Application of recycled organics in mine site rehabilitation

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EXECUTIVE SUMMARY

Since the 1970s, the minerals industry in the Hunter Valley has been looking for ways to rehabilitate mining operations to meet not only the increasingly high standards set by regulatory authorities, but to match the high expectations of the community. The mining process exposes thousands of tonne of nutrient-poor waste rock, subsoils and process wastes that have to be stabilised and revegetated. The Hunter Valley mines face further difficulties with re-establishment of vegetation due to low rainfall and poor quality topsoils in some areas.

In conjunction with the imperative for effective rehabilitation, is the need to find a viable and sustainable reuse option for composts processed from garden materials such as grass clippings, prunings, and leaves. Compostable material has been separated from the waste stream since 1996 and compost products offer a potentially valuable resource, in the right market. However unless this market is identified and adopted, the compostable material, while separated, is not truly out of the waste stream. For these products to be used by industry there needs to be a commercial driver. This will come about if the product provides equal or greater benefits at a cost equal to or less than the current practices. It is important that this research identifies such uses. Public perception can also be a commercial driver.

The research program (an initiative of the NSW Department of Environment and Climate Change, Sustainability Programs Division) investigates the role of various recycled organics in successful establishment, survival and growth of eucalypt plantations. The plantation was established in March 2004

Trial aim

The aim is the trial is to increase the market for recycled organic products in mine site rehabilitation. 'Recycled organics' is a term which is used to describe composts, mulches and soil conditioners which are manufactured from compostable organic materials (garden organics, food organics, residual wood and timber, biosolids and agricultural organics).

The removal of organic material from the waste stream has an important environmental benefit, particularly in the reduction of greenhouse gas emissions. However, the composts manufactured from this diverted organic material must have a viable and sustainable market. The Department of Environment and Climate Change, Sustainability Programs Division, has funded a number of projects aimed at increasing the market intelligence and understanding of recycled organic products.

Trial Objectives

The research program investigates the role of various recycled organics in the successful establishment, survival and growth of eucalypt plantations.

The replicated block design trials 8 treatments: incorporated Biosolids (50 dry t/ha), surface applied Mulch (10cm depth along the 1m wide rows), incorporated Soil Conditioner (5cm depth), incorporated Municipal Solid Waste Compost (MSWC) (80 dry t/ha), standard Fertiliser protocol (100 g/tree NPK), Biosolids+Mulch, Fertiliser+Mulch and a control. The role that these soil amendments have in increasing tree survival and growth, maintaining soil moisture and reducing soil temperature, is being monitored.

Results

After 12 months trees in plots treated with Biosolids, and Biosolids+Mulch exhibited the best growth (both height and diameter). These were closely followed by the Fertiliser+Mulch and Fertiliser treatments. The Soil Conditioner, Mulch and Municipal Solid Waste Compost treatments had growth rates comparable to the control. However in the case of Soil Conditioner and Municipal Solid Waste Compost, survival increased compared to all other treatments and growth rates were more consistent within these treatments.

The plots were split to compare two eucalypt species, *Corymbia maculata* (spotted gum) and a clonal hybrid *Eucalyptus camaldulensis*grandis* (River red gum/flooded gum hybrid). Whist the species grew at different rates, they responded in the same way to treatment.

Soil temperature was assessed using fixed temperature probes (20cm depth). Mulch is proved the most effective in moderating soil temperature and moisture. The other organic amendments (Biosolids, Municipal Solid Waste Compost and Soil Conditioner) moderated the soil temperature but not nearly to the same extent.

Soil moisture is critical in the Hunter Valley, NSW. Average annual rainfall is 750mm, but in the last few years 500–50mm annual rainfall has not been uncommon. Soil moisture has been monitored using Time Domain Reflectometry and a Neutron Probe. The data show that Mulch is the most effective treatment in maintaining soil moisture.

The data indicate that recycled organics can have a significant role in increasing tree growth and survival, and improving soil moisture loss thus making them a valuable resource for mine site rehabilitation. Recycled organics are proving to be very effective amendments for use in the rehabilitation of open cut mine spoil and can provide nutrients whilst ameliorating the negative effects of mineral fertiliser. Organic amendments have the potential to replace or supplement mineral fertilisers.

All of the recycled organics trialled in this experiment improved either the early survival or growth of trees, but in different ways.

- Soil Conditioner and Municipal Solid Waste Compost improve survival, increases soil organic matter, soil N, available P;
- Mulch suppresses weeds, moderates soil temperature and preserves soil moisture;
- Biosolids significantly enhances growth, soil N and available P

Understanding the role of different recycled organics products in maximising the survival and growth of plantation species, allows appropriate combinations of recycled organics to be used to overcome site specific problems.

Key Words

Recycled organics, biosolids, greenwaste, mulch, compost, municipal solid waste, rehabilitation, mines, plantation, forestry, fertiliser, soil moisture, nutrition.

INTRODUCTION

Increasingly, organic residuals are becoming an option as potential fertilisers and soil amendments to improve degraded or marginal lands. Organic residuals, such as biosolids, sewage effluents, composts, animal wastes and food wastes, introduce nutrients, organic matter and moisture back into poor soils. The potential exists to use these wastes, individually or in combination, to create optimal soils on marginal lands for the establishment of any type of vegetation.

The Upper Hunter Valley has approximately 20,000 ha of land requiring rehabilitation. Overburden and spoils from open cut coal mining are characteristically alkaline, often sodic and have moderate to high salt levels (1). Heavy metals can be present in high levels. Essential plant nutrients such as nitrogen and phosphorus are commonly deficient. In the Hunter Valley, pHs of spoils are often greater than 8.5 and bind what little nutrients are present, making them unavailable for plant use.

Topsoil that is stripped before mining operations for reuse in rehabilitation is typically shallow, sandy, slightly acidic, lacks structure, contains competing weed species seed, and is low in organic material and nutrients (unless previously amended) (2). Annual rainfall in the area is also low, around 650mm.

To contend with these difficult substrates, the use of organic, nutrient-rich residual products can provide benefits as a soil amendment, topsoil substitute, or fertiliser (depending on the rate of application) such as:

- a source of plant nutrients;
- rapid establishment of microflora and microfauna needed for plant growth;
- reduced need for separate and repeated fertiliser applications; and
- improved soil structure, moisture retention, soil aeration.

The conventional best practice method for rehabilitating open cut coal mine sites is outlined in a number of handbooks for the coal industry (3, 44, 45). It consists of reshaping and contouring the spoil to stabilise and prevent erosion, removing large rocks from surface soil, adding of topsoil and seeding with a mixture of grasses and legumes. Once established, fertiliser is applied annually to the pasture and weed control is often required (4). Rehabilitation is also determined in consultation with key stakeholders including government departments and the community.

Direct seeding or tubestock planting of tree species can be used in preference to topdressing with grasses/legumes when rehabilitating raw overburden. This limits the heavy weed and pasture competition that occurs in topdressed sites. Currently, several large companies choose to direct seed hardy tree species in 30-50% of their rehabilitated areas (1). Full revegetation with tree species in preference to pasture topdressing is also better for soil retention (5).

DPI NSW (Mineral Resources) has authority over mines (and their rehabilitation) in NSW Australia. DPI have a mandatory requirement that existing stockpiled topsoil be used. This is mainly to help start the revegetation process. However, the continued growth of the plants is dependent on the quality of the underlying material or the hardy nature of the vegetation. Most mines fall short of topsoil (18-27%) due to the swell factor (4), so the quality of the nutrient poor overburdens is often the limiting factor when revegetating. An alternative option is to use topsoil substitutes or overburden/spoil enhancers, such as nutrient-rich residuals and mining process wastes.

There is extensive international literature on the use of recycled organics in agriculture, forestry and mine rehabilitation. Much of the focus is on biosolids or biosolids composts. The absence of published data from Australia is notable, though a number of studies have been conducted. Biosolids has been used in Australia in a range of landscape rehabilitation projects, agriculture and forestry research, with positive results.

While there is little formal literature, biosolids has been used as an amendment prior to establishing seedlings, direct seeding or sowing pasture on the following mines: Rix's Creek, Bloomfield, Camberwell mine, Bulga South Mine, Drayton's Colliery, Ravensworth east (owned by Macquarie Generation), Howick Mine (6, 7, 8, 9), Coal and Allied, Bayswater Power Station and Narama Mine (7, 8).

Mulches can improve forage establishment on mine spoil went they reduce water loss by reducing evaporation, protect the soil from erosion and minimise soil crusting (10, 11). Organic residuals combined with surface mulches, such as low sodium/sulphur coarse coal reject, are considered good for providing a microclimate suitable for germination, reducing crust formation and improving water infiltration (12). Also the use of amendments for improved soil stability, such as gypsum on alkaline soils and lime for acid soils, can balance mixtures.

Panwar and Bhardwaj (13) examined the effect of soil amendment and mulch on the establishment of trees in sandstone mine spoil (India). They showed that farmyard manure (FYM) when added as a soil amendment and mulch, increased survival, height and biomass, however root shoot ratio was maximum in mine spoil alone.

The addition of organic materials adds nutrients and can also improve the soil biological, physical and chemical properties. The key advantage of compost application is the replenishment of organic matter in the soil. Top-ups of conventional inorganic fertilisers (typically N) may still be required, but the improved organic carbon bank will ensure a greater efficiency of use, with losses through leaching and volatilization less likely (14).

Municipal Solid Waste Compost could be a valuable resource, however its application will be dependent on new DECC regulations on Fuel, Fill and Fertilizer due to be released in 2008. From the available literature compost rates of 70–150t/ha of MSW appear to be required to elicit a significant benefit. Cuevas et al (15) concluded that rates of 80 Mg MSW/ha are required to improve soil chemical properties.

Residuals and organic wastes have potential as fertilisers, topsoil substitutes or soil amendments in the rehabilitation of those lands. Forests NSW research trials indicate that recycled organics have a role in developing a viable commercial hardwood venture and can contribute to the soil carbon pool in a significant way.

If an alternative rehabilitation process (recycled organics and trees) proves commercially competitive, and there is a potential income source from that rehabilitation, then mining companies will be more predisposed to using that method and the associated products (eg recycled organics).

The research program investigates the role of various recycled organics in successful establishment, survival and growth of hardwood plantation species. At the conclusion of the trial, the cost benefits have been assessed against traditional rehabilitation to pasture and use of mineral fertilisers.

MATERIALS AND METHOD

Site Description

The trial is on a 5ha block of reshaped overburden at Narama Mine, Ravensworth, NSW, Australia. The mean annual rainfall average is 700–750mm. However during the trial as little as 550mm has fallen annually. The temperature varies between a mean minimum of 2°C in winter and a mean maximum of 40°C in summer. The soil is unconsolidated Permian material. It is nutritionally poor with very little organic matter and a pH of 9 to 9.3.

Plate 1. Trial site prier to establishment

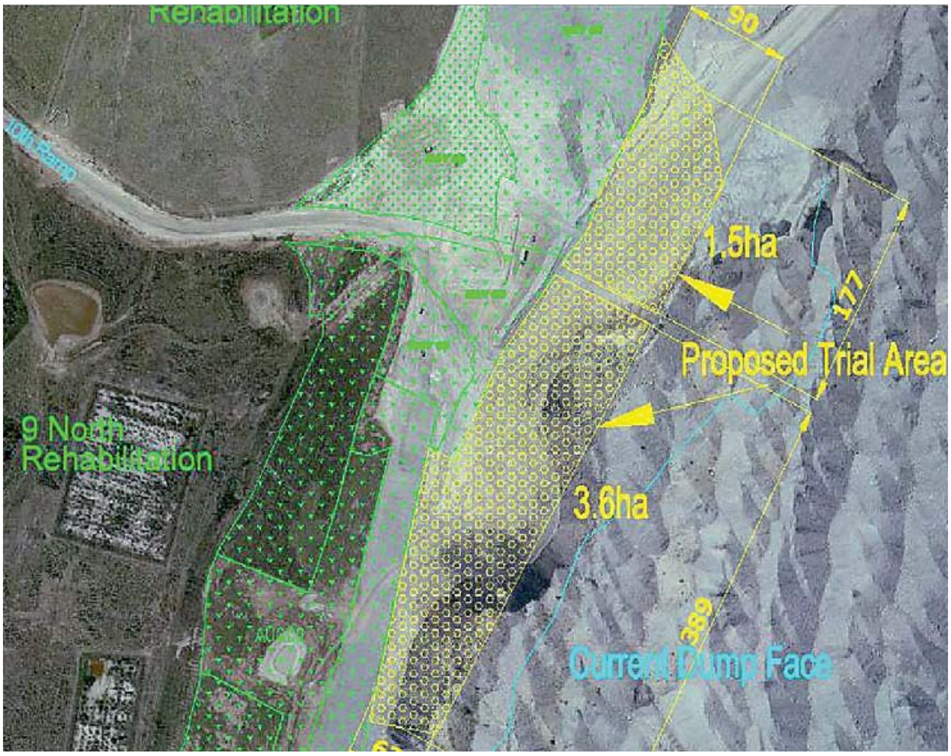


Plate 2. Reshaped overburden ready for revegetation

Treatments and Design

The trial is a replicated (four), randomised, split-block design (*E. camaldulensis*grandis* and *C. maculata*). There are eight treatments (Table 1). Parameters assessed were growth (height and diameters), weed cover, foliar nutrition, soil chemistry, soil moisture (Time Domain Reflectometry and Neutron Probe), and soil temperature.

Table 1. Experimental Treatments

Treatment	Rate	Application technique
Fertiliser	100gNPK per tree plus trace elements	Slotted 20cm from stem
Pasteurised mulch[1]	10 cm depth x 1 metre surface applied	Surface applied
Biosolids	50dryt/ha	incorporated
Fertiliser + Pasteurised mulch	100gNPK per tree plus trace elements 10 cm mulch	Slotted 20cm from stem Surface applied
Biosolids + Pasteurised mulch	50dryt/ha 10 cm mulch	Incorporated Surface applied
Control		
Municipal Solid Waste Compost[1, 2]	75 dry t/ha	incorporated
Soil Conditioner[1] (composted garden organics)	5cm depth	incorporated

[1] Rates applied at producers' recommendation;
[2] includes 4% liquid biosolids as a regular part of the composting process of this product

Whilst some products may benefit from mixing with additional fertiliser, this was not done during the trial so that the benefits of the dominant, end of process product could be determined. This was important to be able to delineate the benefits of individual 'unblended' products and not confound the results. At the operational level, recycled products may be combined or further amended with either organic or inorganic fertilisers to address site specific problems.

Site Preparation

All recycled organics amendments, with the exception of Mulch were broadcast spread and ripped into the surface 30cm (in a replicated design) (Plates 3–7).

Plate 3. Soil Conditioner

Plate 4. Mulch

Plate 5. Municipal Solid Waste Compost

Plate 6. Biosolids

Plate 7. Spreading biosolids

For the plantation establishment, the site was ripped and mounded (with single tyne and offset discs) in one pass, to a depth of 30cm. The rows were them mounded a second time as an alterative to secondary cultivation (Plate 8).

Plate 8. Ripped and mounded rows ready for planting

Rows were established at 4m spacing with trees to planted at 2.5m intervals (Plate 11). Each treatment plot was 36m (9 rows) by 30m (13 trees). The treatment plot was split for two species. Treatments (eight) were randomly allocated within each block (four replicates) (Plates 9–10)

Plate 9. Amendments across site

View of part of Rep 1, 2 and 3. Due to angle of shots, not all treatments can be seen (e.g. Fertlisre only).

