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# Bark residue as a soil amendment in broadacre intensive vegetable production

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Project Number: VG98123

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## Final report for project VG98123 (2003)

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# Horticulture Australia Project VG98123

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**Purpose of project:**

Forestry operations produce large amounts of bark residue per year. This project investigated the costs and benefits associated with using hammer-milled eucalyptus bark residue as a source of organic matter for improving soil structure in agricultural soils that are intensively cultivated.

**Funding:**

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**Disclaimer:**

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**Industry summary**

Bark residue resulting from milling operations constitutes a major waste issue for forestry companies. However, bark residue is potentially a cheap source of organic matter that could be incorporated into intensively cultivated soils to maintain or improve soil structure. This project investigated the costs and benefits associated with the incorporation of aged, hammer-milled eucalypt bark residue into a krasnozem (red ferrosol) cropping soil in northern Tasmania. Replicated plots treated with different rates of hammer-milled bark residue (between 0-100 t/ha) were established on a farm. A typical crop rotation was carried out over the four years of the trial (broccoli – onions – potato – poppy - pasture). Measurements were made of yield and quality of crops and of the physical and chemical properties of the soil. Bark had no deleterious effects on crop growth, but nor did it improve yield or quality of crops. Bark gave some weed control and potential savings in irrigation. However, a cost benefit analysis suggested that that the use of eucalypt bark as a soil amendment at this site was economically marginal. This was due mainly to the cost of transport. However, it is possible that bark residue might improve crop yields at other sites that are low in organic matter or have been degraded from continuous cultivation, and hence be an economically viable amendment for improving soil structure.

**Technical summary**

Bark residue resulting from milling operations is a major waste issue for forestry companies. However, bark residue is potentially a cheap source of organic matter that could be incorporated into intensively cultivated soils to maintain or improve soil structure. This project investigated the costs and benefits associated with the incorporation of aged, hammer-milled eucalypt bark residue into a krasnozem (red ferrosol) cropping soil in northern Tasmania. Replicated plots treated with different rates of hammer-milled bark residue (between 0-100 t/ha) were established on a farm. A typical crop rotation was carried out over the four years of the trial (broccoli – onions – potato – poppy - pasture). Measurements were made of yield and quality of crops and of the physical and chemical properties of the soil. Bark had no deleterious effects on crop growth, but did not improve yield or quality of crops. Bark gave some weed control and potential savings in irrigation. At four years after the start of the trial and during a pasture phase of the rotation, there was a slightly lower level of nitrate-N in soil (0-50 cm) from plots treated with bark at 100 t/ha compared to the control. However, there was no significant difference in the status of other soil nutrients including ammonium-N, P (Colwell), K (Colwell), pH or organic C. Bark at higher rates tended to have less penetration resistance in the 0-150 mm layer. Bark treatments also tended to have greater hydraulic conductivity at higher suctions (-10 and –4 cm) than control plots, and less conductivity at lower suctions (-2 and –1 cm) suggesting a greater number of smaller pores with bark treatment. Aggregate stability was consistently higher in bark treated plots. This suggested that at four years after application, bark had improved the physical properties, but had little effect on the chemical properties of the soil. An economic analysis was conducted which assumed bark applications of between 10-50 t/ha had no effect on yield, but resulted in savings of up to 20% in land preparation, weed and disease control, fertiliser and irrigation costs in a typical crop for two years after application. This equated to savings in production costs of $4676, $7012 and $9530 for 10, 25 and 50 t/ha bark respectively. Assuming a cost of bark ($5/t) and spreading ($4.65/t) and cartage by a bulk cartage semi-trailer ($1.70/km), the breakeven distance for transporting the bark to the farm was calculated as 156, 80 and 38 km from the source of bark, for 10, 25 and 50t/ha bark application respectively. The analysis suggested that broad acre application of bark was economically marginal at this site, due mainly to the costs of

transporting bark. The economics might be improved in a poorer soil type where agronomic returns per tonne of bark might be higher, where the bulk density of bark is increased before cartage (e.g. by compaction), or where bark was placed more strategically (e.g. on irrigator laneways to reduce erosion).

# 1. Introduction

Much of the intensive vegetable production in northern Tasmania occurs on red ferrosol soils (Krasnozems). Continual cultivation of these soils has led to concern with regard to the maintenance of soil structure and long-term sustainability of vegetable production on these soils. Organic matter plays a critical role in the maintenance of aggregate stability and fertility of krasnozem soils. Organic matter can be maintained through cropping practices (e.g. green manuring) or through addition of organic amendments from off-site.

This project investigated the use of bark residue from forestry operations as a soil amendment in a krasnozem soil subjected to vegetable cropping. Approximately 40,000 tonnes of bark residue are produced every year as a result of milling operations by Gunns Ltd. (formerly North Forests) in Tasmania. This constitutes a major waste disposal issue for forestry companies such as Gunns Ltd. However, bark residue is potentially a readily available source of organic matter that could be applied to soils used in vegetable production to maintain organic matter.

The project investigated whether hammer-milled bark residue could provide a cost effective means of maintaining or improving the structure of intensively cultivated krasnozem soils.

### 1.1 Review of literature on bark as an organic amendment.

**Current horticultural uses of bark residue**

Bark constitutes some 10% of the harvested forest crop in terms of both weight and volume (Aaron 1991). Disposal of bark residue from forestry operations is a critical problem facing the forest products industry. For example, each year Gunns Ltd. produce some 40,000 tonnes of bark residue from the Hampshire Mill, near Burnie, Tasmania. Some of this material is currently utilised by garden centres as mulch for home gardens and by local industries as fuel in boilers. More recently, improvements to harvesting machinery have allowed a proportion of bark to be removed from trees in the forest after they have been felled, however, a substantial amount of material is still removed during milling, which contributes to the waste disposal problem.

Bark was first demonstrated as a valuable addition to media for container-grown plants at the Chelsea Flower Show in the UK during the early 1970s and thereafter has become widely used (Aaron 1991). Prior to this development, bark residue accumulated at various wood processing industries including pulp-mills, pit-wood yards and fencing depots and was often too costly to dispose of (Aaron 1991). More recently there have been environmental concerns with regard to the air pollution from burning of bark residue and filling of landfills. Therefore alternative disposal strategies have been sought. Campbell and Tripepi (1992) recognised the disposal of log yard residues as a problem for forestry industries and outlined some of the potential uses for this material. These included composting to reduce volume and mass, while creating a more stable material for horticultural applications. They suggested that composted and un-composted log yard residues could be used for revegetating landfills and polluted sites, as soil amendments for enhancing productivity of marginal land, as mulch for landscape beds and walkways, as a soil cover for mud and erosion control and as a component of container media for container-grown plants.

Most of the work to develop bark residue as a component of container media occurred during the 1960s and was conducted by the Forestry Commission's Research Branch in the UK. This work demonstrated that a range of plants could be grown in pure coniferous bark with the addition of N-fertiliser. Furthermore, mixing bark with sphagnum peat in roughly equal proportions produced a suitable container plant growth media (Aaron 1991). Addition of N-fertiliser was important as bark had a high C:N ratio which contributed to N-drawdown of the media. Drawdown occurs as micro-organisms in the soil metabolise N while they utilise C as a food source, thereby making N deficient for plant growth. Trials in the USA at the same time further suggested pulverised pine bark was a suitable medium for potting and propagation (Pokorny & Gugino 1967, Pokorny & Perkins 1967). The UK Forestry Commission trials also demonstrated other potential problems with the use of bark residue. Fresh bark could severely inhibit the growth of plants and mushrooms, however bark that had been stored in large heaps for several weeks was not phytotoxic (Aaron 1991). Furthermore bark of some tree species was much more phytotoxic than others. Phytotoxicity was attributed to volatile oils, especially monoterpenes (Asplund, 1968, Aaron, 1976, Aaron & Richards, 1990). Phytotoxicity was reduced by stacking of moist bark in piles for up to six weeks during which time the bark becomes 'mature' or 'aged'. The reduction in phytotoxicity arose from fermentation by thermophilic bacteria which i) reduced monoterpene concentrations to non-phytotoxic levels, ii) elevated the stack temperature to around $80^{o}C$ for a number of weeks which kills plant pathogenic fungi, harmful insects and weed seeds, and iii) raised the pH from acidic levels (around pH 4.5) to an acceptable level (pH 5.5) for micronutrient availability (Aaron 1991). The killing of pathogenic fungi during stacking is important, as pathogens such as *Armillaria* can potentially be spread on bark. Handreck and Black (1994) recommended turning piles of bark two or three times during ageing to ensure that outer layers are also incorporated and heated. Ageing is a quicker and cheaper process compared with composting, but aged bark has a greater nitrogen drawdown rate than composted bark.

One of the main benefits of adding bark to container media was to improve aeration. Bark makes little contribution to plant nutrition, providing only calcium, potassium, manganese and iron in appreciable quantities, depending on the nutritional status of the soil in which the trees were growing (Aaron 1991). Another potential concern with regard to utilising bark for horticultural uses was the presence of tannins that could potentially inhibit nitrification. In species such as spruce, the tannin content in bark can be greater than 20% of oven dried weight. However, the mechanical pulverising of bark and the high temperatures obtained during bacterial fermentation destroys a large proportion of tannin (Aaron 1991). In addition, bark of some species has sometimes been implicated in manganese toxicity when used in container culture (Solbraa and Selmer-Olsen 1981). Manganese levels of up to 3900 ppm have been reported in Eucalypt bark (Handreck & Black 1994). However, toxicity problems often arise only when the pH of media fall to below pH 5 and Mn becomes more readily available in soil solution. Manganese toxicity rarely becomes a problem when pH is maintained at an optimum for most plants.

In addition to improving the physical properties of container media, there was a recognition during the 1980s of the ability of composted hardwood bark to suppress plant pathogens in container media (Hoitink, 1980, Sivasithamparam *et al.* 1981, Hoitink *et al.* 1997). Handreck and Black (1994) indicated that *Eucalyptus diversicolor* (karri) and *E. calophylla* (marri) are most commonly used for producing composts. Composted barks of these species have been found to be suppressive to plant pathogens such as *Phytophthora cinnamomi* and *P. dreschleri* for up to 3 years and that as little as 10% by volume imparts suppressiveness to other materials.

Dissanayake and Hoy (1999) reported that bark composts were capable of suppressing root rot and increasing growth of sugarcane in field soil and *Pythium* infested soil when added in either non-sterile or steam treated forms. Chavarria-Carvajal and Rodriguez-Kabana (1998) reported several organic amendments, including pine bark, reduced root-galling, reduced populations of the plant-parasitic nematode *Meloidogyne incognita* and increased populations of non-parasitic nematodes in pot trials. Erhart *et al.* (1999) demonstrated that bark compost was strongly suppressive to *Pythium ultimum* in horticultural media. Potting media containing composted hardwood barks have been shown to be suppressive to a range of soil-borne pathogens. Hardy and Sivasithamparam (1991) demonstrated that composted eucalyptus (*E. calophylla* and *E. diversicolor*) barks suppressed a range of *Phytophthora* spp., with *P. cryptogea* completely suppressed. The suppressive nature of the compost was reduced by steaming, suggesting that the suppressiveness was biological in nature. Kokalisburelle and Rodriguez-Kabana (1994) reported that the addition of powdered pine bark at rates up to 50 g/kg to soil caused changes to soil composition and populations of fungi, increased soil enzyme activities and reduced juvenile populations of the nematode *Heterodera glycines* in roots and the number of adult cysts/g root. However there was no relationship between the rate of bark and populations of root knot nematode *Meloidogyne arenaria* in soil or roots. Mixtures of bark (which had been composted for 30 days) and soil at rates of 4 bark:1 soil up to 1 bark:2 soil (v:v) reduced galling caused by *Meloidogyne hapla* and *M. incognita* by between 75-86% and 94-99% respectively (Malek and Gartner 1975).

Composted hardwood bark has been used successfully in container media for control of *Phytophthora* spp. (Hoitink *et al.* 1977), *Rhizoctonia solani* (Nelson *et al.* 1982;

Stephens *et al.* 1981), and *Fusarium* spp. (Chef *et al.* 1983, Trillas-Gay *et al.* 1986). Container media containing composted hardwood bark was suppressive to *R. solani*, while that amended with fresh hardwood bark were conducive (Chung *et al.* 1988).

In Tasmania, some work on biological control of onion white root rot caused by the fungus *Sclerotium cepivorum* was conducted in conjunction with this project. J. Dennis (pers. comm.) applied eucalypt bark mulch at rates of 20% (v/v) to soil infested with *Sclerotium cepivorum* to trays and planted 20-25 early cream gold onions. At harvest, the incidence of onion white root rot was significantly higher ($P<0.05$) in the control (26.5%) than in soil treated with bark at 0, 3 or 6 weeks before sowing (8.3-11.4%).

While bark has been used widely in container culture, there are few reports of the use of bark or other ligneous residues in broadacre agriculture. Ligenous residues have been shown to influence soil physical and chemical properties (Saini and Hughes 1975; Delas and Molot 1983; Beauchemin *et al*. 1990). However, Gasser *et al*. (1995) reported that N immobilisation often followed application, and this was considered a limiting factor in production of crops such as potato. Beauchemin *et al*. (1990 and 1992), N'dayegamiye and Isfan (1991) and Gasser *et al*. (1995) also suggested that ligneous residues may also present a risk of phytotoxicity if not composted prior to addition to soils. Tremblay and Beuchamp (1998) applied chipped ramial wood (chipped fine branchwood) to plots in a potato crop. They showed fungal populations temporarily increased following incorporation, whereas bacteria and actinomycete populations remained unchanged. Chipped wood did not induce development of common scab (*Streptomyces scabies*) or *Rhizoctonia solani* on tubers. Chipped wood increased soil total carbon (C) and water-holding capacity but did not affect C/N ratio or pH. Available P decreased following incorporation. Gasser *et al*. (1995) reported on a 3-year study on a sandy loam soil comparing the performance of potato crops rotated with green manure crops or following the addition of partially humified bark residues or tree clippings (100 $m^3$/ha) at the beginning of the trial. Ligneous amendments were shown to significantly improve soil water content during the flowering stage that led to significantly increased yields and specific gravity. Partially humified bark induced rapid changes in soil organic carbon and cation exchange capacity. N'dayegamiye and Angers (1993) suggested that ligneous material would have beneficial effects on soil physical properties and on organic matter content and that these effects may persist for several years because of the low decomposition rate.

Some of the potential problems associated with the use of eucalyptus bark residue as a medium for growing plants can be reduced by composting. This project also compared the use of aged bark with eucalyptus bark residue/sewage sludge compost produced by the Central Coast Council, Ulverstone, Tasmania. In comparison to bark, disposal of sewage biosolids also constitutes a major environmental and economic problem. For example Michalk *et al*. (1996) reported that some 150 tonnes (dry weight) of biosolids are produced per day from the treatment of sewage in New South Wales alone. Addition of this material to agricultural land is a potential means of disposal, which would allow recycling of nutrients and organic matter. Michalk *et al*. (1996) reported increased yield of dry matter and perennial grass content from the use of recycled sewage waste products on pastures grazed by sheep. However, sewage waste may also contain heavy metals, persistent pesticides and pathogens which pose a potential environmental and health hazard if the material is used without due regard to these contaminants. For example, Michalk *et al*. (1996) reported increased Zn and Ni concentrations in pasture from the addition of sewage waste products, although this had no effect on the production and health of ewes and their offspring. The composted material from the Central Coast Council meets Grade A stabilisation requirements of the draft Tasmanian biosolids reuse guidelines i.e. *E. coli* and faecal coliforms (<100 most probable number/g; Salmonella and Listeria (not detected/100g). Low levels of heavy metals can be produced at the Central Coast Council Waste Water Treatment Plant. However, all concentrations are either Grade A or B of the Tasmanian biosolids reuse guidelines, and given the amount of dilution with bark during the composting process and a one-off application there would be no risk of heavy metal contamination. Heavy metal contamination is an environmental concern and causes adverse effects to plant growth. For example, Handreck and Black (1994) advise that sewage sludge material with a total zinc content of around 1000 mg/kg should not make up more than 50% of a container mix unless the pH will remain above 6 as a drop in pH below 5 may produce zinc toxicity in some plants.

