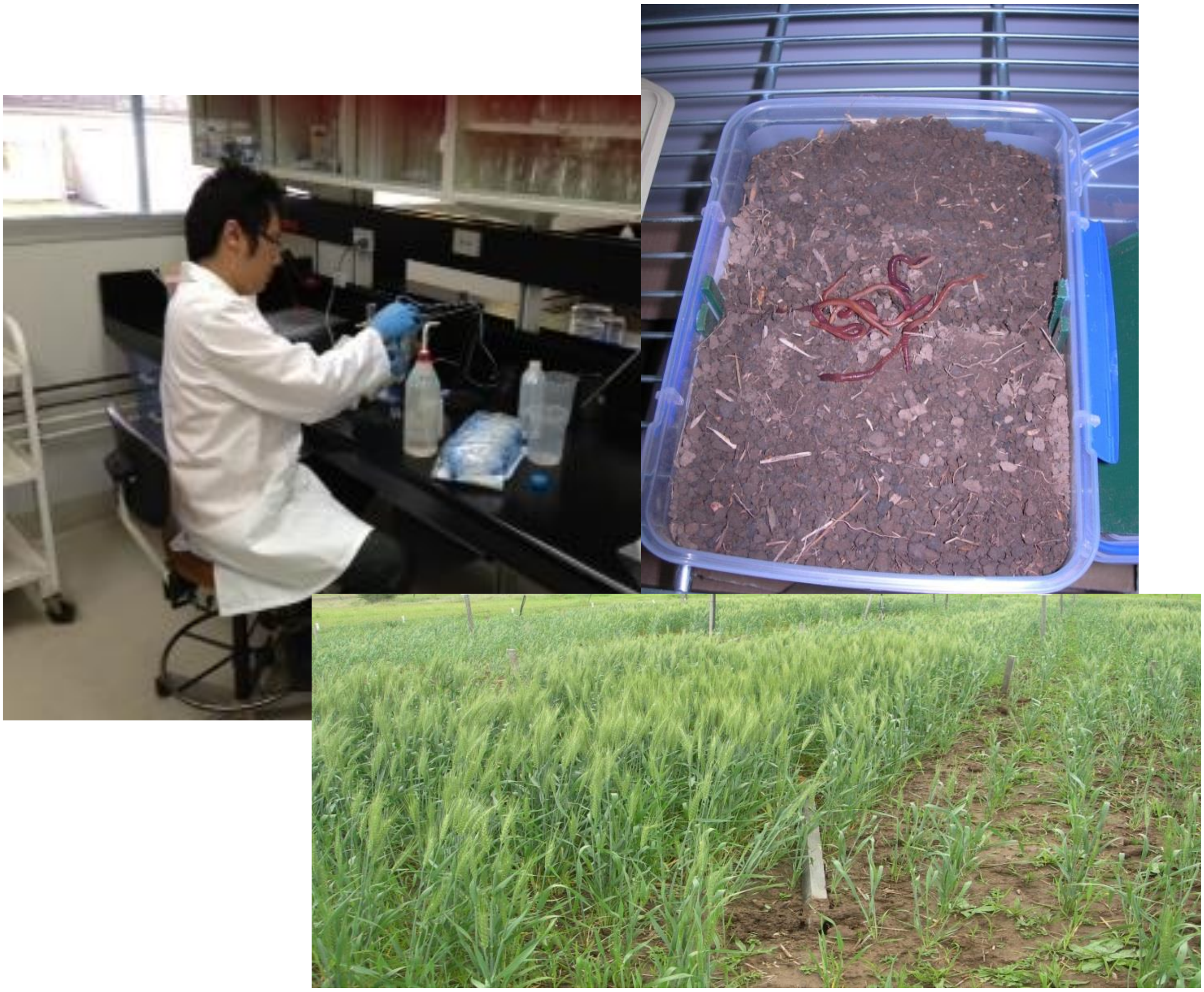
NSW GOVERNMENT

Department of
Primary Industries

# A field evaluation of composted mixed waste organic output tables (MWOO) for use as a soil amendment



## Final Report July 2017

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**Final Report for;** A field evaluation of composted mixed waste organic output tables (MWOO) for use as a soil amendment

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# Executive Summary

NSW EPA has granted a general exemption for ‘organic outputs’ derived from mixed solid wastes (MWOO), to be used as soil amendments under certain land-use scenarios including, mine site rehabilitation, forestry, and for non-contact and broad-acre agriculture (NSW EPA 2014a). The MWOO material is known to contain varying amounts of plant nutrient elements which can boost the productivity of receiving soils. At the same time however, MWOO also contains a range of inorganic and organic contaminants, which may have a detrimental effect. Continuation of the general exemption for MWOO application is dependent on the examination of the environmental and human health impacts of the MWOO materials.