Plate 10. Layout of trial

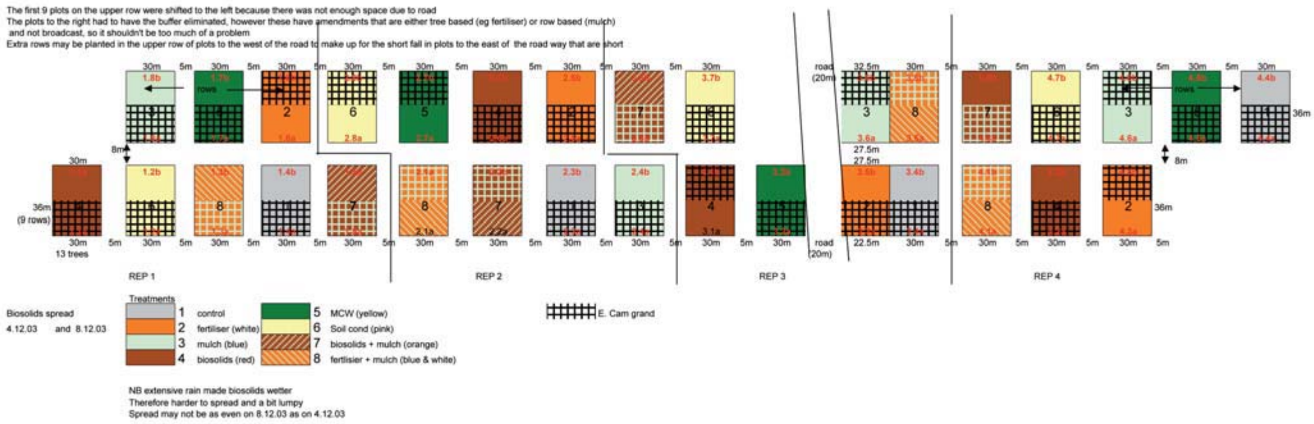


Plate 11. Planting of trial

Plate 12. Seedling in Mulch

Plate 13. Seedling in Municipal Solid Waste Compost

Plate 14. Seedling in Soil Conditioner

Sampling Regime

Plant Survival and Growth

Plants were assessed for % survival and growth (height and diameter) at establishment, 3, 6 and 12 months, 18 months, 2 years and 3 years.

Foliar Chemistry

At 12 months foliage composited samples (5 samples/tree from 5 trees/plot in the upper third of the canopy) were assessed for Tot P, Al, Tot N, Boron, C, K, Mg, K, Na, Mn, Zn, Cu, Fe.

Background Soil Contaminants

Where biosolids is to be spread, the Contaminant Loading Biosolids Application Rate (CLBAR), as outlined by the EPA Guidelines (15), must be determined prior to application. On overburden sites 20–40 sub-samples at 0–15cm are combined to produce one composite sample per 10 hectares.

Soil Chemistry

Soil was analysed at background, establishment, and then year 1 after establishment. Three samples per plot were composited from each of three replicates — resulting in three data points per treatment. Soil was sampled at four depths (where possible): 0–15cm, 15–30cm, 30–45cm, 45–60cm. The soil was analysed for the following analytes: Bray P, Total P, OM, C, Tot N, Bulk density, CEC, Al, Mg, Ca, Na, K, EC, pH.

Soil Moisture

Soil moisture was assessed across the site using Time Domain Reflectometry (TDR) and Neutron probe (NP). The TDR survey consisted of sampling at 30 points per plot, 10 on each measurement row. Three replicates of 5 treatments assessed — Biosolids, Control, Mulch, Municipal Solid Waste Compost and Soil Conditioner. There were 6 sampling events. Neutron probe access tubes (4 per plot) were installed in one replicate. Seven treatments were assessed: Biosolids, Control, Mulch, Municipal Solid Waste Compost, Soil Conditioner, Fertiliser + Mulch, Biosolids + Mulch

Soil Temperature

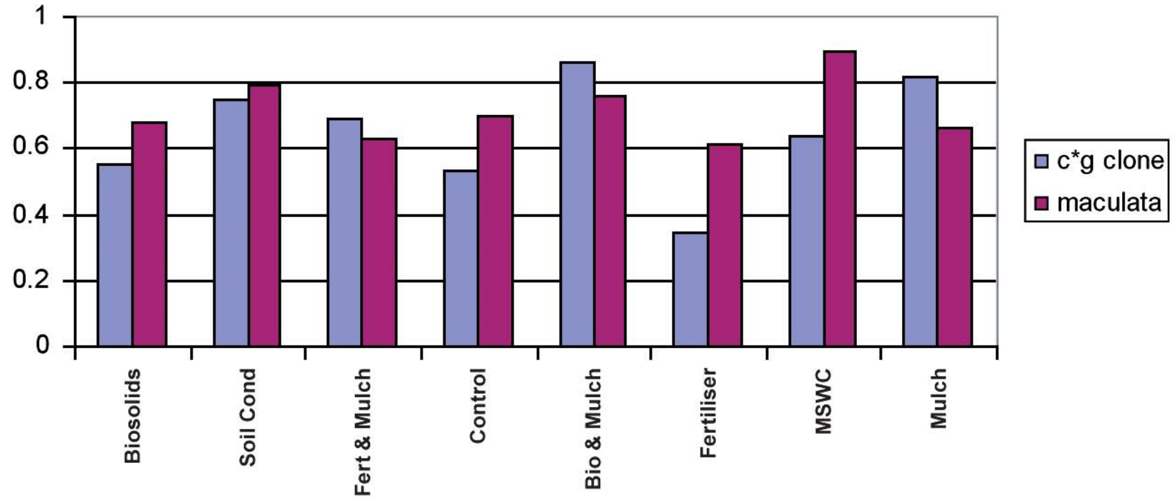
Paired temperature probes were inserted 15cm below the soil surface of the mounds in five treatments: Biosolids, Mulch Soil conditioner, Municipal Solid Waste Compost and control. These were continually monitored using a data logger for 18 months. Air temperature, rainfall, and relative humidity were also logged.

RESULTS

Survival

The critical period for survival is the first 6 months after planting. After 6 months, *C. maculata* in plots amended with Municipal Solid Waste Compost and Soil Conditioner had better survival than other treatments — though not statistically so (due to between plot variation) (Figure 1). For *E. camaldulensis*grandis* trees with Biosolids+Mulch and Mulch alone had better survival. *E. camaldulensis*grandis* is a faster growing species and appears to respond better to a moisture regime, whereas *C. maculata* spend the first few years after planting developing a large root mass and then later put on above ground biomass. The ability for roots to penetrate the soil appears to be more influential in the survival of *C. maculata*. The two treatments with incorporated compost that improves soil structure exhibited better early survival for *C. maculata* than other treatments (Figure 1).

Figure 1. Percentage Survival at 6 Months

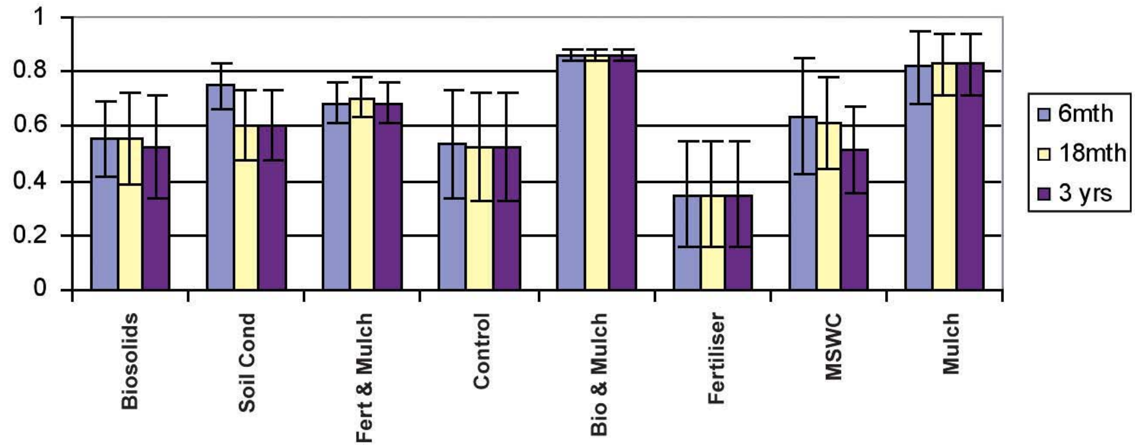


The relative response of trees to various treatments in early survival results remained consistent throughout the trial (Figures 2 and 3).

E. camaldulensis grandis's* response to a moist environment meant that plots with treatments providing a better moisture regime (Fertiliser + Mulch and Biosolids + Mulch) maintained good survival despite 3 years of below average rainfall (500–50mm). However, plots treated with recycled organics other than Mulch experienced some mortality after initial establishment (Figure 2).

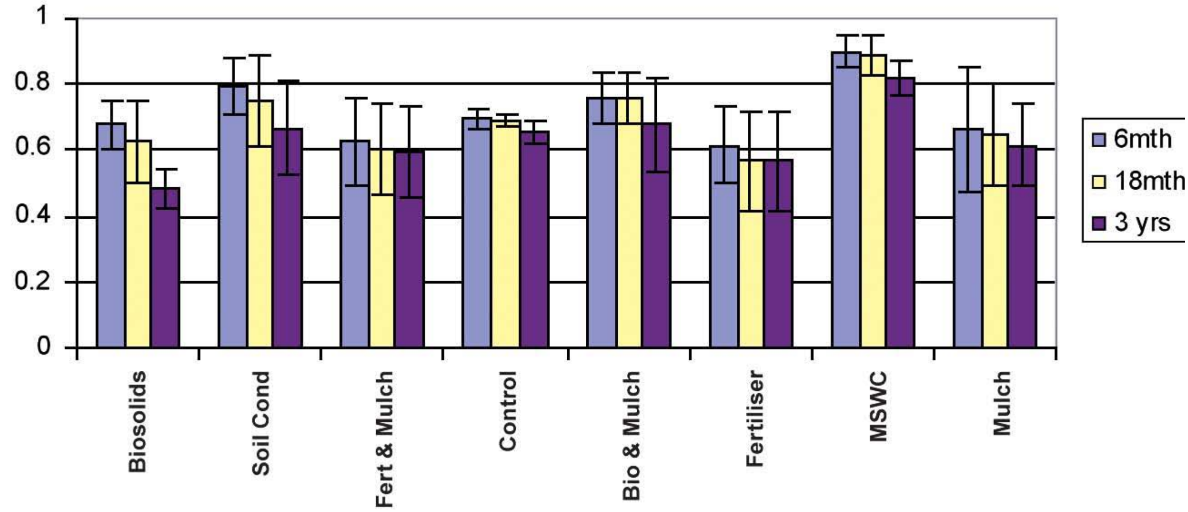
Despite this result survival of *E. camaldulensis* grandis* was better in all plots treated with recycled organics — significantly better that the control and fertiliser treatments.

Figure 2. Percentage Survival *E. Camaldulensis*grandis* over the Trial 2004–07



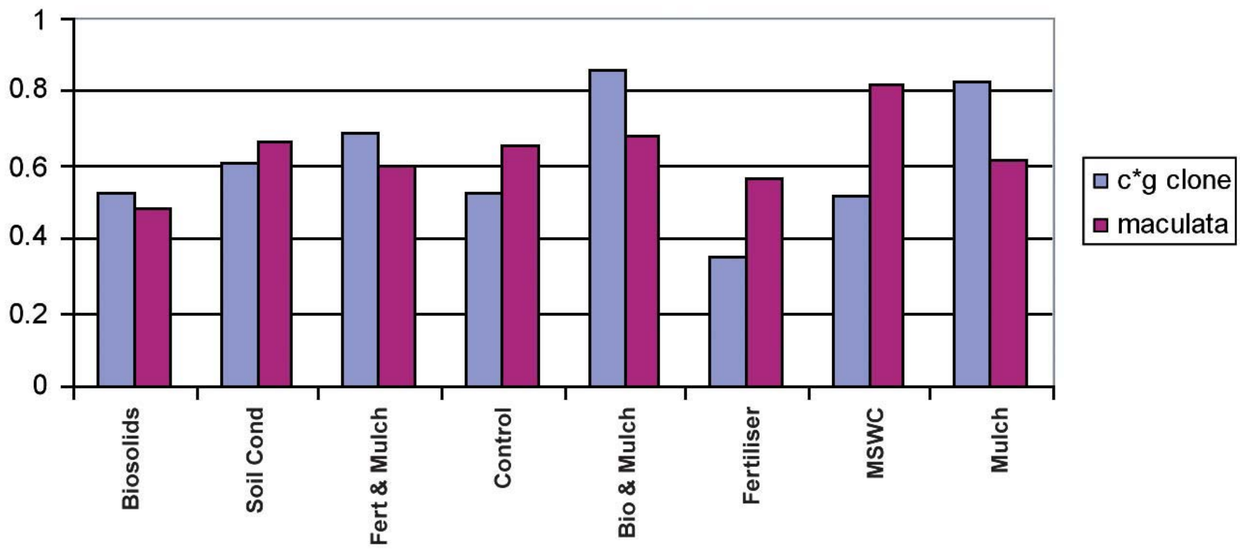
All treatments experienced some increasing mortality over the three year period of the trial, but not to a significant level. For *C. maculata* moisture seemed less critical with the Municipal Solid Waste Compost yielding the best survival results at three years (Figure 3).

Figure 3. Percentage Survival *C. Maculata* over the Trial 2004–07



At 3 years the standout treatments for assisting survival were Biosolids + Mulch, Mulch and Municipal Solid Waste Compost. For faster growing species like the eucalypt clone all recycled organics improved survival outcomes over mineral Fertiliser or Control (Figure 4). In environments where there is little moisture using mineral fertiliser resulted in less survival than applying nothing at all (Control). Without moisture the fertiliser benefits cannot be maximised and any early growth cannot be maintained.

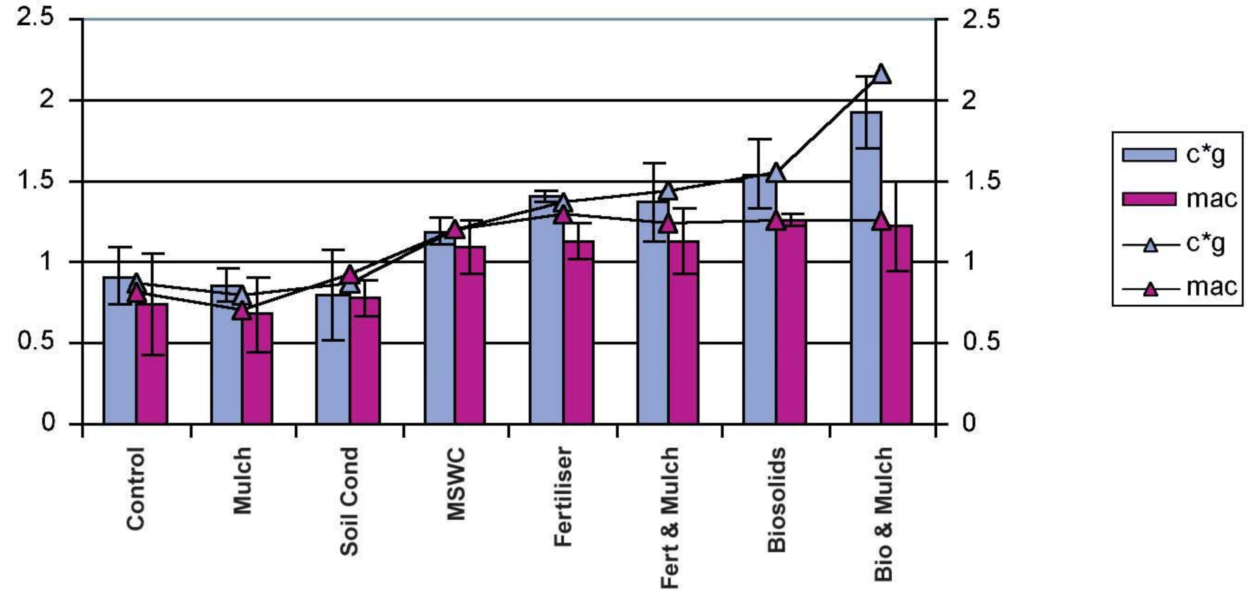
Figure 4. Percentage Survival at 3 Years



Growth

Growth response to treatments at 12 months was consistent with the response at 6 months. *E. camaldulensis*grandis* in the Biosolids+Mulch treatment responded to the amendment significantly more (height and diameter) than those with Biosolids alone, Fertiliser+Mulch, and Fertiliser alone (Figure 5). These in turn grew better than the remaining treatments. Growth in plots amended with Municipal Solid Waste Compost, Soil conditioner and Mulch were not significantly different from the control group. Whilst Soil Conditioner and Municipal Solid Waste Compost improved early survival, it did not improve early growth. For *C. maculata*, which can take 4–5 years to show significant above ground response to organic treatment (16), the Biosolids + Mulch treatment elicited the best growth response (though not to a significant extent).

