5 cm depth CMH7.5-Compost H applied as surface mulch to 7.5 cm depth CSCA30+GCM5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Growers compost applied as surface mulch to 5 cm depth GCM5-Growers compost applied as surface mulch to 5 cm depth				
SA-JB-1999 Almonds C-Control CM5-Composted mulch applied 5 cm deep as surface mulch CM7.5-Composted mulch applied 7.5 cm deep as surface mulch CM15-Composted mulch applied 15 cm deep as surface mulch AH3-Almond husk applied 3 cm deep as surface mulch.		Growth of young almond trees (0-5 scale rating was used for the vigour of young trees. Increased significantly (30-189%) for mulched treatments compared to control during 25 weeks after mulch application. Tree growth increased with mulching depth and highest increase was obtained for highest mulching depth. Almond husk had little effect on the growth of young trees.	Soil moisture– Almond husk was good in soil moisture conservation. Weed growth- Reduced. CM15 provided complete weed control during summer months. Lower rates of composted mulch also reduced weeds.	
SA-JB-1999 Pears C-Control CM1- Composted mulch applied 1 cm deep as surface mulch CM5- Composted mulch applied 5 cm deep as surface mulch CM15- Composted mulch applied 15 cm deep as surface mulch P1- Pellets of cereal/garden organics applied 1 cm		Pear growth after 90 days of mulch application Shoot extension (cm)-Increased with increasing mulching depth from 41-276%. Highest increase was obtained for highest mulching rate. Pellets were less effective than composted mulch. Trunk diameter 25 cm above the ground (cm)- Increased with mulch 8-12 % Fruit yield- Increased by 45% (DNP). Fruit weight was significantly higher even at lowest mulch rate. Effect of composted mulch and iron chelate on leaf colour- (0=yellow, 5=green) after 120 days of application Green clouration of leaf increased highest for composted mulch and iron chelate while only mulch treatment decreased the green colouration.	Soil moisture mid spring (%)- Increased from 15 to 32%. Highest increase was obtained for highest mulching depth. Pellets were less effective.	

Table 3.2 Summary of performance outcomes of recycled organics products used as surface mulches in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
SA-JB-1999 Cherries Control (no mulch) CM5- Composted mulch applied 5 cm deep as surface mulch CM5+VC2- Composted mulch applied 5 cm deep as surface mulch+ 2 cm vermicompost VC2- Vermicompost applied 2 cm deep as surface mulch		Cherry yield (kg/vine) -Increased highest (20%) in vermicompost + composted mulch treatment. Berry size (weight of 50 cherries)- Slight increase (3-9%). Highest increase for vermicompost + composted mulch treatment Berry size grading according to size <22 mm, 22-24, 24-26, >26 mm (price ranged \$4 - \$7) Value of cherry harvest (\$/tree)-Increased 15-20% compared to control. Highest increase was for vermicompost + composted mulch treatment	Soil moisture (%)- Slight increase (5%) at 0-10 cm soil depth for composted mulch and vermicompost + composted mulch treatments.	
SA-JB-1999 Oranges C-Control CM1- Composted mulch applied 1 cm deep as surface mulch CM5- Composted mulch applied 5 cm deep as surface mulch CM15- Composted mulch applied 15 cm deep as surface mulch PPM5- Paper pellet mulch applied 5 cm deep as surface mulch		Leaf greenness of young orange trees after 6 weeks of mulch application (0=yellow, 3=green) Significant increase (46-59%) in greenness for all composted mulch treatments. Highest mulch application produced most green colouration. Flowering development of young orange trees after 6 weeks of mulch application (0=no flower buds open, 3=all buds open)-Increased 15-63%. Highest flower buds were open for lowest composted mulch rates. Growth of young orange trees after 50 weeks of mulch application- Increasing trend. Average orange weight (g) after 50 weeks of mulch application- Increased 450-515%. Highest increase was obtained for paper pellets and lowest for lowest composted mulch.	Soil moisture (%) Increased Soil moisture (%) at the soil surface under young trees after 6 weeks of mulch application-Increased 550-1200%. Highest increase was obtained for highest composted mulch rate and lowest for paper pellets. Soil moisture (%) at 5 cm soil depth under young trees after 6 weeks of mulch application-Increased 4-80%. Highest increase was obtained for highest composted mulch rate and lowest for paper pellets. Soil moisture (%) at 10 cm soil depth under young trees after 6 weeks of mulch application-Increased for composted mulched treatments only and highest increase was found for highest mulching rate.	

3.3 Discussion of results

3.3.1 Reduced risk of crop failure

The main reasons for failure of any fruit crop is due to incidence of pest and diseases, frost damage caused in cool climates and crop stress due to hot climates and low soil moisture availability in non-irrigated conditions.

3.3.1.1 Suppression of diseases

None of the field trials reviewed for this volume have monitored suppression or incidence of fruit crops pest and diseases associated with the application of RO products as surface mulches.

The literature review on application of RO products to soil have reported the ability of composted organic materials to suppress soil borne plant diseases caused by pathogenic microbes (NSW Agriculture, 2000). Similar findings have been reported by NSW Agriculture (2002b) while reviewing international literature on soil carbon sequestration utilizing RO products.

The phenomena for disease suppression are complex and a range of different mechanisms are responsible such as production of antibiotics during the maturation process; increased competition for nutrients and carbon resources through higher microbial activity resulting from application RO products; or induced systematic resistance in the plants (Hointink and Fahy, 1986; Wong, 2001).

The ability of RO products to suppress diseases is variable and the suppression is dependent upon factors such as temperature, moisture, pH and maturity of RO products (de Ceuster and Hointink, 1999; Wong, 2001). To date it is not known which RO products (e.g mature or immature) will show disease suppressive properties, and it is particularly difficult when these products are produced from diverse raw materials (Biala, 2000). Hoitink and Grebus (1994) have found immature composts served as a food source for pathogens, while excessively stabilised organic matter did not support the activity of biocontrol agenets. Some researchers have produced highly suppressive RO products by adding microbial antagonists such as *Trichoderma*, *Flavobacterium* and *Enterobacter* species (Hointink and Boehm,1999).

Peter Fahy and his team studying disease suppression against Pythium and Rhizoctonia diseases in surveys of potting mixes and potting mix components over time involving a range of composters and nursieries have defined the standards to maintain consistent disease suppression (Fahy, 1997) The important characteristics of potting mixes responsible for disease suppression identified in the surveys were electrical conductivity (EC), pH, nitrogen drawdown index (NDI), high microbial activity and air filled porosity (Fahy, 1996 internet publication http://www.ngia.com.au/np/np97_3.html).

Pests and diseases cause significant damage to agriculture worldwide every year. Production of RO products that reduce incidence of pests and diseases will provide two fold incentive to orchardists to include RO products in farming practices. Firstly use of disease suppressive RO products reduce risk of crop failure and economic loss of production. Secondly reduced use of farm chemicals to prevent diseases result in reduced production costs associated with pest management, whilst at the same time fruits produced with reduced farm chemicals has the potential to attract a higher price.

Future trials should monitor the incidence of pest and diseases, particularly in relation to the potential for reduced production and management inputs, and for potential variation in yield and quality.

3.3.1.2 Crop stress

Please note that no field trial reviewed for this report has monitored effect of RO application as surface mulch on reduced risk to crop from hot weather or water stress.

Water stress affects the fruit crops in similar way as discussed for vinegrapes (Volume 2, Section 3.3.1.2) and it varies depending on the crop's stage of development. Dry conditions largely affects overall development of canopy and fruit tree such as irregular budburst, short shoots, fewer flowers and inhibit root growth during early stages of tree development (Coombe and Dry, 1992). The effect of water stress lessens when fruits enter their lag phase and shoot growth slows, after which the main effect of severe stress can be delay in fruit ripening (Coombe and Dry, 1992). These water stress conditions apply to orchards which are not irrigated and/or where irrigation water, for various reasons, may not be available during critical fruit tree growth stages .

Crop stress during crop and fruit development stages has the potential to reduce fruit production and quality, although scientific trials would be required to establish a relationship between RO product application/s and improved production due to reduced crop stress. The potential reduction in crop stress as a result of mulch application would provide growers with an incentive to include RO products in farming practices.

3.3.1.3 Frost risk and delayed bud burst

Please note that no field trial reviewed for this volume has monitored effect of RO application as surface mulch on frost risk and delayed bud burst.

Freeze injury is one of the main limiting factors to crop production and distribution of horticultural crops in cooler climates, and is considered to account for greater losses of fruits than any other environmental and biological factors (Rodrigo, 2000). In temperate climates, important damage to deciduous fruit trees can be produced in buds, flowers and developing fruits after dormancy, and losses due to frost during bloom are usually more important than those due to low winter temperatures (Rodrigo, 2000).

Discussions with Roy Menzies, Research Horticulturist with NSW Agriculture opioned that bare soil absorbs heat during day time and radiates it back overnight keeping air temperatures around tree canopy slightly higher hence reduces risk of frost damage in cooler climates. This phenomena works in opposite way when a mulch layer is applied under fruit trees. Mulch prevents heat absorption during day time keeping soil temperatures few degrees (2-3^{o}C) lower under mulched trees. Over night under trees, mulch does not radiate heat back to canopy and therefore has the potential to increase frost risk however, as cover crops/living mulch is common practice beneath orchard trees, this issue may be overarfted, particularly for evergreen trees with dense canopies.

No information is available as to whether mulch application causes increased frost risk and delayed bud burst of fruit trees. Sandra Hardy, NSW Agriculture advised that generally cover crops are mowed low for winter season in fruit crops to reduce frosk risk and same principle may apply to mulch depth as well.

3.3.1.4 Conclusions: Reduced risk of crop failure

None of the field trials monitored the affect of RO application as surface mulches on incidence of pest and diseases, frost damage in cold climate and crop stress from hot weather or moisture stress.

3.3.2 Increased revenue

The application of mulches can potentially increase the revenue of fruit and orchard production enterprise through increased yield, produce quality and through improved management of time to market.

3.3.2.1 Fruit yield

Yield of fruit trees is determined by the overall growth of fruit trees which is controlled by many factors such as fruit type and variety, environmental conditions and management practices. The components of fruit trees that determine its yield are butt circumference (stem diameter), and trunk cross sectional area (TCSA) (NSW Agriculture, 2000). Butt circumference is an accurate measure of tree growth while trunk cross sectional area (TCSA) determines "tree efficiency" which provides a useful guide to the potential cropping ability of a tree (NSW Agriculture, 2000). Tree efficiency is the weight of fruit produced in kg per cm^2 of butt area (NSW Agriculture, 2000). Butt circumference increases with the age of trees regardless of tree species and butt increment is the increase in butt circumference of a tree per annum and indicates the annual growth of the tree (NSW Agriculture, 2000).

In a natural state fruit trees have capacity to produce certain growth of vegetative parts (branches, shoots, and leaves) and reproductive parts (fruits). Commercial orchardists remove some vegetative growth through the technique called pruning to increase the production of fruits. Pruning of fruit trees can be carried out in winter as well as in summer. Winter pruning is carried out to remove the old growth and to thin new growth branches, while summer pruning reduces the competition of vegetative growth with developing fruit (NSW Agriculture, 2000). Summer pruning allows sunlight to enter into the canopy, fruit colour development and growth of new flower buds for the next season (NSW Agriculture, 2000). Some management practices, such as application of N in excess of the crop's requirement, enhance vegetative growth potential at the expense of reduced crop yield and quality.

Composted mulches produced from garden organics (*Green Life*) and blend of garden organics and biosolids (*Nitrohumus*) used as surface mulches under deciduous fruit trees (peaches and apples) at Bathurst in NSW have found significant increase (20-30%) in lateral shoots and pruning weights of peach trees in winter in the first year of mulch application (NSW Agriculture, 2000). Summer pruning weights of peaches also increased significantly for all mulched treatments. This increase was 40-70% in the first year and 30-50% in the second year of application. The *Green Life* treatment produced the highest pruning weights. Mulched trees extended vegetative growth into autumn, therefore trees did not enter into dormancy, which can be a problem for cooler climates (NSW Agriculture, 2000). Pruning weight of apple trees did not change with mulch application in first and second year after mulch application suggesting different fruit types exhibit varying response to mulch application. This study has found consistently higher soil moisture under mulched trees than unmulched trees. This increase in soil moisture in addition to irrigation might have increased vigour of peach trees compared to apple trees, as the water requirement of peach trees is slightly lower than apples trees. This highlights the importance of selecting appropriate mulch application rates and timing specific to different fruit types.

The studies with RO products across various parts of the world have suggested that crop yields increase with increased RO application rates but responses are variable (NSW Agriculture, 2002b). Most trials that measured tree growth and yield of various fruit trees reviewed for this report suggest that tree growth and fruit yield increased with various mulched treatments compared to unmulched treatments (Wilkinson, 2000; Paulin, 2001; Buckerfield, 1999).

Application of 5 and 10 cm deep composted mulch to 10 years old **cherries** (Summit and Stella varieties) in Victoria have found significant increase (84-104%) of cherry yields of Summit variety second year after mulch application (Wilkinson, 2000). Lower rates of mulch had higher yields. Stella variety also increased yield but was not statistically significant. Use of 10 cm deep *greenchip* composted mulch in another trial have also reported better stem growth for mulched **cherry** trees compared to um-mulched trees in Victoria (Greenchip Recycling Pty Ltd, 1999).

Addition of 5 cm deep composted mulch, 2 cm layer of vermicompost (worm worked cattle manure) and 2 cm layer of vermicompost + 5 cm deep composted mulch as surface mulch to **cherry** trees in South Australia increased cherry yield up to 20% compared to control (no mulch) (Buckerfield, 1999). Combination of 2 cm vermicompost + 5 cm deep composted mulch achieved highest yields. There was a slight increase in berry size (berries were graded according to the size) that resulted into increase in harvest value of cherries by 15-20% compared to control (no mulch). Highest increase was for vermicompost+composted mulch treatment (Buckerfield, 1999).

Growth of **peach** trees (increment in butt circumference) increased significantly 40-60% a year after mulch application, and decreased though not significantly in second year for all mulched treatments (*Green Life* without fertiliser and *Nitrohumus* with and without fertilisers applied as a 10 cm deep surface mulch) (NSW Agriculture, 2000). Butt area, fruit yield and tree efficiency of peach trees were unaffected during both years (1998 & 1999). Although total peach numbers and yield did not change with mulch application, the number of large size peaches for all mulched treatments increased significantly (85-117%) in 1998 and increase was not statistically significant in 1999. Large size fruits constituted about 20% of total fruits which could increase marketability of peaches and profitability for growers. In the case of **apples** in the same trial, application of mulch did not have any effect on butt circumference, butt area, and efficiency of an apple tree, fruit yield, total number of fruits and average weight of an apple fruit in 1998 and 1999. The exception being that total number of apple fruits per plot decreased significantly (19%) for *Nitrohumus*+fertilisers treatment suggesting varying response of different fruit trees to mulch application. It should be pointed out that this trial was overlaid on biosolids trial site which was established in 1992. The plots used for compost trial had been treated in 1992 with products such as N-Viro Soil at the rate of 3.75 & 7.5 dry t ha^{-1} and dewatered biosolids @ 10 & 30 dry t ha^{-1}.

Tree growth i.e increment in trunk diameter increased of establishing as well as established **apple** trees in Western Australian field trials. Highest increase in growth (42%) of establishing tree was produced for soil conditioner plus mulch treatment compared to control (Trial 13, Paulin, 2001). Only mulch treatment increased 21% tree growth (Trial 13, Paulin, 2001). Composted mulch in this case was produced from timber residuals of timber processing and clearing and was applied as a 5 cm deep mulch layer.

The growth of established **apple** trees also increased from 20 to 360% for various treatments. Lowest rate of composted mulch H (mulch application depth varied from 2.5, 5 and 7.5 cm) produced highest tree growth (Trial 14, Paulin, 2001). In this case mulch was produced from land clearing based plant materials. Highest rate of soil conditioners plus grower's composted mulch were not effective. Growers composted mulch was produced from chipped apple tree wood and chicken manure. The results of increased tree growth compared to control suggest the potential to increase fruit yield.

Application of composted mulch at 1, 5 and 15 cm depths increased shoot extension (41-276%) and trunk diameter 25 cm above ground (8-12%) of **pear** trees compared to control (Buckerfield, 1999). Shoot extension increased with increasing depth of mulch and highest depth of mulch produced highest increase in shoot extension. Fruit yield was reported increased 45%, but the yield data was not provided. It has been reported that fruit yield was significantly higher even for lowest mulch rate (Buckerfield, 1999). Pellets of cereal/garden organics applied as 1 cm surface mulch layer in this trial were less effective than composted mulch.