This report details the outcomes of a field trial carried out NSW Department of Primary Industries (NSW DPI), which assessed of some of the potential benefits and risks of using MWOO materials as soil amendments. NSW EPA funded the current research field trial program on the use of MWOO as a soil amendment and which had the following series of general project objectives;

- To indicate rates of MWOO application to the soil that allow measurable benefits to agricultural production and soil health; through examining effects of MWOO on parameters relating to plant production, soil chemical and physical fertility and soil health;
- To compare these same beneficial effects from the added MWOO, with those following the addition of more commonly used organic amendment materials of similar origin such as garden organics (green waste), composted biosolids and animal manure;
- To highlight any potentially negative effects from the application of MWOO materials on agricultural production as well as soil and environmental health; through examining effects of MWOO on parameters relating to plant production, soil chemical fertility, soil and environmental health, including the potential for off-site impacts and by,
- Comparing any differences in agronomic and environmental benefits or risks between different methods of MWOO application; i.e. the different effects surface or incorporation of MWOO.

The field trial project commenced in November 2012 and focussed on the soil response to two different MWOO materials. These were incorporated at rates of application ranging from 10 t/ha (industry practice), followed by rates designed to give an agronomic response (20 - 50 t/ha), through to rates used in mine site rehabilitation and beyond (100 and 200 t/ha). Concurrent surface applications were also tested and were designed to encompass current industry practice, where MWOO is applied to the soil surface only, at rates up to 10 t/ha. Other amendment materials were also used as a comparison with the MWOO, including composted green waste, composted biosolids and poultry manure. The trial continued for three successive cropping seasons during which millet and wheat were grown, and a range of growth and production parameters assessed.

Soil and plant samples were collected at regular intervals (zero [T0], one [T1], two [T2] and three years [T3]), post application. These were analysed for a range of nutrient and contaminant elements, and soils were also analysed for the presence of organic contaminants. The potential for off-site impacts of MWOO contaminants was assessed via an examination of artificially generated run off and via batch extraction techniques. Contaminant bioavailability was also estimated via batch extraction with a neutral salt extracting solution and amounts extracted were compared with those from other amendments studied previously. Soil profiles were sampled for downwards movement of contaminants. A range of other tests were also carried out on the samples including an examination of the functionality of the soils’ post-amendment, microbial population, and effects on soil biota.

Analysis of the metal contaminant concentrations in MWOO 1 material shows that it complies with the NSW EPA Mixed Waste Order, however the MWOO 2 has higher concentrations of Cr, Cu and Pb, which would make it suitable only for mine site rehabilitation. The other materials used in the trial (green waste, composted biosolids and poultry manure), have lower contaminant concentrations which would classify them the contaminant grade 'B', according to NSW EPA guidelines for biosolids application to agricultural soils. Materials must be graded as C or better for use in agriculture. These data are consistent with the previous work carried out on MWOO materials in NSW. The MWOO also contained significant quantities for a range of organic compounds, particularly phthalates (300 mg/kg DEHP) and Bisphenol A (560 – 7,300 mg/kg). There were also quantities of DEET, a component of commonly used insect repellents. The concentrations of these are higher than those measured in other amendment materials such as biosolids. The green waste, composted biosolids and poultry manure did not contain these organic contaminant chemicals or else they were at trace levels only.

Application of each of the amendments resulted in an immediate increase in soil pH for all treatments. However, by the time of the second sampling (T1), this change in soil pH was not as evident. Similarly, initial application of all organic amendments temporarily raised the soil EC to levels some of which exceeded the critical salinity threshold for plant growth. Subsequent to this, the EC levels had declined by the second sampling period (T1), as the soluble salts have been removed from the upper part of the test soils. The application of the amendments increased the concentration of soil fertility parameters such S, plant available P, N, TOC and CEC, all increased in the amended soils following treatment application. Levels of TOC in the amended soils decreased rapidly (by up to 50%) in the three years following application and this decreases was greatest for surface amendment treatments. The concentration of plant available P (Colwell P) in amended soils reached higher than recommended for incorporated MWOO application rates greater than 20 t/ha (greater than 10 for manure), and all MWOO surface applications.