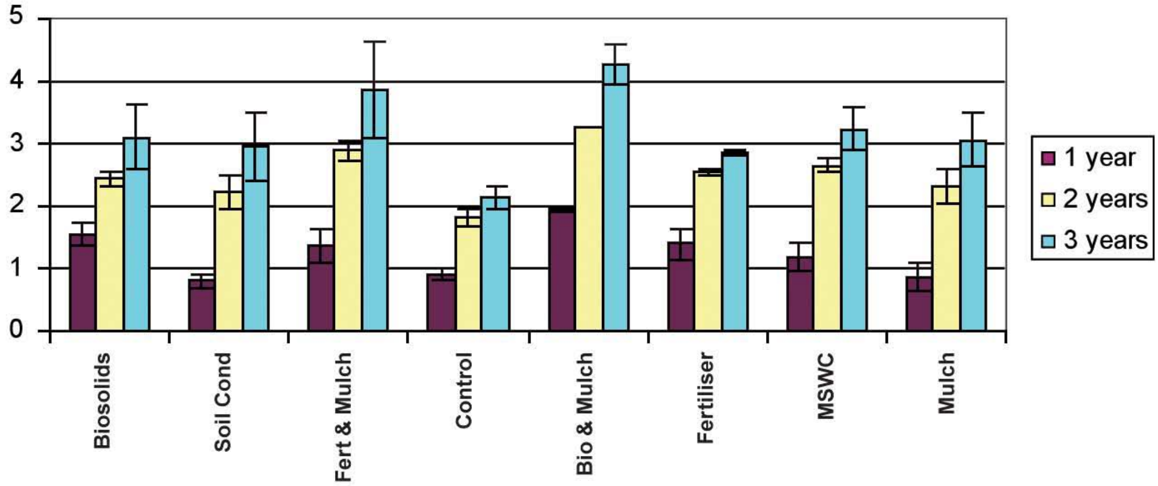
Figure 5. Effect of Treatment on Growth (height in metres) at 1 Year



The site has been experiencing drought throughout the duration of the trial. In each year *E. camaldulensis*grandis* in all treatments with mulch had the largest height increments — particularly those with inorganic or organic fertiliser (Fertiliser +Mulch and Biosolids + Mulch) (Figure 6). The Mulch was important in moderating soil temperature and maximising soil moisture.

By year 3 the treatments fall into three statistical groupings: the best treatments were Biosolids + Mulch and Fertiliser + Mulch, then all other treatments (Mulch, Soil Conditioner, Biosolids, Municipal Solid Waste Compost) which exhibited and equal growth response but slightly higher than Fertiliser, and finally the Control group which had significantly less growth than all other treatments (Figure 8).

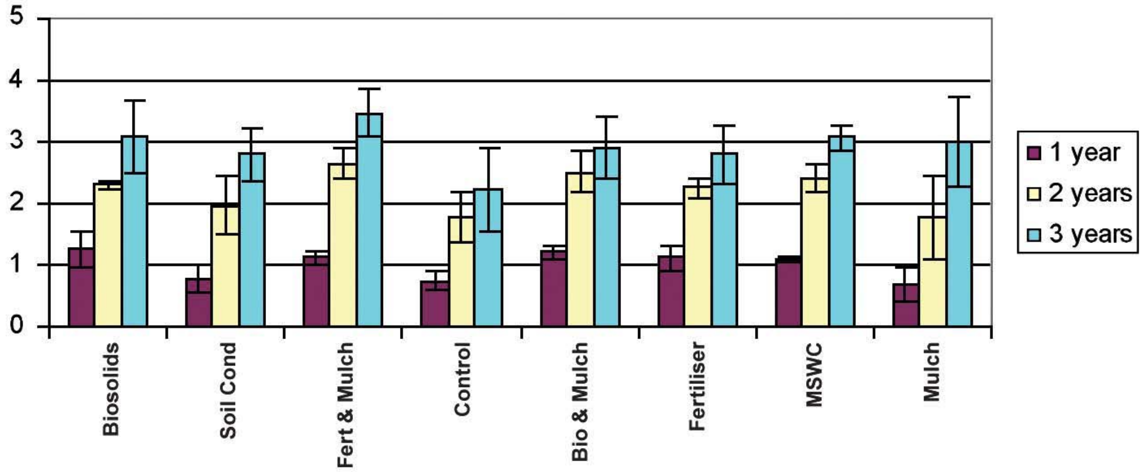
Figure 6. Effect of Treatment on Growth (height in metres) of *E. camaldulensis*grandis* 2004–07



At 12 months there were two clear and significant growths for *C. maculata* growth. The best performers were (in order) Biosolids + Mulch, Biosolids, Fertiliser, Fertiliser +Mulch and Municipal Solid Waste Compost. These were all statistically larger (height) than Soil Conditioner, Control and Mulch (Figure 7). By Year 2 there was less delineation but the three top performers were Fertiliser +Mulch, Biosolids + Mulch and MWC. These three, together with Fertiliser, Biosolids and Soil Conditioner were all significantly better (in terms of growth) than the Control and Mulch treatments.

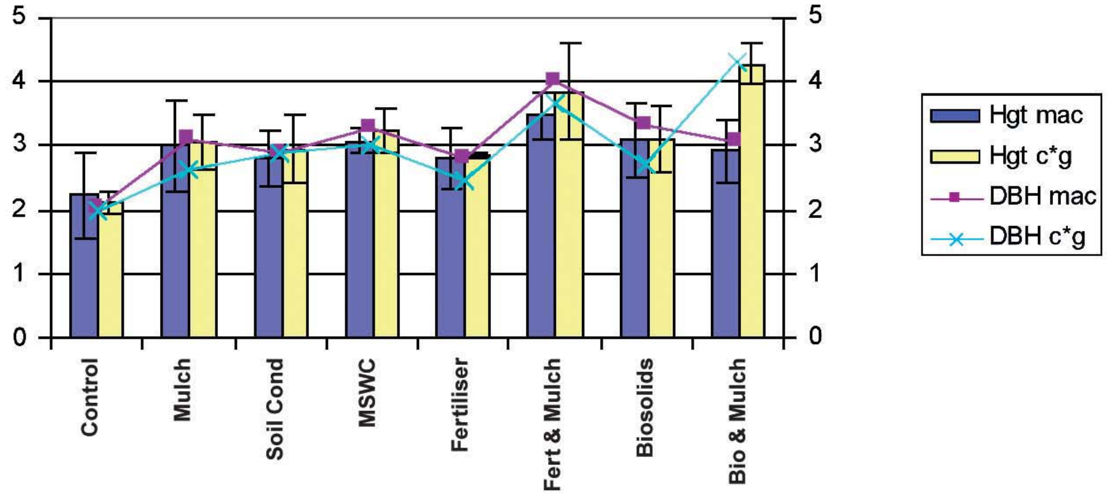
As the drought intensified the benefits of Mulch, in combination with organic or inorganic fertiliser, became more apparent. At Year 3 the treatment with the greatest height increment (yearly growth) was Mulch. For *C. maculata*, at year 3 the best treatment was Fertiliser + Mulch, this was followed by a grouping of all other treatments, with the exception of the Control group which was statistically smaller. Further treatment delineation may become apparent over time as *C. maculata* is known to begin rapid growth at around age 5 years. At this time any below ground biomass development that has been stimulated by treatment will become apparent.

Figure 7. Effect of Treatment on Growth (height in metres) of *C. maculata* 2004–07



The response of tree diameter to treatment was proportional to the height response (Figure 8).

Figure 8. Effect of Treatment on Growth (height in metres) at 3 Years

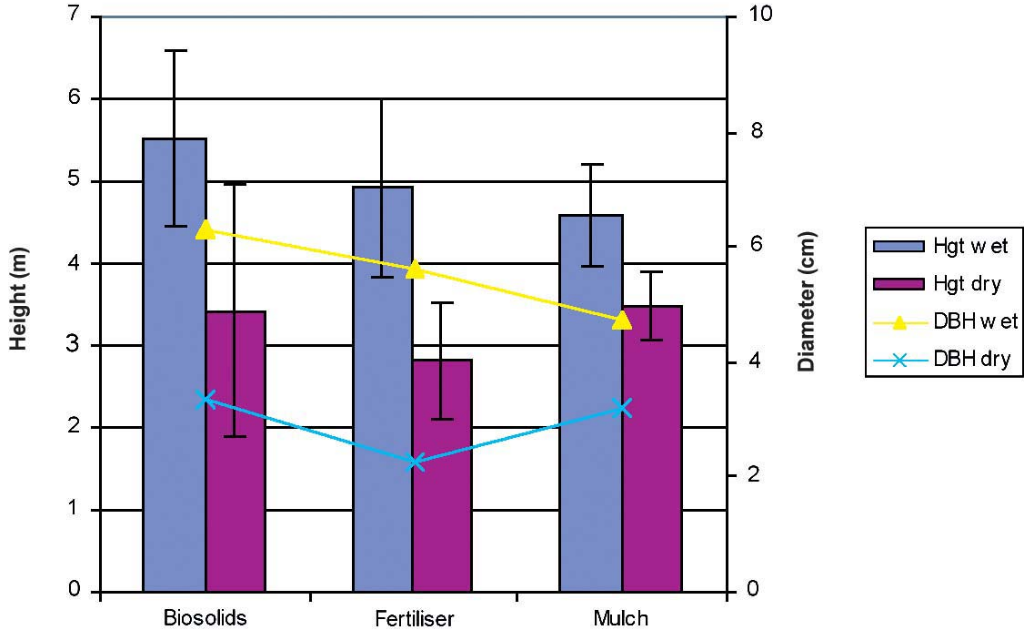


In the final analysis trees or plots considered to be outliers (generating a response independent of treatment and more than 2 standard deviations away from the mean) were excluded. The major exclusions were for plots affected by sodic alluvium. Some sections of the overburden subsided slightly resulting in pooling of water (both rain and subsurface flow). Trees affected by soak were excluded for the general analysis.

While not replicated at the plot level, the data from trees affected by soaks were analysed to give and indication of the impact of these treatments in a wetter environment.

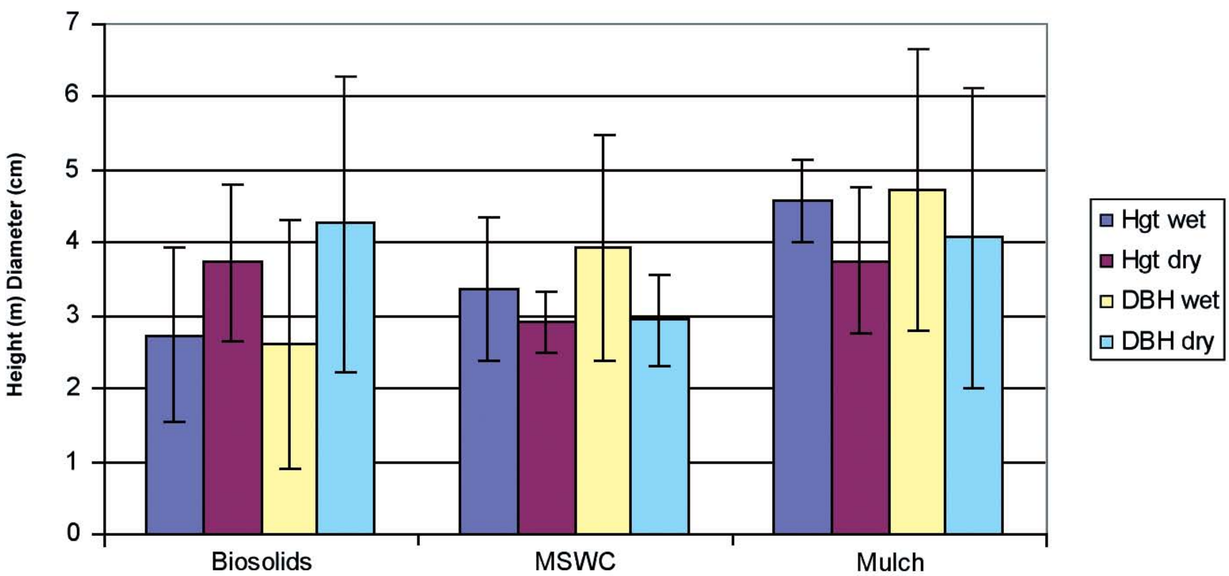
For *E. camaldulensis*grandis*, the treatments that were in soaks (ie had water) displayed a better growth response. Those treated with additional nutrient (Fertiliser or Biosolids) grew best. The relative impact of mulch in a moisture limited environment was negated (Figure 9).

Figure 9. Effect of 'Watering' on Growth at 3 Years — *E. camaldulensis*grandis*



For *C. maculata* data showed similar trends (Figure 10). However the trees in Biosolids plots were soaking in water for most of the time and for *C. maculata* this was deleterious. The *E. camaldulensis*grandis* (River red gum* Flooded gum) coped with inundation. In addition the 'watered' rows of *E. camaldulensis*grandis* were not as badly effected.

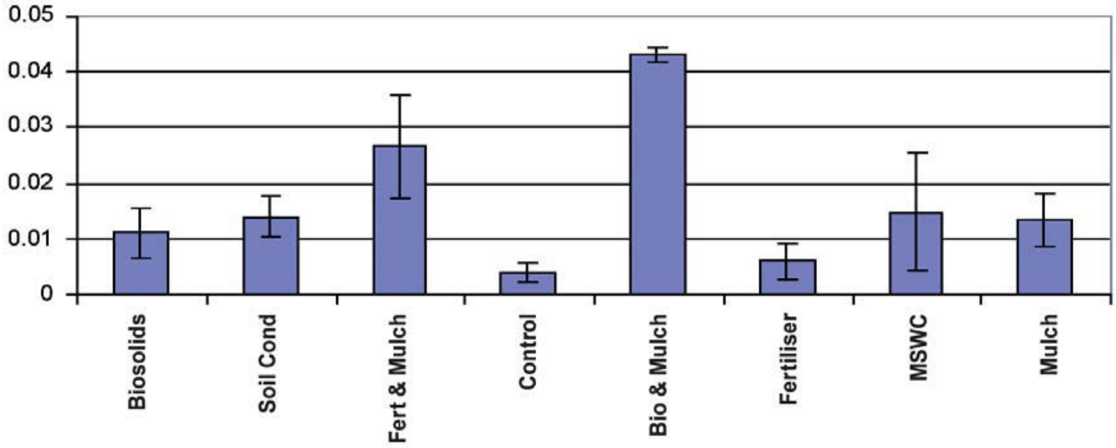
Figure 10. Effect of 'Watering' on Growth at 3 Years — *C. Maculata*



Basal area is a parameter that combines the impacts of treatment on growth and survival. Whilst it is a calculation usually reserved for older plantations it has been implemented here to give an indication of the overall treatment effect.