Similar results were obtained for **citrus fruits**. Application of composted mulch at 1, 5 and 15 cm depths significantly increased greeness (46-59%) of young **orange** trees and number of opened flower buds (15-63%) after six weeks of mulch application (Buckerfield, 1999). Paper pellets applied as 5 cm deep mulch produced highest increase in fruit weight in this trial. Average weight of orange fruit increased significantly 450-515% after 50 weeks application of composted mulch. Highest rate of composted mulch produced most green clouration of leaves and lowest rate of mulch produced highest number of opened flower buds.

Western Australian trials with **citrus fruits** using a range of combinations of composted soil conditioners plus mulches applied at various rates to establihing and established **Navel oranges** have reported increased tree growth 16-34% compared to control (Trial 10, Paulin, 2001). Highest increase was obtained for highest rate of mulch (Composted mulch G applied @ 10 litres to 1 m^2 area around each tree) and raw polutry manure (30 m^3 ha^{-1}). The growth of established **Navel oranges** was not measured because trees were removed and replaced before the next set of measurments (Trial 11, Paulin, 2001).

Growth of **avocado** trees has also increased twelve months after application of varying rates of soil conditioners (ranging from 25 to 200 t ha^{-1}) applied at the planting time plus 5 cm deep composted mulch G. Tree growth increased 30-95% and highest growth was obtained for lowest soil conditioner rate (25 t ha^{-1}) plus composted mulch treatment compared to control (grower's practice).

Application of composted mulch produced from garden organics at the rates of 5, 7.5, 15 and alomond husk to 3 cm depths increased growth of **almond** trees significantly (30-189%) compared to control (no mulch) during 25 weeks after mulch application (Buckerfield, 1999). Highest tree growth was produced for highest mulching depth. Almond husk had little effect on growth of young trees (Buckerfield, 1999).

From the data available there appears to be a clear pattern to increase tree growth with mulch application. Application of composted mulches have increased tree growth of various fruit trees such as apples, pears, oranges, pecahes, cherries, almonds, and avocados compared to control (no mulch). Increase in tree growth does not necessarily mean increased fruit yield.

Fruit yield mesaured in few field trials (3 trials) have found varying results and again does not appear to be any clear pattern of yield increase via mulch application. Please note tree growth and fruit yield data in these trials were mainly obtained from one or two season/s harvest, suggesting long term and statistically significant data is required to demonstrate this performance benefit of mulches in orchard production sytems.

Two field trials (2 trials) that have graded fruits according to fruit size have found increased number of large fruit size (cherries and peaches). Large fruit size attracts higher price in the market hence profit to growers. This incentive can be used to attract growers to include RO products in their farm management practices. More, long term and statistically significant data is required to demonstrate this performance benefit across various fruit types.

South Australian and Western Australian trials that have reported slight to significant increases in tree growth and/or fruit yield did not provide baseline soil quality data/climatic data. Documentation of soil characteristics and climatic data is important for developing a clearer understanding of the relationship between mulch application and yield.

3.3.2.2 Fruit quality

The investigations using RO products in orchard production carried out across various parts of the world and reviewed by NSW Agriculture (2002b) have not only shown positive effects on plant growth but also on fruit quality and again results were variable. The fruit quality parameters vary for different fruit crops and are important for taste, processing and storage.

General fruit quality parameters used for majority of fruit crops include the levels of total soluble solids or Brix which is a measure of sugar content, juice pH and juice acidity. There are other fruit quality parameters which may vary for different fruit types also important for fruit quality include firmness, skin colouration, background skin colouration, concentration of starch, etc.

The effects of RO products on fruit quality have been studied in only one trial with apples and peaches for two years after mulch application and have found variable results (NSW Agriculture, 2000). Most **peach quality** parameters measured (brix, firmness, red skin colouration, background skin clouration, green calyx) did not change with mulch application except Brix and green calyx. The percentage of Brix or total soluble solids increased significantly (6%) for first harvest fruit (1998) for *Nitrohumus* (with or without fertiliser) treatments compared to control, and was unaffected for second harvest fruit (1999) for all mulched treatments. This increase was statistically significant but not of commercial significance. Mulched fruits developed an unusual disorder of having green non ripened area on the calyx end of the fruit. This area remained green even after the remainder of the peach was fully coloured. The percentage of green calyx area was significantly higher (1000%) for first harvest fruit and for all mulched treatments compared to control. Although the percentage of green calyx area decreased for second harvest fruit, it was still significantly higher (350-500%) compared to control. Excess N was considered responsible for such disorder. Nitrogen levels in both leaves (3.8%) and fruits (1.5%) were higher in all mulched treatments but not excessive (optimum levels for leaves are 2.8-3.0%). It has been reported that possibly N levels were higher early in the season and subsequent growth had diluted the concentrations by the time of measurements were taken. The calculations of amount of N added via compost and its utilisation over years have shown that excess N was added through 10 cm deep mulch. The levels of N in leaves and fruits in second season were same for all mulched treatments but fruit green calyx area was still significantly higher suggesting that apart from N concentration other factors may be responsible for the formation of green calyx such as moisture, climate and remobilisation of stored N. The concentration of other major and trace elements in fruits did not change with mulch application during both years of monitoring except concentration of Mn which increased significantly for *Nitrohumus* treatments in 1998. The concentrations of N, P, K and Fe increased and Ca and Mg decreased for all compost treatments compared to control.

The quality of **apples** did not change for first harvest, however for second harvest acidity and total soluble solids of fruits increased for all mulched treatments and for the *Nitrohumus* without fertiliser treatment. There was no impact of mulch application on storage properties. Generally, acidity of apples decreases and sugar content increases during storage (NSW Agriculture, 2000). This study found similar results that acidity decreased and total soluble solids increased over time. The concentrations of total major and trace elements in apples did not change with mulch application except for S and Mg which increased significantly for *Green Life* treatment compared to control in 1998 only. The levels of Mg and S in both types of mulches (*Green Life* and *Nitrohumus*) were same but increased levels in fruits were reported only in *Green Life* treatment suggesting that Mg and S may be readily and immediately available from *Green Life* compared to *Nitrohumus* (NSW Agriculture, 2000)

The fruit quality data available on two fruit types (apples and peaches) from one trial suggest that different fruit crops have varying effect on fruit quality as a result of mulch application, suggesting additional long term and statistically significant data for different fruit types is required to demonstrate that mulch applications do not deteriorate fruit quality. Formation of green calyx on peach fruits again illustrates the importance of appropriate mulch application rate i.e depth and width, timing of application integrating nutrient budgeting and consideration of the best way to integrate RO products use with specific orchard management practices.

3.3.2.3 Time to market

No field trial reviewed for this report included the effect of RO application on growth of trees and maturity time of fruits.

The growth and maturity time of fruits is of interest to growers. If application of surface mulches to fruit crops demonstrates faster crop growth or early ripening of fruit, it provides a significant incentive to growers to adopt RO products as a part of farm management practices.

3.3.2.4 Conclusions: Increased revenue

Most field trials with fruit crops measured tree growth only. Increased tree growth does not necessarily equate to increase in fruit yields. Few trials measured fruit yield and quality parameters and these trials found variable results.

Tree growth and fruit yield and quality data were measured from one or two season harvest/s. Long term and statistically significant data is required to demonstrate reliable performance benefits.

No trial studied the affects of surface mulches on time of growth stages and fruit maturity.

Application of excess N via mulch application may reduce quality and/or yield of some fruits.

3.3.3 Reduced costs in farm management

The research studying beneficial effects of using RO products in intensive agriculture has consistently found that the RO application reduces weed growth, provides nutrients for plant growth and increases soil moisture (NSW, 2000). These beneficial effects of RO products to orchard production have the potential to reduce the production costs of a farm by reducing use of irrigation water, application of chemical fertilizers and farm chemicals.

3.3.3.1 Weed suppression

One of the primary reasons for using mulches is their effectiveness in suppressing weeds and this practice has been in use even before industrialisation. One of the main reasons for weed suppression is the physical presence of a mulch layer which inhibits germination of weed seeds. Germination inhibition increases as the mulch layer increases or the burial depth of weed seeds increases. Other reasons responsible for weed suppression are the action of phytotoxic compounds (particularly where immature “compost” products are applied), higher concentrations of carbon dioxide and temperature resulting from degradation of organic matter present in immature RO products.

International literature reviewed on beneficial effects of RO products have reported that weed growth can be effectively inhibited by the application of mulch to the soil surface (NSW Agriculture, 2000). This review reported that coarse mulches are usually more effective than fine mulches for weed control, and that the weed suppression effect of composted mulches usually lasts longer than standard growers practice of straw (NSW Agriculture, 2000). This performance benefit has been confirmed/demonstrated in all Australian field trials which have monitored weed suppression in orchard production.

The field trials carried out in Victoria, New South Wales and South Australia have studied suppression of weed growth arising as a result of application of RO products as surface mulch and found significant reduction in weed growth ranging from 70 to 100% compared to control (no compost) irrespective of fruit type, variety and location. Thick mulches provided higher weed suppression (Wilkinson, 2000; Buckerfield, 1999). Suppression of grass weeds was highly significant 88-99% (NSW Agriculture, 2000). The Western Australian trials did not measure weed suppression.

Generally it is considered that deeper mulches are more effective in weed suppression as well as reducing water evaporation from the soil surface but excessively thick application of mulches has the potential to cause undesirable effects. The maximum thickness at which a composted mulch can be applied depends also upon the particle size, maturity, and nutrient content of the mulch. Coarse mulches which have had fines removed via screeening can be applied at a thicker application rate without causing negative impacts, there by increasing the longevity of the moisture retention and weed suppresion benefits.

Application of mulch should take into account the nutrient content of the mulch, and the availability of these nutrients over time. Nutrients added through mulch applications should not exceed nutrient requirements of fruit trees as this may reduce fruit yield and quality. Therefore selection of composted mulch that can be applied at a thick enough rate to achieve effective moisture retention and weed suppression for the longest duration without causing negative impacts is recommended, this will require selection of product that has suitable nutrient characteristics such that, at the required rate of application excess nutrients are not applied. It is therefore important to consider the longevity or reapplication time of mulches, particle size, compost maturity and nutrient content to avoid potential negative impacts that can arise from inappropriate product use such as:

- Decreased fruit yield,
- Decreased earthworm activity,
- Inhibit water penetration after rainfall,
- May provide an ideal microenvironment for diseases,
- Cause water logging of heavy soils with restricted drainage,
- May exceed the nutrient requirements of fruit trees,
- May restrict further fertilizer side dressings, and
- N may be lost from the soil by denitrification if the soil is too wet beneath the mulch.

The results of field trials reviewed for this volume demonstrated weed suppressive performance of RO products used as surface mulch, which have great implications in reducing herbicide use in orchard production hence reducing production costs associated with purcahse and application of chemicals. Specific herbicides targetted for specific weed category (e.g for broad leaved weeds) would provide more effective weed control. Most attractive incentive for growers will be to claim higher price for the produce grown with reduced production inputs and intervention, such as the purchase and application of chemicals or without chemicals.

Future investigations should include the effect of composted mulches on weed suppression and diversity of weed species over a longer period of time and the effect of mulches on weed suppression with and without prior application of herbicides.

3.3.3.2 Water usage

An important function of appropriate mulch application, as referred above, is to reduce water evaporation from soil surface. This has the potential to reduce irrigation water usage for irrigated orchards and conserve soil moisture under non-irrigated and/or dryland conditions depending upon mulch characteristics, soil types and irrigation system design and management.

Water usage can also be reduced if application of RO products increases soil's ability to retain more water (relationship between the soil-water content and soil-matric potential) or in other words increases the amount of soil moisture that is available for extraction by plants called as plant available water (PAW). Literature reviewed on soil carbon sequestration using RO products by NSW Agriculture (2002b) has reported that application of RO products increases soil moisture content (gravimetric or volumetric water content present in the soil). However, whilst the soil moisture content or soil water retention can increase in RO amended soils (i.e. incorporation of soil conditioner), but the soil moisture available for plant use is commonly not measured or in some studies as reported in NSW Agriculture (2002b) literature review report remains unchanged. Plant available water is the soil moisture content retained at soil-matric potential between field capacity and permanent wilting point. It is the increase in PAW, which provides opportunity and quantification in reduction in irrigation water requirements. Unfortunately, on the basis of available research, no significant performance benefits can be claimed in relation to PAW or the associated potential for reduced irrigation requirements.

The mechanisms involved to increase retention of soil water include improved porosity and pore size distribution; an increase in the relative number of storage pores, and the colloidal nature and increased surface area of the RO amended soil (NSW Agriculture, 2002b). The changes in soil physical conditions as discussed above can occur after integration of RO products with the soil, which takes a long time particularly in case of mulch applications. Most of trials that have measured soil moisture reported increased soil moisture in the short term after application of mulches, but none of these trials have evaluated the relationship between increased soil moisture and plant available water.

Field trials in Victoria, New South Wales and South Australia that measured soil moisture reported increase in percentage of soil moisture in mulched treatments compared to control. Application of 10 cm deep composted mulch under macadamia trees produced from macadamia husk and chicken manure on Ferrosol soil of NSW North Coast increased water holding capacity of the soil by 50% at 0-2 cm soil depth after 4 months of compost application. However after 8 months of mulch application, water holding capacity of the soil was unaffected. Water holding capacity was also unaffected at 2-10 cm soil depth after 4, 8 and 12 months of application (Cox, 2002 a & b).

Soil moisture of yellow podsolic duplex soils of NSW Central-West was consistently higher (5-10%) under mulched peach and apple trees throughout trial period (two years), but soil moisture available for extraction by plants (PAW) measured two years after mulch application was reported to be unchanged (NSW Agriculture, 2000). The total amount of irrigation water used in first and second year after composted mulch application under peach trees was 3.31 and 2.81 ML ha^{-1} and under apple trees was 2.25 and 1.21 ML ha^{-1} (NSW Agriculture, 2000). A typical (unmulched) apple and peach orchard on the tablelands use up to 4-5 ML ha^{-1} in an average season when regular irrigation is required (NSW Agriculture, 2000). These results suggest that mulched treatments substantially lowered water usage per hectare than typical requirements of 4-5 ML ha^{-1}. However water usage for unmulched (control) treatments for comparison was not provided in the report and/or not recorded. Therefore these results are inconclusive. The reduction in irrigation water was not necessarily the result of mulch application, as reduction in irrigation water could have been the result of specific peculiarities of the trial site and/or variant climatic conditions during these two years (such as rainfall, temperature, wind, etc.). Rainfall data, in the report, has been provided for the first year of irrigation only (i.e. 1997-98).

Soil texture plays an important role in soil moisture retention. The moisture retention potential of sandy soils is generally considered low compared to clayey soils therefore knowledge (and reporting) of soil texture is crucial for the interpretation of soil moisture retention results. Most reports did not provide information on soil texture.

Deeper mulches are considered more effective in increasing soil moisture, as with weed suppression. However, thicker application of unsuitable mulches may have adverse effects on fruit yield and quality. Optimum mulching depth that provides maximum soil moisture increase across multiple growing season without causing any deleterious effect on fruit quality or quantity needs to be selected, with regard to the requirements for each fruit crop and environmental conditions (as discussed in Section 3.3.3.1).

The results of field trials that monitored soil moisture have reported increased soil moisture and reduced usage of irrigation water (based on one trial monitored for two years) as a result of mulch application. However, PAW was found unchanged in the only trial that did reported reduced irrigation.

The most likely reason for increase in soil moisture after application of mulches is the reduction in evaporative losses of water from the soil surface than improvement in soil physical conditions (i.e. soil porosity and pore size distribution) as discussed in Volume 2- Viticulture (ROU, 2003b). In the case of grapevines (ROU, 2003b), it was revealed that mulch can potentially retain a proportion of water from irrigation and/or rainfall (particularly significant in the instance of light rainfall events) and the shallow roots of vines may potentially penetrate into the mulch layer to attain moisture. This needs further investigations for fruit trees and orchard production. It may therefore be an important consideration, particularly in relation to dryland orchards, to select mulches with minimum moisture absorption potential.

Information on the method of soil moisture measurement and at what soil depths measurements were taken is critical for interpretation of results. It is the increase in PAW that is important in terms irrigation water usage and savings. The relationship between increase in soil water content and plant water available has not been characterised therefore needs to be evaluated in future research programs. This information is critical for accurate interpretation of results in terms of irrigation water savings.