## 1.2 Agricultural soils in northern Tasmania.

A large proportion of intensive vegetable production in Northern Tasmania occurs on red ferrosol (Krasnozem) soils. Ferrosols are deep, acidic, heavy textured soils formed on basalt or other basic igneous rocks (Isbell 1994). These soils generally have good physical characteristics. However, there have been some concerns over the capacity of these soils to withstand intensive horticulture over the long term, due to the impact of cultivation on erosion and soil structure.

Erosion is a major issue facing intensive vegetable growers on many krasnozem soils (Cotching 1995). Krasnozems are not inherently erodible due to their naturally strong structure, high clay and organic matter contents, especially when combined with permanent vegetative cover. However, intensive vegetable farming requires soil disturbance and removal of vegetative growth. This increases the risk of erosion, especially when combined with high rainfall, steep topography and long slopes (Cotching 1995). For example, Loughran *et al.* (1992) estimated a net soil loss rate of 19.3 t/ha/year from cropping land on a slope of 14% in Forth, Tasmania, which equated to 2 mm depth of soil per year. Similarly, net soil loss has been estimated at 23-43 t/ha/year from onion crops on slopes of 14% in Forth, Tasmania, equating to 2-4 mm depth of soil per year (Cotching 1995). A single erosion event in a field cropped with brussel sprouts was estimated to cause net soil loss of 48t/ha in Abbotsham, Tasmania (D. Wright pers. comm. in Cotching 1995). Surveys of onion growers in Northern Tasmania demonstrated that a majority of growers rated erosion as moderate to severe in their district (Ewers *et al.* 1988, Chilvers and Cotching 1994), with 30% of growers believing that soil erosion had moderate to substantial effects on farm viability (Cotching 1995). Slopes greater than 20% are not recommended for vegetable cropping on krasnozems in Tasmania by the Kindred Landcare Group (Cotching 1995). In recent years the DPIWE has promoted erosion control measures including straw mulched ripped lines on the contour. Tasmanian vegetable farmers are increasingly adopting these practices on steeper slopes.

Intensive vegetable production also plays a major role in decline in soil structure. Soil structure can be defined as the way that the soil particles (sand, silt, clay) and organic matter are arranged and the size and shape of the spaces between them. Krasnozems have a greater proportion of coarse rather than fine aggregates (El-Swaify 1980) which allows rapid drainage following rainfall and relatively quick access by machinery. However, the high proportion of macroporosity is sensitive to compaction. Some 52% of onion growers in northern Tasmania considered that their soils exhibited moderate to substantial compaction (Chilvers and Cotching 1994). This was believed to result from cultivation and harvesting when the soil was too wet, use of heavy machinery e.g. harvesters and loaded trucks, and excessive cultivation. Bridge and Bell (1994) indicated changes associated with soil compaction to be (i) reduced porosity, aeration and soil water holding, (ii) reduced infiltration resulting in increased runoff and erosion, (iii) increased root impedance due to increased soil strength and plough pan formation and (iv) increased cloddiness. However Sparrow *et al.* (1999) did not identify soil compaction as an issue at any of 25 sites in under continuous cultivation in Tasmania.

Krasnozems have a naturally good structure and aggregate stability (Isbell 1994). The dominant stabilising factors in Krasnozems are non-crystalline iron and aluminium oxides and hydroxides (El-Swaify 1980), unlike in other soils where organic materials are important. The electrostatic attraction that holds together kaolin and sesquioxides is also important for aggregate stability, but is pH dependent (Tama and El-Swaify 1978). Improvements to soil fertility (e.g. liming) can reduce intra-aggregate bonds (El-Swaify 1980) and heavy applications of superphosphate dissolve considerable amounts of iron and aluminium from the soil, decreasing the crystallinity of kaolonite (Coughlan *et al.* 1973) resulting in poor aggregation.

A long- term study of three ferrosols in Southern Queensland (Bridge and Bell 1994) indicated that cropped paddocks had higher bulk densities, lower infiltration rates, lower aggregate stability and lower organic matter content in comparison to uncropped paddocks. Because the clay fraction of ferrosols is dominated by low charge kaolin and sesquioxide minerals, the chemical fertility of ferrosols is more dependent on organic matter compared with other clay soils (Moody 1994).

Several studies (Wright 1988, Oliver 1992, Lobry de Bruyn and Kingston 1997, Doyle and Ballie 1998) have attempted to quantify the effect of different agricultural management on physical properties of Tasmanian ferrosols. Wright (1988) reported that organic C and wet aggregate stability were less in cropped paddocks than in pasture paddocks. Doyle and Baillie (1998) reported that two heavily cropped ferrosols had greater surface soil penetration resistance and shear strength and lower organic C, cation exchange capacity and water stable aggregates compared with an uncropped site. Sparrow *et al.* (1999) studied 25 Tasmanian ferrosols and found that in cropping or pyrethrum paddocks, soil organic C in the top 150 mm was approximately 30% less and microbial biomass C was approximately 60% less than pasture paddocks. Pasture soils had greater shear strength and water contents at the liquid limit in the top 150 mm and more water-stable aggregates in the subsurface soil. Despite these differences Sparrow *et al.* (1999) reported that the absolute values of most of the measured variables in cropping paddocks were indicative of soils in good condition. They suggested that the decrease in organic C in cropped soils had not corresponded with a reduction in cation exchange capacity due to liming which had increased the pH. Bell *et al.* (2001) reported on management strategies on degraded ferrosols in Queensland to overcome soil structural degradation from tillage and soil compaction. Tillage and ley treatments increased the infiltration of rainfall into the soil, due to reduced surface crusting arising from cover and increased labile C. Treatment also increased macroporosity and hydraulic conductivity in the subsoil. However, although these changes reduced runoff and risk of soil erosion, the degraded ferrosols had a relatively low water storage capability, which did not lead to improvements in crop production.

Organic matter plays a major role in the fertility of krasnozem soils. Krasnozems are dominated by low-charge clays (kaolinites) and variable charge oxides of aluminium and iron, therefore the negative charge on surfaces is mainly on organic matter (Oades 1994). Isbell *et al*. (1976) reported that over 70% of the exchange capacity of krasnozems could be accounted for by an organic matter content of 7%. Organic materials therefore are not only a major source of N, P and S, but provide the majority of cation exchange capacity in krasnozems (Cotching 1995). However, the decrease in organic C in cropping soil noted by Sparrow *et al.* (1999) in Tasmania did not translate to reduced CEC. This was attributed to the common practice of liming which increased pH and therefore increased the CEC of the remaining organic C (Sparrow *et al.* (1999). Organic matter also serves to minimise the impact of acidification from fertilisers such as sulphate of ammonia and mono-ammonium phosphate that are commonly used in cropping soils (Ahern *et al*. 1993).

## 1.3 Purpose of the project

This project investigated the costs and benefits associated with the incorporation of aged and hammer-milled eucalypt bark residue into a krasnozem cropping soil in northern Tasmania. A comparison of aged bark with composted sewage sludge/eucalyptus bark obtained from the Central Coast Council composting facility was also undertaken. The trial was established at the TAFE Freer Farm, Burnie, Tasmania and involved the establishment of replicated plots treated with different rates of organic amendments. A typical crop rotation was carried out over the four years of the trial (broccoli – onions – potato – poppy - pasture) and measurements were made of yield and quality of crops and of the physical and chemical properties of the soil. An economic analysis was made detailing the costs and benefits associated with the use of bark in broad-acre agriculture.

# 2. Materials and methods

## 2.1 Bark and compost

Eucalyptus bark was obtained from the Hampshire mill of Gunns Ltd., (formerly North Forests) Burnie, Tasmania. The majority of the bark (approximately 75%) was of the ash group of eucalypts: *Eucalyptus delegatensis* (50%), *E. obliqua* (20%) and *E. regnans* (5%). Other eucalyptus species accounted for less than 25% of the bark (Malcolm Hatcher pers. comm.). Bark was ground in a commercial hammer-mill (Les Walkden Transport) before being applied to plots.

Composted eucalyptus bark/sewage sludge was obtained from the Central Coast Council Waste Water Treatment Plant, Ulverstone, Tasmania. The compost was prepared by mixing de-watered sewage sludge with bark waste (1:1), placed in piles approximately 2 m high and turned weekly for the first few months and then at 3-4 week intervals thereafter. Compost was approximately 5 months old when used.

To assess particle size distribution, bark and composted bark/sewage sludge were sieved on a bank of sieves (50 µm, 100 µm, 200 µm, 500 µm, 1.0 mm, 2.0 mm and 5.0 mm). Samples retained on each sieve were dried (60$^{o}$C for 48 hours) and weighed. A sub-sample of bark and compost was ground in a Glen Creston Mill to a particle size less than 1mm diameter and sent to the Central Science Laboratory, University of Tasmania, Hobart for analysis of total C, H, N and S. The moisture content of the bark and compost was determined gravimetrically by drying four sub-samples of 600 g each overnight at 90°C. The bulk density of bark and compost samples was estimated by weighing sub-samples placed in 55 litre buckets.

Two sub-samples of compost were sent to Environmental Pathogens Pty. Ltd., Canberra for microbiological and parasitological analysis. A flotation method was used to recover parasite cysts and eggs. For viral analysis the samples were processed by polyethylene glycol precipitation and analysed by cell culture. For nucleic acid determination, 6 ml of PEG concentrate was subjected to sucrose density gradient ultra-centrifugation and then analysed for viruses by PCR. The following methods were used in sample processing and analysis: EPWI 501, EPWI 502, EPWI 521, EPWI 429 and EPWI 503. A further 2 samples were sent to Aquahealth, University of Tasmania, Hobart, Tasmania and assessed for faecal coliforms/*E. coli* (AS4276.7-1995), faecal streptococci (AS4276.9-1995), *Clostridium perfringens* (modified from Oxoid manual-1995), Salmonellae (AS4276.14-1995), Shigellae (modified from AS4276.14-1995), Listeria (modified from USDA FSIS-1989)

## 2.2 Trial site

The trial was established at the TAFE Freer Farm, Burnie Tasmania, on a red Ferrosol soil on a north-west facing slope. The Universal Grid Reference from the 1:25,000 Burnie topographic map was 55GDQ 051 526. The site had previously been cropped with potatoes and left fallow for some months prior to the establishment of the trial.

## 2.3 Broccoli

*Site preparation*

In early January 1999 the site was sprayed with herbicide, 2 l/ha Roundup (glyphosate) and 1 l/ha MCPA with wetter (Activator 100 ml/100 l water). The site was then deep ripped and power-harrowed.

The trial site was established as 32 plots in an 8 x 4 lattice (Appendix 1). The following treatments were applied: control (untreated), bark at 10, 50 and 100 t/ha (fresh weight) and compost at 10 and 100 t/ha (fresh weight) applied as a one-off treatment at the start of the trial. In addition, a further treatment of bark at 10 t/ha was included. This treatment was initially planned to test the effect of an annual application of 10 t/ha however, this was changed (see later). Plots were each 15 m by 14 m (210 m$^2$) with 8 replicate plots for the control and 4 replicate plots for all other treatments. Bark and compost were applied by hand on 14/1/1999 and 21/1/1999 respectively by emptying the required volume of material as a series of wheel barrow loads at regular intervals across each plot. Amendments were applied by hand to minimise soil compaction and to ensure even coverage of the plot. Bark and compost was then raked to a uniform depth. Amendments were incorporated into soil with a power-harrow on 3/2/1999.

*Crop agronomy*

Broccoli transplants (cv. 'Marathon') were obtained from Hills Transplants, Devonport, Tasmania and planted 350 mm apart at a density of 33,333 per hectare on 4/2/1999. Plants were arranged two rows to a bed with each bed 160 cm wide. Fertiliser was band placed at a rate of 988 kg/ha 14:16:11 (N:P:K) along with 22.7 kg B, 16.6 kg Zn and 0.35 kg Mo per hectare. On 12/4/1999 and 22/4/1999, broccoli was sprayed with insecticide Ambush (permethrin) at 100 ml/ha and wetter (Activator 10 ml/100 l water) at rate of 200 l water per hectare. Urea (2 kg/ha) was applied along with the spray on 12/4/1999. Due to the regular rainfall over the trial period, irrigation (25-30 mm) was applied at three times only with a travelling gun irrigator. Plots were monitored for water requirements by tensiometers in each plot. However, the regular rainfall during this season obviated the need to differentially water individual treatments. Weeds were controlled mechanically by use of inter-rowing equipment on 25/2/1999 and 17/3/1999.

*Soil and plant assessments*

Soil samples were taken from plots on 22/2/1999 and on 15/3/1999 at a depth of 0-20 cm for nitrate and ammonium analysis by 2 M KCl extraction.

Plots were assessed for weed growth on 23/2/1999 prior to the start of normal weeding operations. Weeds were counted in three quadrats (25 cm x 25 cm) per plot. On 12/3/1999 ten plants per plot were assessed for height and number of fully expanded leaves. Petioles were obtained from broccoli on some plots on 23/3/1999 and expressed sap assessed for leaf nitrate levels using a Horiba nitrate ion meter.

Broccoli was harvested by hand on 30/4/1999, 6/5/1999 and 17/5/1999 from an area 10 m long by 8 rows (13 m) wide (129.6 $m^2$) within the centre of each plot. Heads were removed if they had attained a diameter of approximately 15-20 cm, in line with commercial practice. Heads from each plot were weighed.

## 2.4 Onion

*Soil measurements*

On 11/8/1999 soil samples were sent to Department of Primary Industries, Water and Environment, Mount Pleasant Laboratories, Launceston for analysis of soil pH (1:5, soil:water), nitrate-N, ammonium-N, Colwell P, Colwell K, and organic C (Walkley-Black method). To characterise the site, soil samples were also taken from an untreated section adjacent to the trial site to a depth of 60 cm at 10 cm intervals and analysed for soil nutrients (as above). For nematode extraction, 10 soil cores were taken (2.5 cm diameter, 20 cm depth) on 17/1/2000, from each plot, crumbled and mixed thoroughly. Nematodes were extracted from 200 ml soil over 3 days at room temperature by the Whitehead tray method (Whitehead and Hemming 1965). Nematodes were concentrated on a 30µm sieve, washed into 40 ml containers and the number of plant parasitic and non-plant parasitic types in 4 ml of suspension counted under a compound microscope (50-100X).

*Onion crop*

Regular Creamgold onions were seeded with an Accord precision seeder on 6/8/1999. The seed-bed had been prepared by mulching, ploughing, and deep-ripping. The site was then power harrowed and rolled. Onions were sown in beds 1m wide, with 0.6 m wheel tracks between beds. There were 9 rows of onions per bed, sown at 3.3 kg/ha. The fertiliser and pesticide schedule is given (Table 1). Onions were lifted in late February 2000 and allowed to dry on the soil for 14 days prior to topping. Onions were then collected from a quadrat in the centre of each plot. The quadrat consisted of 5 adjacent beds, 10 m long ($80m^2$). Onions were not collected from replicate 4, as poor coverage with herbicide led to a heavy infestation of weed in some plots which would have influenced results. For this reason onions were collected from 6 replicate plots of control and bark 10 t/ha and 3 replicate plots of other treatments. Onions were

Table 1. Timing and rates of fertiliser and pesticides applied to the onion crop.

| | |
|---|---|
| *Fertiliser regime* | |
| 5/8/1999 | 4-17-8.1 @ 1270 kg/ha pre-drilled with the air seeder |
| 6/8/1999 | Triple super @ 125 kg/ha drilled with onion seed |
| 26/10/1999 | Urea @ 90 kg/ha |
| 16/11/1999 | Urea @ 100 kg/ha urea |
| | Urea/potash @ 125 kg/ha each |
| | |
| *Pesticide regime* | |
| 27/8/1999 | Sprayseed @ 2.4 L/ha, Lorsban @ 700 mL/ha, Stomp 1 L/ha |
| 29/9/1999 | Stomp @ 1 L/ha |
| 16/10/1999 | Tramat @ 800 mL/ha |
| 19/10/1999 | Totril @ 600 mL/ha, Tribunil @ 600 g/ha |
| 25/10/1999 | Totril @ 500 mL/ha, Tribunil @ 500 g/ha |
| 14/11/1999 | Lorsban @ 700 mL/ha |
| 7/12/1999 | Totril 750 mL/ha, Tribunil @ 750 g/ha |
| 22/12/1999 | Totril @ 750 mL/ha, Bladex @ 750 mL/ha |
| 24/12/1999 | Penncozeb @ 2.5 kg/ha |
| 14/1/2000 | Penncozeb @ 2.5 kg/ha, Dominex @ 250 mL/ha |
| 26/1/2000 | Totril @ 500 mL/ha, Bladex 300 mL/ha |

Insecticides: Lorsban (chlorpyriphos), Dominex (alpha-cypermethrin).