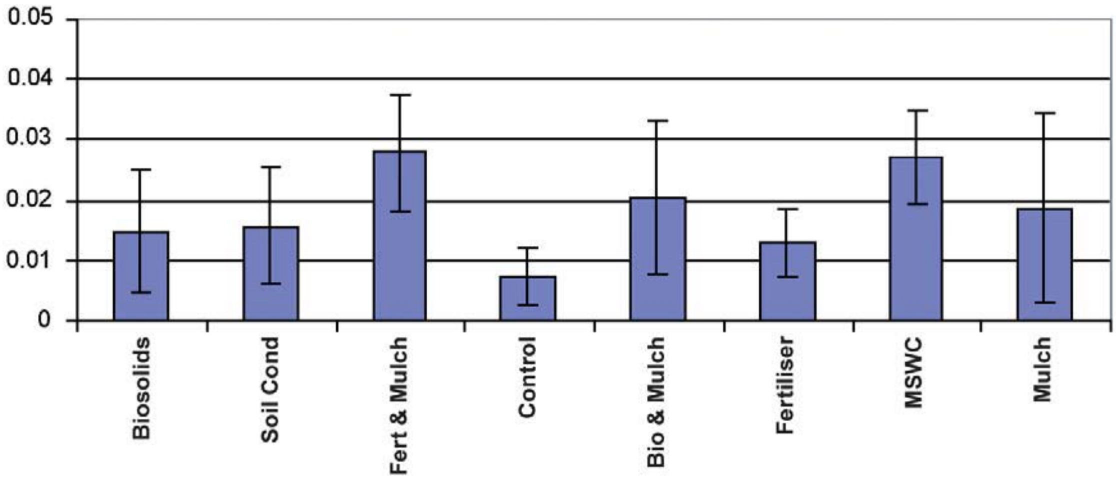
For *E. camaldulensis* grandis* the best treatment is Biosolids + Mulch (Figure 11). This is followed by Fertiliser+Mulch. The mulch is improving survival and growth (when combined with additional nutrients). The mulch retained moisture and created an environment where mineralisation of nitrogen in the biosolids is possible, thus resulting in ongoing nutrient availability. This is not the case for mineral fertiliser which is fully available in the first instance and does not persist. This explains the superior result of Biosolids + Mulch over Fertiliser + Mulch. All other recycled organics (Soil Conditioner, Municipal Solid Waste Compost, Mulch and Biosolids) had similar basal areas. Plots in the Fertiliser and Control groups were the poorest for basal area.

Figure 11. Effect of Treatment on Basal Area (in metres²) of *E. camaldulensis*grandis* at 3 Years



The relative basal area response of *C. maculata* was similar to *E camaldulensis*grandis*, but to a lesser extent, the exception being Municipal Solid Waste Compost which had one of the highest basal areas (Figure 12). The control group was again the poorest for basal area. Inorganic fertiliser improved the basal area but not as much as the recycled organic treatments. Longer term monitoring is required for *C. maculata* to determine the true impacts of the treatments in above ground biomass.

Figure 12. Effect of Treatment on Basal Area (in metres²) of *C. maculata* at 3 Years



Basal area is an indication of overall plantation success and site occupancy. Current rehabilitation practices, using chemical fertiliser, yield very little benefit over no treatment (Control) and significantly less benefit than recycled organics. Judicious combinations of recycled organics can significantly improve the outcomes for plantations on overburden.

Foliar Chemistry

The principal nutrients used for revegetation are nitrogen phosphorous and potassium (NPK). Whilst these three nutrients will be focused upon, the full range of statistical results is given in Table 3.

The treatment effect on foliar nitrogen was consistent between species. Statistically, the best treatment for both species was Biosolids+Mulch. The next best group of treatments was Biosolids and Municipal Solid Waste Compost, followed by all remaining treatments with the Control plots being statistically the lowest for foliar nitrogen. The only three treatments to have foliar nitrogen in the adequate range were Biosolids+Mulch, Biosolids and Municipal Solid Waste Compost. The remaining treatments were all in the marginal range (Table 2, Figure 13a). Trends in foliar nitrogen remained the same at year 3, though totals had decreased over time (Figure 13b).

Figure 13a. Effect of Treatment on Foliar Nitrogen (%) at 1 Year

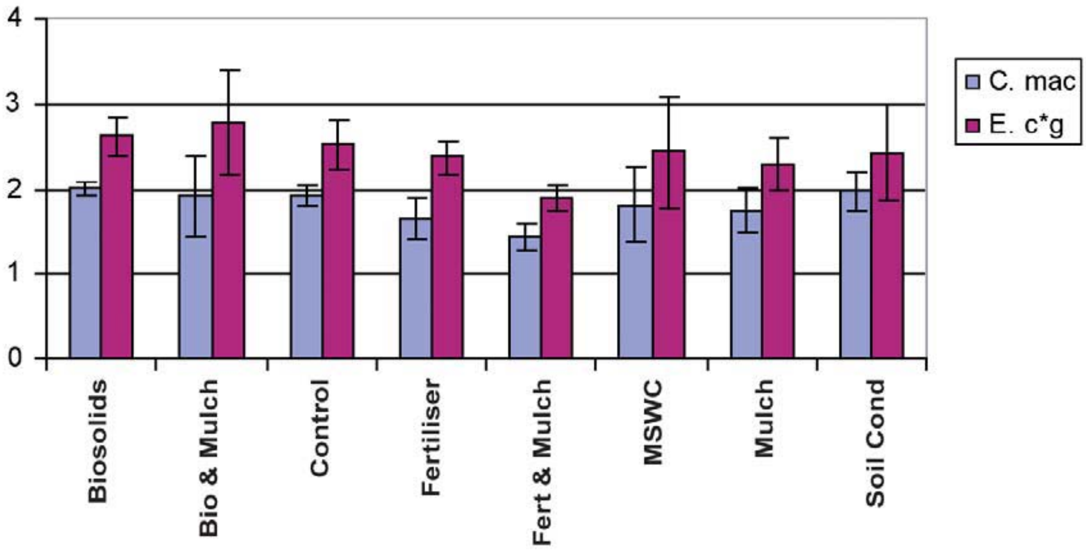
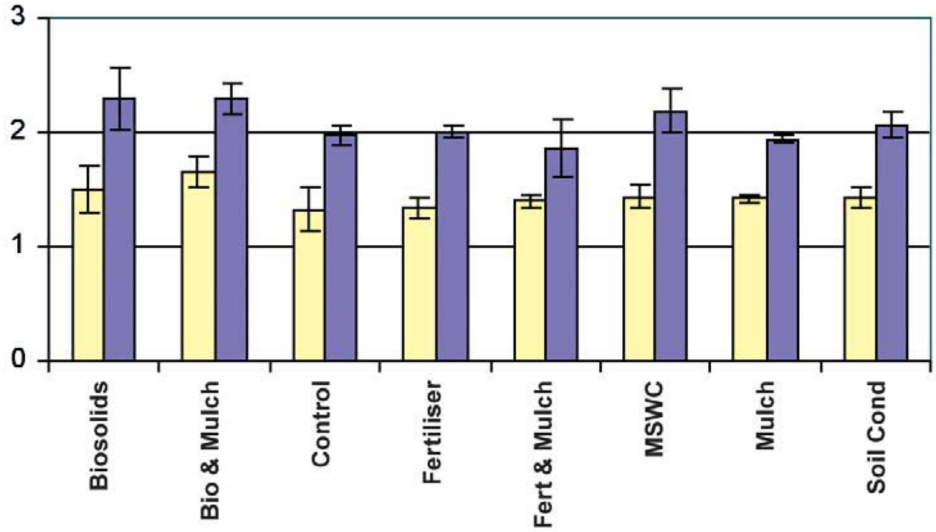


Figure 13b. Effect of Treatment on Foliar Nitrogen (%) at 3 Years



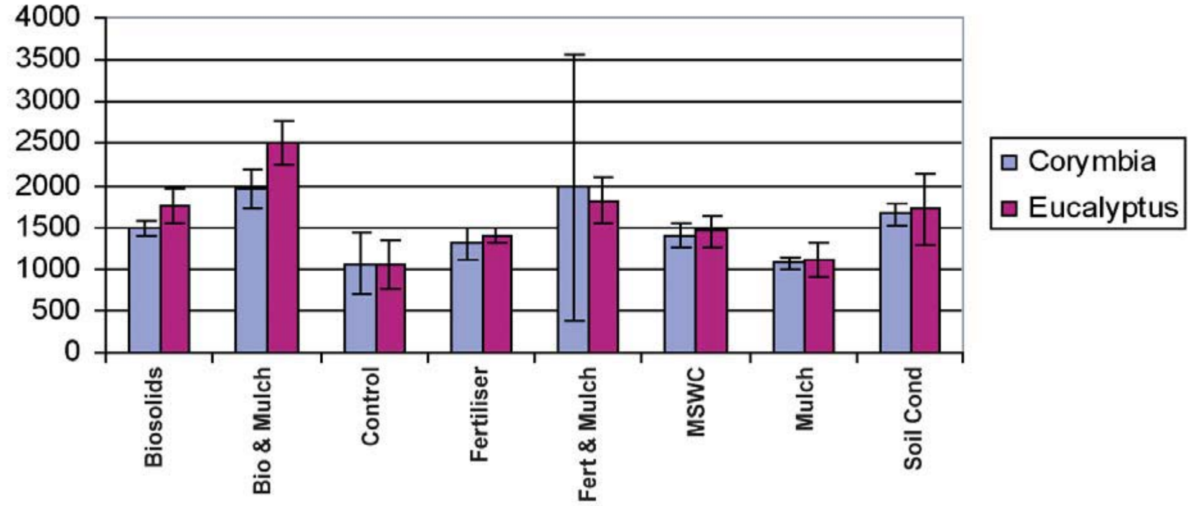
For *C. maculata*, Biosolids+Mulch and Fertiliser+Mulch had significantly better foliar potassium than other treatments (Table 3). However for both species all treatments were in the adequate range for foliar potassium.

Table 2. Eucalypt Nutrient requirements (juvenile) (after Reuter and Robinson 1997).

Species	Nutrient	Nutritional Status			
		Deficient	Marginal	Adequate	High
E. camaldulensis	N%	<1.0	1.0-1.4	1.4-1.8	2.0+
	P(mg/kg)	<800	800-1000	1000-1400	2100-3300
E. grandis	N%	<0.7	1.48-1.8	1.8-3.4	3.5+
	P(mg/kg)	<700	900	1000-3000	3000+
C maculata	N%	1.0-1.2		1.7-2.6	
	P (mg/kg)	400-500	800	1000-2600	

Foliar phosphorus was improved, in both species, after 1 year in Biosolids+Mulch (Figure 14). Fertiliser+Mulch, Biosolids and Soil Conditioner also improved foliar P. However all treatments were in the adequate range for phosphorus nutrition (Table 2).

Figure 14. Effect of Treatment on Foliar Phosphorus (%) at 1 Year



The treatment trends for potassium and nitrogen remained consistent over three years, although totals nutrient status reduced over time. However, by year 3, only treatments that included biosolids maintained phosphorus and nitrogen foliar levels in the adequate range — Biosolids+Mulch and Biosolids (Table 2, Figures 15 and 16)

Figure 15. Effect of Treatment on Foliar Phosphorus (mg/kg) of *C. maculata* at 2–3 Years

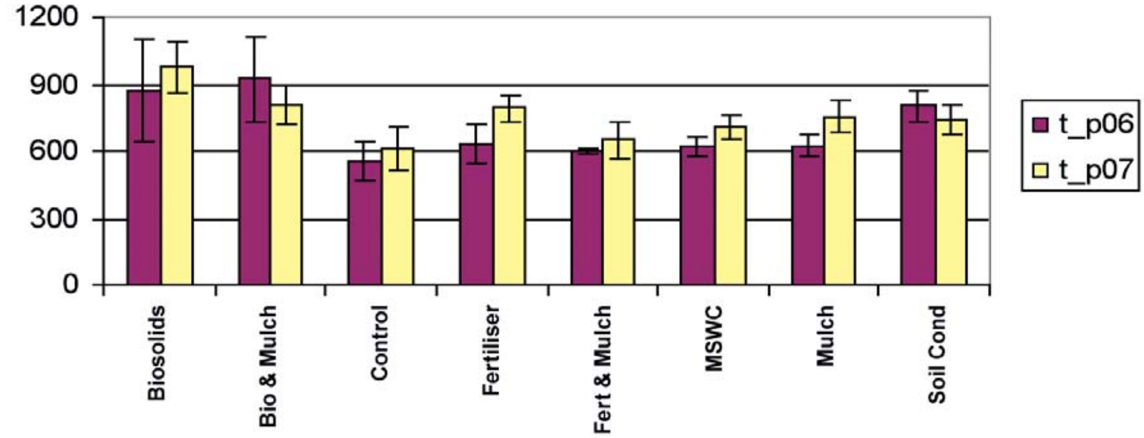
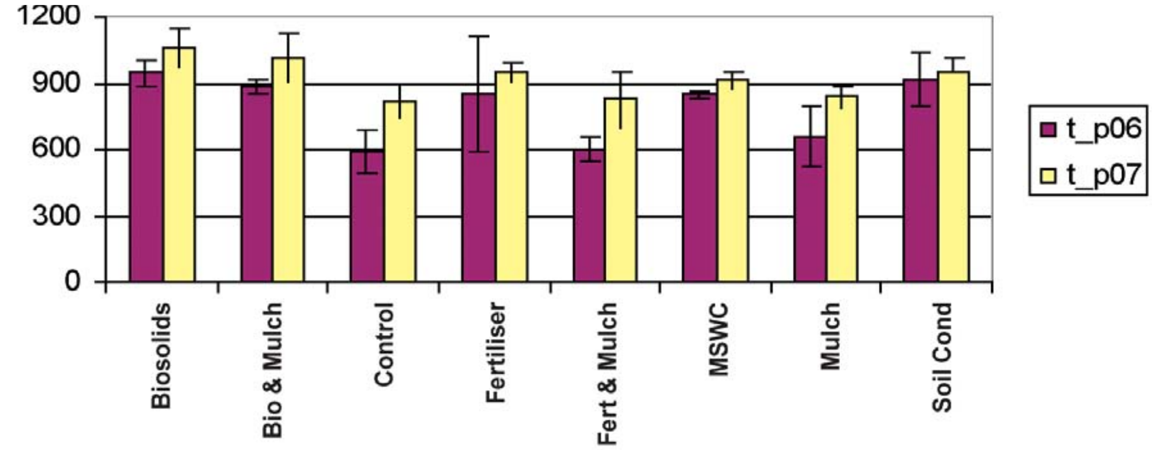


Figure 16. Effect of Treatment on Foliar Phosphorus (mg/kg) of *E. camaldulensis*grandis* at 2–3 Years



There is a strong correlation between N and P, and the Biosolids treatments and Soil Conditioner maximised nitrogen and phosphorus foliar levels (Figure 17). The addition of Mulch to both inorganic and organic fertiliser (Biosolids) increased the phosphorus levels, indicating that the moisture was providing an environment that improved the soil microbial function thus increasing phosphorus availability. The sustained moisture provided by the Mulch increased rate of mineralisation of nitrogen from the Biosolids and therefore improved foliar nitrogen. This improvement in foliar nitrogen was not seen with inorganic Fertiliser+Mulch since the nitrogen is fully available.

For *C. maculata* only the incorporated recycled organic treatments (Biosolids+Mulch, Biosolids, Municipal Solid Waste Compost and Soil conditioner — in descending order) improved foliar nitrogen to the adequate range (Figure 18) of 1.8–2.6 (see Table 2). All other treatments remain in the marginal range for foliar nitrogen.