Documentation and quantification of actual irrigation water applied (in properly managed irrigation systems) based on irrigation scheduling that maintains equivalent soil moisture for mulched and un-mulched treatments will provide actual irrigation water savings. The quantification of potential irrigation water savings in properly managed irrigation systems is likely to be of key interest to growers in terms of cost-benefit and needs to be investigated. Growers currently have tremendous and increasing pressure to reduce irrigation water as a result of implementation of water reforms in NSW and rapidly increasing costs of irrigation water. With the introduction of water reforms in NSW, growers are increasingly paying for water extraction on volumetric basis.

Irrigation water savings from irrigation water usage of mulched and unmulched treatments under properly managed irrigation systems needs to be calculated. Proper soil moisture retention characteristics for varying mulch rates and soil texture classes over long term are necessary to determine the irrigation water savings.

3.3.3.3 Fertiliser application

None of the field trials reviewed for this volume have measured release and availability of nutrients from the application of RO products.

Recyled organics products contain nutrients such as N, P, potassium (K), calcium (Ca) and magnesium (Mg) and micronutrients in higher concentrations than agricultural soils, and when applied to the soil these nutrients are released over time becoming available for plant use, depending upon the nutrient content and maturity of mulch products, and on environmental conditions. Therefore RO products can be used to replace chemical fertilisers either fully or partially.

It should be noted that nutrient requirements of most fruit crops is relatively low. Application of RO products as surface mulches that supply excess nutrients than the requirements of fruit crops has the potential to increase vegetative growth potentially at the expense of reduced fruit yield and quality. Therefore the nutrient requirements of fruit crops should be taken into account when RO products are used in fruit and orchard production (NSW Agriculture, 2000) via nutrient budgeting. Nitrogen, P and K are three major elements that are required in higher amounts for growth of most plants. Nitrogen makes up about 1-2%, phosphorus makes about 0.1 to 0.3% and potassium makes up to 3% of the dry matter yield of most fruit crops (Biala, 2000).

When RO products, or RO products in combination with fertilisers are applied at rates that supply excess N, it may have adverse effects on fruit yield and quality (NSW Agriculture, 2002b). Firstly, excess N may increase vegetative growth that could have adverse effect on the productivity of fruit crops. Secondly, the higher N levels in the soil have the potential to leach from the soil particularly in sandy soils, which have low nutrient holding capacity. Nutrients requirements of different fruit crops vary and are mainly determined by the yield and variety of a crop.

Literature reviewed on use of RO products in viticulture by Biala (2000) has reported most or a high proportion of K, Ca and Mg present in RO products become available for plant use immediately (within short time period), and the small remaining portion over the subsequent 4-5 years (Biala, 2000). About 20% of P in RO products is in the mineral form, which becomes available immediately while the remainder is in the organic form and is available to plants as a result of mineralisation of RO products (Biala, 2000). Virtually all K applied with RO products can be utilised by plants within short time (Biala, 2000).

The situation with N is different. More than 95% N present in RO products is in organic form which becomes available for plant use after mineralisation. It is considered that about 10-20% organic N mineralises each year over 4-5 years and the major part of this becomes available for plant use (Biala, 2000), whist a small proportion is lost through different processes such as volatilisation, leaching, denitrification and temporary loss via immobilisation. Approximate availability of nutrients to plants from composted products based on overseas studies (mainly European) has been provided in Table 3.3.

Table 3.3 Approximate utilisation of nutrients from composted products over time (Source: Biala, 2000).

Nutrient availability	N (%)	P (%)	K (%)
Ist Year	15	40	80
2nd Year	20	40	20
3rd Year	10	20	-
Total over 3-5 years	40-50	100	100

The rate at which RO products are mineralized and nutrients are released depends on the nutrient content and maturity of RO products, as well as environmental conditions. The knowledge of nutrient availability from various RO products during the growth of fruit crops and over a longer time period is important to calculate the RO application rates that would maximise the fertiliser value of the mulch over the application life, but not supply excess nutrients, which may have a negative effect on fruit production and cause negative environmental impacts.

Data on release and availability of nutrients over multiple growing seasons from the application of RO products on different soil types and climatic conditions is required. This will help to calculate RO application rates considering mineralisation of RO products and crops nutrient requirements.

3.3.3.4 Conclusions: Reduced costs in farm management

The result of Australian trials with fruit crops have demonstrated that mulches can significantly reduce growth of weeds and increase soil moisture.

Deeper mulches are more effective in weed suppression and soil moisture retention but may exceed nutrient requirements of fruit crops.

Selection of optimum mulching depths that provide maximum weed suppression, soil moisture retention over a longer period of time without exceeding nutrient requirements of fruit crops should be identified.

Weed suppressive performance of mulches decreases over time (within 1 year), while soil moisture retaining ability can continue for perhaps 3-5 years therefore mulch longevity and reapplication time of mulches should consider these issues for realising maximum cost benefit advantage to growers, and therefore maximising grower affordability.

3.3.4 Increased farm capital value

3.3.4.1 Introduction

Agricultural activities, particularly cultivation of soil reduces levels of soil organic matter (SOM). It is estimated that about 80% of Australian soils have lost up to 50% of the total soil organic carbon (SOC) in the top 20 cm of soil profile (Australian Greenhouse Office, 2000). By world standards, Australian soils have low SOC and in 1983 it was estimated that 75% of Australian soils have <1% SOC in their surface horizons (Spain et al., 1983), this situation can only have continued to declined since.

Soil productivity determines long term production of crops hence reflects on farm capital value. Organic carbon is a significant component of the RO products, and when added to the soil, over time will increase SOM and restore and enhance soil health. Soil organic matter is a major determinant of biological, physical and chemical fertility of the soil, and consequently soil productivity (Charman and Roper, 1991).

3.3.4.2 Soil biology

Recyled organics products are not only a source of nutrients and organic matter, when added to the soil they influence the growth of microorganisms including the size, biodiversity and activity of the microbial population that plays crucial role in soil health and sustainability (NSW Agriculture, 2002b).

Two (2) field trials out of total 14 trials reviewed for this volume have studied the effects of RO products application as surface mulches on soil biology. Application of different types of composted mulches have shown increased soil enzyme amd microbial activity. The soil enzymes and micobial activity have been found higher in the topsoil compared to lower soil layers after addition of composted mulches, whilst enzymes and microbial activity of compost itself decreased 48-60% after 3-4 months onwards (Cox, 2001 and Cox, 2002 a & b).

Application of 10 cm deep composted mulch under macadamia trees in NSW North Coast increased soil enzyme activity by 6-15% initially, but decreased slowly 4 months after application at 0-2 cm and 2-10 cm soil depths (Cox, 2002 a & b). Composted mulch was produced from macadamia husk and chicken manure at the farm in a windrow over two months period. Dynamics of soil microbial activity varied at soil depths and over time. There was hardly any change in soil microbial activity in the begining at both soil depths (0-2 and 2-10 cm) between mulched and un-mulched-control treatments. Soil microbial activity measured in the mulched treatment increased 45% after 4 months of application and 50% after 8 months of application compared to control-no mulch treatment at 0-2 cm soil depth. However, soil microbial activity when measured after 12 months of mulch application waws same as that of control (no-mulch) at 0-2 cm soil depth. At 2-10 cm soil depth, soil microbial activity increased by 14% in mulched compared to control-un-mulched treatment. After 8 months of mulch application, soil microbial activity decreased by 38% in mulched treatments than in control-unmulched treatment. Again soil microbial activity measurements of mulched and un-mulched treatments taken 12 months after mulch application was same at 2-10 cm soil depth (Cox, 2002 a & b).

In another experiment, soil microbial activity was measured after application of 10 cm deep two different composted mulches (one made from macadamia husk and another from garden organics). After three months of mulch application, soil microbial activity at 0-2 cm soil depth increrased by 94% (for macadamia husk mulch) and 22% (for garden organics mulch) compared to control-nomulch. At 2-10 cm soil depth, soil microbial activity after 3 months of mulch was 35-40% higher for both composted mulches than control-no mulch. There was no change in soil microbial activity in the beginning at 0-2 cm soil depth but have been reported increased 15-20% for both mulch treatments compared to control-no mulch at 2-10 cm layer which seems quiet strange.

Application of RO products with higher enzyme and microbial activity has shown increased soil enzyme and microbial activity. Mulches can create environmental conditions that favour increased biological activity. Long term and statistically significant data is required to demonstrate that application of mulches enhances overall soil health through improvement in soil biology.

3.3.4.3 Soil physical properties

Inappropriate soil management practices in tillage based agricultural production systems have adversely affected the soil structure. Soil structure is the architecture of the soil, describing the size, shape and arrangements of soil particles or aggregates and the voids between them (Chan, 2001). Soil physical properties such as bulk density and soil porosity and hydraulic properties, can be linked to one of the most fundamental properties of the soil, that being soil structure (NSW Agriculture, 2002b). A soil with strong structure that has stable aggregates exhibits desirable values for bulk density and porosity for a given type of soil, and provides adequate soil aeration and available water (NSW Agriculture, 2002b). A well structured soil also have no surface crusting, and will exhibit infiltration and hydraulic conductivity properties that minimise runoff and retain water for plant use (NSW Agriculture, 2002b). These characteristics define the physical environment of the soil ecosystem and are critical for a healthy soil and for sustainable agriculture (NSW Agriculture, 2002b).

Benefits of RO products listed in a literature review report on soil carbon sequestration by NSW Agriculture (2002b) explains that the addition of RO products increases organic matter of the soil which in turn improves soil aggregate stability and physical parameters such as bulk density and porosity, water holding capacity and infiltration. The initial effects of RO products on the soil properties would primarily be restricted to the soil surface beneath the mulch application, until further decomposition and natural mixing takes place (NSW Agriculture, 2002b). Brief description and desirable limits of important soil physical properties are discussed below.

Aggregate stability is the stability of soil structural units (aggregates) when immersed in water (Hazelton and Murphy, 1992). Instability may be indicated by *slaking* or clay dispersion. An improvement in water stability of soil aggregates is linked to improvement in soil structure. Literature review by NSW Agriculture (2002b) on soil carbon sequestration utilising RO products stated that the role of organic matter in aggregate stability is complex, and is associated with the binding properties of persistent humic acids and microbial derived carbohydrates and gums (formed during the decomposition of organic matter) interacting with the mineral fraction of the soil (NSW Agriculture, 2002b). The improvement in soil aggregate stability as a result of RO addition reflects in improvement in soil porosity and infiltration rates. However the magnitude of change is dependent upon the initial texture of the amended soil (NSW Agriculture, 2002b), the composition of the RO product, and the manner in which the RO product is applied (i.e surface mulch or incorportaion into soil).

Total soil porosity is the total amount of pores present in the soil and is equal to the sum of the pores filled with water and those filled with the air (Hazelton and Murphy, 1992). Most plants cease to grow when percentage of pores filled with air falls below 10% (Hazelton and Murphy, 1992).

Soil hydraulic conductivity (K) is a measure of the rate at which water moves into (penetration) and through the soil (infiltration/percolation). Hydraulic conductivity is usually measured as saturated hydraulic conductivity (K_{sat}) which measures water penetration into and through the soil and is expressed as mm h^{-1}. K_{sat} of >120 is very high, 20-60 is moderate, and <0.5 is extremely low (Hazelton and Murphy, 1992). For example sandy soils have very high hydraulic conductivity and clayey soils have low hydraulic conductivity.

Soil bulk density is the oven dry weight of soil per unit volume and is expressed as Mg m^{-3} or g cm^{-3}. It is closely linked with porosity and the ability of plant roots to penetrate the soil profile. The critical values of soil bulk density varies with soil texture however 1.3-1.6 Mg m^{-3} is considered a moderate range (Hazelton and Murphy, 1992).

Soil strength determines the resistance of the soil to shearing (to cut through the soil) (Hazelton and Murphy, 1992). Plant roots often need to cause soil to shear in order to grow. The value of soil strength, which limits root growth depends how the soil strength is measured. The soil strength is very dependent on the soil moisture content at which it is measured, and this needs to be taken into account when interpreting results. The soil strength value of <1 MPa is optimum for root growth, and value of 2.4 MPa significantly restricts the root growth (Hazelton and Murphy, 1992).

Few field trials have studied the effects of RO products as surface mulches on soil properties such as bulk density and soil hydrology.

Soil bulk density and water infiltration was found unaffected two years after application of *Green Life* and *Nitrohumus* composted mulches (NSW Agriculture, 2000) of yellow podzolic duplex soils. Soil bulk density of ferrosol of volcanic origin improved slightly with the application of composted mulch produced from macadamia husk and chicken manure (Cox, 2001 a & b). Water pooling under irrigation drippers occurred 12-18% less frequently for cherry trees applied with 10 cm deep composted mulch (Wilkinson, 2000).

Long term and statistically significant data for different soil types is required.

3.3.4.4 Soil chemical properties

As discussed earlier the addition of RO products to the soil has the potential to increase SOM and this is largely responsible for much of the chemical properties of soils such as pH, cation exchange capacity (CEC), electrical conductivity (EC) and nutrients.

Soil pH – is a measure of acidity or alkalinity, and characterises the chemical environment of the soil. It provides guide to likely deficiencies and/or toxicities, and of nutrient availability. The ideal pH for plant growth ranges between 5 to 8. Nutrient availability for plant use may be affected, and deficiency or toxicity of elements may occur outside this pH range (Hazelton and Murphy, 1992).

Cation exchange capacity (CEC) – is the capacity of the soil to hold and exchange cations. It is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and soil's reaction to chemical fertilisers and other soil amendments. Cation exchange capacity is expressed as centimoles of positive charge per kg of soil (cmol(+) kg^{-1}). The CEC of the soil in the range of 12 to 25 is considered moderate and 6 to 12 is considered low for optimum plant growth (Hazelton and Murphy, 1992).

Electrical conductivity (EC) – is a measure of soil salinity which relates to the presence of water soluble salts in soil solution, mainly of chlorides, sulphates, carbonates and nitrates of sodium (Na), Ca, and Mg. Salinity is usually determined by measuring electrical conductivity of soil:water suspension and is expressed as decisiemens per metre ($dS\ m^{-1}$). The salinity of saturated extract (EC_e) <2 $dS\ m^{-1}$ has negligible effect on most crops and EC_e in the range of 4-8 $dS\ m^{-1}$ affects many crops mainly reducing crop yields (Hazelton and Murphy, 1992). The salinity of saturated extract is obtained by multiplying EC of soil:water suspension with a multipication factor depending upon texture of the soil which ranges from 6 to 17. Heavy textured soils such as clays are multiplied with lower multipication factor while light textured soils such as sandy, loamy sand and clayey sand are multiplied with higher multipication factor (Hazelton and Murphy, 1992).

Nutrients – As mentioned earlier (Section 3.3.3.3) when RO products are added to the soil have the potential to contribute nutrients to the soil which therefore become available for plant use. Therefore RO products can be used to replace chemical fertilisers fully or partially. The main nutrients that are added via RO products, depending upon source and quality of the product, are usually N, P, K, Ca and Mg.

Only Two (2) New South Wales field trials have measured soil chemical properties out of the total 14 RO product field trials conducted for fruit and orchard production in Australia.

Total soil carbon and nitrogen increased by 31 and 47% at 0-2 cm, and by 16-18% at 2-10 cm soil depths compared to control (no-mulch) 4 months after application of 10 cm deep composted mulch (Cox, 2002 a & b). However when these same soil parameters were measured 8 months after application, total soil carbon and nitrogen were same as that of control (no-mulch) suggesting continuous change occuring in total soil carbon and nitrogen over time.

Application of 10 cm deep *Green Life* and *Nitrohumus* composted mulches slightly changed certain soil chemical properties compared to control measured at 0-10 cm soil depth two years after application (NSW Agriculture, 2000). The soil properties measured included pH, EC, SOC, total N, available P, exchangeable cations, Ca:Mg ratio and heavy metals. The levels of total soil N, available P, excahngeable Ca & Mg, heavy metals (Cu, Zn, Cd and Ni) and CEC did not, however, change significantly. There was slight though significant increase in soil pH and EC for *Nitrohumus* treatments only. Increase in soil pH was desirable while increase in soil salinity was not of any concern. Total soil organic carbon increased 27% for *Nitrohumus* plus fertiliser treatment suggesting positive implications for overall soil health. The levels of exchangeable K, Ca and Mg increased for *Nitrohumus* plus fertiliser treatment, and Ca:Mg ratio increased for all mulched treatments which also shows positive implications for soil health. Soil and plant health should be monitored after regular additions of RO products.