Herbicides: Stomp (pendimethalin), Tramat (ethofumesate), Tribunil (methabenzthiazuron), Totril (ioxynil), Bladex (monoethylene glycol and cyanazine), Sprayseed (paraquat and diquat).

Fungicides: Penncozeb (mancozeb),

weighed and graded according to size and disorders, both in terms of weight and number of onions.

*Irrigation regime*

Tensiometer readings from the previous broccoli crop had indicated that plots with high rates of bark remained wetter for longer than untreated plots. To investigate whether bark application could lead to reduced water use, treatments were watered differentially according to tensiometers placed 150 mm deep in three replicate plots of each treatment and six replicate plots for the control. Watering of each treatment was conducted when one or more of the tensiometers for each treatment was reading 50 kPa or above.

*Soil water*

On 19/1/2000 soil samples were taken for pressure plate analysis of volumetric water content. In each plot, undisturbed cores were collected in metal rings (48 x 20 mm) from each of two depths (5-7 and 10-12 cm depth). Two samples were taken at each depth from each plot. Samples were taken 1 row away from the sprinkler and either side of the sprinkler. Samples were saturated and placed in a gas chamber to equilibrate. Volumetric water content was measured between 10 kPa suction (an estimate of water content at field capacity) and 100 kPa suction (an estimate of a point where plants have to work harder to extract water and growers would probably be irrigating). The difference in water content between 10 and 100 kPa is readily available water.

**2.5 Potato**

On 28/9/2000, further application of hammer-milled bark was made to plots that had received 10 t/ha bark in year one (appendix 1). Half the plots (4) each received twelve barrow loads of bark (24.6 t/ha fresh weight) and the other 4 received 24 barrow loads (49.2 t/ha fresh weight). Bark was distributed evenly over the soil surface of the plots by raking. Three samples of 700 g hammer-milled bark were weighed and reweighed after drying (100°C for 48 hours) to determine dry matter content. The mean dry matter content and standard deviation was 38.7% and 0.97% respectively.

Following preparation of the site by ploughing and rotary hoeing, the trial was planted with Russet Burbank potato seed along with fertiliser (N:P:K, 11:13:19) at 1500 kg/ha on 7/12/2000. Preliminary soil tests from samples taken randomly from the site on 25/10/2000 gave a pH of 5.5-6.0 (1:5, soil:water). On 12/1/2001 weed counts were conducted on each plot. Weeds were counted in a 625 $cm^2$ quadrat at 3 randomly selected points in each plot. On 18/1/2001, potato plants were remoulded. Irrigation was applied at 25 mm/week from 2/1/2001 to 27/4/2001 unless there had been over 25 mm rainfall for the week. On 31/1/2001, ten randomly selected plants were dug from each plot, dried overnight (100°C) and weighed. The $4^{th}$ or $5^{th}$ petiole and leaflets were removed from 20 randomly selected plants in each plot, cooled and frozen for analysis of sap nitrate. Sampling was conducted early to mid morning. Leaflets were removed, and sap expressed from the petioles in a garlic press. Sap (100 μl) was placed on a Horiba nitrate ion meter and nitrate (ppm) recorded. Two aliquots of sap were measured from each plot.

Fungicides Score (difenoconazole) and Dithane (mancozeb) with wetter were applied at label recommendations on 6/2/2001, 21/2/2001 and 6/3/2001 to control blight. On 10/5/2001 plots were sprayed with the herbicide Sprayseed at label rates to reduce weeds, and the plots were slashed on 13/5/2001. An area 4 rows wide by 5 m long (16.2 $m^2$) was harvested from the centre of each plot on 31/5/2001. Potatoes were graded at DPIWE Forthside Vegetable Research Station. Potatoes were placed into size categories (0-80g, 80-250g, 250-650g, 650-850g, >850g or waste (misshapen, cracked, rotted) and assessed for specific gravity, colour, and hollow heart.

On 21/5/2001 soil samples were taken for pressure plate analysis of volumetric water content. In each plot, undisturbed cores were collected in metal rings (48 x 20 mm) from each of two depths (5 and 10 cm). Two core samples were taken at each depth from each plot. Core samples were taken between rows, and only in rows that had no traffic. Cores were stored at 2$^{o}$C for 5 weeks prior to measurement, then saturated and placed in a gas chamber to equilibrate. Volumetric water content was measured between 10 kPa suction (an estimate of water content at field capacity) and 100 kPa and 300 kPa suction (an estimate of around field capacity) and 1500 kPa (considered to be permanent wilting point). Bulk density of soil in rings was determined from the dry weight of soil and the volume of the ring.

**2.6 Sowing trial**

Plots were established at the side of the current trial to investigate the effect of freshly applied bark on seedling emergence and early growth of other crop species. Barrow loads of bark were placed onto plots on 28/9/2000 and raked over the surface to distribute evenly. There were 3 replicate plots of each of the following - control (untreated), bark 34.4 t/ha and bark 68.9 t/ha. Plots were each 25 m$^2$ in area. Fertiliser (N:P:K, 7:12:9) was added at 500 kg/ha and poppies and onions sown on 23/10/2000.

**2.7 Poppy**

Following cultivation, poppy seed was sown with an air seeder on 14/9/2001 by Tasmanian Alkaloids Pty. Ltd. Fertiliser (N:P:K 6:19:5 +Boron) was applied at a rate of 500kg/ha at planting.

On 25/10/2001, the trial was becoming weedy, with white clover (*Trifolium repens*), black nightshade, black bindweed, fathen, fumitory and hog weed predominating. The following herbicides were applied: Command (clomazone 480 g/L) @ 500 ml/ha, Starane (fluroxypyr 200 g/L @ 1 litre/ha, Asulox (asulam 400 g/L) @ 6 l/ha followed 5 days later by an evening application of Reglone (diquat dibromide monohydrate 200g/L) @ 800 ml/ha and Alta (wetting agent) @ 350 ml/ha.

Poppy capsules were hand harvested from two, 3 x 3 m quadrats (18m$^2$/plot) and weighed on 26/2/2002. Alkaloid analysis for anhydrous morphine alkaloid content was conducted by Tasmanian Alkaloids Pty. Ltd., Westbury, Tasmania. Samples were air dried and ground to less than 2 mm diameter. Ground material (3.5 g) was added to 0.3 g of lime and 50 ml of $H_2O$ and shaken for 30 minutes. Oxalic acid (12.5 ml) was added, mixed and filtered. The filtrate was analysed using a Waters HPLC system with phenomenex phenosphere 5µm 5CX 80A column. Samples were tested against standards of known concentration.

After harvest, soil resistance was measured with a Rimik CP-20 penetrometer fitted with 12.9 mm diameter cone with a $30^o$ included angle. Measurements were taken to 585 cm depth at 15 mm intervals in control, bark 50 and bark 100 t/ha plots. Five readings were taken from each plot and averaged.

**2.8 Pasture**

Prior to sowing pasture, the site was sprayed with herbicide Roundup (Glyphosate) at 2.5 l/ha on 2/8/2002. The field was ploughed and rotary hoed on 29/10/2002 to form a seed bed. On 4/2/2003, tetraploid ryegrass was sown at a rate of 10 kg/ha with superphosphate at 250 kg/ha. Broadleaved weeds were controlled with application of 750 ml/ha Banvil (dicamba) and 2 l/ha MCPA 500 in late March 2003.

Soil samples were collected on 24/2/2003 from 6 positions in each plot. Samples were taken with a trowel to a depth of 30 cm, crumbled and mixed. Due to some wash of soil in replicate 1, only 3 replicates for treatments and 6 replicates for the control were sampled. Nematodes were extracted from 200 ml soil over a period of 48 hours at room temperature by Whitehead tray technique (Whitehead and Hemming 1965). Extractions were from 3 replicate plots for all treatments and 6 replicate plots control. Pasture growth was measured with a rising plate meter on 18/3/2003 and 28/4/2003 at 30 positions in each plot, with 3 replicate plots for all treatments and 6 replicate plots for the control. The rising plate meter (Earle and McGowan 1979) consists of a plate which exerts a downward pressure (4-7 kg/$m^2$) on the pasture and measures pasture height in 0.5 cm steps. The relationship between the pasture height over the plate area surveyed for the summer period during which measurements were taken was: Herbage mass (Kg dry matter/ha) = 320 x average meter reading (cm) + 500 (D. Donaghy, TIAR, pers. comm.).

## 2.9 Soil physical measurements

Soil resistance to cone penetration was measured on 24/3/2003 using a recording penetrometer (Rimik 12.9 mm diameter cone with $30^{o}$ included angle). Readings were recorded at 15 mm intervals to a depth of 600 mm at three random locations in the control and bark 50 t/ha plots. Soil samples were also collected at 10, 20, 30, 40, 50 and 60 cm for gravimetric water content.

Unsaturated hydraulic conductivity was determined in the field on 7/4/2003 following McKenzie *et. al.* (2002). Disc permeameters were used at suctions of –10, -4, -3, -2 and –1 cm suction to determine unsaturated hydraulic conductivity and to estimate saturated hydraulic conductivity on the control and bark 50 t/ha plots in April 2003. Due to the slope of the trial site an area was excavated (10 cm depth on average) and picked back to provide a level surface for the permeameter measurements. Four measurements were made on each plot.

Wet aggregate stability was determined using the technique of Gradwell and Birrell (1979) with the following modifications. Sieve sizes of 4, 2, 1, 0.5, 0.25 and 0.125 mm were used, with a sieving time of 15 minutes. Replicate samples were measured on each of the control, bark 50 t/ha and bark 100 t/ha plots. Samples were collected from the 0-15 cm depth and sealed and stored at $2^{0}$ C until processing.

Soil samples were collected for nutrient analysis with an auger to a depth of 50 cm on 26/3/2003. Three samples were taken from 6 control plots and 3 plots from each of the treatments bark 50 t/ha, bark 100 t/ha and compost 100 t/ha. Samples were air dried, mixed and ground to <1mm and mixed before sending to CSBP Laboratories, Western Australia for chemical analysis (Table 24).

# 3. Results

### 3.1 Broccoli

*Chemical and physical analysis of bark and compost.*

The particle size analysis indicated that on a dry weight basis some 46.3% of bark particles and 60.9% of compost particles were smaller than 5.0 mm (Table 2). Applications of even 100 t/ha bark did not fully cover the surface of the soil and were easily incorporated into the soil during cultivation (Plate 1)

Table 1. Dry weight of bark and compost (grams) retained on sieves of differing aperture size and percentage composition on a dry weight basis.

| | Bark weight g (%) | Compost weight g (%) |
|---|---|---|
| Sieve size | | |
| 5.0 mm | 130.2 (53.5%) | 161.6 (39.0%) |
| 2.0 mm | 50.9 (20.9%) | 129.5 (31.2%) |
| 1.0 mm | 25.0 (10.3%) | 61.5 (14.8%) |
| 500 µm | 15.6 (6.4%) | 5.9 (1.4%) |
| 200 µm | 12.5 (5.1%) | 14.5 (3.5%) |
| 100 µm | 5.9 (2.4%) | 25.8 (6.2%) |
| 50 µm | 2.9 (1.2%) | 15.8 (3.8%) |
| Total | 243.0 | 414.6 |

The C, H and N content of a 2 mg sample of bark was 39.8%, 5.3% and 0.2% respectively, and for a 2 mg sample of compost was 21.9%, 2.4% and 1.2% respectively. Sulphur was not detected in either sample (<0.02%). The average percentage dry matter for the bark and compost was 40.5% and 39.8% respectively. The bulk density for bark and compost was 320 kg/m$^3$ and 794 kg/m$^3$ respectively.

Plate 1. Bark 100 t/ha (left) and 10 t/ha (right) on soil surface prior to incorporation. (ruler = 30 cm).

Plate 2. Weed growth in untreated plot (left) and plot treated with 100 t/ha bark (right)

Plate 3. Trial site on 9/3/2000 following topping of onion crop.

*Microbial analysis of composted sewage sludge/ eucalyptus bark*

No viruses were isolated in cell culture from either sample of composted sewage sludge/eucalyptus bark. Adenovirus was detected by PCR amplification in both samples, but Reovirus and Enterovirus were not. *Cryptosporidium* oocysts, *Giardia* cysts and *Taenia* ova occurred at less than 0.05 per 4 g of sample and *Ascaris* ova were not detected. Faecal coliform, *E. coli*, faecal streptococci and *Clostridium perfringens* were present at 46,000/g, 22,000/g, 24/g and <10,000/g respectively in sample 1 and 7200/g, 6300/g, 350/g and 30,000/g respectively in sample 2. *Salmonellae*, *Shigellae*, *Listeria* and *Listeria monocytogenes* were not detected.

*Broccoli growth and yield*

No significant difference was noted between treatments with respect to the number of expanded leaves per plant on 12/3/1999, one month after transplanting (Table 3). However, the mean height of plants in the 100 t/ha compost plots was greater than in other treatments at this time (Table 3). Initial weed growth was suppressed by all amendments compared to the control plots (Table 3), with plots which received 50 and 100 t/ha bark having significantly less weeds than all other treatments (Plate 2).

Plots which received bark at 50 t/ha and 100 t/ha had significantly reduced weight and number of broccoli heads per quadrat in the first harvest compared to the control (Table 4). However, compost treatments and bark at 10 t/ha were not significantly different from the control. The weight per head was not significantly different between treatments. By the second harvest, there was no significant difference between treatments in the number of heads per quadrat or in the mean head weight (Table 5). Although only bordering on statistically significance, the weight of heads harvested per quadrat was again lowest in the plots treated with bark at 100 t/ha (Table 5). At the third harvest, the weight and number of heads harvested per quadrat was highest in plots treated with the two highest rates of bark (Table 6), with no significant effect on weight per head. Overall there was no significant effect of amendment type or rate on the total weight and number of heads harvested or on the weight per head (Table 7).

*Soil analyses*

On 22/2/1999, plots that had received compost at 100 t/ha had significantly higher mean soil nitrate-N content than plots that had received other treatments (Table 8). Ammonium-N was less than 3.0 mg N/kg for all plots except for one of the plots treated with 100 t/ha compost in which it was 5.1 mg N/kg. For soil samples taken on 15/3/1999, plots that received compost at 100 t/ha had significantly higher nitrate levels than plots treated with bark. Soil samples from plots treated with 50 t/ha bark had significantly lower nitrate levels than all treatments except for soil from plots treated with 100 t/ha bark. No ammonium-N was detected in soil samples at this time. Petiole samples taken from plants within four control plots and four plots treated with bark (100 t/ha) averaged 12,271 and 12,649 ppm $NO_3^-$ respectively. The $NO_3^-$ content of plants from a single plot of compost 10 t/ha and compost 100 t/ha were 11,023 ppm and 11,950 ppm respectively.

Although plots which received bark at 100 t/ha recorded the lowest mean tensiometer readings at four times during the life of the crop, this was statistically significant only at one time (Table 9). Rainfall and irrigation events occurred at regular intervals over the duration of the trial (Figure 1).

Table 3. Effect of bark and compost amendments on height and number of expanded leaves on broccoli and on weed emergence one month after transplanting.

| | Height of broccoli (cm) | No. leaves/ broccoli plant | Weeds/625cm$^2$ |
|---|---|---|---|
| Control | 11.6 a | 15.2 | 91.1 a |
| Compost 10 t/ha | 11.1 a | 16.0 | 63.7 b |
| Compost 100 t/ha | 12.5 b | 15.4 | 72.8 b |
| Bark 10 t/ha | 11.3 a | 15.7 | 64.8 b |
| Bark 50 t/ha | 11.6 a | 16.6 | 17.8 c |
| Bark 100 t/ha | 11.3 a | 15.2 | 10.4 c |
| *P*= | 0.04 | ns | <0.001 |

Means in columns followed by the same letter are not significantly different according to F-test and mean separation by least significant difference. ns= not significant.