Figure 17. Relationship between Foliar N and P (%) — *E. camaldulensis*grandis*

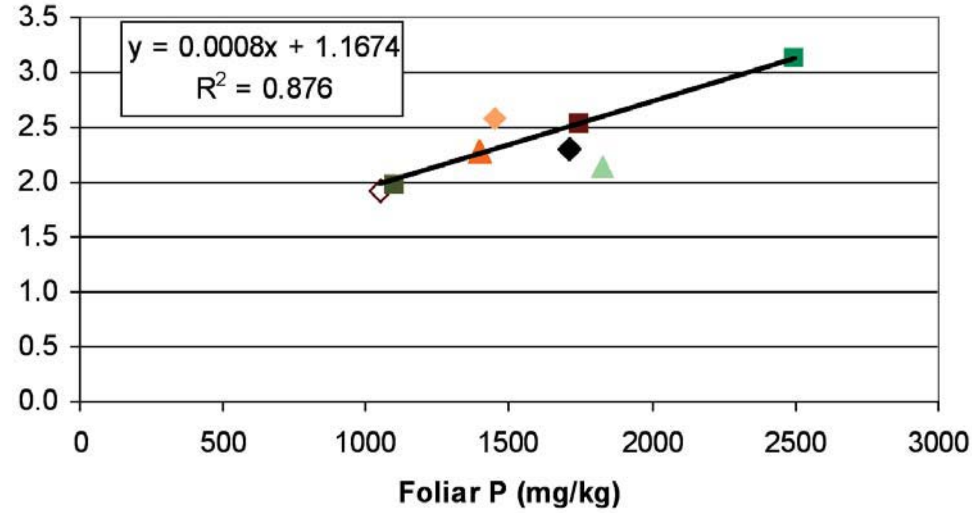
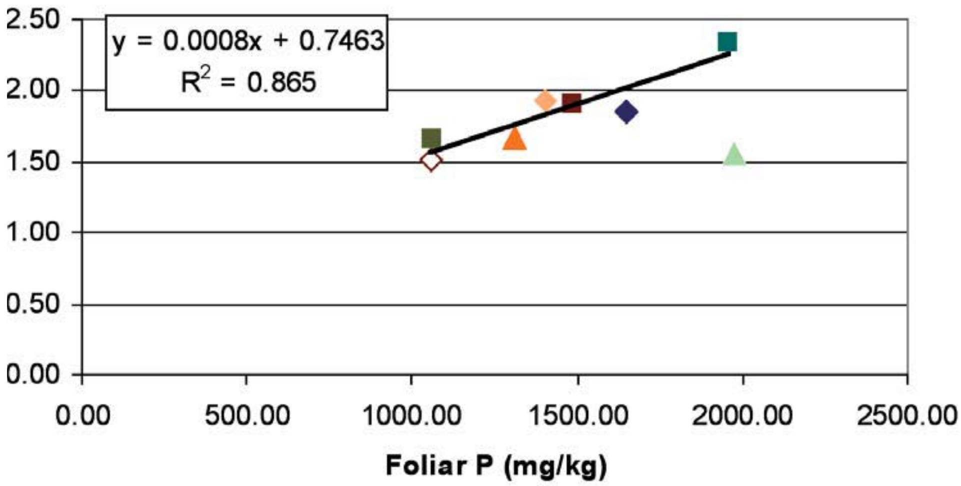


Figure 18. Relationship between Foliar N and P (%) — *C. maculata*



Legend

	Biosolids		Fertiliser and Mulch
	Biosolids and Mulch		MSWC
	Control		Mulch
	Fertiliser		Soil Conditioner

Table 3. ANOVA and Duncan's Test for Foliar Nutrition Year 1

dom genus	NAM	DF	PROB				Duncan Test				
Corymbia	t_al	7	0.9272	a - M	a - SC	a - B	a - C	a - BM	a - FM	a - F	a - MSWC
Corymbia	t_b	7	0.0039	a - FM	b - F	b - SC	b - BM	b - B	b - MSWC	b - M	b - C
Corymbia	t_ca	7	0.1624	a - M	ab - C	ab - MCW	ab - BM	ab - SC	ab - B	ab - FM	b - F
Corymbia	t_cd	7	0.4097	a - M	a - C	a - SC	a - B	a - F	a - BM	a - FM	a - MSWC
Corymbia	t_co	7	0.0399	a - M	ab - FM	abc - SC	bc - F	bc - C	bc - B	bc - MCW	c - BM
Corymbia	t_cr	7	0.8043	a - M	a - MSWC	a - B	a - FM	a - F	a - C	a - SC	a - BM
Corymbia	t_cu	7	0.0205	a - MCW	a - M	ab - C	abc - SC	abc - BM	bc - B	bc - FM	c - F
Corymbia	t_fe	7	0.9538	a - M	a - F	a - B	a - C	a - MSWC	a - SC	a - FM	a - BM
Corymbia	t_k	7	0.0016	a - BM	a - FM	ab - SC	abc - MSWC	bcd - M	cd - B	cd - C	d - F
Corymbia	t_mg	7	0.0134	a - M	ab - C	abc - FM	bc - MSWC	bc - SC	c - F	c - B	c - BM
Corymbia	t_mn	7	0.0066	a - M	ab - FM	bc - C	c - F	c - SC	c - MSWC	c - BM	c - B
Corymbia	t_mo	7	0.0349	a - M	ab - BM	abc - SC	abc - B	bc - FM	c - MSWC	c - F	c - C
Corymbia	t_na	7	0.4386	a - M	a - FM	a - FM	a - SC	a - B	a - BM	a - C	a - MSWC
Corymbia	t_n	7	0.0027	a - BM	b - MSWC	b - B	bc - SC	bc - F	bc - M	bc - FM	c - C
Corymbia	t_ni	7	0.0235	a - M	ab - FM	abc - SC	bc - C	bc - F	bc - B	bc - MSWC	c - BM
Corymbia	t_p	7	0.0303	a - FM	ab - BM	b - SC	b - B	b - MSWC	b - F	b - M	b - C
Corymbia	t_s	7	0.5851	a - M	a - BM	a - FM	a - B	a - C	a - MSWC	a - SC	a - F
Corymbia	t_zn	7	0.2106	a - M	ab - SC	ab - B	ab - BM	ab - MSWC	ab - FM	b - F	b - C
Eucalyptus	t_al	7	0.8121	a - F	a - C	a - B	a - FM	a - MCW	a - BM	a - M	a - SC
Eucalyptus	t_b	7	0.004	a - FM	b - F	b - BM	b - SC	b - B	b - C	b - M	b - MSWC
Eucalyptus	t_ca	7	0.1204	a - M	ab - BM	ab - C	ab - SC	ab - B	ab - MSWC	ab - FM	b - F
Eucalyptus	t_cd	7	0.5653	a - F	a - MSWC	a - C	a - M	a - FM	a - BM	a - BM	a - SC
Eucalyptus	t_co	7	0.5142	a - F	a - MSWC	a - FM	a - BM	a - SC	a - C	a - M	a - BM
Eucalyptus	t_cr	7	0.3697	a - C	a - FM	a - M	a - F	a - MSWC	a - B	a - SC	a - BM
Eucalyptus	t_cu	7	0.1547	a - BM	a - MSWC	ab - SC	ab - M	ab - FM	ab - B	ab - C	b - F
Eucalyptus	t_fe	7	0.8702	a- B	a - FM	a - C	a - BM	a - M	a - MSWC	a - F	a - SC
Eucalyptus	t_k	7	0.0077	a - SC	ab - BM	abc - FM	abcd - M	bcde - MSWC	cde - B	de - F	e - C
Eucalyptus	t_mg	7	0.0576	a - C	ab - M	ab - SC	ab - FM	abc - B	abc - F	bc - MSWC	c - BM
Eucalyptus	t_mn	7	0.0006	a - FM	b - FM	bc - C	bc - M	bc - B	bc - BM	bc - SC	c - MSWC
Eucalyptus	t_mo	7	0.001	a - SC	b - BM	b - MSWC	bc - M	bc - FM	c - C	c - B	c - F
Eucalyptus	t_na	7	0.5894	a - FM	a - MSWC	a - C	a - FM	a - M	a - B	a - BM	a - SC
Eucalyptus	t_n	7	0.0004	a - BM	b - MSWC	b - B	bc - SC	bc - F	bc - FM	c - M	c - C
Eucalyptus	t_ni	7	0.0014	a - FM	ab - M	ab - C	bc - F	bc - SC	c - MSWC	c - B	c - BM
Eucalyptus	t_p	7	0.0001	a - BM	b - FM	b - B	b - SC	bc - MSWC	bc - F	c - M	c - C
Eucalyptus	t_s	7	0.0374	a - BM	ab - FM	abc - B	bc - SC	bc - M	bc - MSWC	Bbc - C	c - F
Eucalyptus	t_zn	7	0.0211	a - MSWC	ab - BM	abc - SC	bc - M	bc - B	bc - FM	bc - C	c - F

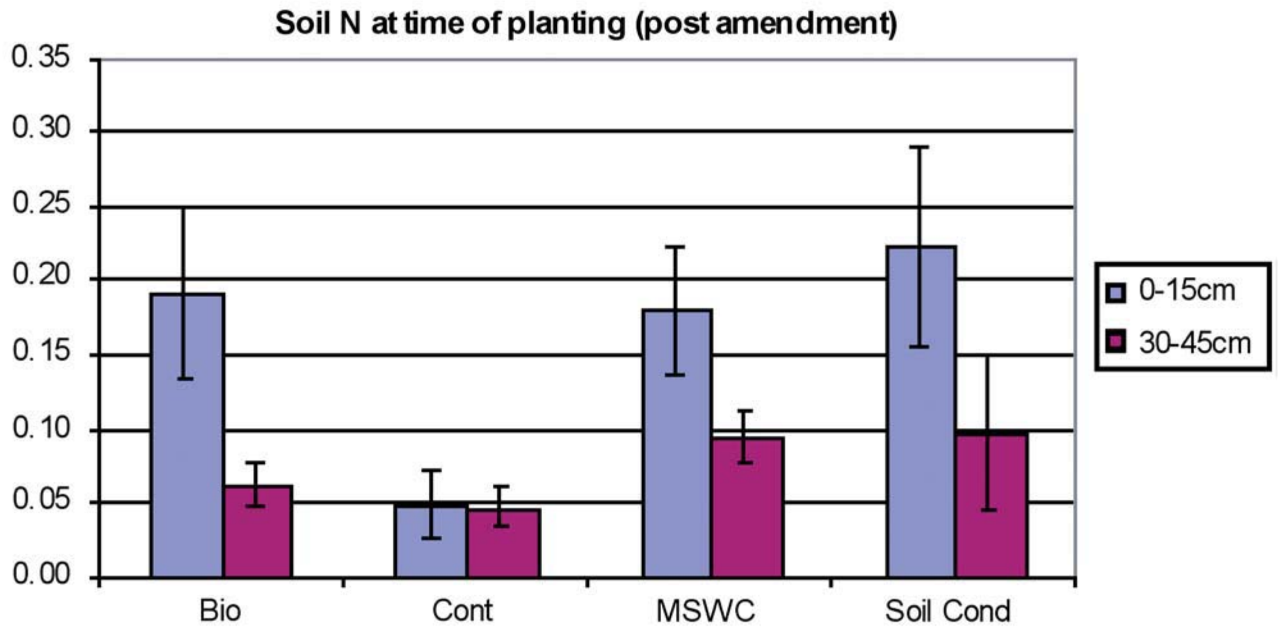
There can be concerns that adding recycled organics may introduce extra metals to the environment. However there was no significant difference between treatments for most metals (Table 3). For *C. maculata*, zinc, chromium iron and aluminium there was no significant difference between treatments. All foliar levels of copper were in the adequate range, although some treatments improved foliar Cu: Municipal Solid Waste Compost, Mulch, Soil Conditioner and Biosolids+Mulch (in descending order).

For both *C. maculata* and *E. camaldulensis*grandis* Mulch, Fertiliser +Mulch and Soil Conditioner increased foliar nickel levels. Foliar zinc was improved by Municipal Solid Waste Compost, Biosolids+ Mulch and Soil Conditioner in *E. camaldulensis*grandis*, although all treatments were in the adequate range. For Cu, Cr, Fe, and Al there was no significant difference between treatments in foliar levels of these metals.

Soil Chemistry

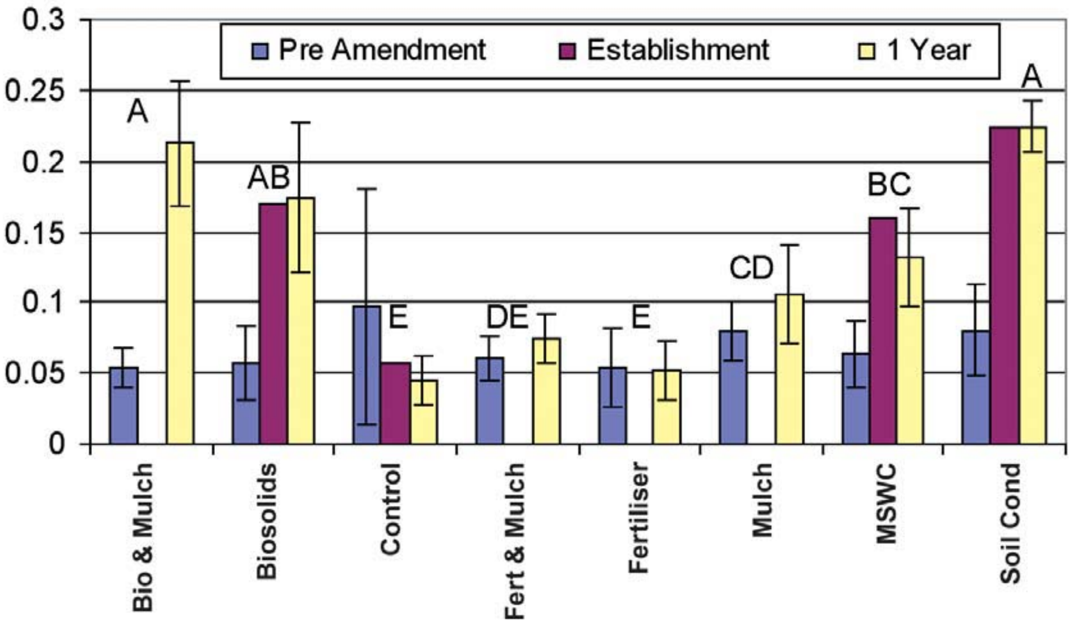
Incorporated soil amendments (Biosolids, Soil Conditioner and Municipal Solid Waste Compost) significantly increased soil nitrogen the time of planting (2 weeks post amendment) (Figure 19). These elevated nitrogen levels were maintained throughout the first year. The impact of the amendments at this early stage was only in the surface soil. Amendments were incorporated to 30cm (ripping and mounding). The slightly elevated levels of soil N in 30–45cm zone for Municipal Solid Waste Compost and Soil Conditioner reflect the availability and mobility of N in these composted products. The biosolids treatment was sampled 3 months post application as it was incorporated in December 2003 and other amendments were incorporated in March 2004.