Although the improvement in soil conditions is desirable and would be expected to continue steadily over time, of significant importance for growers is that application of RO products do not cause any undesirable effects on soil conditions. It is noteworthy that field trials that measured soil properties did not find any negative effect on soil chemical properties resulting from application RO products (negative effects may have included increase in EC and the levels of heavy metals, or decrease in soil pH, CEC and Ca:Mg ratio). In fact results of these trials have shown slight improvement in SOM, exchangeable K, Ca, Mg and Ca:Mg ratio as measured only a short time after application of RO products, demonstrating positive implications of RO use in fruit and orchard production. Long term field trials in Europe have demonstrated significant improvement in SOM and soil chemical properties resulting from compost applications (NSW Agriculture, 2002b).

The results of the few field trials that have measured soil physical, biological and chemical properties have demonstrated the potential performance of RO products as surface mulches to improve soil bulk density, microbial activity, water infiltration, and soil chemical properties.

3.3.4.5 Conclusions: Increased farm capital value

A longer timeframe than that of the duration of previous trials is required to realise many of the beneficial changes in soil properties that can arise from the application of mulches therefore long term data is necessary to fully demonstrate this performance benefit.

None of the trials to date have provided sufficient data upon which to calculate the potential for increased farm capital value.

Section 4 Soil conditioner application in fruit and orchard production

4.1 Description of field trials

This section provides information on performance outcomes of RO products used as soil conditioners in fruit and orchard production. Soil conditioner in this context refers to any composted or pasteurized organic product that is incorporated into the soil. There are other terms used for soil conditioners such as ‘soil amendment’, ‘soil additive’, ‘soil improver’, and other products used to condition the soil, such as lime and gypsum, however this section refers only to either composted or pasteurized soil conditioners as defined in the relevant Australian Standard AS 4454 (2003). Soil conditioners have not more than 20% by mass of its particles with a maximum size of equal or greater than 16 mm as defined in the Australian Standard for composts, soil conditioners and mulches (AS 4454, 2003).

A total of six field trials have evaluated the application of soil conditioner to fruit and orchard production (one in Victoria and five in Western Australian) and various information is provided as below:

- A detailed description of field trials that studied the performance benefits of RO products used as soil conditioners and soil conditioners in combination with mulches in fruit and orchard production is provided in Appendix 4,
- The scope and location of these trials is detailed in Table 4.1 and Figure 4.1,
- The documented performance outcomes are summarised in Table 4.2, and
- Specific and detailed performance outcomes are documented in Appendix 6.

Strawberries were grown on soil amended with *Pontec* (worm castings produced from vegetable waste), in a Victorian field trial. *Pontec* was applied at different rates to compare its performance with standard practice of applying Nitrophoska blue fertiliser to strawberries.

In Western Australia Trial 9, two different composted soil conditioners (A and F at the rate of 5 and 10 L per planting hole) were applied at the time of citrus establishment and the performance of these soil conditioners were compared against control with no soil conditioner.

Western Australian Trial 10 investigated total 10 treatments out of which 6 treatments were tested for different rates of composts A & F as soil conditioners at the time of establishing citrus trees. Three (3) treatements were tested for varying rates of compost G as surface mulch around citrus trees (Western Australian trial 10).

Western Australian Trial 12, investigated establishment of avacado trees using RO products. In this trial total 10 tretaments were investigated which included treatments with different rates of compost A as soil conditioner incorporated into soil and treatments with different rates of compost A as soil conditioner plus 5 cm deep compost G applied as surface mulch.

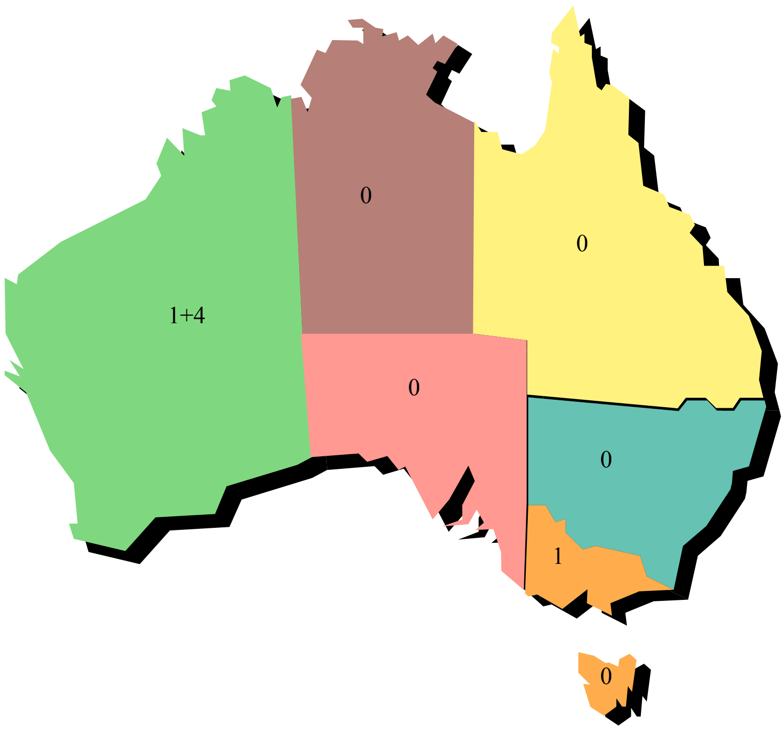
Western Australian Trial 13 investigated apple establishment using RO products. Treatments of this trial included a treatment of compost E applied as soil conditioner, compost E applied as soil conditioner plus compost I applied as surface mulch and a treatment of compost I applied as soil conditioner.

Western Australian Trial 14 investigated the establishment of apple trees using a soil conditioner and varying rates of composted mulch after (post) planting. Treatments of this trial included treatments with varying rates of compost H applied as surface mulch and treatments with compost A applied as soil conditioner plus varying rates of compost H applied as surface mulch.

Table 4.1 State-wise summary of field trials conducted across Australia in fruit and orchard production using RO products as soil conditioners.

Name of state	Number of trials	Recycled Organics Products used	Fruit type and variety tested
Victoria	1	Pontec (worm casting produced from fresh vegetable waste)	Strawberry variety-Marksman
Western Australia	1 (soil conditioners) & 4 (soil conditioners plus surface mulch)	Composted soil conditioners A (produced from animal manure, straw and vegetable crop waste), F (made from composted worm castings from straw and animal manure), E (garden organics with addition of N screened to 15 mm, recomposted for 8-10 weeks with 20% by volume polutry manure and 10% by volume green waste vermicompost).	Apple-Sundowner and Pink Lady, Avacado-Hass, Oranges-Navel and Navelina.

Figure 4.1 Number of field trials conducted in fruit and orchard production using soil conditioners in various states across Australia.



Like surface mulches, as discussed in the Section 3.1, the performance outcomes of soil conditioners vary and are mainly controlled by factors as mentioned below:

- The RO product quality (chemical, physical and biological characteristics),
- Environmental conditions (temperature, rainfall, soil types), and
- Farm management systems (crop variety and age, RO application method and rate, irrigation/non irrigation, use of fertilisers, herbicides and insecticides)

The information on these factors is therefore necessary to interpret the results of performance benefits of RO products used as soil conditioners. Next section will discuss information on these factors existed in fruit and orchard production field trials using soil conditioners across Australia, reviewed for this report.

4.1.1 RO product type and quality

Soil conditioners are mainly used in agriculture to improve soil conditions by adding organic matter, and to supply nutrients particularly nitrogen N, P, K, Ca and Mg. Therefore the qualities of soil conditioners are important and are mainly determined by the qualities of raw materials and the compost processing technology and management practices.

The important quality parameters of soil conditioners for use in fruit and orchard production are particle size, the levels of macro nutrients (particularly N), organic matter, heavy metals, compost maturity, nitrogen drawdown index (NDI), and impurities (plant propugules, pathogens, stones, glass, plastics, etc.). Chemical and physical characteristics of soil conditioners used in these trials and provided in the reports are presented in Appendix 2.

Pontec (a dry worm casting from vegetable waste) used in the Victorian strawberry trial met the requirements of AS 4454 (2003) for composted soil conditioner.

Western Australia trials 9, 10, 12, 13 and 14 have tested three soil conditioners (A, E and F) produced from various organic raw materials. Composted soil conditioner A used in Trials 9, 10, 12, and 14 was produced from animal manure, straw and vegetable crop waste. The raw material for this compost was composted for 12-14 weeks. It had slightly high pH, high concentration of ammonium and low levels of ammonium+nitrate-N, low toxicity and organic matter than required as per AS 4454 (2003). Composted soil conditioner F used in Trials 9 and 10 was made from composted worm castings, straw and animal manure, however relevant quality data has not been provided. Composted soil conditioner E used in Trial 13 was made from garden organics with addition of N and was composted for 18 weeks, screened to 15 mm, and then recomposted for 8-10 weeks with 20% by volume of polutry manure and 10% by volume of green waste vermicompost. Soil conditioner E met all requirements of AS 4454 (2003) for composted soil conditioners. The contents of heavy metals and boron (B) for all soil conditioners used in Western Australian trials have not been provided.

4.1.2 Environmental conditions

The variation in environmental conditions such as climate (rainfall and temperature), soil types and properties will have varying effect on the outcomes of soil conditioner applications in fruit and orchard production. For example the decomposition of soil conditioners in sandy soils is faster than in clayey soils (Chae and Tabatabai, 1986), sandy soils also have greater potential to leach nutrients from the soil profile therefore reducing fertiliser efficiency and leaving less nutrient available for plant use than the clayey soils (Maynard, 1999) so the impact of soil conditioner application will therefore vary according to soil types. Unlike mulches, when soil conditioners are incorporated to clayey soils with restricted drainage water infiltration is improved as the organic matter added to the soil will improve soil structure via reduction in soil bulk density.

No information on climatic conditions was provided for Western Australian trials, and soils of the trial sites were mainly sandy. Victorian trial using *Pontec* was established on clay soils and climatic conditions were not known.

4.1.3 Agricultural management practices

Fruits and orchard crops grown in these experiments included strawberry, apples, avacado, and oranges.

As discussed, the main roles of soil conditioners is to add organic matter to improve soil health and supply plant nutrients, therefore different application rates of the same soil conditioner will add different amounts of organic matter and nutrients to the soil, which will result in variation of performance outcomes. Similarly, different soil conditioners may have significant variation in nutrient content, therefore nutrient budgeting must be considered when applying soil conditioner to ensure the required quantity of nutrients are applied to a crop either from the RO products, or from a combination of RO product and supplementary fertilisers. Higher application rates of soil conditioners, or soil conditioners with high N content may not be suitable where this result in the excess N, as this may increase vegetative growth at the expense of fruit production and quality.

The soil conditioners in Western Australian trials were applied at different rates at the time of establishing different fruit crops, either in the planting hole, or as a strip along the planting row and incorporated into the soil. Western Australian Trial 9 applied composted soil conditioners A & F at the rate of 5 and 10 litres per planting hole and Trial 10 applied same soil conditioners at the rate of 2, 5 and 10 litres per planting hole. Western Australian Trial 12 applied composted soil conditioner A at the rate of 25, 50, 100 and 200 t ha^{-1} to 1.5 m wide planting strip and rotory hoed to 20 cm soil depth while Trial 13 applied composted soil conditioner E at the rate of 50 m^3 ha^{-1} to 2 m wide strip centred on planting row and rotory hoed to 20 cm soil depth, and Trial 14 applied composted soil conditioner A at the rate of 30 m^3 ha^{-1} to a 0.8 m wide strip centred on tree row and rotory hoed to 20 cm soil depth.

In the Victorian trial a worm casting soil conditioner, *Pontec* was applied at the rate of 1000, 1500 and 3000 kg ha^{-1}.

The standard farming practices such as fertiliser application may mask the nutrient supply performance of soil conditioners when nutrients added via compost and fertilisers are not matched with crop nutrient requirements because nutrients applied via inorganic fertilisers are more readily available to plants than from RO products (particularly, N and P). Plants will absorb those nutrients that are immediately available (i.e from inorganic fertiliers) and therefore may not use nutrients released by soil conditioners. This means applying reduced rate of supplementary fertilisers with RO application, accounting for nutrient content of RO application and also rate of release and availability of nutrients.

The application of soil conditioners under irrigated conditions will have different performance when compared under non-irrigated conditions. Soil conditioners in non-irrigated conditions may improve water retention by the soil after rainfall therefore has the potential to reduce crop stress and increase crop growth and productivity. Under irrigated conditions, application of soil conditioners may potentially reduce irrigation water requirements if increased soil moisture retention result in increased plant available water, however this potential is yet to be quantified.

The standard farming practices including use of insecticides or herbicides were unchanged in most trials. The standard fertiliser practices varied for these trials. The trials were mainly irrigated and the quality of irrigation water has not been provided.

4.1.4 Experimental methodology

All field trials reviewed for soil conditioner section were appropriately designed scientific trials. The experimental design used in Western Australian field trials was mainly replicated, and randomised block designed. Western Australian Trial 12 had Split Plot design fully randomised and replicated and Trial 14 was replicated Latin Square design. Voctorian trial had randomised complete block design.

Monitoring parameters of trials varied greatly. Victorian trial had monitored large number of RO performance benefits such as crop growth, fruit yield and quality, plant chemical quality, and nutrient releases. Western Australia trials have monitored only crop growth.

As trial constraints in terms of funding planning and duration are not known, and at the original objectives to which the reaseach is directed are commonly not available, it is difficult to determine whether the reaseach plan for trials and monitoring criteria were relevant and appropriate in each instance.

4.2 Documented performance outcomes

Unlike surface mulches, when soil conditioners are incorporated or mixed with the soil they quickly interact with and decompose in the soil, therefore performance benefits of soil conditioners are likely to vary more widely than for mulches. For example mulches are more effective in weed suppression as opposed to soil conditioners. Soil conditioners will improve soil chemical and physical properties comparatively faster than mulches do.

The detailed results of performance outcomes of RO used as soil conditioners in fruit and orchard production have been provided in Appendix 5 and summary of these results are presented in Table 4.2. The results of performance outcomes have been presented under the following four performance categories:

- Reduced risk of crop failure,
- Increased revenue (from increased yield, improved produce quality and time to market),
- Reduced costs in farm management (reduced water usage, fertilizer application, farm chemicals), and
- Increased farm capital value (soil health).

Table 4.2 Performance outcomes of recycled organics products used as soil conditioners in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
VIC-DBMS-2001 (Strawberries) NP500-Nitrophoska 500 kg/ha as fertilisers P1000-Pontec 1000 kg/ha as fertilisers P1500-Pontec 1500 kg/ha as fertilisers P1500+SG6000-Pontec plus Soil Guard 1500 plus 6000 kg/ha as fertilisers P3000- Pontec 3000 kg/ha as fertilisers NP500+P1500- Nitrophoska 500 plus Pontec 1500 kg/ha as fertilisers	Pest and Disease assessments- The plants within the trial area were less susceptible to fungal diseases. This was influenced by the lower leaf area and more vigorous growth of younger plants.	Crop Vigour-measured 16/11/00 to 12/12/00. Vigour was rated from 0 to 9. Crop vigour ratings ranged from 6.5 to 8. Crop vigour ratings decreased in all treatments except Pontec 3000 kg/ha. The lowest overall ratings were given to the Pontec+Nitrophoska and Pontec+Soil Guard. Yield (kg/plant)- Increased 2-48% and highest increase was for P3000. Brix level- Increased 8-23% and did not change for P3000. Petiole Sap analyses-measured from 12/12/00 sampling and changes in all analytes are compared with standard mineral fertiliser. Nitrates (ppm)- Decreased in P 1500 and P1500+SG6000. P, Ca, Mg, K (ppm)- Decreased in P1500+SG6000 and K increased in P3000 Copper (ppm)- Increased (40-110%) for P1500 and P3000. Manganese (ppm)- Decreased 70% for P1500. Iron (ppm)- Decreased (40-60%) in P1500 and P1500+S6000. Zinc (ppm)- Decrerased (40-50%) in P1500 and P1500+S6000 and increased (26%) in P3000.	Soil nitrate analysis (N kg/ha)-After 19 days of planting, soil nitrates levels in Pontec treatments were lower (320 applied 50) compared to a similar N -application rate of commercial standard containing mineral form easy available N (420 applied 60). Residual soil nitrate at harvest 12/12/00 (N kg/ha) was high (38-104) for various Pontec rates compared to mineral N fertiliser (20).	
WA-BP-2001 Citrus establishment trial (Trial 9) C1-Control (replanted) CSCA5-Compost A @ 5 lt/hole as soil conditioner in the planting hole CSCA10-Compost A @ 10 lt/hole as soil conditioner in the planting hole CSCF5-Compost F @ 5 lt/hole as soil conditioner in the planting hole CSCF10-Compost F @ 10 lt/hole as soil conditioner in the planting hole C2-Control (not replanted)		Tree growth - Composted soil conditioner A at highest rate doubled the trunk circumference over 12 months period after application. Average tree growth (%)-Increased for compost A (13-63%) and decreased for compost F (2-23%). Highest increase in trunk diameter was obtained for highest rate of compost A.		