Table 4. Effect of bark and compost amendments on fresh weight of broccoli heads, number of heads and weight per head (cut 1).

| | Wt. heads/ quadrat (kg) | No. heads/ quadrat | Weight/ head (kg) |
|---|---|---|---|
| Control | 30.5 a[1] | 62.3 a | 0.48 |
| Compost 10 t/ha | 27.1 ab | 53.8 ab | 0.50 |
| Compost 100 t/ha | 30.2 a | 62.5 a | 0.49 |
| Bark 10 t/ha | 25.5 ab | 51.5 ab | 0.50 |
| Bark 50 t/ha | 19.7 bc | 38.3 bc | 0.51 |
| Bark 100 t/ha | 12.2 c | 25.5 c | 0.47 |
| *P*= | <0.005 | <0.005 | ns |

[1]Means in columns followed by the same letter are not significantly different according to F-test and mean separation by least significant difference.

Table 5. Effect of bark and compost amendments on fresh weight of broccoli heads, number of heads and weight per head (cut 2).

| | Wt. heads/ quadrat | No. heads/ quadrat | Weight/ head (kg) |
|---|---|---|---|
| Control | 52.4 | 96.1 | 0.54 |
| Compost 10 t/ha | 55.9 | 103.5 | 0.54 |
| Compost 100 t/ha | 53.4 | 96.5 | 0.55 |
| Bark 10 t/ha | 52.5 | 96.1 | 0.55 |
| Bark 50 t/ha | 54.8 | 100.3 | 0.55 |
| Bark 100 t/ha | 42.7 | 82.5 | 0.52 |
| *P*= | 0.07 (ns) | ns | ns |

Table 6. Effect of bark and compost amendments on fresh weight of broccoli heads, number of heads and weight per head (cut 3 ).

| | Wt. heads/ quadrat (kg) | No. heads/ quadrat | Weight/ head (kg) |
|---|---|---|---|
| Control | 19.7 c[1] | 35.1 c | 0.55 |
| Compost 10 t/ha | 18.1 c | 29.3 c | 0.61 |
| Compost 100 t/ha | 18.5 c | 32.5 c | 0.57 |
| Bark 10 t/ha | 26.1 bc | 41.1 bc | 0.63 |
| Bark 50 t/ha | 29.7 b | 50.3 b | 0.59 |
| Bark 100 t/ha | 46.0 a | 74.3 a | 0.62 |
| *P*= | <0.001 | <0.001 | ns |

[1]Means in columns followed by the same letter are not significantly different according to F-test and mean separation by least significant difference

Table 7. Effect of bark and compost amendments on fresh weight of broccoli heads, number of heads and weight per head per quadrat (all harvest times) and calculated yield per hectare.

| | Wt. heads/ quadrat (kg) | No. heads/ quadrat (kg) | Weight/ head (kg) | Yield/ hectare |
|---|---|---|---|---|
| Control | 102.5 | 193.6 | 0.53 | 7.9 |
| Compost 10 t/ha | 101.1 | 186.5 | 0.54 | 7.8 |
| Compost 100 t/ha | 102.0 | 191.5 | 0.53 | 7.9 |
| Bark 10 t/ha | 104.2 | 188.8 | 0.55 | 8.0 |
| Bark 50 t/ha | 104.2 | 188.8 | 0.55 | 8.0 |
| Bark 100 t/ha | 100.8 | 182.3 | 0.55 | 7.8 |
| *P*= | ns | 0.1 (ns) | ns | ns |

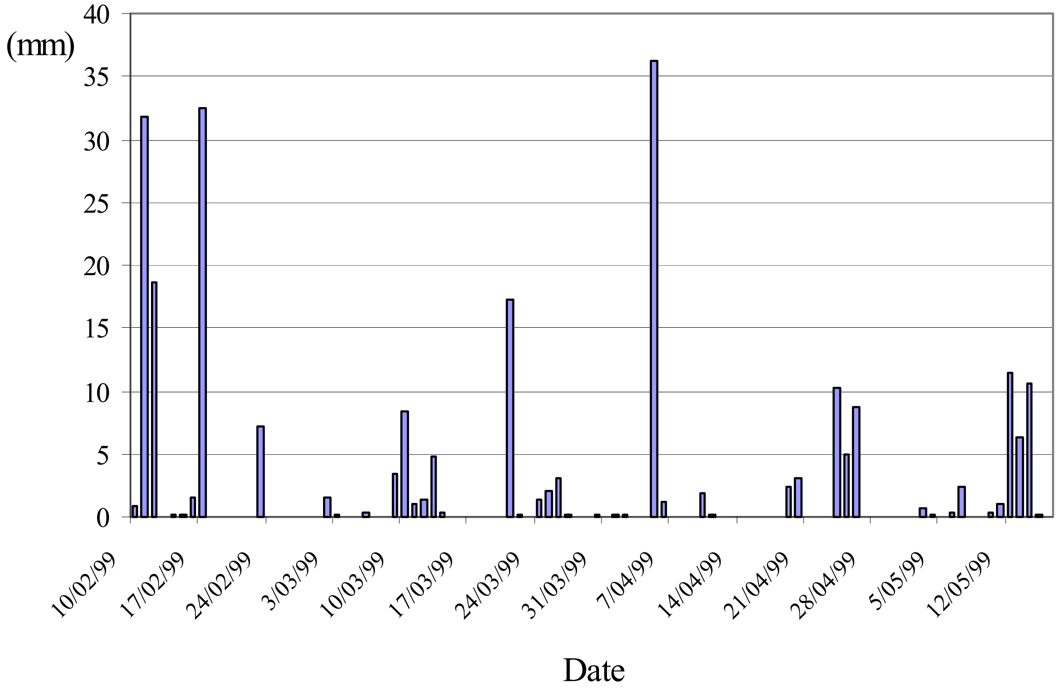
Table 8. Effect of bark and compost amendments on soil nitrate nitrogen (mg N /kg)

| | 22/2/1999 | 15/3/1999 |
|---|---|---|
| Control | 23.1 a | 24.8 ab |
| Compost 10 t/ha | 18.7 a | 23.9 ab |
| Compost 100 t/ha | 33.4 b | 27.9 a |
| Bark 10 t/ha | 18.2 a | 19.3 b |
| Bark 50 t/ha | 18.1 a | 12.6 c |
| Bark 100 t/ha | 18.5 a | 18.6 bc |
| *P*= | 0.04 | 0.005 |

Table 9. Mean tensiometer readings (kPa) from plots taken at intervals during the broccoli crop.

| | Replicates | 19/3/1999 | 23/3/1999 | 8/4/1999 | 21/4/1999 | Average |
|---|---|---|---|---|---|---|
| Control | 6 | 30.2 | 41.2 | 27.7 | 70.2a | 42.3 |
| Compost 10 t/ha | 3 | 33.0 | 35.7 | 30.0 | 73.7a | 43.1 |
| Compost 100 t/ha | 3 | 34.3 | 25.7 | 29.7 | 70.0a | 39.9 |
| Bark 10 t/ha | 6 | 30.3 | 31.3 | 21.3 | 75.7a | 39.7 |
| Bark 50 t/ha | 3 | 31.0 | 32.3 | 24.7 | 70.7a | 39.7 |
| Bark 100 t/ha | 3 | 21.7 | 13.3 | 11.0 | 39.0b | 21.3 |
| *P*= | | ns | ns | ns | 0.02 | ns |

Figure 1. Rainfall and irrigation recorded on the broccoli crop between 10/2/1999 and 16/5/1999.




## 3.2 Onion

Soil chemical analysis after the preceding broccoli crop showed that amendments had no effect on pH, available soil P, available soil K and organic C (Table 10). However nitrate nitrogen was lower in plots treated with high rates of bark, suggesting a slight N-drawdown effect. Ammonium N (mg N/kg soil) was less than 4 mg/kg for all plots except a compost 100 t/ha plot (5.8 mg N/kg), bark 100 t/ha plot (4.8 mg N/kg) and a compost 10t/ha plot (6.5 mg N/kg). In comparison to the control plots, the untreated area had a similar pH, lower nitrate-N and available P, and higher available K and organic C (Table 11). In late December 1999 and early January 2000 there was no significant effect of amendment on plant density or the fresh and dry weight of 50 onion plants collected at random from each plot (Table 12). However, although not statistically significant, it was notable that the weight of onions from plots treated with bark at 100 t/ha was lower at this time compared with other treatments.

Table 10. Effect of organic amendments on pH and soil nutrients prior to planting the onion crop.

| | pH[1] | Nitrate-N (mg N/kg) | Available soil P[2] (mg P/kg) | Available soil [2] (mg K/kg) | Organic C[3] (%C) |
|---|---|---|---|---|---|
| Control | 6.01 | 38.6ab | 177.4 | 198.9 | 4.19 |
| Compost 10 t/ha | 6.39 | 48.4a | 152.0 | 203.7 | 4.08 |
| Compost 100 t/ha | 6.14 | 40.0ab | 172.8 | 177.5 | 4.41 |
| Bark 10 t/ha | 6.38 | 37.5ab | 148.1 | 194.6 | 4.55 |
| Bark 50 t/ha | 6.01 | 28.2bc | 150.0 | 203.4 | 4.00 |
| Bark 100 t/ha | 6.09 | 21.0c | 195.0 | 182.3 | 4.28 |
| *P*= | 0.32 | 0.03 | 0.30 | 0.91 | 0.57 |
| LSD (*P*=0.05) | - | 16.1 | | - | - |

[1] 1:5, soil:water [2] Colwell method [3]Walkely-Black method

Table 11. Characterisation of soil nutrients at different depths in an untreated part of the trial site (11/8/1999).

| Depth | pH[1] | Nitrate-N (mg N/kg) | Ammonium (mg N/kg) | Available soil P[2] (mg P/kg) | Available soil K[2] (mg K/kg) | Organic C[3] (%C) |
|---|---|---|---|---|---|---|
| 0-10 cm | 5.9 | 8.1 | 13.7 | 73.7 | 467.2 | 7.1 |
| 10-20 cm | 5.4 | 7.3 | 4.3 | 43.7 | 288.5 | 6.1 |
| 20-30 cm | 5.0 | 1.5 | 1.5 | 26.1 | 119.7 | 4.0 |
| 30-40 cm | 4.9 | 1.0 | 0.9 | 10.5 | 157.6 | - |
| 40-50 cm | 4.9 | 1.8 | 0.4 | 7.1 | 153.8 | - |
| 50-60 cm | 5.0 | 0.7 | 0.9 | 4.9 | 134.9 | - |

[1] 1:5, soil:water [2] Colwell method [3] Walkley-Black method

Table 12. Effect of treatments on plant density (12/1/2000) and fresh weight and dry weight of onions (22/12/1999).

| | Plants/ $0.5m^2$ | Fresh weight of 50 onion plants (g) | Dry weight of 50 onion plants (g) |
|---|---|---|---|
| Control | 18.2 | 386 | 38 |
| Bark 10 t/ha | 21.0 | 373 | 38 |
| Bark 50 t/ha | 19.1 | 376 | 37 |
| Bark 100 t/ha | 17.4 | 338 | 33 |
| Compost 10 t/ha | 19.9 | 387 | 38 |
| Compost 100 t/ha | 20.4 | 426 | 41 |
| *P*= | ns | ns | ns |

At harvest (Plate 3), yield was significantly lower in plots treated with bark at 50 and 100 t/ha compared with other treatments (Table 13). The average weight per onion was also lower in plots treated with high rates of bark compared to the control (Table 13). The percentage of onion bulbs in the 51-60 mm range was greater in plots treated with high rates of bark than in the control (Table 14). Conversely, the percentage of onion bulbs in the 81-100 mm range was lower in plots treated with high rates of bark compared to the control (Table 14). There was no effect of treatment on the percentage of discarded onions (Table 15). Similarly, there were a greater percentage of onions by weight in the 51-60 mm and lower percentage of onions by weight in the 81-100 mm category in plots treated with high rates of bark than the control (Table 16). There was no effect of amendment on the percentage of onions by weight in each discard category (Table 17).

By watering according to tensiometer readings, plots treated with high rates of bark received less irrigation than other treatments (Table 18 and Figure 3). Control plots received an average of 175 mm during the season compared to 115 mm for bark at 50 t/ha and 108 mm for bark at 100 t/ha.

Pressure plate analysis showed that there was no significant effect of amendment on gravimetric water content at 10 kPa (Table 19). At 100 kPa, bark 100 t/ha had the

Table 13. Effect of organic amendments on mean yield of onions (kg/plot), mean estimated yield of onions (t/ha) and average weight per onion.

| Treatment | Replicates | Yield (kg/plot) | Yield (t/ha) | Average wt./ onion (g) |
|---|---|---|---|---|
| Control | 8 | 487.5a[1] | 63.5a | 223.0a |
| Compost 10 t/ha | 4 | 452.3a | 58.9a | 201.5abc |
| Compost 100 t/ha | 4 | 498.6a | 64.9a | 215.2ab |
| Bark 10 t/ha | 8 | 472.5a | 61.5a | 209.6abc |
| Bark 50 t/ha | 4 | 365.1b | 47.5b | 190.0bc |
| Bark 100 t/ha | 4 | 367.3b | 47.8b | 185.5c |
| | | | | |
| *P*< | | 0.001 | 0.001 | 0.08 |
| LSD (*P*=0.05) | | 48.3 | 5.96 | 27.5 |

[1]Means in columns followed by the same letter are not significantly different according to F-test and mean separation by least significant difference

Table 14. Effect of organic amendments on the mean percentage of onions by number in each size category.

| | | Size grading (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Replicates | 0-35 | 36-50 | 51-60 | 61-80 | 81-100 | >100 |
| Control | 6 | 1.9[1] | 8.9 | 14.6b[3] | 50.3 | 14.5a | 0.0 |
| Compost 10 t/ha | 3 | 1.6 | 8.9 | 19.2a | 54.1 | 7.2bc | 0.0 |
| Compost 100 t/ha | 3 | 1.8 | 10.5 | 15.1b | 48.7 | 12.1ab | 0.1 |
| Bark 10 t/ha | 6 | 1.8 | 10.6 | 17.5ab | 51.4 | 9.1bc | 0.1 |
| Bark 50 t/ha | 3 | 1.7 | 13.2 | 18.9a | 52.0 | 6.2c | 0.0 |
| Bark 100 t/ha | 3 | 1.9 | 13.8 | 19.5a | 49.2 | 6.6c | 0.0 |
| *P*= ( )[2] | | 0.78 | 0.20 | 0.04 | 0.63 | 0.01 | 0.68 |

[1] Back transformed means
[2] Data transformed prior to analysis (square root (x+1))
[3] Means within columns with the same letter are not significantly different according to LSD (*P*=0.05).

Table 15. Effect of organic amendments on the mean percentage of onions by number in each discard category.

| Treatment | Replicates | bolters | burst | doubles | misshapen | rot |
|---|---|---|---|---|---|---|
| Control | 6 | 0.1[1] | 0.7 | 2.8 | 4.9 | 0.6 |
| Compost 10 t/ha | 3 | 0.4 | 0.7 | 1.7 | 5.4 | 0.6 |
| Compost 100 t/ha | 3 | 0.6 | 0.6 | 2.5 | 6.2 | 0.7 |
| Bark 10 t/ha | 6 | 0.2 | 0.5 | 2.3 | 5.2 | 0.3 |
| Bark 50 t/ha | 3 | 0.3 | 0.3 | 1.5 | 4.0 | 0.3 |
| Bark 100 t/ha | 3 | 0.6 | 0.5 | 2.3 | 4.9 | 0.2 |
| *P*= ( )[2] | | 0.39 | 0.19 | 0.13 | 0.65 | 0.14 |

[1] Back transformed means
[2] Data transformed prior to analysis (square root (x+1))

highest gravimetric water content, significantly higher than bark 10 t/ha, compost 10 t/ha and control, but not significantly different from other treatments (Table 19). On a volumetric basis, bark 10 t/ha had significantly higher water content at 10 kPa than all other treatments except compost 100 t/ha (Table 19). At 100 kPa, bark 10 t/ha had significantly higher volumetric water content than all but the bark 50 t/ha treatment. The control and compost 10 t/ha treatments had the lowest volumetric water content at 100 kPa, but not significantly lower than bark 100 t/ha or compost 100 t/ha (Table 19). Bark 10 t/ha had the highest bulk density with compost 100 t/ha and bark 100 t/ha having the lowest bulk density (Table 19).