Figure 19. Effect of Treatment on Soil Nitrogen (%) 2 Weeks Post-Application



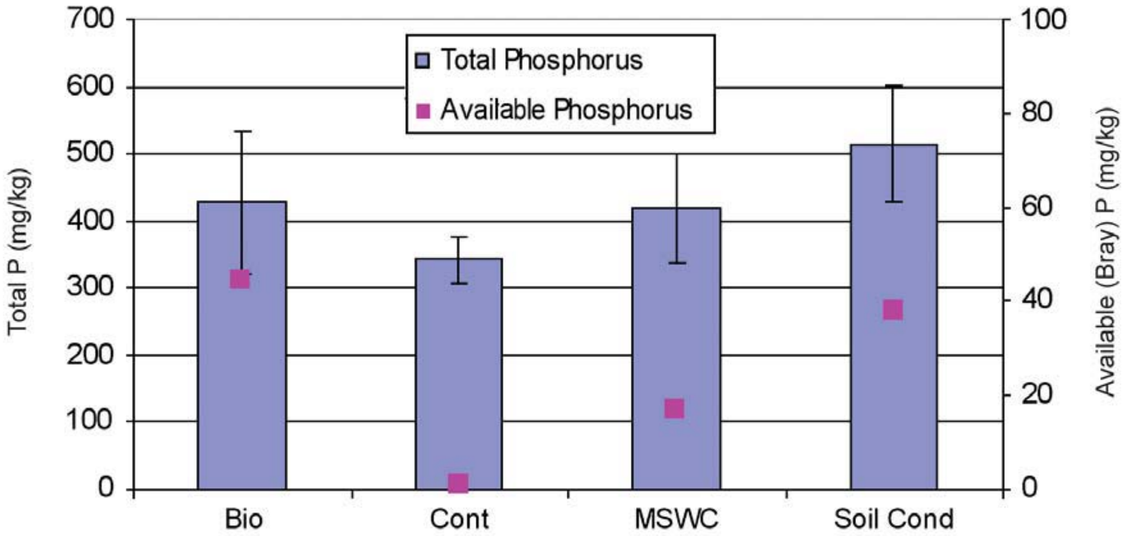
By Year 1 the treatments with the highest soil total nitrogen were Biosolids+Mulch and Soil Conditioner, followed by Biosolids (Figure 20) . Municipal Solid Waste Compost also had relatively high soil nitrogen, but not as high as Biosolids+Mulch and Soil Conditioner and Biosolids. Nevertheless, all incorporated recycled organics induced significantly higher soil total nitrogen compared to any of the other treatment (Mulch, Fertiliser +Mulch, Fertiliser and Control — in descending order).

Figure 20. Effect of Treatment on Soil Nitrogen (0–15cm) (Total N %w/w)



Total soil phosphorus was high across the site, with no significant difference between treatments. However, available P (Colwell) was significantly different between treatments. Addition of Biosolids and Soil Conditioner significantly increased available P in the soil when compared to Municipal Solid Waste Compost which in turn had significantly more available P than the control (Figure 21). Immediately after application Biosolids, Soil Conditioner and Municipal Solid Waste Compost increased available P into the moderate to high range, whereas all other treatments had low available P. The disparity in total P and available P may be influenced by the very high pH (8.2–9.3) of these sites. Again Biosolids was incorporated 3 months prior to planting. At a comparative period post application the soil phosphorus in biosolids treated plots would likely have been higher.

Figure 21. Effect of Treatment on Soil Phosphorus (0–15cm) 2 Weeks Post-Application



By year 1 only those treatments which applied biosolids (Biosolids+Mulch and Biosolids) had adequate soil P levels (Figure 22, Table 4). Biosolids+Mulch was statistically the highest followed by Biosolids which in turn had significantly more soil P than all other treatments. In addition the P in Biosolids+ Mulch and Biosolids treatments was plant available (Colwell P), as evidenced by the correlation between Total P and Colwell P (Figure 22).

Figure 22. Effect of Treatment on Soil Phosphorus (0–15cm)

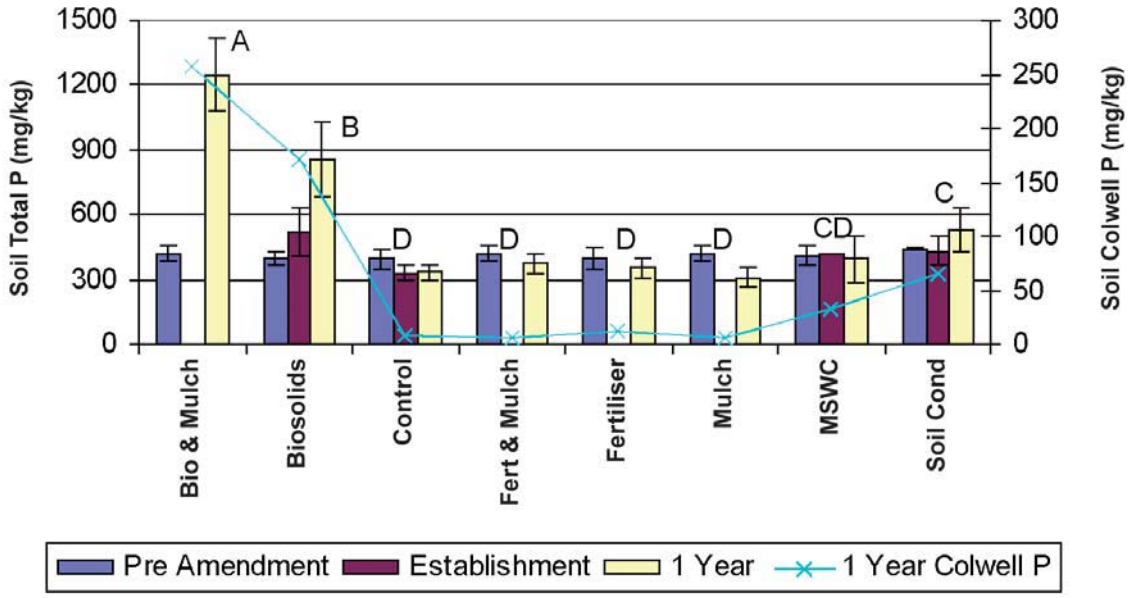
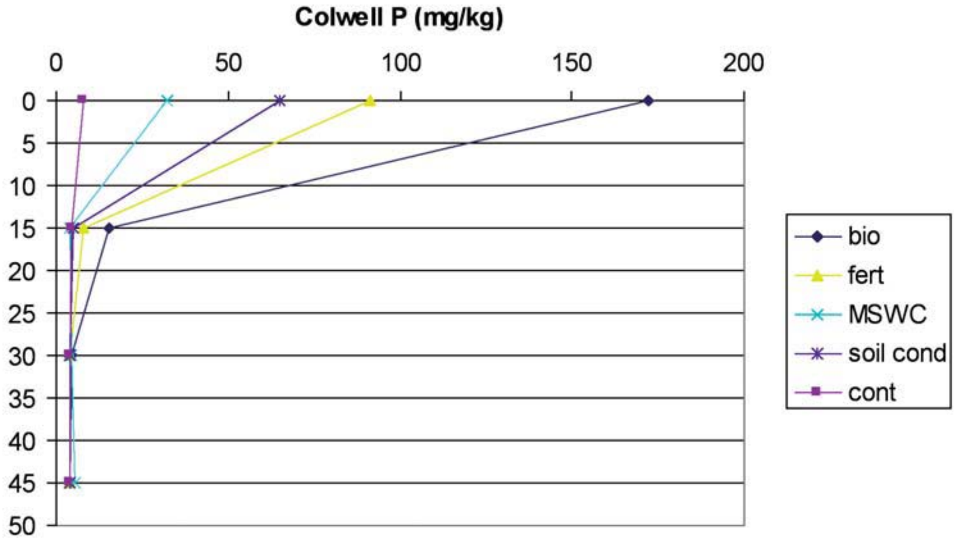


Table 4. Availble Phosphorus Levels in Soil

Colwell P range (mg/kg)	Level
<20	Low
20–30	Moderate
<35	High

Phosphorus was most available at 0–15cm in the profile (Figure 23). Even in the topsoil the only treatments that provided high available P were Biosolids+Mulch, Biosolids and Soil Conditioner. Municipal Solid Waste Compost provided moderate levels of available P (Table 4). All other treatments were low in available P (Figure 23).

Figure 23. Available Phosphorus down the Soil Profile (Depth in cm)



Levels of organic carbon in the soil were also significantly affected by treatment. Levels in soils amended with Soil Conditioner (made from100% composted green waste) were the highest (Figure 24). Organic carbon levels in soils amended with Biosolids and Municipal Solid Waste Compost were also significantly elevated but not to the same extent (Table 5). All other treatments had significantly less organic matter than Soil Conditioner, Biosolids+Mulch and Municipal Solid Waste Compost.

Figure 24. Effect of Treatment on Soil Organic Matter at 0–15cm (%w/w)

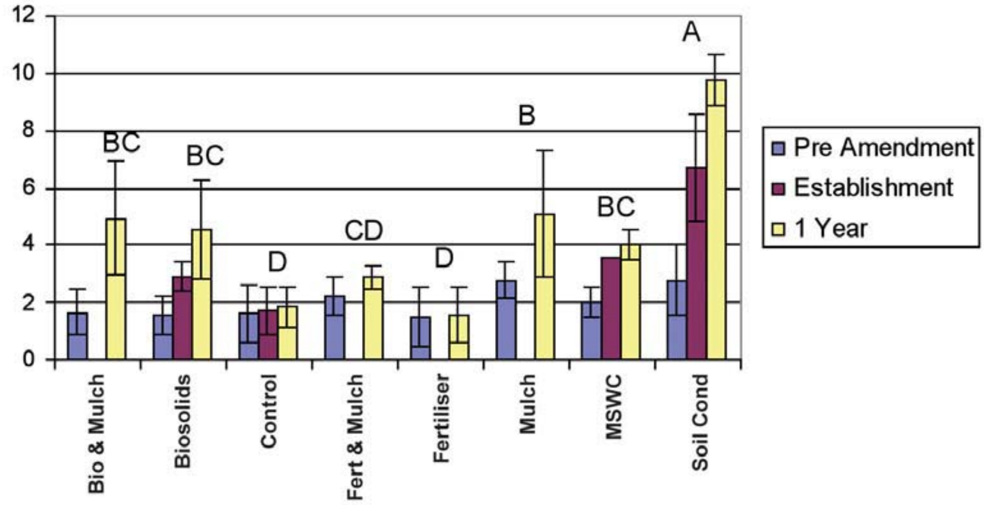
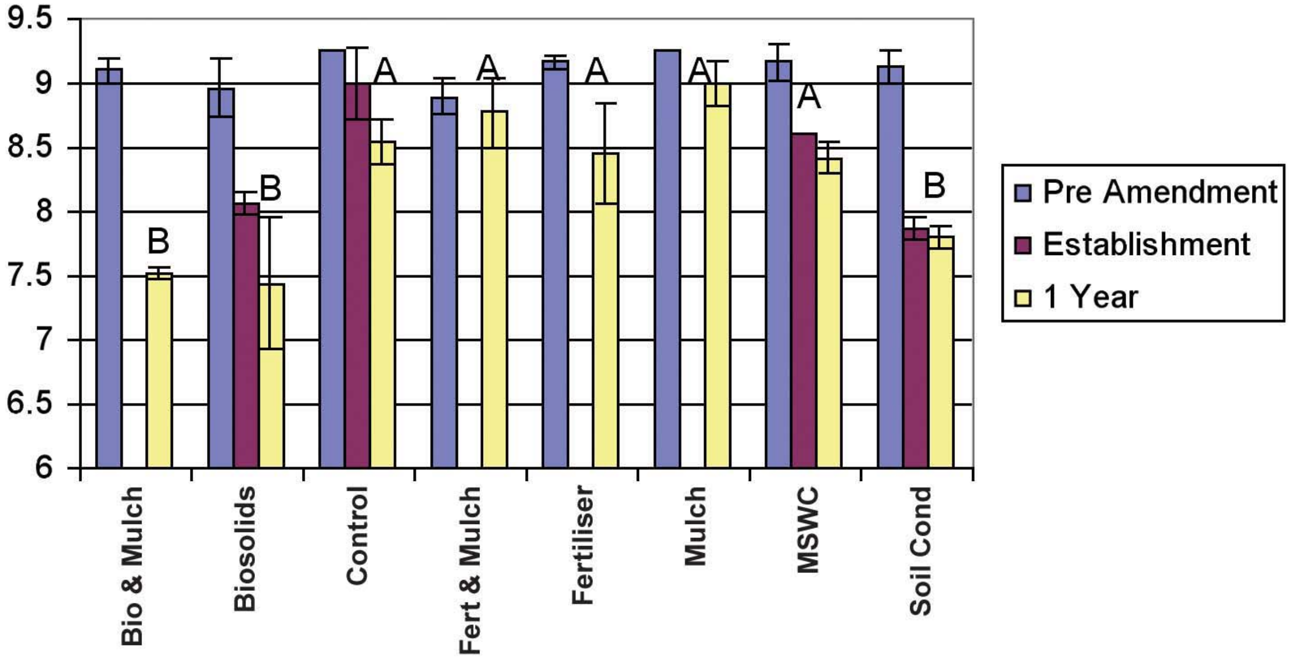


Table 5. Effect of Incorporated Treatments on Soil Properties

Analyte	Significance level	Treatment and Duncan's ranking			
pH (H2O)	0.001	Control	MSWC	Biosolids	Soil Cond
		A	A	B	B
Total N (%)	0.05	Soil Cond	Biosolids	MSWC	Control
		A	A	A	B
Total P (mg/kg)	0.05	Soil Cond	Biosolids	MSWC	Control
		A	A	A	B
Available P (mg/kg)	0.001	Biosolids	Soil Cond	MSWC	Control
		A	A	B	C
Organic Carbon (%)	0.001	Soil Cond	MSWC	Biosolids	Control
		A	B	BC	C

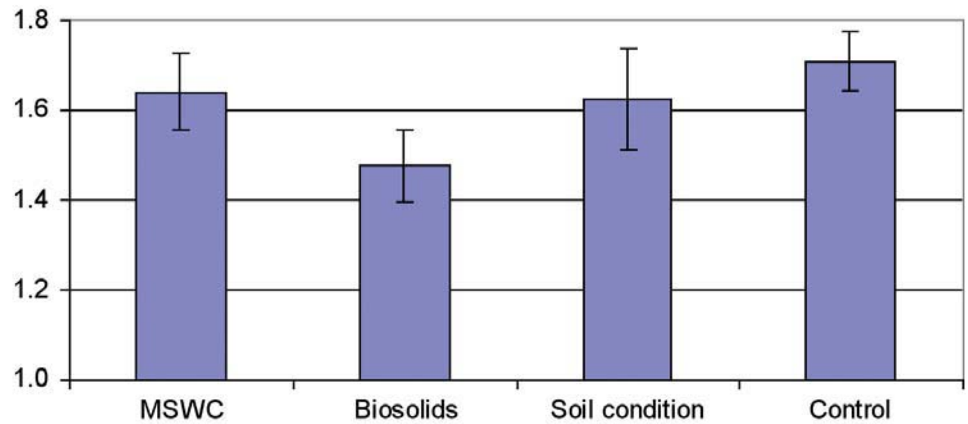
Amendment of the soil with highly organic material had a significant effect on soil pH. The strongly overburden alkaline soils were moderated by application of Biosolids and Soil Conditioner (Figure 25). The pH fell from 8.8 in the Control, to 7.9 and 7.8 in the Biosolids and Soil Conditioner, respectively (Table 5). By year 1 the pH of soils in all treatments had dropped slightly (due to the plant soil interaction). However, Biosolids and Soil Conditioner continued to have the greatest effect bringing these once highly alkaline soils down to 7.4–7.7.

Figure 25. Effect of Treatment on Soil pH (CaCl2) at 0–15cm Depth



Bulk density has a significant impact on the ability of tree roots to penetrate soil and access moisture and nutrition. In addition soils with high bulk density can have low permeability, which impacts on the soil's moisture holding capacity. All incorporated recycled origins reduced bulk density, with Biosolids reducing bulk density to the greatest extent (Figure 25). Bulk density can have an impact on growth and in this trial there is a correlation between lower bulk density and higher growth.

Figure 26. Effect of Treatment on Soil Bulk Density at 0–15cm (g/cc)



Weed Control

Incorporation of Biosolids induced significant weed growth. The weed growth was significantly controlled by the mulch treatment see Biosolids compared to Biosolids plus Mulch (Figure 27). The incorporation of Biosolids as a soil amendment induced significant weed growth — over seven times more weed cover than the next highest treatment, Fertiliser. The addition of Mulch significantly reduced the weed growth in addition to improving soil moisture and moderating soil temperature. These conditions led to improved tree growth in the Biosolids +Mulch and Fertiliser +Mulch treatments — superior to that of Biosolids or Fertiliser alone.