Table 4.2 Performance outcomes of recycled organics products used as soil conditioners in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	Increased farm capital value (soil health)
WA-BP-2001 Citrus establishment trial (Trial 10) C-Control CSCA2-Compost A @ 2 lt/hole as soil conditioner in the planting hole CSCA5-Compost A @ 5 lt/hole as soil conditioner in the planting hole CSCA10-Compost A @ 10 lt/hole as soil conditioner in the planting hole CSCF2-Compost F @ 2 lt/hole as soil conditioner in the planting hole CSCF5-Compost F @ 5 lt/hole as soil conditioner in the planting hole CSCF10-Compost F @ 10 lt/hole as soil conditioner in the planting hole CMG2-Composted mulch G @ 2 lt to $1m^2$ area around each tree as surface mulch. CMG5-Composted mulch G @ 5 lt to $1m^2$ area around each tree as surface mulch. CMG10-Composted mulch G @ 10 lt to $1m^2$ area around each tree as surface mulch. Raw Poultry Manure-Applied about 30 m^3/ha		Tree growth – Application of Soil conditioners increased tree growth although statistically not significant during initial 12 months of tree growth. Increase in average tree growth (%)-Increased about 3-25% for composted soil conditioner A and 11-24% for soil conditioner F. Highest rate of soil conditioner A and lowest rate of soil conditioner F produced highest tree growth.		
WA-BP-2001 Avocado establishment trial (Trial 12) C-Control (growers practice) C+CMG5-Control+ Compost G applied 5 cm deep as surface mulch CSCA25-Compost A @ 25 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth CSCA25+CMG5-Treatment 3+ Compost G applied 5 cm deep as surface mulch CSCA50-Compost A @ 50 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth CSCA50+CMG5-Treatment 5+ Compost G applied 5 cm deep as surface mulch CSCA100-Compost A @ 100 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth CSCA100+CMG5-Treatment 7+ Compost G applied 5 cm deep as surface mulch CSCA200-Compost A @ 200 t/ha as soil conditioner in 1.5 wide planting strip and rotary hoed to 20 cm depth CSCA200+CMG5-Treatment 9+ Compost G applied 5 cm deep as surface mulch.		Tree growth increase (%). Tree growth after 12 months of treatment increased 30-78%. Highest tree growth was obtained from lowest rate of soil conditioner plus mulch. Soil conditioner A at the rate of 50 t/ha produced maximum tree growth of 29% compared to control. Further increase in soil conditioner decreased tree growth.		

Table 4.2 Performance outcomes of recycled organics products used as soil conditioners in fruit and orchard production.

Trial code and treatments	Reduced risk of crop failure	Increased revenue (yield, time to market, produce quality)	Reduced costs in farm maintenance (water usage, fertiliser application, reduced farm chemicals	
WA-BP-2001 Apple establishment trial (Trial 13) Control (no treatment) CSCE50-Composted soil conditioner @ 50 m3/ha applied to a 2 m wide strip centred on planting row rotary hoed to 20 cm depth CSCE50+CMI5-Treatment 2+ Compost I applied as surface mulch to 5 cm depth to a 1 m wide strip after two weeks of planting CMI5-Compost I applied as surface mulch to 5 cm depth to a 1 m wide strip after two weeks of planting		Tree growth– Improved . Trunk diameter (mm)- Increased highest (42%) for soil conditioner plus mulch treatment compared to the control. Only soil conditioner treatment increased about 5% tree growth.		
WA-BP-2001 Apple trial post plant apple tree establishment (Trial 14) C-Control (growers practice) C+CSCA30-Control (growers practice)+ Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row CSCA30+CMH2.5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 2.5 cm depth CMH2.5-Compost H applied as surface mulch to 2.5 cm depth CSCA30+CMH5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 5 cm depth CMH5-Compost H applied as surface mulch to 5 cm depth CSCA30+CMH7.5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Compost H applied as surface mulch to 7.5 cm depth CMH7.5-Compost H applied as surface mulch to 7.5 cm depth CSCA30+GCM5-Compost A applied as soil conditioner @ 30 m3/ha in 0.8 m wide strip centred to tree row + Growers compost applied as surface mulch to 5 cm depth GCM5-Growers compost applied as surface mulch to 5 cm depth		Tree growth (mm) (SNA) Trunk diameter (mm)- Increased in 9 months from 20-360% for various treatments. Highest increase was obtained for lowest composted mulch rate. Composted soil conditioner plus lowest mulch rate increased tree growth about 200%.		

4.3 Discussion of results

4.3.1 Reduced risk of crop failure

As mentioned in Section 3.3.1 that fruit crops can fail due to incidence of pest and diseases; frost damage caused in cool climates; crop stress in hot climates or low rainfall periods; and low soil moisture availability for non-irrigated conditions.

Western Australian trials did not monitor or measure any parameters that reduce risk to crop such as incidence of pest and diseases; frost damage; and crop stress.

Victorian Trial that used different rates of *Pontec*, a worm castings as soil conditioner/fertiliser have observed that plants within trial area were less susceptible to fungal diseases. The trial report has suggested that it was influenced by the lower leaf area and more vigorous growth of young plants.

4.3.1.1 Conclusions: Reduced risk of crop failure

Long term and statistically significant data on incidence of pest and diseases, frost damage and crop stress and/or failure is required to assess the performance of RO products used as soil conditioners.

4.3.2 Increased revenue

Fruit growers can increase the revenue of their farm through increased yield, improved produce quality and time to market as a result of RO application as soil conditioners.

4.3.2.1 Fruit yield

Fruit yield data was not provided/available for all Western Australia trials at the time of writing this report. However, the data on tree growth measured 12 months after application of soil conditioners in Western trials have shown increase in trunk circumference over control in all trials.

Composted soil conditioner A (made from animal manure, straw and vegetable crop waste) was more effective than composted soil conditioner F (composted wormcastings based on straw and animal manure) in citrus establishment Trials 9 and 10 (Westren Australia). Highest rate of composted soil conditioner A (10 lt per planting hole) and lowest rate of soil conditioner F (2 litres per planting hole) produced highest increase in citrus tree growth (25-63%) over control in Trials 9 and 10. Higher rates of composted soil conditioner F (applied at the rate of 5 and 10 litres per planting hole) decreased the growth of young citrus trees (2-23%) compared to control in Trial 9.

In Western Australian Trial 12 (avacado establishment trial) growth of avacado trees increased 30-78% over control. Lowest rate of soil conditioner plus mulch (25 t ha^{-1}+ 5 cm deep mulch) compared to control produced highest tree growth. Application of soil conditioner A alone at the rate of 50 t ha^{-1}

produced maximum tree growth of 29% compared to control. Further increase in soil conditioner rates decreased tree growth.

Western Australian Trial 13, apple establishment trial increased highest tree growth (42%) for soil conditioner plus mulch treatment when compared with control. Only soil conditioner treatment increased tree growth by 5%. However post establishment apple Trial 14 increased highest tree growth (360%) for lowest mulch rate applied at 2.5 cm depth while composted soil conditioner A plus mulch treatment increased tree growth about 200%.

Results of tree growth data from Western Australian trials showed that lower rates of soil conditioners tended to result in greater increase in tree growth, it should be noted that these trials were largely conducted in light sandy soils. Highest tree growth was produced from lower rates of soil conditioners plus application of surface mulch.

Application of a worm castings product (*Pontec*) as soil conditioner/fertiliser on clay soils in the Victorain trial increased strawberry yield 2-48%, and highest increase was obtained for *Pontec* applied at the rate of 3000 kg ha^{-1} compared to standard fertiliser practice of Nitrophoska fertiliser application at the rate of 500 kg ha^{-1}.

4.3.2.2 Fruit quality

Western Australian trials did not measure the fruit quality. Victorian trial with *Pontec* found levels of Brix increased 8-23% for various *Pontec* application rates, compared to standard practice of Nitrophoska fertilisers application. Pontec treatment applied at 3000 kg ha^{-1} did not change the Brix level.

4.3.2.3 Time to market

No measurements were taken.

4.3.2.4 Conclusions: Increased revenue

Long term and statistically significant data using RO products as soil conditioners is required for growth stages, maturity, fruit yield, and fruit quality.

4.3.3 Reduced costs in farm management

It is well documented that RO products as soil conditioners, when incorporated into soil improves SOM content of the soil, provides nutrients for plant growth and improves soil moisture retention. These benefits have the potential to reduce production costs of fruit and orchard production as a result of potential reduction in use of irrigation water, and reduced application of chemical fertilizers. There is also potential for reduced intervention as a result of disease suppression properties that have been documented in relation to various compost products, with the associated reduction in management intervention, machinery use and associated treatment, products, chemical or otherwise. Such disease suppression potential is still be the subject of international R & D.

4.3.3.1 Weed suppression

None of trials using soil conditioners for fruit crops have studied weed suppression.

Generally it is considered that soil conditioners do not suppress weeds, unlike mulches.

4.3.3.2 Water usage

None of these field trials using soil conditioners for fruit crops have studied change in soil moisture conditions.

Literature reviewed on soil carbon sequestration using RO products by NSW Agriculture (2002b) has reported increase in soil moisture due to application of RO products. The mechanisms involved include improved porosity and pore size distribution. With an increase in the relative number of storage pores, and the colloidal nature and increased surface area of the RO amended soil, soil water retention is increased. Although the capacity to store water can increase in RO amended soils, but the water available to plants is often reported to be unchanged (NSW Agriculture, 2002b).

4.3.3.3 Fertiliser application

One Victorian trial has measured the nutrient releases after application of soil conditioners. The soil nitrate levels measured after ninteen days of planting were lower (320 N kg ha^{-1}) in *Pontec* treatments compared to similar N application rate of commercial standard fertiliser containing mineral form of easily available N (420 N kg ha^{-1}). Residual soil nitrate levels at harvest were high in various *Pontec* treatments (38-104 N kg ha^{-1}) compared to mineral fertiliser Nitrophoska (20 N kg ha^{-1}) demonstrating slow release of N through organic fertilisers.

Western Australian trials did not measure the nutrient availability to fruits crops as a result of using of soil conditioners.

4.3.3.4 Conclusions: Reduced costs in farm management

Long term and statistically significant data on soil water usage and nutrient releases and availability are required to demonstrate and quantify performance benefits.

4.3.4 Increased farm capital value

As discussed (Section 3.3.4) the cultivation of agricultural soil reduces levels of SOM and hence reduces soil productivity, crop production and farm value. Incorporation of organic matter via the addition of RO products as soil conditioners to the soil has the potential to increase SOM and improve soil health as determined by biological, physical and chemical properties of the soil. Unlike surface mulches, soil conditioners are likely to improve soil health relatively quickly because soil conditioners are incorporated into the soil. Due to incorporation, soil conditioners mineralize relatively quickly compared to mulches, and the mineralised organic matter directly interacts with soil mineral component leading to improvement in soil structure, the architecture of soil productivity.

4.3.4.1 Soil biological, physical and chemical properties

The effects of soil conditioners on the activity of soil microorganisms, and on soil chemical and physical properties have not been studied in any of these field trials.

4.3.4.2 Conclusions: Increased farm capital value

Long term and statistically significant data on soil biological, physical and chemical properties are required to claim this performance benefit.

Section 5 Gaps and limitations of the existing studies

The review of project reports on field trials that have used RO products in fruit and orchard production across Australia have reported a range of performance benefits to fruit production. The short term nature of these studies, due to short term funding, could not confirm and/or study many potential performance benefits of RO products in fruit and orchard production identified elsewhere. The gaps and limitations identified from this review are listed below:

1. The main limitation of most studies was that performance benefits were recorded over one season or similar short term period, which is not sufficient duration for evaluating a system such as Soil+RO products. Many of performance benefits in these studies were measured as one of the parameters or as a side issue. Specific investigations targeting specific performance benefits over long term and statistically significant data (over 3-6 years) is necessary to demonstrate the performance of RO products in fruit and orchard production.

2. The vast majority of trials have neither included adequate characterisation of the composted products applied, nor of cultural practices of the grower, nor climatic data (i.e. rainfall) for the period of the trial. Whilst such information may be self evident in the immediate to short term in the local region in which the trial was conducted, this creates significant limitations in terms of identifying trends and outcomes via comparison of different trials, and/or applying performance data beyond the local region. Many studies claim to have applied composted products, however in many instances whilst the materials have been composted there is no possibility of identifying whether material has been composted for sufficient duration to meet maturity and/or phytotoxicity standards for mature composts. In the vast majority of cases we have no idea of the extent of the level of maturity of the product applied, no reference is made to any product standard and commonly product characteristics are largely undefined. Under such circumstances it is fundamentally unrealistic to expect any consistent results.

3. Application of mulches has demonstrated significant increases in soil moisture, therefore it has been concluded that soil moisture increase will reduce irrigation water requirement. It the increase in soil moisture that can be extracted by plants or so called plant available water (PAW), which is important in terms of water savings. None of these trials have evaluated the relationship between increase in soil moisture and irrigation water savings. This information is critical for valid results. Quantification of actual irrigation water applied (in properly managed irrigation systems) based on irrigation scheduling that maintains equivalent soil moisture for mulched and un-mulched treatments will allow quantification of actual irrigation water savings, and simply monitoring the difference in soil moisture as is the common practice, is inadequate for this purpose. Most reports did not provide information on the method of soil moisture measurement, nor at what soil depths measurements were taken. As a result we still have no valid quantification data relating to potential for reduced irrigation.

4. Only one trial has studied the release of nitrates after application of soil conditioners for one season and found slow release of nitrates compared to mineral fertilisers. In relation to quantifying nutrient availability over time from RO products, treatments must maintain equal conditions for trees in terms of nutrient availability so as to isolate performance benefits of RO products. Continuing the same fertiliser regime to mulched and soil conditioner treatments without regard to the nutrient contribution to meet specific crop requirements of the mulch/soil conditioner effectively produces distorted results which may relate to additional (and potentially excess) fertiliser application rather than to benefits from the actual mulch/soil conditioner application. Recycled organics products release nutrients variably and slowly over 3-5 years after the decomposition of organic matter present in the compost products. Mineralisation of RO products, and release and availability of major nutrients for plant use under various Australian environmental and crop management conditions are not known and not been evaluated in any of these trials. This information is critical for reliable and accurate estimation of nutrient contribution through RO product applications and to inform the integration of RO products into farm management systems. Long term data on nutrient release and availability for all three major plant nutrients (N, P and K) over time is necessary in this regard.

5. Disease control is a significant issue for all horticultural crops. International literature has reported that RO products can have the potential to suppress soil borne plant diseases and improve fruit quality. None of these field trials studied effects of RO products on incidence of pests and diseases except one trial had reported reduced incidence of fungal diseases. Identification and quantification of such performance benefits in terms of reduced risk to crop loss, reduced grower intervention and associated farm inputs may provide growers with additional incentive to use RO products. Trials should monitor incidence of pest and diseases, even if only to identify an absence of increased incidence associated with RO applications.

6. Crop stress in hot climate leads to loss of production and reduced fruit yield and quality, this has significant implications for non-irrigated areas. None of these trials studied effects of RO products on crop stress.

7. All field trials reviewed for this report have measured growth of various fruit trees and have found significant increases in tree growth compared to control when establishing new and/or young trees. However, few field trials have measured fruit yield and fruit quality. Fruit yield and quality data were based either on one season or two season measurements after application of RO products. A longer time period (at least 3-6 years) is required to confirm quantitative effects due to the surface mulches and soil conditioners in terms of the relationships between tree establishment, earliest commercial bearing and future commercial yield/quality.

8. None of these trials studied effects of RO applications on growth stages of fruit trees, fruit maturity and storage quality.

9. A few trials studied effects of RO products on soil biological, physical and chemical properties after application of RO products over the short term. These trials have found soil properties unchanged, or in some cases indicated improving trends in soil biological, chemical and physical properties. Longer term trials are required to demonstrate and quantify improvement in soil properties arising from application of RO products.

10. All trials that measured weed growth, demonstrated that mulches significantly reduced total weed growth, and one trial has also shown reduced total grass weeds. Higher weed suppression resulted from higher mulching depths. The extent of weed suppression over time and also without prior herbicide application requires further investigations.