Table 16. Effect of organic amendments on the percentage by weight of onions in each size category.

| Treatment | Replicates | Size category (mm) 0-35 | 36-50 | 51-60 | 61-80 | 81-100 | >100 |
|---|---|---|---|---|---|---|---|
| Control | 6 | 0.2[1] | 2.7 | 7.9b[3] | 52.1b | 25.7a | 0.1 |
| Compost 10 t/ha | 3 | 0.2 | 2.8 | 11.5a | 61.5a | 14.0c | 0.0 |
| Compost 100 t/ha | 3 | 0.3 | 3.1 | 8.6b | 52.0b | 23.1ab | 0.2 |
| Bark 10 t/ha | 6 | 0.3 | 3.3 | 10.2ab | 58.3ab | 17.1bc | 0.2 |
| Bark 50 t/ha | 3 | 0.3 | 4.8 | 12.6a | 61.0a | 12.3c | 0.0 |
| Bark 100 t/ha | 3 | 0.3 | 4.7 | 12.2a | 58.4ab | 13.3c | 0.0 |
| *P*= ( )[2] | | 0.81 | 0.11 | 0.009 | 0.057 | 0.004 | 0.69 |

[1] Back transformed means
[2] Data transformed prior to analysis (square root (x+1))
[3] Means within columns with the same letter are not significantly different according to LSD (*P*=0.05).

Table 17. Effect of organic amendments on the percentage by weight of onions in each discard category.

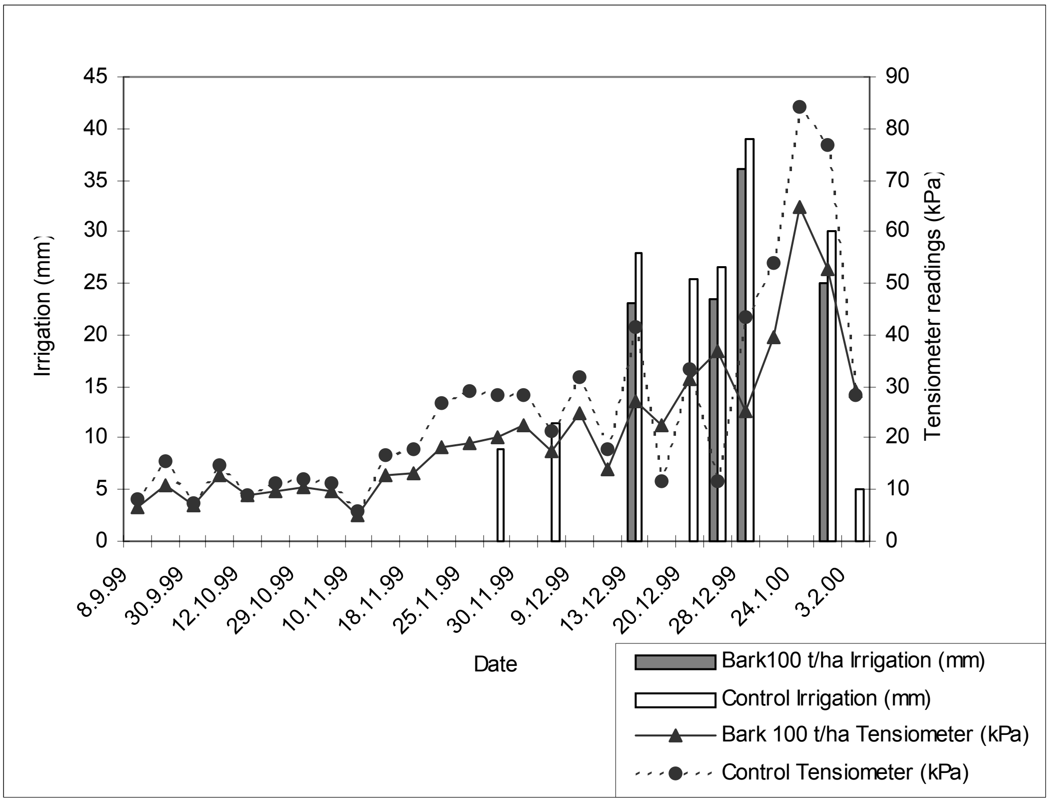
| Treatment | Replicates | bolters | burst | doubles | misshapen | rot |
|---|---|---|---|---|---|---|
| Control | 6 | 0.1[1] | 0.7 | 4.4 | 5.0 | 0.5 |
| Compost 10 t/ha | 3 | 0.3 | 0.4 | 2.8 | 5.5 | 0.5 |
| Compost 100 t/ha | 3 | 0.5 | 0.7 | 4.1 | 6.5 | 0.6 |
| Bark 10 t/ha | 6 | 0.3 | 0.4 | 3.9 | 5.2 | 0.3 |
| Bark 50 t/ha | 3 | 0.3 | 0.3 | 2.7 | 4.7 | 0.3 |
| Bark 100 t/ha | 3 | 0.3 | 0.6 | 4.1 | 5.2 | 0.2 |
| *P*=( )[2] | | 0.62 | 0.41 | 0.19 | 0.79 | 0.68 |

[1] Back transformed means [2] Data transformed prior to analysis (square root (x+1))

Table 18. Mean amount of irrigation water supplied to each treatment over the season (mm).

| | Control | Compost 10t/ha | Compost 100t/ha | Bark 10t/ha | Bark 50t/ha | Bark 100t/ha |
|---|---|---|---|---|---|---|
| *No. replicates* | 8 | 4 | 4 | 8 | 4 | 4 |
| *Date* | | | | | | |
| 29/12/1999 | 9.2 | 7.5 | 10.1 | 0 | 0 | 0 |
| 7/12/1999 | 11.5 | 10.6 | 10.1 | 11.9 | 0 | 0 |
| 14/12/1999 | 28.1 | 27.9 | 27.0 | 30.2 | 24.1 | 23.0 |
| 22/12/1999 | 25.4 | 0 | 27.1 | 28.4 | 0 | 0 |
| 28/12/1999 | 26.6 | 25.1 | 26.0 | 27.0 | 24 | 23.4 |
| 4/1/2000 | 39.1 | 37.4 | 38.0 | 38.4 | 37.4 | 36.1 |
| 3/2/2000 | 30.2 | 29.1 | 37.9 | 31.1 | 29.0 | 25.0 |
| 7/2/2000 | 4.9 | 3.3 | 8.5 | 6.6 | 0 | 0 |
| *Total* | 175.0 | 140.9 | 184.8 | 173.5 | 114.6 | 107.5 |

Figure 3. Irrigation (mm) and tensiometer (kPa) readings from control and bark 100 t/ha plots during the onion crop.




Depth of sampling had no statistically significant effect on gravimetric water content at 10 kPa or 100 kPa (*P*=0.450 and 0.209 respectively). However, depth of sampling had an effect on the volumetric water content at 10 kPa with a mean of 42.9% v/v and 45.9% v/v for 5-7 cm and 10-12 cm respectively. Similarly at 100 kPa, a statistically (*P*<0.001) greater amount of water was obtained from 10-12 cm depth than 5-7 cm depth (40.0% v/v and 36.6% v/v respectively). The effect of sampling depth on bulk density was also statistically significant (*P*<0.001) with a mean bulk density of 0.922 $Mg/m^3$ at 5-7 cm and 0.992 $Mg/m^3$ at 10-12 cm. The interaction between amendment type and depth of sampling was not significant for gravimetric or volumetric water content or for bulk density.

The total number of nematodes was significantly higher in the compost 10 t/ha treatment than the control (Table 20), while all other treatments were not significantly different from the control. Root lesion nematode (*Pratylenchus* spp.) occurred at low numbers with no significant difference in populations between treatments (Table 20).

Table 19. Gravimetric and volumetric water content at 10 and 100 kPa measured on pressure plate apparatus and bulk density of soil (g/cm$^3$).

| | Gravimetric water content (% w/w) | | Volumetric water content (% v/v) | | Bulk density |
|---|---|---|---|---|---|
| | 10 kPa | 100 kPa | 10 kPa | 100 kPa | (Mg/m$^3$) |
| Control | 45.7 | 38.8 c[1] | 43.2 b | 36.7 c | 0.946 bcd |
| Compost 10t/ha | 45.3 | 38.9 c | 43.2 b | 37.2 c | 0.956 bc |
| Compost 100t/ha | 47.7 | 40.5 ab | 44.4 ab | 37.7 bc | 0.930 cd |
| Bark 10t/ha | 45.8 | 39.7 bc | 46.6 a | 40.5 a | 1.018 a |
| Bark 50t/ha | 46.7 | 40.5 ab | 42.6 b | 39.8 ab | 0.982 ab |
| Bark 100 t/ha | 46.9 | 41.6 a | 42.6 b | 37.9 bc | 0.913 d |
| *P*= ( ) | 0.082 | <0.001 | 0.003 | 0.005 | <0.001 |

[1] Means within columns followed by the same letter are not significantly different at *P*=0.05.

Table 20. Effect of amendments on nematode populations (per 200 ml soil).

| | Total nematodes | *Pratylenchus* |
|---|---|---|
| Control | 1550 bc[1] | 33 |
| Compost 10t/ha | 2155 a | 50 |
| Compost 100t/ha | 1828 ab | 30 |
| Bark 10t/ha | 1313 bc | 30 |
| Bark 50t/ha | 1355 bc | 59 |
| Bark 100 t/ha | 1197 c | 24 |
| *P*= ( ) | 0.02 | 0.36 (ns) |

[1] Means within columns followed by the same letter are not significantly different at *P*=0.05.

### 3.3 Potato

*Crop growth and yield*

Potato plants were observed emerging on bark 10+50 t/ha plots on 19/12/2000, bark 10+25 t/ha plots on 21/12/2000 and controls on 22/12/2000. By 2/1/2001, plants on all treatments had emerged, with bark 50 t/ha and compost 10 t/ha plots slightly more developed than bark 100 t/ha and compost 100 t/ha. At 55 days after planting (31/1/2001), plants from plots that had received bark at 10+25 t/ha and 10+50 t/ha had the greatest mean dry weight (Table 21), however this was not statistically significant. Sap nitrate at 55 days after planting bordered on statistical significance (10% level) with plants from plots that received bark at 10+50 t/ha having the lowest mean sap nitrate levels (Table 21), perhaps as a result of the increased growth in these treatments, resulting from earlier emergence. At harvest, the mean yield of tubers and number of tubers bordered on statistical significance (10% level), with highest mean yields and tuber numbers obtained from plots which received 10+50 t/ha and 10+25 t/ha bark and the lowest on bark and compost at 100 t/ha (Table 21).

Treatment had no significant effect on the yield of tubers in different size categories, or the percentage of tubers in those categories on a weight or number basis (Table 21). Treatment had no significant effect on quality of potatoes including specific gravity, colour, percentage fry grade, percentage waste, or percentage hollow heart (Table 21).

Amendment had no statistically significant effect on the density of weeds at 36 days after planting (Table 22), including fat hen (*Chenopodium album*), nightshade (*Solanum nigrum*), storksbill (*Erodium cicutarium*), staggerweed (*Stachys arvensis*), spurry (*Spergula arvensis*), stinging nettle (*Urtica urens*), radish (*Raphanus raphanistrum*), clover (*Trifolium* spp.), thistle (*Sonchus* spp.), mallow (*Malva parviflora*), and fumitory (*Fumaria densiflora*).

Table 21. Effect of amendment on mid season growth and nitrate content of potato plants and yield and tuber composition at harvest.

| | Control | Bark 10+25 | Bark 10+50 | Bark 50 | Bark 100 | Compost 10 | Compost 100 | *P*= |
|---|---|---|---|---|---|---|---|---|
| 31/1/2001 | | | | | | | | |
| Dry weight (g/plant) | 36.6 | 40.5 | 42.9 | 34.5 | 34.7 | 34.4 | 31.8 | 0.69 |
| ppm $NO_3^-$ ($x10^2$) | 29.5 | 29.3 | 22.5 | 31.0 | 30.8 | 30.5 | 31.3 | 0.08* |
| | | | | | | | | |
| 31/5/2001 | | | | | | | | |
| Total yield (t/ha) | 36.7 | 38.2 | 44.3 | 33.2 | 32.2 | 37.1 | 31.4 | 0.09* |
| 0-80g (t/ha) | 1.48 | 1.34 | 1.73 | 1.36 | 1.29 | 1.43 | 1.43 | 0.52 |
| 80-250g (t/ha) | 18.2 | 20.5 | 22.1 | 16.8 | 16.0 | 17.4 | 15.7 | 0.13 |
| 250-650g (t/ha) | 13.8 | 14.1 | 17.1 | 13.6 | 12.3 | 14.6 | 11.6 | 0.71 |
| 650-850g (t/ha) | 0.39 | 0.11 | 0 | 0 | 0 | 0 | 0.46 | 0.22 |
| >850g (t/ha) | 0.14 | 0 | 0 | 0 | 0 | 0 | 0 | 0.84 |
| Waste (t/ha) | 2.69 | 2.16 | 3.44 | 1.49 | 2.61 | 3.66 | 2.13 | 0.29 |
| 80-650g (t/ha) | 32.0 | 34.6 | 39.2 | 30.4 | 28.3 | 32.0 | 27.4 | 0.16 |
| Fry grade >80g (t/ha) | 32.5 | 34.7 | 39.2 | 30.4 | 28.3 | 32.0 | 27.8 | 0.19 |
| | | | | | | | | |
| Percentage by weight | | | | | | | | |
| 0-80g (%) | 4.1 | 3.6 | 3.9 | 4.2 | 4.1 | 3.9 | 4.6 | 0.81 |
| 80-250g (%) | 49.8 | 53.9 | 50.3 | 51.0 | 50.6 | 47.6 | 50.1 | 0.98 |
| 250-650g (%) | 37.2 | 36.6 | 38.1 | 40.0 | 36.6 | 38.9 | 36.8 | 0.99 |
| 650-850g (%) | 1.1 | 0.2 | 0 | 0 | 0 | 0 | 1.4 | 0.20 |
| >850g (%) | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.84 |
| Waste (%) | 7.6 | 5.7 | 7.8 | 4.8 | 8.6 | 9.7 | 7.2 | 0.65 |
| Fry grade (%) | 43.7 | 40.7 | 43.3 | 43.8 | 42.0 | 45.2 | 43.4 | 0.99 |
| | | | | | | | | |
| Average wt./tuber (g) | 115.6 | 110.2 | 117.1 | 112.2 | 111.7 | 117.2 | 109.6 | 0.88 |
| Colour | 2.4 | 2.5 | 3.0 | 2.3 | 3.3 | 2.5 | 3.0 | 0.87 |
| Dry matter (%) | 21.2 | 20.9 | 21.6 | 20.5 | 20.8 | 20.7 | 20.9 | 0.47 |
| Hollow percent | 10.0 | 2.5 | 12.5 | 5.0 | 10.0 | 10.0 | 15.0 | 0.64 |
| Specific gravity | 1.09 | 1.08 | 1.09 | 1.08 | 1.08 | 1.08 | 1.08 | 0.41 |
| | | | | | | | | |
| Tuber number/plot | 319.4 | 345.3 | 379.5 | 295.0 | 286.3 | 317.5 | 286.8 | 0.10* |
| 0-80g (no./plot) | 53.9 | 50.5 | 60.5 | 46.0 | 45.2 | 50.5 | 53.7 | 0.48 |
| 80-250g (no./plot) | 181.9 | 209.0 | 218.8 | 171.3 | 165.3 | 174.8 | 160.5 | 0.22 |
| 250-650g (no./plot) | 67.1 | 73.0 | 82.0 | 68.5 | 59.7 | 73.5 | 58.2 | 0.70 |
| 650-850g (no./plot) | 0.88 | 0.25 | 0 | 0 | 0 | 0 | 1.0 | 0.20 |
| >850g (no./plot) | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0.84 |
| Waste (no./plot) | 15.4 | 12.5 | 18.3 | 9.3 | 15.8 | 18.8 | 13.3 | 0.45 |
| | | | | | | | | |
| Percentage by number | | | | | | | | |
| 0-80g (%) | 16.8 | 14.8 | 15.9 | 15.8 | 16.0 | 15.9 | 19.1 | 0.51 |
| 80-250g (%) | 56.8 | 60.5 | 57.5 | 58.2 | 57.7 | 54.9 | 55.5 | 0.89 |
| 250-650g (%) | 21.0 | 21.0 | 21.7 | 22.8 | 20.4 | 23.3 | 20.2 | 0.97 |
| 650-850g (%) | 0.3 | 0.07 | 0 | 0 | 0 | 0 | 0.4 | 0.21 |
| >850g (%) | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.84 |
| Waste (%) | 5.0 | 3.7 | 5.0 | 3.3 | 5.9 | 6.0 | 4.8 | 0.68 |

* Bordering on statistical significance ($P<0.10$).