Figure 27. Effect of Treatment on Weed Cover (%) at 9 Months Post-Treatment

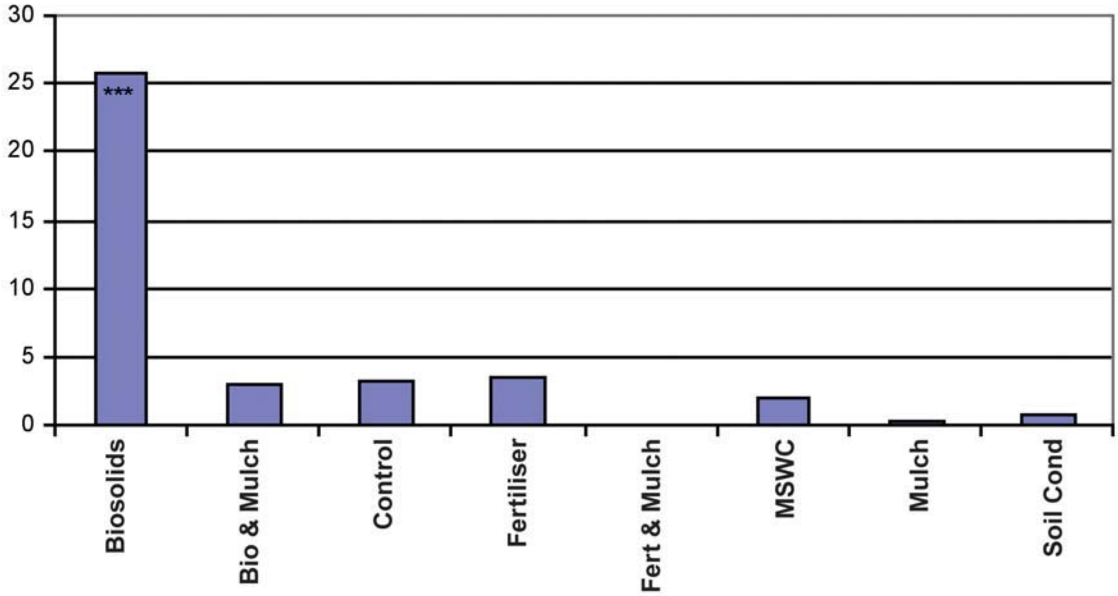


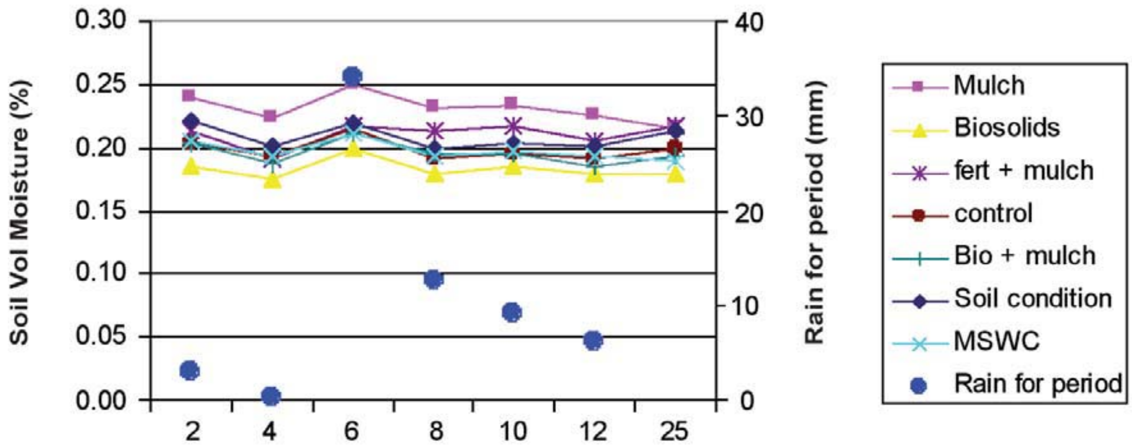
Plate 15. Mulch Suppressing Weeds on the Mound

Soil Moisture and Temperature

Mulch has had a significant effect in preserving soil moisture. This is particularly evident in the upper soil profile. The greatest effect of the Mulch on soil moisture was seen at 15–30cm. This is important as this is the zone where early root development takes place. At lower depths the impact of the Mulch was not significant. All other organic amendments (with the exception of Biosolids) had higher volumetric moisture than the Control (Figures 28a–d).

The lower moisture content of the Biosolids treatment may be due to the increased growth response of trees in this treatment or to the increased weed cover. However it is more likely that the increased tree growth and resultant drawdown of the soil moisture is the reason behind the soil moisture differences. This is supported by the fact that the Fertiliser+Mulch treatment (a fast growing treatment) is drier than the Mulch only treatment. Nevertheless the addition of Mulch improves soil moisture conditions as evidenced by the comparison between Biosolids only and Biosolids+Mulch (two of the fastest growing treatments). The Biosolids +Mulch treatment is wetter than the Biosolids alone and yet both have similar growth rates. Whilst monitoring of these treatments in the absence of trees would give a less confounded result, the absence of the root/soil interaction would make the data less relevant to the reality of the impacts of recycled organics on revegetation.

Figure 28a. Effect af Treatment on Soil Moisture at 15cm Depth



The topsoil (0–15cm) responded to rainfall immediately (Figure 28a), however the response to rainfall at lower depths (30–45cm) lagged 2–4 weeks after the rainfall event (Figure 28c).

Figure 28b. Effect of Treatment on Soil Moisture at 15–30cm

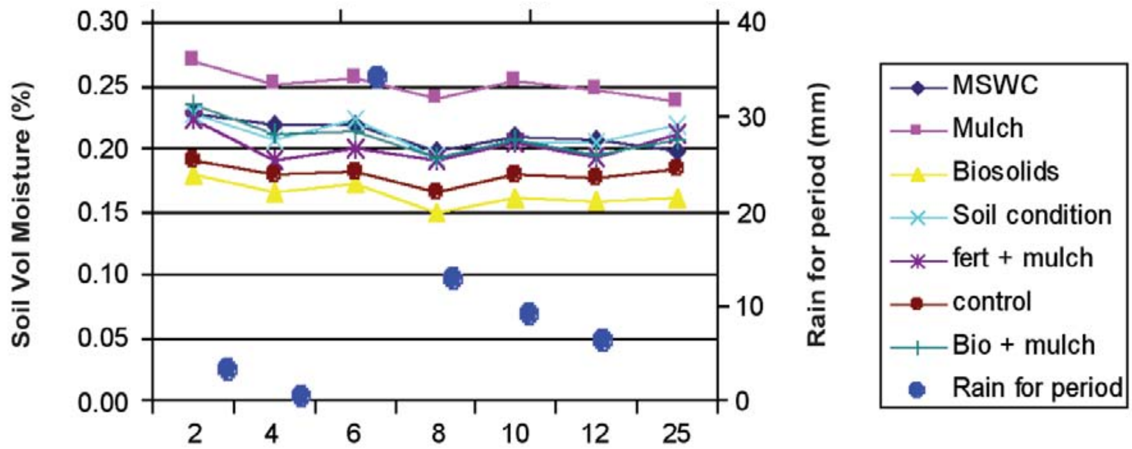


Figure 28c. Effect of Treatment on Soil Moisture at 30–45cm

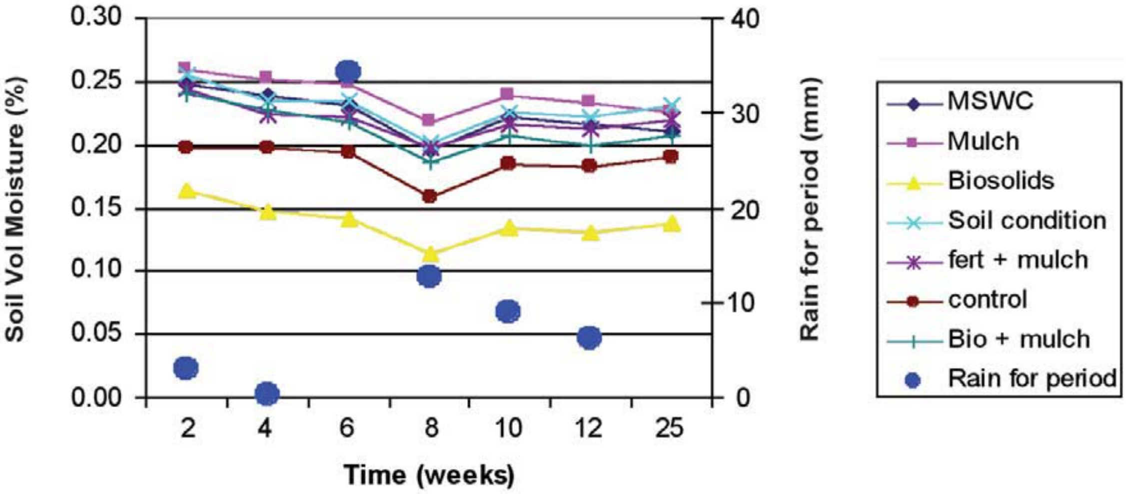


Figure 28d. Effect of Treatment on Soil Moisture at 45–60cm

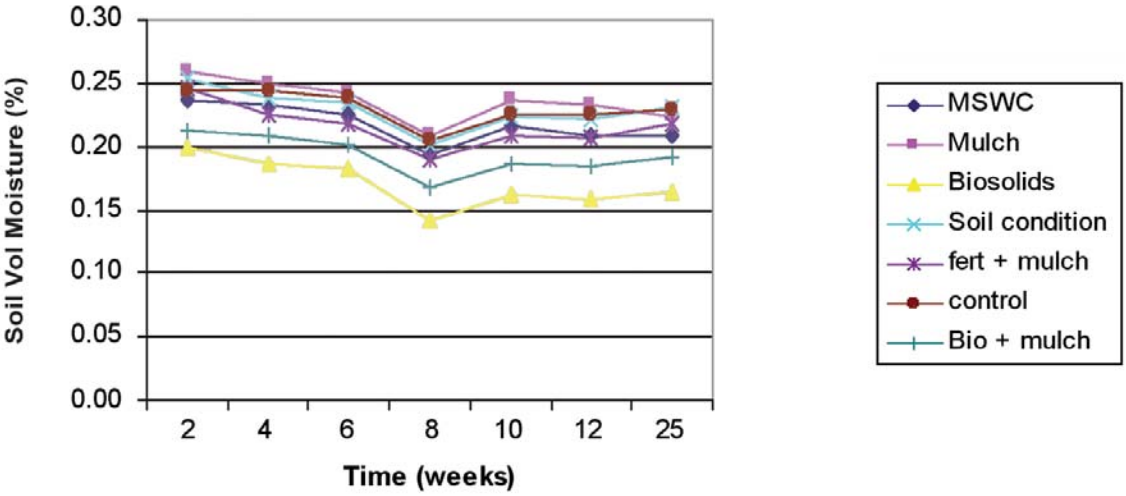


Plate 16. Installing Neutron Probe Access Tubes

Soil temperature was significantly moderated by the Mulch treatment. This held true for both high and low ambient temperatures (Figure 29). All other treatments showed a similar response to the control, with Biosolids having a slightly elevated soil temperature in the heat of the day. This may be due to the dark colour of this product. It is unlikely to be the result of residual biological activity, as the slightly elevated temperature continued 18mths after biosolids applciation (Figure30).

Figure 29. Effect of Mulch on Soil Temperature (°C)

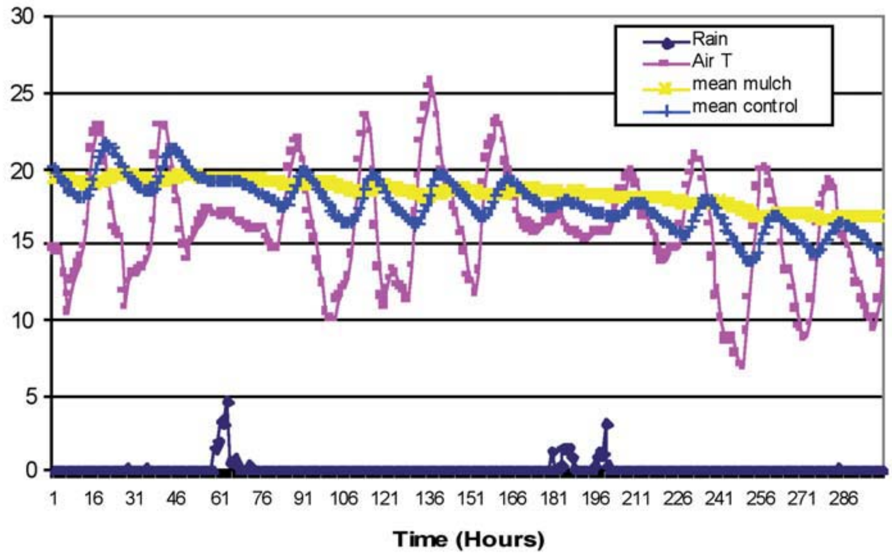


Figure 30. Effect of Treatment on Soil Temperature (°C)

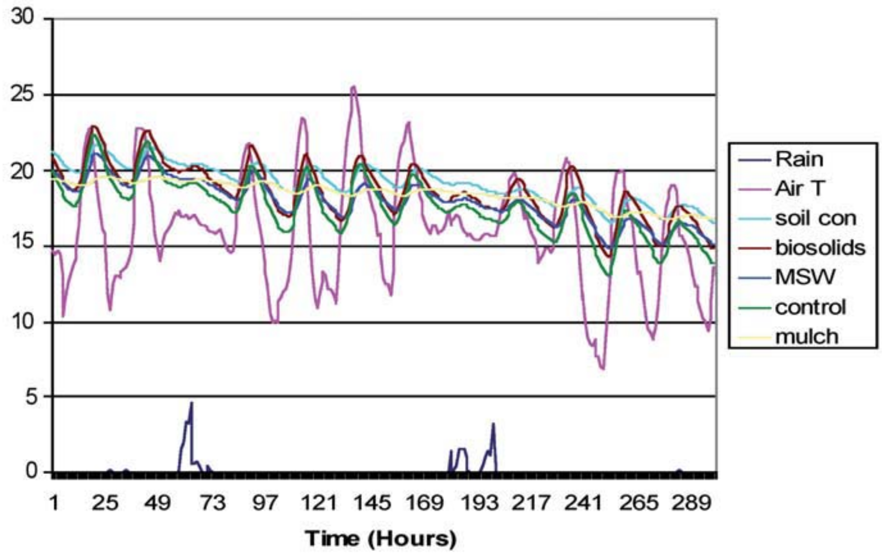


Plate 17. Data Logger for Soil Temperature Probes

COST BENEFIT

Recycled organics have a role in providing nutrients and organic matter to the degraded sites, which in turn provides a more appropriate environment for microbial activity and nutrient cycling. However, the major considerations are the product cost and the cost of transport to the site. Transporting organics for long distances of 250km can cost up to $25–30 per product tonne. This is a conservative figure based on periodic backloading. Therefore, the choice of amendment will often depend on its close proximity. The application of recycled organics has the associated costs of appropriate spreading equipment and incorporation into the soil. Hire of spreading equipment may cost around $15 per product tonne. Other equipment needed, such as tractors and front-end loaders, would generally also be used or available for a normal mineral fertiliser/topdressing operation.

Plate 18. Delivery of Recycled Organics (Biosolids)

Forest NSW, in a scoping study on organics in the Hunter, concluded that that some residuals such as composts and biosolids are competitive when used as topsoil substitutes rather than as fertilisers. However, their proven fertiliser advantage is worth investigating when establishing commercial plantations, as the timber revenue and carbon credits generated may offset any economic disadvantages.

Mining companies fully fund rehabilitation costs and would be amenable to competitively priced amendment products and topsoil substitutes if available. However, for mining companies to adopt new strategies (e.g. the use of recycled organics in rehabilitation) they need to be commercially competitive. It is therefore important that the recycled organics achieve a consistent outcome and this requires a consistent product.