11. Mulch application in cool climates can potentially increase frost damage or risk. None of field trials studied frost risk or damage.

12. It is strongly suggested that future trials on the performance of RO products should focus on RO products of known specifications, designed to meet application/crop specific requirements, and to maximise cost-benefit advantage to growers.

Section 6 Conclusions

The main conclusion from the review of field trials conducted across Australia using RO products in fruit and orchard production is that application of RO products has demonstrated a range of performance benefits. Due to the short term funding of these projects, most performance benefits have been measured over one season. Many specific performance benefits have been studied in only a small number of field trials, and over short term duration. As a result, the use of such performance data must be quantified with associated limitations. A number of important performance benefits have not been studied at all in these trials.

This study provides a structure for the consideration of performance benefits which will assist in the design of future trials. These issues are addressed in recommendations in Section 7.2. The provision of this table does not mean that all performance benefits should be studied in a single trial, nor does it mean all performance benefits need to be studied in future trials. However, it is highly recommended that future trials should be designed in a way that specific performance benefit/s is/are studied thoroughly and over the long term to obtain conclusive results. Performance benefits that are considered to require attention in the future R & D program are prioritised in Section 7.3 after Table 7.3.

The performance benefits of RO products used as surface mulches and soil conditioners in fruit and orchard production from the review of 14 field trials carried out across Australia have been summarised in Table 6.1 and are discussed below.

<u>Weed suppression</u>

Addition of RO products as surface mulches under fruit trees can reduce the growth of weeds from 80 to 100% in the first season after mulch application. Soil conditioners did not suppress weeds. Higher mulching rates (10 and 15 cm deep) were more effective in weed suppression.

<u>Soil moisture</u>

Application of RO products increased soil moisture from 10 to 80% when applied as surface mulches. Thick mulches (10 cm deep and higher) produced greatest increase in soil moisture. It is not known whether, or to what extent this increase in soil moisture has impacted on the capacity of the soil to retain moisture available for plant use. Increased soil moisture does not relate directly to increased plant available water in the soil. It is the increase in soil moisture that can be extracted by plants (known as plant available water) that directly reduces plant stress and reduces requirement for irrigation. An increase in soil moisture that relates to reduced irrigation water requirements carries great importance for growers in rainfed as well as in irrigated conditions (properly managed irrigation systems). This has not been evaluated in any of the scientific trials. Soil water is a limiting factor in agricultural production, and water deficit can result in increased plant stress, significant reduction in yield or even crop failure. With implementation of the NSW Government's water reforms, growers are under tremendous pressure to pay water prices based on the volume of water extracted for irrigated agriculture. If mulch application demonstrates reduced water requirement in irrigated agriculture (in properly managed irrigation systems) and/or moisture conservation in dryland (rainfed) conditions, this can reduce growers water bills and/or reduce the risk of crop stress/failure, thereby providing significant incentives for incorporating RO products into farm management practices.

Disease suppression

Soils amended with particular RO products under some circumstances have been found less susceptible to fungal diseases.

Yield and quality

All trials have found increased growth of young fruit trees (10-300%) due to application of mulches and soil conditioners when compared to juvenile trees established without composts. A combination of the lowest rates of soil conditioners (25 to 50 t ha^{-1}) and surface mulch (2.5 to 5 cm deep) produced the highest growth of young fruit trees. A small number of field trials that have measured fruit yield found varying results. Increases in fruit yield have varied widely from 20-400%.

The most attractive finding for growers was that the total number of large sized fruit has increased (in two field trials with peaches and cherries) when fruits were graded according to size. Larger fruit size attracts premium price at the market, and can provide significant incentive to growers for including RO products in farm management practices.

Application of RO products as surface mulch did not change most fruit quality parameters of peaches, apples and cherries (based on results of two trials only) with the exception of Brix levels of apples, peaches and cherries which increased. In one trial, peaches developed a green area even when fruit was fully matured. Formation of green calyx/area is an undesirable effect and was the result of the application of excess N (via mulches) than that required by peach trees. This negative highlights the importance of considering nutrient budgeting when selecting and applying RO products and supplimentary fertiliser regime to match the nutrient requirements of the crop.

Nutrient availability

One field trial studied the release of nitrates after application of soil conditioners and found a relatively slow release of nitrogen compared to chemical N fertilisers. Recycled organics products release nutrients variably and slowly over 3-5 years after the decomposition of organic matter present in the RO products. Release and availability of plant nutrients from RO products under various Australian environmental and farm management conditions are not known and have not been specifically evaluated in any of these trials. This information is critical for the estimation of RO product application rates and nutrient contribution to meet specific crop requirements without having any detrimental impact on crop yield and quality as well as on environment.

Soil health

Application of mulches had a varying effect on soil health over the short term. In some cases there was improvement in soil properties such as infiltration, increased soil microbial and enzyme activity, increased levels of SOM, Ca, nitrogen, and Ca:Mg ratio. Application of RO products over time eventually increases SOM, consequently improving all soil properties, and resulting in increased soil productivity and reduced land degradation.

Application rate

Application of thick mulches (greater than 10 cm) were found to be effective in weed suppression and increasing soil moisture, however, thick mulches or higher rates of soil conditioners with high nutrient content can supply excess nutrients to plant requirements, promoting vegetative growth which can result in a reduction of fruit yield and quality, or cause other deleterious effects. Selection of optimum mulching depth and particle size that provides maximum benefit in terms of weed suppression and soil moisture increase without any detrimental impact on crop productivity is necessary. A relatively low nutrient composted mulch that can be applied at a higher application rate may be preferred in this regard. Nutrient budgeting is a necessary consideration when specifying products and application rates for particular crops.

Longevity of benefit

Mulches maintained the effect of soil moisture increase over a long time (3-5 years), while weed suppression effect decreases over time (after 6-12 months). Reapplication time of mulches should take into account these issues to maximise benefits of mulch application to fruit and orchard production.

Opportunities for inclusion of RO products in fruit and orchard production

The majority of agricultural soils within and around the Sydney basin have inherently low fertility. Decades of intensive cultivation of these soils for agricultural production have further excerbated their poor condition due to continuous decline in SOM causing loss of soil structure, increased surface crusting and hardsetting, reduced water infiltration and increased soil erosion, all of which contribute to a loss of soil productivity. Addition of organic matter via application of RO products to these soils over time will eventually improve all these soil conditions and help to sustain productivity of land and crops.

The use of RO products as surface mulches has demonstrated significant reduction in weed growth, reduced water evaporation from soil surface, and increased percentage of large fruit size. All these performance benefits would assist growers to maintain long term land and crop productivity, whilst potentially reducing irrigation water and the use of farm chemicals and hence reducing production costs.

Many performance benefits have not been studied in these trials, and the gaps identified in research data have been identified and presented in Table 6.1. Other performance benefits have been studied in only a few trials and over only a short term period (Table 6.1). In addition, results have in some instances not been statistically analysed. Long term and statistically significant data is required to demonstrate and quantify predictable performance benefits that can demonstrate cost-benefit advantage and support increased demand. It is reccommended that a comprehensive, multisite, long term strategically designed R & D program be conducted that specifically targets vital performance benefits and covers the crucial gaps identified in Section 5. This program should use RO products of suitable and known specifications, to provide reliable performance data to inform valid cost-benefit analysis. Such a program may be supported by deliberately complementary demonstration trials and other strategies, which may be conducted concurrently on growers properties in the fruit production regions. The results of these trials and strategies will inform integration of RO products into farm management practices and will provide complementary data (particularly with regard to yield and quality) to accelerate RO product uptake in fruit and orchard production.

Table 6.1 Brief summary of performance outcomes of RO products used in fruit and orchard production.

Performance categories	Performance outcomes	RO products as surface mulches	RO products as soil conditioners	Comments
Reduced risk to crop failure	Incidence of pest and diseases	Not investigated.	Less susceptible to fungal diseases. (1)	
	Frost risk in cooler climates	Not investigated.	Not investigated.	
	Crop stress in hot climate	Not investigated.	Not investigated	
Increased revenue	Tree growth (establishment of juvenile plantings)	Tree growth increased in all cases (20-360%) (~10).	Tree growth increased in all cases and ranged 5- 63% (6).	Lower mulching depths & soil conditioner rates have produced higher yields, however varying compost maturity may account for this trend. Increased fruit size attracts higher price in the market.
	Fruit yield	Fruit yield varied and when it increased, the increase ranged 20-400% for various crops. Fruit size has been reported to increase in some cases. (4)	Yield has increased up to 48% (1)	
	Fruit quality	Unaffected mainly, but increased greenness of peaches (where excess N was applied) which continued even when fruit was fully ripe. (1)	Unaffected. (1)	Addition of larger amounts of N than required for fruit crops deteriorates fruit quality.
	Time to market	Not investigated	Not investigated	
Reduced farm maintenance costs	Weed suppression	Confirmed weed suppression from 85-100% (3)	Not investigated. Generally do not suppress weeds.	Deeper mulches were more effective in weed suppression but has the potential to cause other deleterious effects depending upon product maturity, particle size and nutrient content.
	Reduced irrigation water usage	Confirmed increases in soil moisture (10-80%). Available water capacity did not change. Highest increase was found within surface to topsoil layer (5).	Not investigated.	Deeper mulches were more effective to increase soil moisture but may cause other detrimental effects (see above). No data to support irrigation saving claims.
	Reduced fertiliser application	Not investigated.	Slow release compared to mineral fertiliser. (1)	Rates of mulches and soil conditioners should not exceed nutrient requirements of fruit crops. Absence of data relating to nutrient release and availability over time.
Increased farm capital value	Increased soil health (soil biological, physical and chemical properties)	Increased microbial and enzyme activity and increase was highest in the topsoil. Tendency to increase SOM, N, Ca, Ca:Mg, infiltration (4).	Not investigated.	Long term application would eventually improve soil health

Note: the figures in brackets are number of trials that have mesaured/investigated that performance outcome out of total 14 field trials reviewed for this report.

Section 7 Recommendations

7.1 Product performance objectives for fruit and orchard production

Surface mulch is the dominant product relevant for application to established fruit orchards as a perennial with established roots. Whilst there may be opportunity to apply composted soil conditioner to orchards as a pre-planting soil preparation (Bukerfield, 1996), to improve soil structure and water holding capacity, this represents a single application across the life of a fruit tree, whereas mulch applications can be reapplied every 3-5 years.

7.1.1 Mulch products

Based on the results of field trials that have used various RO products in fruit and orchard production, broad product performance objectives of RO products suitable for all types of fruits has been identified. Complimentary and/or specific performance objectives can be identified for particular regions and crops.

Compostable organic materials that are pasteurised according to Australian Standard (AS 4454, 2003) pose little risk to spread plant pathogens and/or plant propugules (Buckerfield, 1999b).

Compostable organic materials that are processed to achieve the maturity levels specified in Australian Standard 4454 for composted products are unlikely to contain phytotoxic characteristics, or cause the nitrogen draw-down that can be associated with straw, woodchips or paper pulp products. Composted products applied as surface mulches do not seem to pose any problems associated with straw mulches in fire and frost prone areas, if applied at appropriate rates.

Coarser composted mulches were effective in eliminating weeds and conserving water. Finer grades of composted products may be appropriate for incorporation in the soil at planting time to add organic matter and improve soil structure and water holding capacity.

Most fruit crops have relatively low nutrient requirements, which vary at different growth stages and for each fruit variety. Higher nutrients are required for promoting vegetative growth and rapid establishment of young trees. However, nutrient requirement is relatively low at the fruit ripening stage. Whilst soil conditioners with high levels of nutrients may be applied at the time of tree establishment, composted mulches with lower nutrients are recommended for surface application to production trees.

The following suggestions are provided on the basis of existing data for consideration in developing composted mulch product specification for fruit and orchard applications:

- **Generic mulch product for irrigated orchards currently under production**

1. Mature coarse composted mulch (i.e. screened) with no inherent phytotoxic qualities that has been effectively pasteurised to destroy pathogens and plant propogules.

2. Apply at the maximum depth possible to maximise mulch effectiveness and longevity of moisture retention and weed suppression (thereby maximising avoidance of irrigation and herbicide application) without

   i. causing negative impact on yield or “quality”,

   ii. supplying excess nutrients to fruit trees,

   iii. increasing incidence of pest and/or disease,

   iv. causing anaerobic soil conditions, and

   v. causing increased rate of frost damage.

3. Application rate and nutrient content of the composted mulch should seek to maximise the avoidance or reduction of supplementary fertiliser required.

4. Product specifications should consider application technology and methods and provide lowest cost per tonne applied (i.e. cost of product plus cost of application).

- **For dryland orchards**

1. Mulch must not inhibit limited rainfall from reaching the soil (i.e. mulch should not contain significant proportion of fine particles that will absorb moisture. Mulch should be coarse to allow moisture to reach soil).

Whilst these basic performance requirements should be relevant to most fruit orchards, there are also a range of other performance goals that may demand products that are additional and specifically tailored to the needs of specific regional, varietal and soil requirements to optimise cost benefit advantage to growers, and therefore affordability.

- **Optimum mulch product**

The optimum composted mulch product may potentially offer a range of the following performance benefits:

1. Increase yield without negative impact on fruit yield.

2. Increase fruit quality (this is likely to relate to variety specific fruit qualities).

3. Reduce incidence of pest or disease (this may be general or specific suppression; and may be relevant to disease or pest incidence in specific regions and varieties).

4. Support organic or other environmental and/or quality certification for the orchard or produce.

5. Embody specifications that offer particular benefits to a specific soil type (such as a proportion of fine particles in light soil to improve nutrient and moisture retention) or grower need.

7.1.2 Soil conditioner products

The following suggestions are provided on the basis of existing data for consideration in developing composted soil conditioner product specifications that offer maximum cost-benefit advantage for the establishment of fruit orchards.

- Mature composted soil conditioner that has been effectively pasteurised to destroy pathogens and plant propogules, and that has no phytotoxic qualities.

- Soil conditioner should offer high water absorption/retention qualities. Therefore moisture content and raw materials from which soil conditioner is manufactured should be considered to ensure moisture repellent products are not applied (See Appendix D, AS 4454, 2003).

- Application rate and nutrient content should seek to optimise nutrient provision over time.

- The goal is to maximise vegetative growth and plant survival/health. Therefore the value of composted soil conditioners that offer increased survival and vigour via suppression of pest and/or disease will be preferred.

- Application that can reduce the time between planting to commercial bearing, and/or increase bearing at younger age may offer increased value to growers.

7.2 Recommended research and development

Orchards vary substantially in the quantity and quality of fruits they produce. Differences in environmental conditions (soil types and climatic conditions), RO product type and quality, and farm management practices influence the specific performance of RO product applications in fruit and orchard production.

The results of research carried out to date in Australia using RO products in fruit and orchard production have demonstrated a range of performance benefits of RO products to orchardists, in particular weed suppression and soil moisture increase. Increased utilisation of RO products in fruits and orchards requires documentation of quantitative costs and benefits of RO products over time. Short term funding of past research has jeopardised monitoring of several important performance parameters and has not allowed the implementation of trials of a sufficiently long duration. On the basis of previous field trials and identified gaps in knowledge, recommended experimental design and monitoring parameters are provided below to guide future research in this area.

7.2.1 Recommended methodology for scientific field trials in fruit and orchard production.

Field trials should be conducted in prominent fruit growing regions and should focus on trial contexts most likely to increase RO product use. The trial context should target:

- Trial sites representative of dominant regional climatic conditions,
- Dominant regional soil types (under fruits and orchards), particularly light and heavy textured soils that are likely to exhibit beneficial response,
- Specific regional area or area of an orchard that shows maximum beneficial response,
- Dominant regional fruit types,
- Fruit types/varieties most likely to evidence beneficial response,
- RO products of relevant and known specification and application rates that offer greatest opportunity to maximise benefits whilst minimising risk (including consideration of nutrient budgeting and application timing), and
- Irrigated and non irrigated conditions.

7.2.1.1 Initial site and soil assessment

The research trials involving soil+RO products should begin with an initial site assessment and soil survey to provide baseline information about the site and soils. The baseline information is crucial to measure, compare and quantify the various performance benefits of RO products within a context that gives meaningful results.

Sites selected for trials should be assessed for previous and current farming practices, landform and topography. Selection of the specific area for the trial should target dominant soils (i.e. heavy and light) and varieties in the region that are likely to evidence a beneficial response so as to maximise the value and broad regional relevance of the findings.