Table 22. Number of weeds (no./625cm$^2$) at 36 days after planting potato (12/1/2001)

| | Control | Bark 10+20 | Bark 10+40 | Bark 50 | Bark 100 | Compost 10 | Compost 100 | *P*= |
|---|---|---|---|---|---|---|---|---|
| 12/1/2001 | | | | | | | | |
| Clover | 0.42 | 0.25 | 0.50 | 0.33 | 0.08 | 0.25 | 0.08 | 0.85 |
| Fat hen | 20.5 | 21.7 | 25.2 | 19.6 | 23.2 | 20.8 | 27.3 | 0.97 |
| Fumitory | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0.33 |
| Mallow | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0.33 |
| Night shade | 4.2 | 4.3 | 3.1 | 3.6 | 2.9 | 4.8 | 4.8 | 0.99 |
| Radish | 0.13 | 0.33 | 0.08 | 0.17 | 0.92 | 0.08 | 1.0 | 0.27 |
| Spurry | 0.04 | 0 | 0.08 | 0.08 | 0 | 0.08 | 0.08 | 0.89 |
| Stinging nettle | 0.17 | 0 | 0 | 0 | 0.17 | 0.08 | 0 | 0.87 |
| Staggerweed | 0.04 | 0.25 | 0.42 | 0.33 | 0.50 | 0.58 | 0.42 | 0.60 |
| Storksbill | 0.08 | 0.25 | 0.17 | 0.25 | 0.42 | 0.83 | 0.50 | 0.13 |
| Thistle | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0.33 |
| Total weeds | 25.6 | 27.1 | 29.6 | 24.5 | 28.3 | 24.4 | 34.2 | 0.97 |

*Soil measurements*

The effect of depth on bulk density was not significant (*P*=0.86) with a mean bulk density of 0.95 Mg/m$^3$ at both 5 cm and 10 cm depth across all treatments. Treatment also had a non-significant (*P*=0.77) effect, with a mean bulk density of 0.96, 0.95 and 0.94 Mg/m$^3$ for control, bark 100 t/ha and bark 50 t/ha respectively. The interaction between depth and treatment was not significant (*P*=0.93).

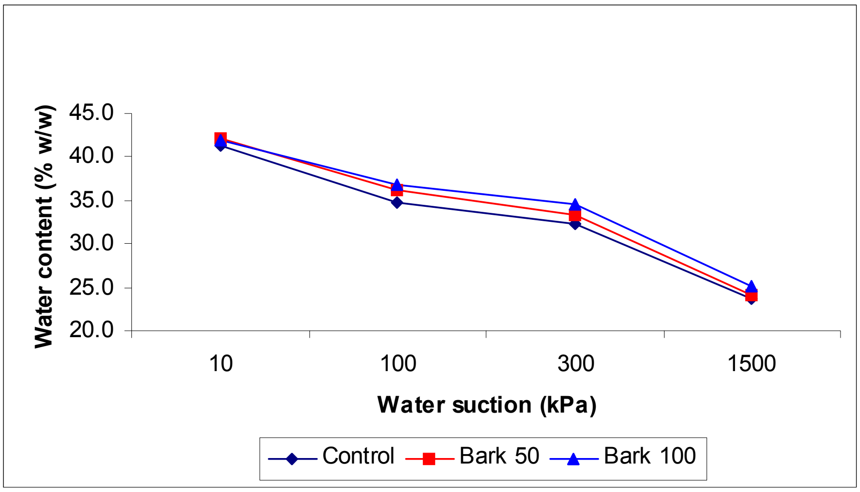
Depth of sampling had a slight but highly significant (*P*=0.005) effect with a volumetric water content of 32.1% v/v and 33.2% v/v at 5 and 10 cm respectively. Suction had a significant effect (*P*<0.001, LSD=0.006) with a volumetric content of 40.2, 34.8, 32.5 and 23.0% v/v at 10, 100, 300 and 1500 kPa respectively. Treatment had a significant (*P*=0.034, LSD=0.005) effect on volumetric water content with an average of 32.2, 32.3 and 33.4% v/v for control, bark 50 t/ha and bark 100 t/ha respectively. There were no significant interactions between treatment, depth of sampling or suction for volumetric water content.

Depth of sampling had a significant (*P*<0.001) effect with a mean gravimetric water content of 33.8 and 35.0% w/w at 5 and 10 cm depth respectively. As expected, suction also had a significant (*P*<0.001, LSD=0.003) effect with gravimetric water content of 42.4, 36.7, 34.3 and 24.2% w/w at 10, 100, 300 and 1500 kPa respectively.

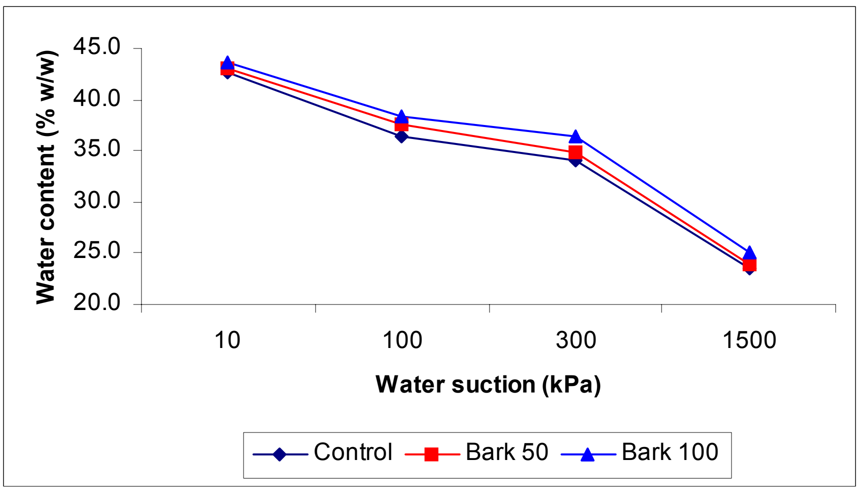
Treatment had a significant ($P$=<0.001, LSD= 0.003) effect with gravimetric water content of 33.6, 34.4 and 35.2% w/w for control, bark 50 t/ha and bark 100 t/ha. There were no significant interactions between treatment, depth of sampling or suction for gravimetric water content, except for depth by suction ($P$=0.027, LSD=0.005). At 5 cm depth the gravimetric water content at 10, 100, 300 and 1500 kPa was 41.8, 35.9, 33.4 and 24.3 % w/w respectively and at 10 cm depth was 43.1, 37.5, 35.1 and 24.2 % w/w respectively. This indicated that there was more water on a weight basis held at lower suctions at 10 cm than at 5 cm. There was a general trend for more water to be extracted at all suctions tested from plots that received higher rates of bark (Figure 3).

Figure 3. Gravimetric water release curves for soil treated with different rates of bark amendment.

a) 5 cm depth




b) 10 cm depth



### 3.4 Sowing trial

In plots established next to the main bark trial, bark had no effect on emergence of onion or poppy seedlings. The mean density of poppy plants at 3 months after sowing was 533, 227 and 287 per $m^2$ from untreated, bark at 34 t and bark at 69 t/ha respectively ($P$=0.61). Similarly the mean density of onion plants was 71, 120 and 105 per $m^2$ at 3 months after sowing in untreated, bark at 34 t and bark at 69 t/ha ($P$=0.58).

### 3.5 Poppy

Treatments had no effect on the weight of poppy capsules harvested or anhydrous morphine alkaloid content (Table 22).

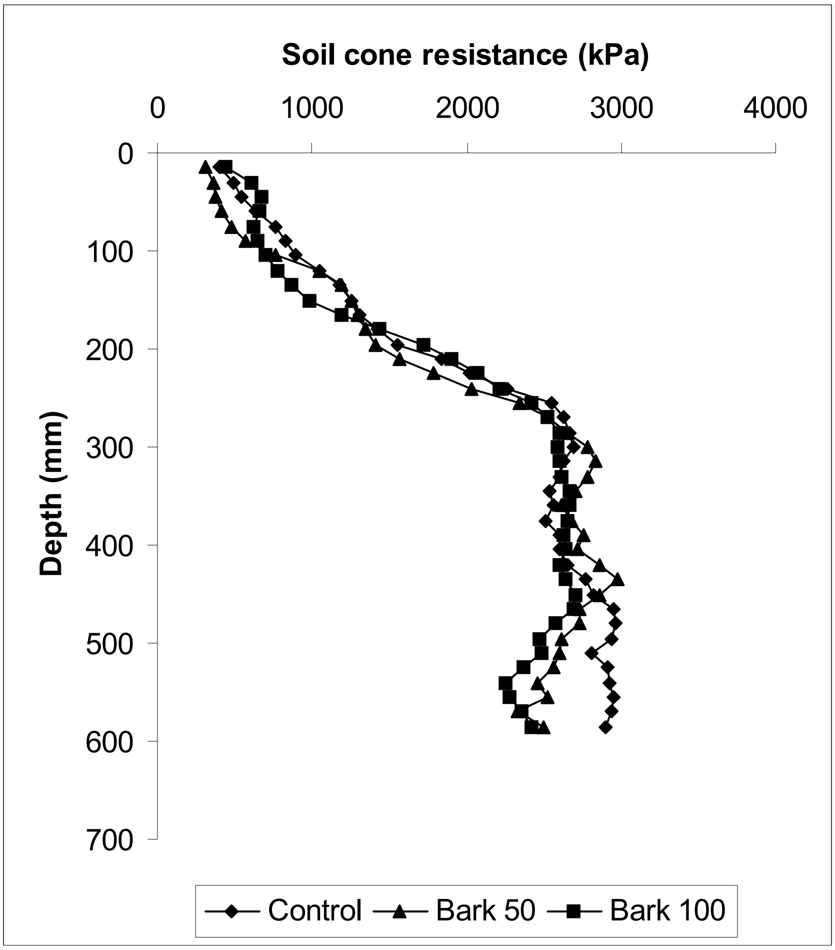
Table 22 . Effect of organic amendments on yield of poppy.

| | Capsule weight (t/ha) | AMA[1] (kg/ha) |
|---|---|---|
| Control | 4.05 | 86.0 |
| Bark 10+25 t/ha | 3.72 | 74.6 |
| Bark 10+50 t/ha | 3.58 | 73.4 |
| Bark 100 t/ha | 3.76 | 77.4 |
| Bark 50 t/ha | 3.85 | 77.0 |
| Compost 10 t/ha | 3.64 | 69.7 |
| Compost 100 t/ha | 3.96 | 85.8 |
| | | |
| $P$= ( ) | 0.62 | 0.26 |

[1] anhydrous morphine alkaloid content

As would be expected, the effect of soil depth on resistance of soil to penetration was statistically significant ($P$<0.001, LSD = 303.1) with increasing resistance to 300 mm (Figure 4). There was a significant difference ($P$<0.001, LSD=83.0) between treatments in mean soil penetration resistance averaged over all depths with the control (mean = 2051 kPa) being significantly higher than plots treated with bark at 50 t/ha (mean = 1951 kPa), which in turn was significantly higher than plots treated with bark at 100 t/ha (mean = 1825 kPa). The treatment by depth interaction was not significant ($P$=0.904).

Figure 4. The effect of amendment on soil penetrometer resistance at different depths.




### 3.6 Pasture

*Biological measurements*

There was no significant treatment effect on pasture growth as measured with a rising plate meter on 18/3/2003 or 28/4/2003 (Table 23). The numbers of plant-parasitic *Pratylenchus* nematodes in all plots were low and there were no significant differences between treatments (Table 23). *Paratylenchus* spp. was also present in three plots at low numbers (<38/200 ml soil).

Table 23. Effect of amendments on pasture growth and populations of root lesion nematode (*Pratylenchus* spp.)

| | Pasture (kg/ha) growth on: 18/3/2003 | 28/4/2003 | *Pratylenchus*/ 200 ml soil 24/2/2003 |
|---|---|---|---|
| Control | 1274 | 1789 | 20.3 |
| Bark 10+25 t/ha | 1368 | 1785 | 24.7 |
| Bark 10+50 t/ha | 1201 | 1680 | 8.2 |
| Bark 100 t/ha | 1392 | 2048 | 14.3 |
| Bark 50 t/ha | 1275 | 1835 | 3.5 |
| Compost 10 t/ha | 1184 | 1707 | 26.3 |
| Compost 100 t/ha | 1321 | 1945 | 12.5 |
| | | | |
| *P*= ( ) | 0.44 | 0.63 | 0.70 |

*Soil chemical analysis*

Nutrient analysis of soil samples taken on 26/3/2003 suggested that there were no statistically significant differences between treatments in any of the measured nutrients except nitrate-N (Table 24). The mean amount of nitrate-N in plots treated with bark 50 t/ha was significantly lower than all other treatments except compost 100 t/ha. This suggested that bark was causing a nitrogen drawdown effect. However, plots treated with higher rate of bark (100 t/ha) had levels of nitrate-N not significantly different to the control. There was no significant difference in organic C, despite the addition of amendments. Similarly, the levels of cations did not differ between treatments, suggesting that addition of organic matter had not improved cation exchange capacity (Table 24). It is possible that bark had not broken down sufficiently over the period of the trial to note any substantial changes in soil nutrients.

Table 24. Nutrient analysis of soil on 26/3/2003 (0-50 cm) from plots treated with bark or compost.

| | Control | Bark 50 t/ha | Bark 100 t/ha | Compost 100 t/ha | *P*= |
|---|---|---|---|---|---|
| No. replicates | 6 | 3 | 3 | 3 | |
| $NO_3^-$ N (mg/kg) | 16.7a[1] | 9.7c | 14.3ab | 13.3abc | 0.03 |
| $NH_4^+$ N (mg/kg) | 10.8 | 3.3 | 6.7 | 4.0 | 0.56 |
| P Colwell (mg/kg) | 69.2 | 78.0 | 70.7 | 78.7 | 0.53 |
| K Colwell (mg/kg) | 134.7 | 119.7 | 149.7 | 110.0 | 0.39 |
| S (mg/kg) | 91.2 | 77.3 | 99.2 | 74.7 | 0.69 |
| Organic C (%) | 3.22 | 3.11 | 3.25 | 3.41 | 0.80 |
| Reactive Fe (mg/Kg) | 7176 | 7192 | 7178 | 7066 | 0.99 |
| Conductivity (dS/m) | 0.147 | 0.131 | 0.144 | 0.128 | 0.73 |
| pH $CaCl_2$ | 5.23 | 5.00 | 5.20 | 5.27 | 0.22 |
| pH $H_2O$ | 5.73 | 5.53 | 5.70 | 5.73 | 0.51 |
| Cu DTPA (mg/Kg) | 2.35 | 2.41 | 2.23 | 2.35 | 0.95 |
| Zn DTPA (mg/Kg) | 1.25 | 1.29 | 1.28 | 1.37 | 0.73 |
| Mn DTPA (mg/Kg) | 26.2 | 21.5 | 24.8 | 23.6 | 0.92 |
| Fe DTPA (mg/Kg) | 114 | 164 | 107 | 149 | 0.65 |
| Exchangeable Ca (meq/100g) | 7.31 | 6.46 | 7.35 | 7.31 | 0.73 |
| Exchangeable Mg (meq/100g) | 3.05 | 2.38 | 2.85 | 2.91 | 0.43 |
| Exchangeable Na (meq/100g) | 0.127 | 0.087 | 0.117 | 0.110 | 0.13 |
| Exchangeable K (meq/100g) | 0.35 | 0.31 | 0.40 | 0.30 | 0.26 |
| Exchangeable Al (meq/100g) | 0.09 | 0.22 | 0.12 | 0.14 | 0.19 |

[1]Means within rows followed by the same letter are not significantly different at *P*=0.05.

*Soil physical measurements*

Soil cone resistance was measured on the control and bark 50 t/ha plots in March 2003 (Fig 5). There was no significant difference in soil water content between treatments (data not shown). The bark 50 t/ha plots were weaker in the 0-150mm layer compared with the control plots. This has implications for crop emergence. Soil resistance increased markedly below this depth, which corresponds to the depth of cultivation. This indicates that a plough pan or traffic pan may be developing at about the 150 mm depth. Root growth can be restricted considerably at resistance values of 200 kPa, which are exceeded below 150 mm.