To further assess the benefits of the recycled organics used in this trial, all expenditure was captured (Table 6) and analysed against rehabilitation outcomes. It is important to note that this was a small scale research trial which experienced fixed costs that could not be amortised over a larger scale operational activity. It is not valid, therefore, to translate costs in to a per hectare amount. The costs have been determined using a plot basis as a point of equivalence. In addition some 'newer' products were supplied free of charge as part of their research and market development, whereas more established products were charged at retail rates. It is also feasible that equivalent products may be available locally which would reduce their cost per unit considerably. The challenge will be for producers of recycled organics to price their product at a level that is justified by the benefit. It may be that mine site rehabilitation is only suitable, in a fiscal sense, for certain recycled organics. The challenge for the user is to spend sufficient funds such that the results are positive and can be sustained. It is false economy to opt for a cheaper solution if the site needs to be re-established in a few years.

Nevertheless the comparison was made by generating a percentage response with respect to the control. By definition this gave the Control (no treatment and no extra expense) a value of 1. Any response above 1 was increased benefit, below one was worse than no treatment. This can then be measured against the expense of the treatment (Figure 31–33).

Table 6. The Benefits of Recycled Organics

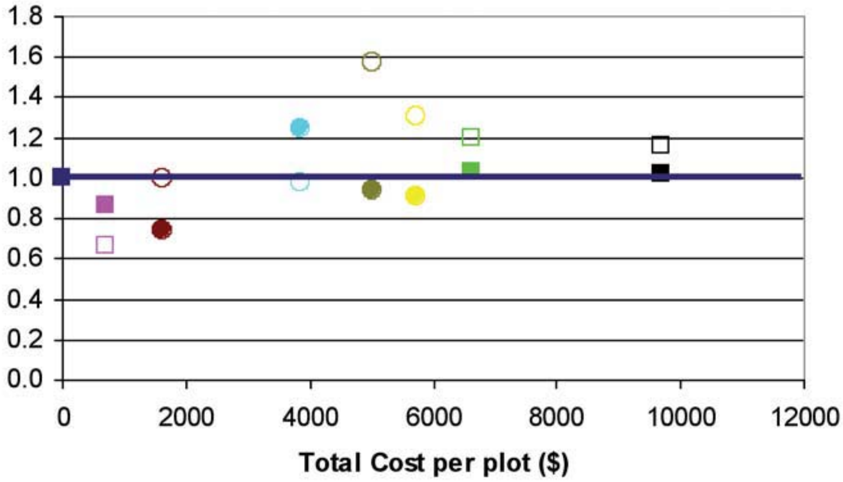
Product/ Treatment	Subsidy from Producer	Product Cost to Mine ($)	Spreading cost ($)	Other costs (e.g. bunding)	Total Treatment Cost ($)
Control		0	0		0
Fertiliser		355.68	340		695.68
Biosolids	product + delivery	0	1352.5	262.7	1615.2
MSWC	product + delivery	0	3841		3841
Soil Conditioner		6292	3420		9712
Mulch		3491	1530		5021
Fertiliser + Mulch		3846.68	1870		5716.68
Biosolids+ Mulch		3491	2882.5	262.7	6636.2

Some treatment improved survival, whilst other treatment improved growth. In some cases treatment that improved growth had reduced survival. These factors have been assessed separately (Figure 31 and 32). However to give an overall understanding of site success and occupancy a factor for Basal Area was also calculated (Figure 33). It must be noted however, that basal are is a calculation usually reserved for older stands. Assessment of all these factors at a later stage in the plantations development will be important in understanding the sustainability and long term impacts of the treatments.

For *C. maculata* the only treatment that improved survival significantly more than the control was Municipal Solid Waste Compost. For the faster growing *E. camaldulensis*grandis* all recycled organics improved survival. In particular the Mulch improved survival being 1.6 times the survival of the control. The stress generated by increased growth is indicated by the slightly lower percentage survival of Fertiliser+Mulch and Biosolids+Mulch compared to Mulch alone. However, Mulch did improve response of those treatments containing added nutrition (Fertiliser+Mulch and Biosolids+Mulch) compared to the treatment with extra nutrition only (Fertiliser and Biosolids). Fertiliser alone had lower survival than the control and Biosolids had equivalent survival to the Control.

Treatments for each of the factors assessed (survival, diameter and basal area), and assigned a category based on low, medium, and high cost. Categories were also distributed based on benefit with respect to the Control: low, marginal, good and high — see Tables 7–12. Treatments consistently in the good to high cost-benefit categories for both species were Fertiliser + Mulch, Biosolids + Mulch, Municipal Solid Waste Compost and Biosolids. However the land user needs to decide which assessment factors are relevant to their situation.

Figure 31. Cost-Benefit for Increasing Survival (% compared control)



Control	Soil Conditioner
Fertiliser	Mulch
Biosolids	Fertiliser + Mulch
MSWC	Biosolids+ Mulch

Solid = *C. maculata*; Outline = *E. camaldulesnis*grandis*

Table 7. Treatment Cost-Benefit Table for *E. Camaldulensis*grandis* Survival

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Fertiliser	Control, Biosolids		
Medium		MSWC	Fert+Mulch, Biosolids+Mulch	Mulch
High		Soil Conditioner		

(yellow)	Low Cost-Benefit
(light green)	Medium Cost-Benefit
(green)	Good Cost-Benefit

Table 8. Treatment Cost-Benefit Table for C. Maculata Survival

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Fertiliser, Biosolids	Control,		
Medium			Fert+Mulch, Biosolids+Mulch, MSWC	Mulch
High		Soil Conditioner		

Figure 32. Cost-Benefit for Increasing Growth (Diameter) (% compared to control)

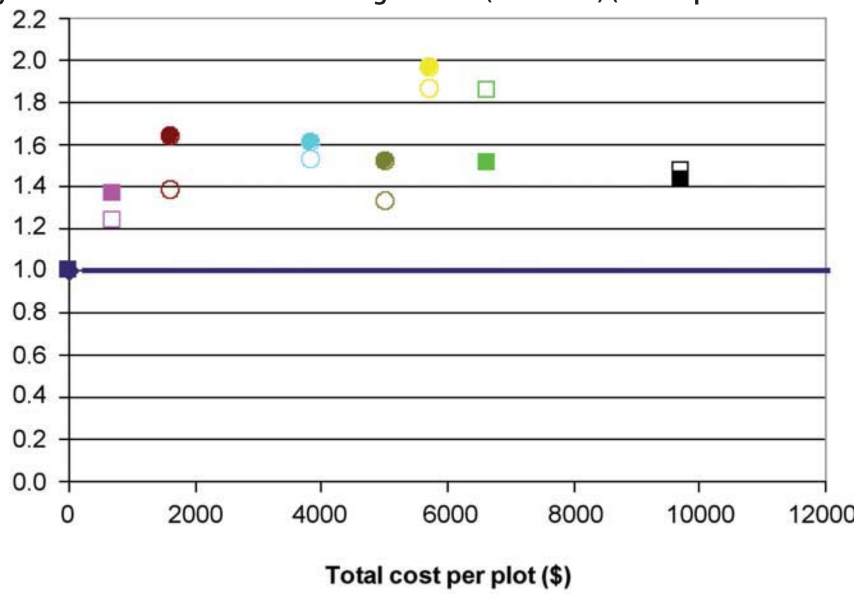


Table 9. Treatment Cost-Benefit Table for E. Camaldulensis*grandis Growth (Diameter)

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Control	Fertiliser, Biosolids		
Medium		Mulch	MSWC,	Fert+Mulch, Biosolids+Mulch
High			Soil Conditioner	

Table 10. Treatment Cost-Benefit Table for *C. Maculata* Growth (Diameter)

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Control	Fertiliser	Biosolids	
Medium			Biosolids+Mulch, MSWC, Mulch	Fert+Mulch,
High			Soil Conditioner	

Figure 33. Cost-Benefit for Increasing Basal Area (% more than control)

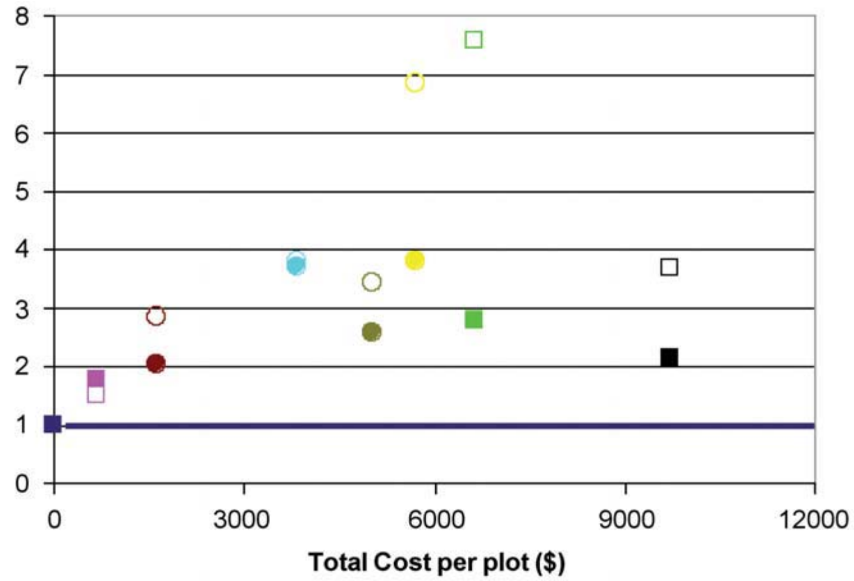


Table 11. Treatment Cost-Benefit Table for *E. Camaldulensis*grandis* Basal Area

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Control	Fertiliser	Biosolids	
Medium			MSWC, Mulch	Fert+Mulch, Biosolids+Mulch
High			Soil Conditioner	

Table 12. Treatment Cost-Benefit Table for *C. Maculata* Basal Area

Cost	Treatment Benefit			
	Low	Marginal	Good	High
Low	Control	Fertiliser	Biosolids	
Medium			MSWC, Mulch	Fert+Mulch, Biosolids+Mulch,
High			Soil Conditioner	

Survival may the most important initial factor for mine site rehabilitation, since a principal objective is to stabilise the site. However, initial survival must be coupled with good and sustained growth to achieve a sustainable land use. Therefore factors such as growth and basal area must also be considered. Both these factors are also important for biodiversity reason (giving good cover and habitat), and carbon sequestration (large above ground biomass). The set of parameters determining the final treatment selection will be different for each site. Soil properties are increasingly being considered in terms of sustainable land use and rehabilitation. These levels have not, as yet, been defined for rehabilitation targets and have not been considered in this economic analysis. However the data show that Soil Conditioner, Municipal Solid Waste Compost and Biosolids increases soil organic matter, soil N, available P. This may be parameter that landholders choose to include in future determinations regrading site preparation and use of soil amendments.

DISCUSSION

Recycled organics is a generic term used to describe compostable organic materials, including garden organics, food organics, residual wood and timber, biosolids and agricultural residues (17). Composted recycled organics contain nutrients such as nitrogen, phosphorus and a number of micro nutrients in higher concentrations than in agricultural soils (18).

In this trial, the Fertiliser+Mulch and Biosolids+Mulch treatment elicited the best growth response, with biosolids providing nutrient and organic matter and the mulch suppressing weeds, moderating soil temperature and preserving soil water. Results from this study are in line with the existing literature. Elsewhere, Biosolids incorporated at 50 dry t/ha prior to planting has been a very effective amendment in improving tree growth on mine sites and associated buffer land (7, 8, 9, 16, 19, 20). Biosolids was found to enhance forest productivity (21, 22) improves soil chemical and physical properties (23, 24).

The surface mining process has been reported to increase the content of exchangeable bases in the reclaimed surface layer by bringing up fresh material that weathers and results in mine spoil with high base saturation and greater concentrations of basic cations for plant utilization compared the other overlying natural soils (25). Successful restoration depends on accumulating N in the system and establishing a functional N cycle. In this study all incorporated recycled organics (Biosolids, Soil Conditioner and Municipal Solid Waste Compost) all increased soil nitrogen and play a key role in the more rapid restoration of a functional N cycle.

Phosphorus is another major limiting nutrients in fresh mine spoil due to rapid fixation into unavailable forms and generally low total amount present (26, 27). Organic matter addition may increase P availability directly by mineralization of the organic matter or indirectly by releasing organic constituents that block soil sites that might otherwise lock up existing or added P (28). Data from this study show that recycled organics have a significant impact on the amount of available phosphorus and therefore on plant establishment and growth.

Many short-term benefits have been noted but the longer-term benefits of increased nutrients and organic matter, have received less research (29, 30). Enhanced soil structural properties are linked with increased soil organic matter (31) and the literature contains considerable evidence that a range of recycled organic amendments increases the organic matter of soil (32, 33, 34). Lindsay and Logan (35) found that organic C increased linearly with sludge application, and 4 years after application there was three times as much C in the 300 Mg/ha plots as in the zero sludge control plots. Many of the observed differences in soil physical properties were due to the effects of added organic matter and these effects persisted for at least 4 years.

In this study plots amended with Biosolids, Municipal Solid Waste Compost and Soil Conditioner all had increased soil organic carbon levels, with Soil Conditioner (a compost of 100% greenwaste) increasing levels the most. The key advantage of compost application is the replenishment of organic matter in the soil. Most commercial composts are specifically designed and amended for the particular application. Top ups with conventional inorganic fertilisers (Typically N) may still be required, but the improved organic carbon bank will ensure a greater efficiency of use, with losses through leaching and volatilization less likely (14).

Enhanced soil and physical properties following application of Municipal Solid Waste Compost have been reported on several occasions (36, 37, 38). The data from this study confirm these findings: the improved soil organic carbon and nutrition (N and available P) contributed to the improved early survival of trees in plots treated with MWC observed in this study.

It has been found that the addition of 10% w/w sewage sludge improved soil structure, increased water capacity and decreased bulk density of the plough layer in a sandy soil (39). El Shafei, (40) found that sludge may increase the ability of sands to store water for plant use. Holz et al (41) found that application of sewage sludge significantly increased soil moisture and organic matter contents in the top 3 cm of soil. Bulk density significantly decreased, and porosity, moisture retention increased with increasing sludge application. In this study biosolids applications did not improve soil moisture. It is likely that the greater tree growth induced by biosolids, and its associated improved soil nutrition, has drawn down the soil water supplies. Alternatively it could be the increased weed population in the biosolids plots that is using the available soil moisture. This is supported by the fact that the soil moisture in the Biosolids+Mulch plot is higher that the Biosolids alone, but lower than the Mulch alone. The mulch is suppressing weeds and reducing competition for soil moisture.

Soil temperature was significantly moderated in plots where mulch was applied. The data from this study support those of McGuinnies (10) and Schuman et al (11): Mulches can improve forage establishment on mine spoil as they reduce water loss by reducing evaporation, protect the soil from erosion and minimise soil crusting.

Plate 19. Young Plantation on Reshaped Overburden

CONCLUSION

Organic amendments have the potential to replace or supplement mineral fertilisers. Increased mineral fertiliser is applied to accommodate a lack of soil quality. However, the survival rate in plots that were treated with fertiliser was lower than in the control plots. As more fertiliser is added, the microbiological activity in the soil reduces and the soil becomes more unstable (42). As more nutrients are applied to the soil, there is the increase likelihood of nutrient runoff. Use recycled organics may provide nutrients whilst ameliorating the negative effects of mineral fertiliser.

All of the recycled organics trialled in this experiment improved either the early survival or growth of trees but in different ways:

- Biosolids significantly enhances growth, soil N and available P;
- Mulch suppresses weeds, moderates soil temperature and preserves soil moisture; while
- Soil Conditioner and Municipal Solid Waste Compost improve survival, increases soil organic matter, soil N, available P.

Understanding the role of individual recycled organics in maximising the survival and growth of plantation species, allows appropriate combinations of recycled organics to be used to overcome site specific problems.

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