7.2.1.2 Chemical and physical characteristics of recycled organics products

Baseline type and quality of RO products is equally important to interpret the results of investigations using RO products in fruit and orchard production. It is highly desirable to have knowledge of raw materials used for producing RO products. Composite samples of RO products intended for use in trials should be collected before their application and analysed for parameters outlined in AS 4454 (2003) particularly particle size grading, pH, EC, organic matter, moisture content, toxicity, total and available nutrients (N, P, K, B). Selection of parameters for compost analyses will mainly depend on the objectives of the trial. For example analyses of compost for microbial acitivity will most likely be required if impact of compost application on soil microbial activity is being investigated in the study.

It is suggested that trial products must comply with specifications in AS 4454 (2003), but rather that AS 4454 provides a datum point for the characterisation of RO products. It is essential to document characterisatics such as maturity and particle size for the trial to have any value.

7.2.1.3 Experimental design

Given that performance of RO products in agricultural production systems is influenced by several factors, the research and development (R & D) program for such systems should be based on appropriate methodology i.e. scientifically based experimental design and monitoring. This will provide valid and credible quantitative and qualitative data that can be interpreted with due consideration of the effects of environmental conditions when claiming performance benefits of RO application.

Due to unforeseen changes in climatic conditions within a single growing season, across growing seasons and varying soil conditions, agricultural trials should be designed in a way that variation in climatic conditions could be taken into account in the interpretation of results. An experimental design of a scientific trial should therefore have replicated and randomised treatments. The experimental design should incorporate relevant control treatments for comparison. The type of experimental design, number of replications and plan of statistical analysis should be best determined with advice from a biometrician.

Recycled organics products specifications and application rate should aim to maximise benefits such as moisture retention, nutrient contribution, reduced erosion and weed suppresion. Products should also be selected such that at the preferred application rate (e.g. for moisture retention), the same level of available nutrients to plants across the growing season are applied. Recycled organics products release different nutrients at different rates across a number of years, this may require the addition of supplementary fertilisers regime. Nutrient budgeting must be considered for all treatments so that total nutrients added to each treatment via composted products and/or mineral fertilisers meet nutritional requirements of fruit trees and aims to provide the same level of nutrients in all treatments. If such nutrient budgeting is not considered, then the trial is actually testing the response to different levels of available plant nutrients for the RO products and control treatments. Such introduction of an unquantified variable will make interpretation of results very difficult.

7.2.1.4 Product specification and application rates

Results of research using various RO products and fruit crops have shown that mulching depth of 10 cm and greater are more effective in weed suppression and reducing evaporation of water from the soil surface, but greater rates also have the potential to have other undesirable effects as discussed earlier. The following combination of treatments are proposed, and advice from a professional biometrician is recommended for confirmation of trial design and layout before establishment of trials. This is important in palnning the statistical analysis that will be used for field trial results. The combination of the following treatments is proposed for the future investigations as presented in Table 7.1.

Table 7.1. Proposed treatments for future investigations.

Treatments	For establishing fruit trees	For established fruit trees
Different fruit types (pome, stone, citrus and berries)	√	√
Different rates of RO product application	Three rates of soil conditioners applied at the time of planting: 1. 1st rate - calculated based on tree's nutrient requirements and taking into account mineralisation of organic matter in RO products and availability of nutrients for plant use; 2. Half application rate of treatment 1; 3. Two times application rate of treatment 1; 4. Control with no soil conditioner. Treatments above should be assessed with the addition of 10 cm mulch, and with no mulch.	Three mulching rates –10, 12.5 and 15 cm depths applied in late autumn/early winter, plus control treatment with no mulch. • Annual supplementary application of fertiliser to maintain equivalence in terms of nutrient availability with that of control treatment. • Particle size, maturity and toxicity should be appropriately documented, and same for the three mulch treatments.
Width of mulch in a row	Total 1.5 and 2.0 m	Total 1.5 and 2.0 m
Herbicide and non herbicide	√	√
Irrigated and non irrigated situations (where irrigated-schedule irrigation to maintain equivalent soil moisture for all treatments)	√	√
Control (managed as per "normal" management practices)	√	√

7.2.2 Monitoring requirements and plan of analyses

Long term and appropriate observation, measurements and analyses are essential for the success of a scientific trial in an agricultural production system, and for statistically significant results which can be used to claim performance benefits of RO products. The following monitoring program for 5 years after application of soil conditioner and/or surface mulches is proposed. This program can be amended to suit local conditions, facilities, budget and research objectives. It is not intended to monitor all parameters listed in Table 7.2 in a single trial. Table 7.2 lists all parameters that are most likely to be monitored in a fruit orchard trial. Researchers should select specific monitoring parameter/s for specifically desgined trial/s. For example a trial designed to study weed suppression for an orchard should measure weed cover and species over time, and record the use of herbicides and/or other chemicals, type of composted product used and depth of application in all treatments including control (un-mulched).

Table 7.2. Proposed monitoring requirements and plan of analyses.

Monitoring requirements and frequency	Establishing trees	Established trees
Observation during growth season every year of experimental trial		
Observation of incidence of pests and diseases (weekly)	√	√
Observation of overall crop health (weekly)	√	√
Observing crop stress in hot climates (weekly)	√	√
Observation of frost risk/damage in cool climates (winter time weekly)	√	√
Recording environmental parameters during growth season every year of experimental trial		
Soil moisture (weekly)	√	√
Soil temperature (weekly)	√	√
Amount of irrigation water applied to maintain equivalent soil moisture levels in all treatments (on irrigation event)	√	√
Rainfall and air temperature (after rainfall and weekly)	√	√
Recording weed suppression during growth season every year of experimental trial		
Weed growth and weeds species (initially 2 months after mulch application and thereafter every month until harvest)	√	√
Herbicide application	√	√
Crop monitoring during growth season every year of experimental trial		
Different stages of tree growth (growth stages)	√	√
Stem diameter (initial and then every month until harvest)	√	√
Number of shoots, shoot length and number of nodes, buds per node and bud weight (during growth stages)	√	√
Pruning weight (after pruning)	√	√
Plant uptake of major nutrients during growth season every year of experimental trial		
Recording fertiliser application/reapplication to maintain nutritional requirements of fruit trees for all treatments	√	√
Measurement of N, P and K in leaf petioles during growth season (monthly). Heavy metal levels should be measured in leaves if RO products used had significantly high concentrations of these metals.	√	√
Fruit yield and fruit quality at harvest time every year of experimental trial		
Timing of fruit maturity when ready to harvest	√	√
Fruit yield (fresh fruit weight per tree, total fruit number, fruit grading according to size or weight of each fruit and percentage of each fruit size to total fruit number).	√	√
Nutrient contents in fruits (if required)	√	√
Fruit quality specific for each fruit type (may be sugar content, juice pH, juice acidity, firmness, colour, starch, etc.). Heavy metal levels should be measured if RO products used had significantly high concentrations of these metals.	√	√
Storage quality at the end of harvest every year		
Storage quality (specific for each fruit type)	√	√
Soil monitoring during experimental period		
Soil microbial and earthworm activity at two depths (consult soil microbiologist for detailed method/plan)	√	√
Soil bulk density, available water capacity, infiltration and soil structure at the beginning and end of the trial at two depths (0-10 and 10-20 cm)	√	√
Soil chemical properties at two depths (0-10 and 10-20 cm) Soil pH, EC, SOM, CEC, total major elements after 2nd and 5th years of RO products application. Heavy metal levels should be measured if RO products used had significantly high concentrations of these metals.	√	√
Nutrient releases (Nitrates, available P and K) during crop growth at two depths (0-20 and 20-40 cm) every year during trial period.	√	√

7.2.3 Reporting of trial outcomes

Trial reports commonly state only that “compost” was applied. Reports must specify the relevant characteristics of the product applied, its specific characteristics including particle size, maturity and chemical characteristics, application rate and whether the compost product was applied as a surface application, or incorporated into the soil. Reports must specify soil type and environmental conditions. Reports must specify whether compost application treatments have had the same, reduced level or no supplementary fertiliser/herbicide applied (to allow comparison with other treatments). Without such information, the reported results are inconclusive at best.

7.2.4 Demonstration trials

Demonstration trials should ideally be implemented after scientific trials, where such demonstration sites intended to demonstrate specific performance outcomes that have already been proven by scientific trials. Demonstration trials should be conducted on influential orchards in prominent fruit production regions.

Fruit orchards should be selected for demonstration trials on the basis of criteria which seek to maximise uptake of the practice of approprite RO application. Such criteria include consideration of location, soil type, fruit type and variety and climatic conditions that are most relevant to the opportunities for uptake of RO use in the region. The reputation (i.e credibility) and enthusiam of the grower may also need to be taken into account, as these factors can be very relevant to the level of influence that the trial can have on uptake of alternative growing practices in the region.

Demonstration trials may also provide opportunities to work closely with enthusiatic growers to resolve practicalities associated with application and integration of RO use into existing farm management practices.

7.3 Standard performance categories for designing and assessing research plans

Review of the trial reports and applied experience has led to the development of a number of standard performance categories and monitoring parameters for consideration in designing recycled organics product application field trials to inform cost-benefit analysis and environmental impacts.

The performance categories presented in Table 7.3 provide a framework for structuring, interpreting and reporting performance data that can speak with meaning to growers. The monitoring parameters within each of these performance categories can provide quantitative and/or qualitative data that will assist to carry out cost-benefit analysis and identification of environmental impacts (whether beneficial or detrimental).

Table 7.3 supports the integration of monitoring parameters with specific trial objectives. The table provides a guide that allows researchers and the relevant industry and/or government client to transparently identify, prioritise cost and manage research trials. Use of this table allows clients to specify required deliverables, to compare different research trial proposals, to clearly identify whether proposals are relevant to needs/objectives, to have realistic expectations from limited budgets, to share responsibility for outcomes, and to evaluate project delivery. The use of this template is recommended for both industry and government to ensure research plans are transparent and relevant to project objectives. The structure of performance outcomes provided in the table is recommended for reporting of product application trials and for conducting cost-benefit analysis in a manner that is relevant to identifying, aggregating and communicating results from different trials.

7.3.1 Research and development priorities

Table 7.3 is not intended to be absolutely comprehensive, nor to be applied prescriptively. All parameters are not necessarly desirable nor affordable for monitoring in all trials. It is suggested that future trials should target specific monitoring parameter/s and those parameters be studied in specific trials throughly over a long time (3-6 years). Based on the knowledge gathered from this review, the following monitoring parameters have been identified to be given priority in consideration for future R & D programs:

- Trials should be of relevant duration. Soils, climatic conditions, characteristics of recycled organics products, and farm management practices are known and documented. Recycled organics products selected are of optimum characteristics to maximise agricultural performance and cost-benefit advantage.
- Reduced irrigation water usage - Quantification of the increase in soil moisture arising as a result of application of composted mulches and composted soil conditioners and evaluation of the relationship between increase in soil moisture and irrigation water savings in properly managed irrigation systems.
- Reduced fertiliser application – Quantification of the release and availability of major nutrients (N, P and K) for plant use through application of composted mulches and composted soil conditioners.
- Duration of weed suppression – Quantification of weed suppression over time from different depths of composted mulches.

Table 7.3. Standard performance categories and monitoring parameters for consideration in RO product application trials to inform cost benefit analysis and environmental impacts.

Field trial monitoring parameters				
Risk of crop failure	**Increased farm revenue**	**Reduced costs in farm management**	**Increased farm capital value**	**Environmental impacts[2]**
Frost risk • Increased frost risk for surface mulch applications in cooler climates **Crop stress** • Reduced crop stress in hot climate • Variation in crop yield **Crop failure** • Change in germination rate • Incidence of pest and/or diseases • Complete crop failure	**Crop yield (per ha, per input)** • Increased vigour • Increased weight of crop/fruit harvested for sale • Increased number of crop/fruit harvested for sale • Increased size of crop/fruit harvested for sale **Crop quality** • Improved crop/fruit quality parameters specific for each crop/fruit type • Improved crop/fruit quality parameters for storage purposes • Improved crop/fruit quality parameters for processing • Change in heavy metal contents in crop/fruit relative to MPC where low quality (with high heavy metals concentrations e.g. contaminant C grade product) products are applied **Time to market** • Duration to reach first productive cropping • Timelines of maturity (relative to optimum for best price at market) **Ability to continuously grow crops (ability to get crop in)** • Related to soil moisture • Related to soil structure/chemistry*	**Weed suppression** • Reduced number of weeds or weed coverage/time • Reduced specific weed species • Reduced herbicide applications* • Duration of weed suppression benefit **Reduced irrigation water usage** • Increased volumetric soil moisture/time • Increased plant available soil moisture/time[1] • Extent and duration of water efficiency benefit **Reduced fertiliser application** • Contribution to plant nutrients in the soil over time • Reduced application and/or reapplication of fertiliser side dressings* • Nutrient loss due to leaching* • Rate of nutrient releases/time **Reduced other farm management inputs** • Reduced effort/ machinery input/ monitoring or products* **Incidence of pest and diseases** • Reduced incidence of pests • Reduced incidence of soil borne plant diseases • Reduced use of pesticide applications*	**Improved soil biological properties** • Increased total biomass of bacteria, fungus, and actinomycetes • Increased activity of microorganisms • Increased activity of enzymes • Increased earthworm activity **Improved soil chemical properties** • Improved pH & EC • Increased SOM and CEC* • Total and plant available nutrient content • Rate of nutrient releases/time • Increased content of heavy metals in the soil where low quality products are applied (with high concentrations of heavy metals e.g. contaminant C grade product) **Improved soil physical properties** • Improved soil bulk density • Improved soil structure* • Improved water infiltration • Increased plant available water capacity • Reduced susceptibility to erosion*	**Ecological integrity and biodiversity** • Sustained soil health • Reduced water usage leads to increased environmental flows in rivers and improved water quality hence lead to ecological integrity and biodiversity of water resources • Reduced impact on water quality (resulting from reduced erosion and nutrient leaching) **Resource depletion** • Reduced use of agricultural chemicals and fertilisers leads to reduced resource depletion • Reduction in soil structure decline • Reduction in topsoil loss • Reduction in soil organic carbon loss **Global warming** • Reduced use of agricultural chemicals and fertilisers hence reduced production of fertilisers and agricultural chemicals leads to reduced greenhouse gas emissions • Sequestration of carbon in the soil leads to reduced global warming **Soil erosion** • Improvement in soil physical properties leads to reduced soil erosion **Eutrophication** • Slow and sustained release of nutrients leads to reduced nutrient leaching hence reduced eutrophication of water resources

1. Plant available water measurement evaluates potential water savings
2. A number of parameters included in other columns are also applicable here, therefore these parametrs are marked with *

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Section 9 Glossary

All terms defined in this glossary are based upon definitions given in the Recycled Organics Industry Dictionary and Thesaurus, 2nd Edition (2002) unless otherwise noted.

Term	Definition
Agricultural organics	Any residual organic materials produced as by-products of agricultural and forestry operations, including: weeds (woody and non-woody); animals (processing residuals, stock mortalities, pests), and crop residuals (woody and non-woody), and manures.
Australian Standard	A Standard is a published document, which sets out specifications and procedures designed to ensure that a material, product, method or service is fit for its purpose and consistently performs the way it was intended to.
Bacteria	Microscopic single celled organisms occurring everywhere in nature. Theycan be harmful (cause diseases in plants and animals) and beneficial (decompose organic matter in the soil or compsoting pile or fix nitrogen on legumes from atmosphere).
Biosolids	Organic solids or semi-solids produced by municipal sewage treatment processes. Solids become biosolids when they come out of an anaerobic digester or other treatment process and can be beneficially used. Until such solids are suitable for beneficial use they are defined as waste-water solids. The solids content in biosolids should be equal to or greater than 0.5% weight by volume (w/v). Biosolids are commonly co-composted with garden organics and/or residual wood and timber to produce a range of recycled organics products.
Buffer zone	An area of vegetated land located between development site and a drainage line, creek, river or sensitive area.
Carbon to nitrogen ratio (C:N ratio)	The ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material. Material with a large ratio (20:1) will break down slowly, while a small ratio (8:1) will quickly breakdown. Composted material with high C:N ratio when incorporated into the soil may cause a temporary nitrogen deficiency.
Carbon sequestration	Natural or man-made processes that remove carbon from the atmosphere and store it for extended periods or permanently. A store of sequestered carbon (e.g. forest or soil) is known as a carbon sink.
Cation exchange capacity	The ability of a soil to hold cations, preventing them from being leached. Soils with high clay and organic matter and low sand have high cation exchange capacity.
Clay	Soil particles less than 0.002 mm in diameter.
Compost	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation and a specified level of maturity. Compost is suitable for the use as soil conditioner or mulch and can improve soil structure, water retention, aeration, erosion control, and other soil properties.
Compostable organics	Compostable organics is a generic term for all organic materials that are appropriate for collection and use as feedstocks for composting or in related biological treatment systems (e.g. anaerobic digestion). Compostable organics is defined by its material components: residual food organics; garden organics; wood and timber; biosolids, and agricultural organics.
Composted fine mulch	Any pasteurised product, which has undergone composting for a period of not less than 6 weeks (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Composted fine mulch has not more than 15% by mass of its particles with a maximum size above 15 mm.
Composted mulch	Any pasteurised product, which has undergone composting for a period of not less than 6 weeks (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Composted mulch has at least 70% by mass of its particles with a maximum size of greater than 15 mm.
Composted products	An organic product that has undergone controlled aerobic and thermophillic biological transfpormation to achieve pasteurization and a specified level of maturity.