The soil conductivity data indicated relative differences between the control and bark 50 t/ha plots (Figure 6). Large coefficients of variation precluded statistical analysis. The hydraulic conductivity of both plots was rapid, suggesting that all applied water

Figure 5. The effect of amendment on soil penetrometer resistance at different depths during pasture phase.

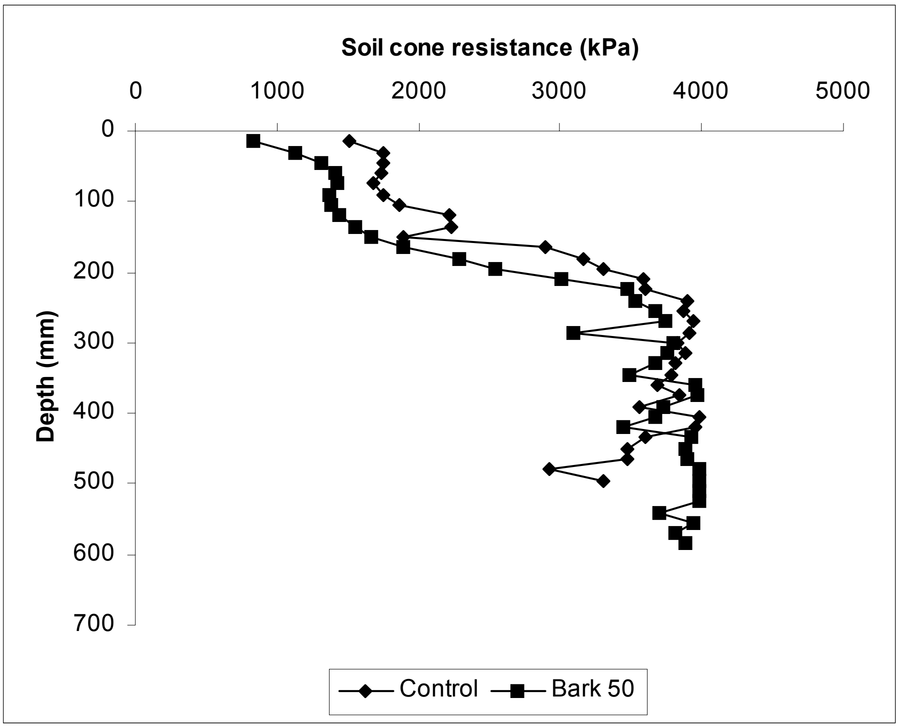
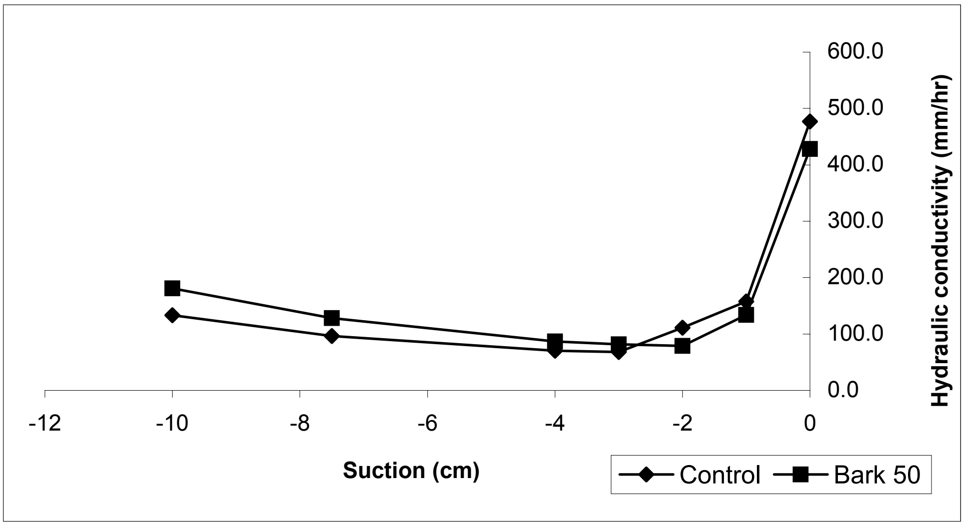


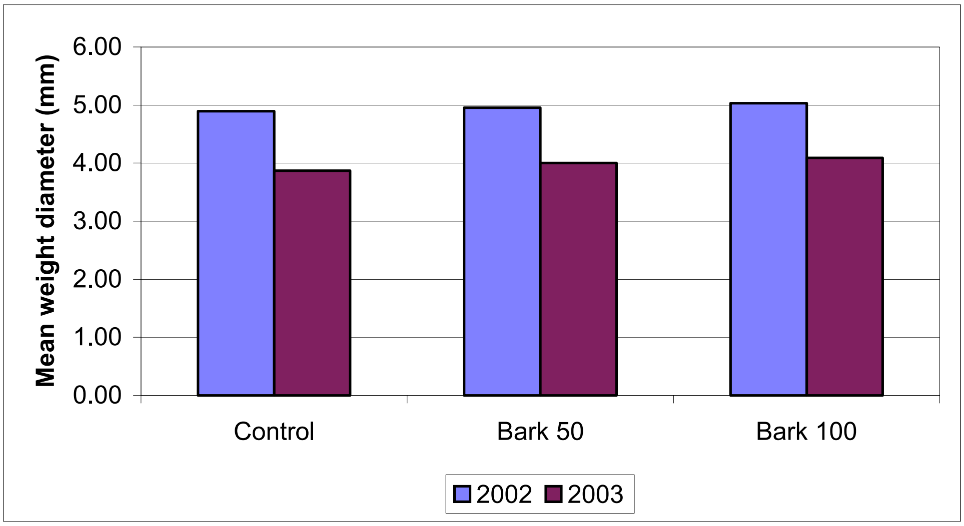

Figure 6. Hydraulic conductivity of soil in control plots and plots treated with 50 t/ha bark during the pasture phase.




would infiltrate into the soil. The bark 50 t/ha plots had greater conductivity at higher suctions (-10, -4 cm) compared with the control. The opposite was the case at lower suctions (-2, -1 cm). The inference of this is that there were a greater number of smaller soil pores in the bark 50 t/ha treatment than on the control.

For aggregate stability, there were no significant differences between treatments in both years of assessment. There was a trend, however, of increased stability in both years in the order of control<bark 50 t/ha<bark 100 t/ha (Figure 7). The difference between years may reflect environmental conditions and previous cultivation history.

Figure 7. The effect of bark amendment on aggregate stability in 2002 and 2003.




## 3.7 Cost benefit analysis

*Broadacre application of bark*

The potential benefits of using any organic amendment need to considered in relation to the cost of the material, its transport and application. An economic analysis was conducted on the use of eucalyptus bark residue.

The current cost of disposal of bark residue to the forest company was assumed to be \$10/t (Table 25). If instead, the bark was to be provided for use in broad acre agriculture, the material could be hammer-milled for the same price as disposal and the hammer-milled product provided to the farmer at a low cost (e.g. $5/t). Note that there would be some costs associated with the movement and storage of this material, especially if it had to be aged at the forestry company site for a period of weeks prior to making it available for use.

Due to the relatively low bulk density of eucalyptus bark, one of the major considerations is the cost of transport. The capacity and transport rates of different vehicles are given (Table 26). For the purposes of this analysis, a tandem tipper and trailer (4.8 t capacity) and bulk cartage semi-trailer (14.5 t capacity) were chosen (Table 26).

Table 25. Costs and revenue to the forest company of providing 100 tonnes hammer-milled eucalyptus bark.

| | Costs | Revenue |
|---|---|---|
| Hammer mill bark ($10.00/t) | $1000 | |
| Current disposal costs ($10.00/t) | | $1000 |
| Revenue ($5.00/t) | | $500 |
| Net benefit | | $500 |

Table 26. Costs of transport of bark residue and capacity of different vehicles.

| | $m^3$ | tonnes[1] | $/hr | $/km |
|---|---|---|---|---|
| Single axle tipper | 6 | 1.9 | 43.50 | 0.87 |
| Tandem tipper | 8 | 2.6 | 51.50 | 1.03 |
| Tandem tipper and trailer | 15 | 4.8 | 66.50 | 1.33 |
| Triaxle tipper | 25 | 8.1 | 75.00 | 1.50 |
| Bulk cartage semi-trailer | 45 | 14.5 | 85.00 | 1.70 |
| Bulk cartage semi trailer | 60 | 19.4 | 103.00 | 2.06 |

[1] Assume 1 t = 3.1 $m^3$ bark

Based on the above experimentation it was assumed that application of bark residue would lead to savings in the costs of land preparation weed and soil-borne disease control and irrigation. Reduced costs of land preparation might arise if bark was incorporated as part of normal tillage practices and if bark improved the soil physical properties to allow easier tillage (e.g. reduced bulk density of soil). It was also assumed that addition of bark residue would provide additional exchange sites and therefore reduce fertiliser requirements. Although no improvement in soil nutrient status was noted in this project, Gasser *et al.* (1995) reported improved cation exchange capacity from additions of bark residue. It was assumed that there would be no yield increases due to bark application due to the lack of a yield response in the trials reported here over the four years of the project. It was further assumed that rates of bark residue of 10 t/ha, 25 t/ha and 50 t/ha would lead to savings in some production costs of 10, 15 and 20% respectively in a typical onion crop (Table 27) grown on 10 ha. Costs were taken from (DPIWE, 2000). These assumptions led to a saving of $2338, $3506 and $4675 for 10, 25 and 50 t/ha bark respectively (Table 27). Given the cost of bark and its application, the net savings equated to $1373, $1094 and -$150 for 10, 25, and 50 t/ha bark respectively (Table 27). These net savings are the amounts that could be allocated to the cost of transporting the bark to the farm and were used to calculate a breakeven transport radius from the depot to the farm gate.

For a tandem tipper and trailer carrying 4.8 t per load the breakeven radius from the depot was 25 km and 8 km for 10 t/ha and 25 t/ha bark respectively (Table 27). As the 50 t/ha rate of bark returned a negative net saving it would have been uneconomic to transport in this scenario. For a bulk cartage semi-trailer carrying 14.5 t per load the breakeven radius from the depot was increased to 58 km and 19 km for 10 t/ha and 25 t/ha bark respectively (Table 27). Again, it was uneconomic to buy, transport and apply bark at the 50 t/ha rate, even assuming that it returned a 20% saving in some production costs.

The influence of transport rates on the breakeven transport radius are given (Table 28). This shows that if transport rates per kilometre could be reduced, the transport radius could be extended considerably.

The above assumed that the savings from bark would be seen only over one crop. However, bark is likely to have long-term effects as it breaks down. If savings can be made on successive crops then the economics become more favourable and the breakeven transport distance is extended. In a further scenario, it was assumed that similar savings could be made over two crops from a single application of bark at

Table 27. Cost benefit analysis of different rates of bark residue on a 10 ha onion crop assuming savings in the costs of land preparation, fertiliser, weed control, disease control and irrigation.

| | | Without bark | 10 t/ha | 25 t/ha | 50 t/ha |
|---|---|---|---|---|---|
| Assumed savings | | 0% | 10% | 15% | 20% |
| Land preparation [1] | | | | | |
| Mouldboard plough (1x) | 1.5 hr/ha @ $62.50/hr | $938 | $844 | $797 | $750 |
| Agroplough (1x) | 3 hr/ha @ $80/hr | $2400 | $2160 | $2040 | $1920 |
| Tyne cultivation (2x) | 1 hr/ha @ $62.50/hr | $1250 | $1125 | $1063 | $1000 |
| Fertiliser 14:16:11 | 0.625 t/ha @ $472/t | $295 | $266 | $251 | $236 |
| Lime Super | 125 kg/ha @ $214/t | $270 | $243 | $230 | $216 |
| Nitram (2x)[2] | 125kg/ha @ $500/t | $125 | $125 | $125 | $125 |
| Cartage of fertiliser | | $120 | $108 | $102 | $96 |
| Lime | 2 t/ha @ 21.50/t | $140 | $126 | $119 | $112 |
| Weed control | Herbicides[3] | $13,000 | $11,700 | $11,050 | $10,400 |
| Contract sprayer | 7 sprays @ 0.6 hr/ha @ $17/hr | $714 | $643 | $607 | $571 |
| Folicur[4] post emergent | 1l/ha @ $140/l | $1400 | $1260 | $1190 | $1120 |
| Contract sprayer | 1 spray @ 0.6 hr/ha @ $17/hr | $102 | $92 | $87 | $82 |
| Irrigation | 360 mm/ha @ $19.07/25 mm | $2746 | $2471 | $2334 | $2197 |
| **Total costs** | | **$23,500** | **$21,163** | **$19,934** | **$18,825** |
| **Savings in crop production costs** | | **-** | **$2338** | **$3506** | **$4675** |
| Amount of bark required for 10 ha (tonnes) | | | 100 | 250 | 500 |
| Cost of bark | $5/t | | $500 | $1250 | $2500 |
| Cost of spreading[5] | $4.65/t | | $465 | $1163 | $2325 |
| Net savings left over for transport of bark | | | $1373 | $1094 | -$150 |
| Cartage by tandem tipper & trailer, 4.8t capacity @ $1.33/km | | | | | |
| Maximum transport distance @ $1.33/km (km) | | | 1032 | 823 | - |
| Number of loads required | | | 21 | 52 | 104 |
| Breakeven transport radius (km) from depot ($1.33/km) | | | 25 | 8 | - |
| Cartage by bulk cartage semi-trailer 14.5 t capacity.@ $1.70/km | | | | | |
| Maximum transport distance @ $1.70/km (km) | | | 808 | 644 | - |
| Number of loads (bulk cartage semi-trailer (14.5 t capacity) | | | 7 | 17 | 35 |
| Breakeven transport radius (km) from depot ($1.70/km) | | | 58 | 19 | - |

[1] Contracting rates

[2] Same amount of Nitram added to compensate for any N-drawdown effect.

[3] Herbicide (number of applications): Propachlor (1), diquat (1), paraquat (1), chloropropham (2), ethofumesate (1), methazole (1), linuron (1), ioxynil (1)

[4] Folicur for control of onion white root rot disease caused by the soil-borne fungus *Sclerotium cepivorum*.

[5] Spreading costs of $1.50/m^3$, assuming 3.1 $m^3$ = 1 tonne

different rates (Table 29). In this case the net savings for transport at the 10 t/ha rate became $3711 and the breakeven transport radius for a tipper and trailer became 66 km and for a bulk cartage semi-trailer became 156 km. Similarly the net savings available for bark transport at the 25 t/ha rate became $4599 and the breakeven transport radius for a tipper and trailer became 33 km for a tipper and trailer and 80 km for a bulk cartage semi-trailer (Table 29).

The economic analysis suggested that relatively optimistic savings in costs of land preparation, weed and disease control, fertiliser and irrigation would be required for bark to be an economic proposition. For the purposes of this analysis, figures of 10 to 20% savings from bark at 10t/ha to 50t/ha in one crop were used. However, it is possible that from one bark application, savings over a number of successive crops may be achievable, which would improve the economics. Furthermore, the addition of bark residue to a more degraded site might be expected to increase yield, which would also improve the economics of utilising bark residue.