Term	Definition
Composted soil conditioners	Any composted product, including vermicast, manure and mushroom substrate, that is suitable for adding to soils. This term also includes 'soil amendment', 'soil additive', 'soil improver' and similar terms, but excludes polymers which do not biodegrade, such as plastics, rubber and coatings. Soil conditioner has not more than 20% by mass of particles with a maximum size above 16 mm.
Composting	The process whereby organic materials are pasteurised and microbially transformed under aerobic and thermophilic conditions for a period not less than 6 weeks. By definition, it is a process that must be carried out under controlled conditions yielding mature products that do not contain any weed seeds or pathogens.
Cover crop	A crop that is grown to reduce soil erosion, conserve nutrients, and provide organic matter. A cover crop may also be grown to nurse or protect another tender species until it is established.
Cultivation	Working the soil with implements in order to prepare it for sowing of crops.
Decomposition	The breakdown of organic waste materials by micro-organisms.
Demonstration trials	Demonstration trials are designed to demonstrate specific performance outcomes that have been proven by scientific trials.
Denitrification	An anaerobic biological process, which converts nitrogen, compounds to nitrogen gas or nitrous oxide.
Dry matter	The portion of a substance that is not comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%).
Electrical conductivity	A measure of a solution's ability to carry an electrical current; varies both with the number and type of ions contained in the solution. Usually measured in deci-Siemens per metre ($dS\ m^{-1}$).
Enterprise	The production of a particular commodity, for example oranges
Erosion	The wearing away of the soil by water or wind. This may be natural or induced by land management practices.
Evapotranspiration	Removal of moisture from soil by evaporation and by transpiration by plants growing in the soil.
Exchangeable cations	Cations that are held by electrical charge to negatively charged clay or humus surfaces in the soil and can be exchanged with other cations in the soil solution.
Extensive agriculture	Refers to the market segment within the recycled organics sector, which incorporates: Pasture Farming, Broadacre Farming, and Forestry Farming.
Fallow	A farning practice in which land is left without a crop or weed growth for extended periods to accumulate soil moisture.
Feedstock	Organic materials used for composting or related biological treatment systems. Different feedstocks have different nutrient concentrations, moisture, structure and contamination levels (physical, chemical and biological).
Fertiliser	A substance that is added to the soil to supply essential nutrients for plant growth. Fertilisers may be natural or manufactured.
Field capacity	The amount of water remaining in the soil after free draining due to gravitation. It is the maximum amount of water that a soil can hold under free drainage conditions.
Fine mulch	Any composted and pasteurised organic product (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Fine mulch has more than 20% but less than 70% by mass of its particles with a maximum size above 16 mm and complies with the appropriate criteria.
Food organics	The food organics material definition is defined by its component materials, which include: fruit & vegetable material; meat & poultry; fats & oils; seafood (including shellfish, excluding oyster shells); recalcitrants (large bones >15mm diameter, oyster shell, coconut shells); dairy (solid and liquid); bread, pastries & flours (including rice & corn flours); food soiled paper products (hand towels, butter wrap); biodegradables (cutlery, bags, polymers). Such materials may be derived from domestic or commercial and industrial sources. The definition does not include grease trap waste. Food organics is one of the primary components of the compostable organics stream.
Garden organics	The garden organics material definition is defined by its component materials including: Putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs; stumps and rootballs. Such materials may be derived from domestic, commercial and industrial and commercial and demolition sources. Garden organics is one of the primary components of the compostable organics stream.

Term	Definition
Hard setting soils	A soil that compacts hard when dry. A hard setting soil can lead to erosion.
Heavy metals	A group of metallic elements that include lead, cadmium, zinc, copper, mercury, and nickel. Can be found in considerable concentrations in sewage sludge and several other waste materials. High concentrations in the soil can lead to toxic effects in plants and animals ingesting the plants and soil particles.
Herbicides	Agents used to inhibit plant growth or kill specific plant types.
Humic acids	The chemical or biological compounds composed of dark organic substances that are precipitated upon acidification of a basic extract from soil or compost.
Humus	The dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter.
Immobilisation, nitrogen Or Nitrogen Drawdown Index or Nitrogen Drawdown	Conversion of nutrient compounds from an inorganic form, available to plants, into the organic tissue of microorganisms (or other plants). The nutrients are unavailable until the microorganisms die and the microbial tissues containing these nutrients decompose. Nitrogen immobilisation occurs when materials with a high C:N ratio are land applied. The microorganisms that use the carbon also assimilate the available nitrogen, rendering it unavailable to plants.
Infiltration	The downward movement of water into soil. It is largely governed by the structural condition of the soil, the nature of the soil surface including presence of vegetation, and the antecedent moisture content of the soil.
Integrated Pest Management	A system of pest control that uses a combination of most appropriate control measures including pesticides, cultural, mechnical and biological means.
Intensive agriculture	Refers to the market segment within the recycled organics sector which incorporates: Nurseries – production, Nurseries – wholesale, Fruit & Orchard Growing, Market Gardening, Mushroom Farming, Turf Grass Growing, and Viticulture.
Land application	The spraying or spreading of solid, semi-solid or liquid organic products onto the land surface, or their injection below the land surface.
Land degradation	The decline in land quality caused by improper use of the land.
Macronutrient or major nutrient	An essential nutrient that is needed in relatively large amounts. For example nitrogen, phosphorus, potassium.
Micronutrients or trace elements	An essential nutrient that is needed in small amounts. Foe example zinc, copper, boron, molybdenum.
Manure	Refers to all faecal and urinary excretion of livestock and poultry that are appropriate for collection and use as feedstock materials for composting or in related biological treatment systems. This material may also contain bedding, spilled feed, water or soil. See also agricultural organics. Such material may be derived from agricultural sources. These materials form one of the material description subcategories within the Agricultural Organics material description.
Market penetration	Strategy for selling existing or conventional products into an existing or established market.
Market segmentation	The process of dividing markets into groups of consumers who are similar to each other, but different to the consumers in other groups.
Maturation	Final stage of composting where temperatures remain steady below 45ºC, and the compost becomes safe to use with plants due to the absence of toxins.
Maturity of compost	Is related to the level of composting feedstock material receives. A mature product is stable and does not cause toxicity to plants. See also Maturation and Stability.
Mineralisation	The breakdown of organic matter into its constituent inorganic components, carried out chiefly by decomposer microorganisms, and, for carbon, during respiration when carbon dioxide is returned to the environment.
Mulch	Any composted and pasteurised product (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Mulch can be either composted mulches or pasteurised mulches. Mulch has at least 70% by mass of its particles with a maximum size of equal or greater than 16 mm.
Municipal solid waste	The solid component of the waste stream arising from all sources within a defined geographic area.
Nitrate nitrogen	A negatively charged ion comprised of nitrogen and oxygen (NO_3^-). Nitrate is a water soluble and mobile form of nitrogen. Because of its negative charge, it is not strongly held by soil particles (also negative) and can be leached away.
Nitrification	The biochemical oxidation of ammonia-nitrogen to nitrate.
Nitrogen (N)	Chemical symbol for nitrogen.

Term	Definition
Nitrogen Drawdown Index	A measure of the ability of a composted organic product to supply soils and/or plants with soluble nitrogen. See also immobilisation, nitrogen.
Nutrient availability	The relative proportion of a nutrient in the soil (or compost) that can be absorbed and assimilated by growing plants.
On farming composting	The aerobic conversion of organic materials by microorganisms with technologies based on-farm. By definition, it is a process that must be carried out under controlled conditions yielding cured products. On-farm composting systems are usually outdoors and are based on simple and inexpensive technologies, such as: turned piles, passively aerated or forcedly aerated static piles.
Organic farming	A farming based on the use of natural materials for supplying nutrients and protection to plants and animals. No chemicals such as artificial fertilisers, pesticides or herbicides are allowable for a farm, which is certified organic.
Organic matter	Chemical substances of animal or vegetable origin, consisting of hydrocarbons and their derivates.
Pasteurisation	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation, but is relatively immature and lacking in stability compared to compost.
Pasteurised fine mulch	Any pasteurised organic product (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Pasteurised fine mulch has not more than 15% by mass of its particles with a maximum size above 15 mm.
Pasteurised mulch	Any pasteurised organic product (excluding polymers which do not degrade such as plastics, rubber and coatings) that is suitable for placing on soil surfaces. Mulch has at least 70% by mass of its particles with a maximum size of greater than 15 mm.
Pasteurised products	An organic product that has undergone pasteurisation (a process whereby organic materials are treated to significantly reduce the numbers of plant and animal pathogens and plant propagules) but is relatively immature and lacking stability.
Pasteurised soil conditioner	Any pasteurised organic material that is suitable for adding to soils. This term also includes 'soil amendment', 'soil additive', 'soil improver' and similar terms, but excludes polymers, which do not degrade such as plastics, rubber and coatings. Soil conditioner has not more than 15% by mass of particles with a maximum size above 15 mm.
Pathogens	Microorganisms capable of producing disease or infection in plants or animals. Pathogens can be killed by heat produced during thermophilic composting.
Performance data	Quantification of performance benefits. For example quantifying mulching effcets on weed suppression.
Permanent wilting point	The amount of water still held in the soil when plants wilt to the extent that they won't recover even if water is added. Soils differ in the amount of water still held at permanent wilting point.
pH	A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Material that has a pH of 8 has ten times fewer hydrogen ions than a material with a pH of 7. The lower the pH, the more hydrogen ions are present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.
Phosphorus (P)	Chemical symbol for phosphorus.
Photosynthesis	The process of plants converting carbon dioxide into carbohydrates by chlorophyll using the energy of sunlight.
Plant avialable nutrient	A nutrient that can be easily taken up by palnts from the soil solution.
Plant available water	Soil moisture that can be used by plants and is held between field capacity and permanent wilting point.
Plant propagule	Plant or part of a plant that could generate a new plant, e.g. a seed, part of a rhizome, corm, bulb, etc.
Potassium (K)	Chemical symbol for potassium
Potting mix	A growing medium suitable for the establishment and development of a wide range of plants in containers.
Processing	Subjecting a substance to a physical, chemical or biological treatment or a combination of treatments. Composting, for example, is a form of processing.
Product development	Strategy for selling new or non-conventional products into an existing or established market.

Term	Definition
Pruning	Removal of plant parts to keep a better form or to control the direction and amount of growth.
Recycled Organics	The term Recycled Organics has been adopted by NSW Waste Boards and EcoRecycle Victoria as a generic term for a range of products manufactured from compostable organic materials (garden organics, food organics, residual wood and timber, biosolids and agricultural organics).
Recycled Organics Industry	A range of related business enterprises involved in the processing of compostable organics into a range of recycled organics products, and the development, assessment, marketing, promotion, distribution and application of those products.
Runoff	Rainfall that is not immediately absorbed into the soil. Water flows across the soil surface and depending on the soil condition the runoff may pick up soil particles and cause erosion.
Saturated Extract	A solution derived by saturating a soil sample with water under standard conditions for a period long enough to dissolve any salts present.
Scientific trials	Scientific trials are conducted to test the performance of particular treatments such as products, latest technologies and practices over existing or standard approaches to statistically demonstrate whether the treatment produced a significant effect or not. An experimental design of a scientific trial should be uniform, replicated, randomized and have a control for comparison.
Screening	The process of passing compost through a screen or sieve to remove large organic or inorganic materials and improve the consistency and quality of the end-product.
Selective herbicide	A herbicide that kill only certain groups of plants. For example 2, 4-D kills broadleaf plants, but not grasses.
Slaking	Breakdown of soil aggregates in water into smaller groups, or micro-aggregates.
Soil aggregate	Groups of soil particles clumped together to form the structure of the soil.
Soil buffering capacity	The ability of a soil to withstand changes in pH. Soils with high levels of clay or organic matter have high buffering capacity.
Soil conditioners	Any composted or pasteurised organic product, including vermicast, manure and mushroom substrate that is suitable for adding to soils (excluding plymers which do not biodegrade, such as plastics, rubber and coatings. Soil conditioners any be either composted soil conditioners or pasteurised soil conditioners. Soil conditioners has not more than 20% by mass of particles with a maximum size above 16 mm and complies with appropriate criteria.
Soil degradation	Soil in which the structure has been damaged, compaction or erosion has occurred. It may also refer to soil acidity and salinity and the loss of nutrients from a soil.
Soil profile	Description of each of the layers (soil horizones) in the soil. Examination of the profile is made to detremine depth, drainage, texture, structure and classification of the soil.
Soil structure	The combination or arrangement of primary soil particles into secondary particles, unit, or peds. Compost helps bind primary soil particles to improve the structure of soil.
Soil texture	A characterisation of soil type, based on the relative proportions of sand, silt, and clay in a particular soil.
Soil type	A general term used to describe the features of particular soils in terms of fertility, colour, texture and parent material.
Stability of compost	The rate of change or decomposition of compost. Usually stability refers to the lack of change or resistance to change. A stable compost continues to decompose at a very slow rate and has a low oxygen demand. See also maturation.
Subsoil	Soil in the lower horizons of the soil profile. The nature and depth of the subsoil is important for drainage and the growth of deep-growing plant roots.
Sustainability	In agriculture, sustainable practices are those, which are, and will continue to be, profitable for farmers, that will conserve soil, vegetation and water resources and protect the environment, and that will assure adequate and safe food supplies into the future.
Temperate	Plant species that grow best in cool climates, or during the cooler months of the year; (as opposed to tropical plants, which grow in warmer climates).
Topography	The shape of the ground surface, such as hills, mountains, or plains. It also refers to the slope of the land.

Term	Definition
Topsoil	The top part of the soil profile that contains the most fertile portion of the soil. It is usually darker than the subsoil, because it contains most organic matter. The topsoil is the most important part of the soil for agriculture, and must be protected by wise management regime surface layer of soil from grassland, bushland or cultivated land.
Toxicity	The potential or ability of a material to cause adverse affects in an organism.
Vermicast	Solid organic material resulting from the biological transformation of compostable organic materials in a controlled vermiculture process.
Vermiculture	System of stabilising organic materials under controlled conditions by specific worm species and microorganisms under mesophilic temperatures. Commercial vermiculture systems include: windrows or beds; stackable trays; batch-flow containers, and continuous flow containers.
Water Holding Capacity	The amount of water held in a soil after any excess has drained away following saturation, expressed as a percentage of the oven-dry weight of the soil.
Waterlogged	The condition of a soil, which is saturated with water and in which most or all of the soil air has been replaced. The condition, which is detrimental to most plant growth, may be caused by excessive rainfall, irrigation or seepage, and is exacerbated by inadequate site an/or internal drainage.
Weeds	A plant growing where it is not wanted.
Whole farm planning	A process that assists landholders to analyse the farm operation from the ecological, economic and social perspectives, and social perspectives, and integrates these in redesigning farm layout and management in order to ensure more sustainable production.
Wood and timber	The material description, Wood and Timber is defined by its component materials, which include any contaminated or uncontaminated, treated or untreated, solid or composite wood material that include: off-cuts; crates; pallets and packaging; saw dust, and timber shavings. Such materials may be derived from domestic, agricultural, commercial and industrial, and construction and demolition sources. These materials may be contaminated with paint, laminate and fasteners. See treated timber. Wood and Timber is one of the primary components of the compostable organics stream.

Appendices

Appendix 1: Detailed description of field trials using recycled organics products as surface mulches in fruit and orchard production

Appendix 2: Quality of recycled organics products used in some fruit and orchard production field trials

Appendix 3: Conversion of mulching depth and width to volume of mulch applied per hectare

Appendix 4: Detailed performance outcomes of recycled organics products used as surface mulches in fruit and orchard production

Appendix 5: Detailed description of field trials using recycled organics products as soil conditioners in fruit and orchard production

Appendix 6: Detailed performance outcomes of recycled organics products used as soil conditioners in fruit and orchard production