Table 28. The effect of tonnes of bark spread on 10 ha and transport costs on breakeven transport radius (km) from the depot, assuming the costs/benefits in Table 27 and transport of either 4.8 t or 14.5 t bark/trip.

| | Tonnes of bark spread/ha on 10 ha | | | | | |
|---|---|---|---|---|---|---|
| | Tandem tipper and trailer (4.8 t) | | | Bulk cartage semi-trailer (14.5 t) | | |
| | 10t/ha | 25t/ha | 50t/ha | 10 t/ha | 25 t/ha | 50 t/ha |
| Number of trips required. | 20.8 | 52.1 | 104.2 | 6.9 | 17.2 | 34.5 |
| Breakeven radius (km) | | | | | | |
| Transport cost/km | | | | | | |
| $0.40 | 82 | 26 | - | 249 | 79 | - |
| $0.60 | 55 | 18 | - | 166 | 53 | - |
| $0.80 | 41 | 13 | - | 124 | 40 | - |
| $1.00 | 33 | 11 | - | 100 | 32 | - |
| $1.20 | 27 | 9 | - | 83 | 26 | - |
| $1.40 | 24 | 8 | - | 71 | 23 | - |
| $1.60 | 21 | 7 | - | 62 | 20 | - |
| $1.80 | 18 | 6 | - | 55 | 18 | - |

Table 29. Assumed savings from the use of bark on 10 ha over two crops.

| Potential cost savings (10 ha) | | Without bark | 10 t/ha | 25 t/ha | 50 t/ha |
|---|---|---|---|---|---|
| Assumed savings | | 0% | 10% | 15% | 20% |
| **Savings in crop production costs** | | **-** | **$2338** | **$3506** | **$4675** |
| **Savings in crop production costs over 2 crops** | | **-** | **$4676** | **$7012** | **$9350** |
| Amount of bark required for 10 ha (tonnes) | | 0 | 100 | 250 | 500 |
| Cost of bark | $5/t | | $500 | $1250 | $2500 |
| Cost of spreading | $4.65/t | | $465 | $1163 | $2325 |
| Net savings left over for transport of bark | | - | $3711 | $4599 | $4525 |
| Cartage by tandem tipper & trailer, 4.8t capacity @ $1.33/km | | | | | |
| Maximum transport distance @ $1.33/km (km) | | | 2790 | 3458 | 3402 |
| Number of loads required | | | 21 | 52 | 104 |
| Breakeven transport radius (km) from depot ($1.33/km) | | | 66 | 33 | 16 |
| Cartage by bulk cartage semi-trailer 14.5 t capacity.@ $1.70/km | | | | | |
| Maximum transport distance @ $1.70/km (km) | | | 2183 | 2705 | 2662 |
| Number of loads (bulk cartage semi-trailer (14.5 t capacity) | | | 7 | 17 | 35 |
| Breakeven transport radius (km) from depot ($1.70/km) | | | 156 | 80 | 38 |

*Bark for use on irrigator laneways*

An alternative use for bark residue in cropping land might be to cover irrigator laneways as a means of reducing weed growth, reducing run-off of surface water and associated erosion. Farmers generally leave these areas bare or put in grassed laneways. A comparison of costs was done between grassing laneways and using bark residue to cover them. The comparison assumed 20 ha of cropping land with 11 irrigation laneways, each 300 m long by 3 m wide (0.99 ha in total). Cost comparisons suggested that a rate of 14.6 t bark/ha on 0.99 ha of irrigator laneways was comparative to the cost of establishing grass laneways (Tables 30 and 31). However, it is unknown if this rate would be sufficient to provide benefits in terms of improved infiltration rate, reduced run-off of water and hence reduced soil erosion. A heavier rate of 50 t bark/ha on laneways would cost approximately $758 per 0.99 ha, which is prohibitively expensive in comparison to grassing laneways.

Table 30. Costs of establishment of grassed laneways (DPIWE 2000)

| | | Rate ($) | $/ha |
|---|---|---|---|
| Land preparation[1] | 3.5 hr/ha | $5.26/hr | 18.41 |
| Seed | 10 kg ryegrass | 2.70/kg | 27.00 |
| | 2 kg white clover | 5.50/kg | 11.00 |
| Fertiliser | 0.25 t Mo Super | 274.00/t | 68.50 |
| | Freight | 25.00/t | 6.25 |
| | Lime 2.5 t/ha | 21.50/t | 53.75 |
| Sowing | 1 hr/ha | 5.26/h | 5.26 |
| Mowing (4x) | 1 hr/ha | 5.26/h | 4.21 |
| Total | | | 215.42 |
| Total cost per 0.99 ha of laneway | | | 213.27 |

[1] Assume 1 disc plough, 1 disc cultivation, 1 harrow.

Table 31. Costs of transport and application of different rates of bark to irrigation laneways (0.99 ha) assuming a round trip of 50 km.

| | Rate of bark application (total required) | | |
|---|---|---|---|
| | 10 t/ha (9.9t) | 25 t/ha (24.8 t) | 50 t/ha (49.5t) |
| Number of trips required[1] | 1 | 2 | 4 |
| Bark ($5.00/t) | $49.50 | $124.00 | $247.50 |
| Spreading ($4.65/t) | $46.03 | $115.32 | $230.18 |
| Cartage $1.70/km (50 km round trip) | $85.00 | $170.00 | $280.00 |
| Total cost per 0.99 ha of laneway | $180.53 | $409.32 | $757.68 |

[1] Assume bulk cartage semi-trailer carrying 14.5 t per load

# 4. Discussion

### 4.1 Broccoli

Overall, the type and rate of amendment had no significant effect on the total weight and number of broccoli heads compared to untreated plots. However, there appeared to be a slight delay in the development of the broccoli in plots treated with bark at 50 and 100 t/ha. This was demonstrated by the lower yield in these treatments in comparison to the control in the first harvest, and the higher yield from these treatments at the third harvest. It is not known what contributed to this delay. Although soil nitrate levels were lowest (compared to other treatments) in the bark plots at five to six weeks after transplanting, there was no apparent N-deficiency in plants from plots treated with high rates of bark, as shown by the similar sap nitrate levels at seven weeks after transplanting. In addition there was no obvious signs of deficiency on leaves during the trial. It is possible that there may have been some phytotoxic effect of the bark on plant growth that slowed the development of the broccoli plants. This would have explained the reduced weed populations on plots treated with the higher rates of bark. However, no evidence of growth suppression of broccoli transplants was noted in plots at five weeks. Thus the reduced weed growth on bark plots at 100 t/ha may have resulted from a combination of the higher susceptibility of seedling weeds (in comparison to broccoli transplants) to leachate from the bark and the 'smothering' effect of bark that was left on the surface in patches which would have provided some localised control.

Due to the regular rainfall over the course of the crop, no benefits from differential irrigation were seen in the first part of the trial. However, tensiometer readings were generally lower in the plots treated with bark at 100 t/ha, which suggested increased water holding capacity and that some savings in irrigation may be possible or that less water was being utilised by the plants.

In conclusion, bark at a rate of up to 100t/ha was demonstrated to have no deleterious effects on the broccoli crop. The higher water retention and reduced weed counts in plots treated with high rates of bark indicates that some savings in irrigation and weed control may be possible from the use of this material.

## 4.2 Onion

The reduction in yield and size of onions from plots treated with 50 and 100 t/ha bark compared to other treatments is most likely to have resulted from a combination of plant maturity and the differential watering regime.

*Plant maturity*

In the first crop grown in the plots (broccoli), there was a notable delay in maturity of plants on plots treated with 50 and 100 t/ha bark. This was shown by the yield of broccoli from bark plots being lower than that from the control and other treatments in the first harvest and higher than other treatments in the third harvest.

In the onion crop there was no statistical evidence for a delay in maturity based upon the weight of 50 onion plants taken from each plot in late December 1999. However, it was notable that onions from plots treated with bark at 100 t/ha had the lowest mean weight at this time. Bulbs from plots that received the high rates of bark were smaller than bulbs from other treatments, which also indicated that plants were at a lesser stage of development in the bark plots.

Therefore, if onions on plots treated with 50 and 100 t/ha had been allowed longer to mature (harvested later), the yield differential between bark and control plots would have been smaller.

*Watering regime*

Tensiometer readings showed no difference in gravimetric water content at 10 kPa. However, bark 50 t/ha, bark 100 t/ha and compost 100 t/ha had higher gravimetric water content at 100 kPa, perhaps suggesting that in soil treated with amendments more water was being held in smaller pores.

By watering according to tensiometers, savings in irrigation were achieved on the plots that received high rates of bark. On the basis of tensiometer readings, water was not limiting for most of the season. This is confirmed with the sample of 50 plants taken in late December, which showed no difference in plant weight at that time. In January, irrigation was stopped in anticipation of lifting the crop. However, the lifting date was delayed by the company that was to pack the onions, and irrigation was not resumed until early February. If onions on the bark plots had been less mature, reduced availability of water at this time would have had more impact upon the ability of onions in bark plots to increase in bulb size compared to onions in other treatments that may have been closer to a mature size. Alternatively if bark plots did retain moisture for longer throughout the early part of the season, onion in these plots may have been more shallowly rooted and therefore less able to extract water from deeper in the soil profile during the period where irrigation was not applied. Had irrigation been applied over this period, onions in the bark plots may have continued growth and the yield difference between bark and control plots would have been less.

**4.3 Potato**

Yield and quality of potato was unaffected by bark amendment. Although the mean yield was highest from plots that had received the most recent applications of bark (bark 10+50 t/ha), there was no statistically significant difference between this treatment and the untreated control. Plants were observed to emerge slightly earlier on plots treated with 10+50 t/ha bark, and at eight weeks after planting in plots treated with 10+50 t/ha bark, plants had the highest mean dry weight (although not statistically significantly different from the untreated). Earlier emergence might have arisen from increased soil temperatures in treated plots, however this was not measured. Plots that received bark at 50 t/ha and bark at 100 t/ha initially at trial establishment were the lowest yielding, although not statistically significantly lower than the untreated control. This contrasts with the study of Gasser *et al*. (1995) who found that addition of humified bark at a rate of 100 $m^3$/ha to a sandy loam soil increased potato yields. Assuming a similar bulk density to the material used in our study (1 t = $3.1m^3$), Gasser *et al*. (1995) would have applied approximately 32 t/ha bark which is lower than the highest rates used in our study.

Bark had no significant effect on emergence of a range of weed species in the potato crop. This was surprising as significant weed suppression was noted at least initially after the application of bark in 1999. The suppression at the first application was thought to be due to compounds leaching from the bark rather than any mulch effect as the bark had been incorporated into the soil. The lack of effect noted after the most recent application may indicate that different sources of bark may have differing abilities to suppress weeds.

Bark treatment appeared to have an effect on gravimetric and volumetric water content at different suctions with a general trend for less water being held at different suctions with reduced rates of bark. This difference might be expected to equate to a saving of one irrigation per crop. Gasser *et al*. (1995) also reported that bark amendment prior to potato caused an improvement in soil water content during the critical flowering stage and that this led to improved potato yield and specific gravity.

## 4.4 Other crops

*Poppy*

In agreement with previous crops, the amendments were found to result in no improvement to crop yield or quality of poppy.

*Pasture*

Amendment had no effect on pasture growth as measured by a rising plate meter. In addition, amendment had no effect on populations of root lesion nematode. Neither bark residue or compost appeared to affect the soil nutrient analysis at four years after application, other than an apparent effect of reduced nitrate-N in plots treated with bark 50 t/ha initially. This perhaps indicated that a longer period of decomposition would be required for bark and composted bark, before improvements to soil chemistry would be seen.

*Sowing trial*

This trial indicated that freshly applied bark had no effect on emergence of onion or poppy seedlings, suggesting that smaller seeded crops might be successfully sown into soil treated with bark. However, caution is required as the literature would suggest that phytotoxicity can occur. Factors such as bark composition and age are important factors that would influence the level of phytotoxicity.

## 4.5 Soil physical properties

Changes in soil physical properties occurred, but generally they were not significant. There was a general trend for the addition of bark as an amendment to improve soil physical properties such as aggregate stability and soil strength. This was also reflected in differences in soil hydraulic conductivity and soil water retention. Aggregate stability tended to increase as the amount of added bark increased and this also corresponded with a decrease in soil strength in the surface layer. Soil hydraulic conductivity was greater at higher suctions on the bark plot compared with the control, indicating the presence of smaller connected pores. The reverse was the case at lower suctions, which indicates that larger pores are conducting water. These pores would also drain more readily resulting in less water being available for plant growth. This is borne out by the fact that the tensiometer readings showed that the bark plots remained wetter for longer periods of time after rain or irrigation. The fact that changes in soil physical properties were not significant reflects the relatively short time of the trial and the nature of the added material. Woody material takes longer to break down compared with herbaceous material. It may be expected that differences would develop with time and the effect of adding bark as a soil amendment needs to be considered over a longer time frame than this current trial.

## 4.6 Cost benefit analysis

From the results of this 4 year trial at one site, the use of bark would be considered economically marginal. Relatively optimistic savings in cost of land preparation, weed and disease control, fertiliser and irrigation would be required for bark to be an economic proposition. The economic situation might be improved if a more degraded site had been used at which greater benefits might have been more apparent. Similarly, the slow decomposition rate of bark might suggest that benefits may be apparent over a number of years, which might further improve the cost/benefit ratio. Bark may become economic when used more strategically, for example in irrigator laneways as an alternative for grass and as an alternative method of erosion control. Further improvements to the economics might be gained by compacting bark prior to transport to increase its bulk density (e.g by using compactor trucks similar to that used for municipal rubbish collection).

# 5. General conclusions

### 5.1 Conclusions

This project has demonstrated that aged, hammer-milled eucalyptus bark can be successfully used without any major deleterious effects in a broad-acre agriculture on a range of crops. However, the project has not shown any clear benefits from bark application at the study site, other than potential savings in irrigation and a transient effect on weed populations. These benefits were outweighed by the cost of bark and its transport and application.

It is possible that additional benefits might have been observed on a more degraded soil, a soil type that was lower in organic matter, or following further decomposition of bark over a longer time period. Furthermore, the literature suggests that high rates of bark may play a role in suppressing soil-borne disease. This aspect was unable to be investigated as part of this project as the site had no appreciable soil-borne disease problems. In these situations, bark residue may be economic as a soil amendment.

In summary, some of the potential benefits of utilising bark would be a) irrigation savings, b) improved water infiltration into soil, c) reduced erosion in cropping soil and laneways, d) weed suppression in crops and laneways, e) easier cultivation, f) suppression of soil-borne disease, g) provision of additional cation exchange capacity in soil and less loss of nutrients by leaching.

This would need to be balanced against the costs of utilising bark including the cost of hammer-milling, transport, spreading and perhaps additional N-fertiliser to compensate for the drawdown effect of adding material with a high C:N ratio. The current cost of stockpiling or disposal of bark residue would need to be considered with respect to the cost of bark.

Some potential problems which could arise on farm from the use of bark residue would include, a) phytotoxicity to some crops depending on type of bark and its age (a slight effect was noted on the broccoli crop in this project) b) the risk of wood fragments in root crops (no evidence of this was noted in the onion or potato crops in this project), c) potential problems with seed placement and germination of fine seeded precision sown crops, but this would be likely only at high rates of bark.

However, on the basis of this project located at one site in northern Tasmania, the costs of utilising bark outweighed the benefits. Therefore bark residue could not be recommended as a soil amendment in broad acre agriculture in this situation.

**5.2 Future work**

Future work should be carried out on sites with degraded ferrosols or soils with low organic carbon contents (<3% C). In these situations, the addition of bark residue may have a greater benefit than was observed in the current project. In addition, the impact of bark residue on soil-borne diseases should be assessed. While research in container culture suggests that large amounts of bark amendment need to be incorporated to obtain suppression of pathogens, smaller quantities added to soil might give some cost savings in disease control.

More strategic use of bark in broadacre agriculture might also improve the economics. The addition of bark in strips as opposed to broadcast application may provide localised benefit for longer periods of time. The use of bark on irrigator laneways and headlands could also be investigated as a means of reducing water run-off and soil erosion. Compacting bark prior to transport to increase bulk density might reduce the number of trips required to deliver a specific tonnage to the farm, and therefore may improve the economics of bark use.

The effect of bark addition may only be expressed in the longer term and thus not be immediately evident. A longer-term trial may provide an insight to benefits and thus increase the economic benefit of bark as an amendment. This needs to be undertaken especially with respect to soil structure, organic matter, soil-borne diseases and weed control.

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**Appendix 1**. Trial plan

1. Control ................... Untreated
2. Control ................... Untreated
3. B10 A ...................... Bark 10t/ha (January 1999) + bark 25 t/ha (September 2000)
4. B10 B ...................... Bark 10t/ha (January 1999) + bark 50 t/ha (September 2000)
5. B50 .......................... Bark 50t/ha (January 1999)
6. B100 ........................ Bark 100t/ha (January 1999)
7. Comp 10 .................. Compost 10t/ha (January 1999)
8. Comp 100 ................ Compost 100t/ha (January 1999)

| | | | | |
|---|---|---|---|---|
| Control 1 | | B 50 | B10 A | B100 |
| Comp 10 | | Control 3 | Control 5 | B50 |
| B10 A | | Comp 10 | Comp 100 | B10 A |
| B100 | | B10 B | Control 6 | Control 7 |
| Comp 100 | | Control 4 | B10 B | Comp 100 |
| B10 B | | Comp 100 | B100 | B10 B |
| Control 2 | | B100 | B 50 | Comp 10 |
| B 50 | | B10 A | Comp 10 | Control 8 |