Soil metal concentration increased when MWOO was applied to the trial soils. The extent of this increase varied between the metals tested and between the various amendments and application rates. Soil metal concentrations were also raise with the application of green waste, composted biosolids and poultry manure, but not to the extent of those following MWOO application. Post-application, soil metal concentrations were below the Resource Recovery Exemption Order for MWOO maximum allowable contaminant concentrations (MACC's) (NSW EPA 2014), for all metals applied via green waste, biosolids and manure treated amendments, even where these were applied at rates up to 200 t/ha. For the MWOO treatments however, concentration of all metals were below the MACC except for Cd, Cu Zn on the high (greater than 100 t/ha) incorporation treatments. Soil metal concentrations were generally higher for the surface applied treatments, with application rates of equal to or above 30 t/ha, exceeding the MACC for the same three metals. These three contaminant elements have been identified as having the greatest potential to adversely impact food production or soil health following the application of various amendments, including compost and biosolids

The concentrations of organic contaminants increased in the amended soils and depended on the rate of application, but were generally higher following surface application. As the MWOO materials contained significant quantities of organic compounds associated with plastics manufacture and plastics breakdown, including phthalates (DEHP, DBP) and Bisphenol A, the soil concentrations of some of the organic compounds increased with MWOO application and exceeded the ERL (where these exist) for phthalates found in incorporation treatments, while for surface applications these were exceeded at doses as low as 20t/ha to 30 t/ha. Although the concentration of these compounds decreased in subsequent years, post-application, of some concern is that concentration of these are still detectable in the amended soils after three years, where it would be expected that these compounds would have been degraded by soil microbial populations.

Generally, early plant growth responded positively to the incorporation of the of the amendment materials but less so where they were applied to the soil surface. However, positive yield responses (greater than the control treatment) usually occurred at high application rates only (greater than 60 t/ha). For millet, gains in plant dry matter production did not always translate into increases in grain yield and none of the amendments increased grain yield above those of the control treatment. For wheat, applications greater 60 t/ha resulted in grain yields exceeding control and control fertilizer levels. Similarly, incorporation of GW (greater than 60 t/ha), composted biosolids (incorporated at 10 and 60 t/ha), and manure applications (incorporated at rates of 10 t/ha and above), resulted in greater yields than the control. Overall yields for the second wheat crop increased on average by up to 31%, due to improved environmental conditions during the growing season, but again significant responses to MWOO were seen at rates exceeding 60 t/ha for incorporated MWOO and greater than 30 t/ha for surface applied MWOO. For the second crop, we also found that incorporation of GW at rates greater than 60 t/ha, and all manure applications (incorporated at rates 10 to 100 t/ha), resulted in yield greater than control levels. Surface applications of GW at rates at or above 20 t/ha also increased grain yields to above those of the control treatment.

The concentration of metal and nutrient elements increased in plant tissue and grain with the addition of the various amendments to the soil and plant metals concentration were generally higher in the MWOO treated soils. At no stage did heavy metal accumulation reach a level where toxicity and subsequent yield loss may have been expected, although the highest levels of metal accumulation were seen in the high rate MWOO and manure treatments. Likewise, metal accumulation did not affect product quality (e.g. for Cd) and concentration were well below limits set for human consumption. The assessment of feed quality carried out on the millet grain data suggests that the quality of the grain improved slightly where sufficient rates of the amendments were applied to the soils, although once again, this improvement was more obvious where high application rates (greater than 60 t/ha) were used. The same improvement for the second wheat crop was seen following the use of inorganic fertiliser.

High rate applications of MWOO resulted in medium-term improvements in soil physical properties through increased water holding capacity and reduced soil bulk density. This effect was only observed however with incorporation of the material and at rates greater than 100 t/ha.

High rate incorporation (200 t/ha) and surface applications (greater than 30 t/ha) of MWOO, reduced the volume of run off collected following simulated rainfall on the treated plots, compared to control soils. At the same time, MWOO application increased the concentrations of As, Cd, Cr, Cu, Mo, Ni, Pb, and Zn in run off solutions compared to the control treatment, especially for the surface application treatments.

We used the 1:5 soil water extract to indicate the maximum concentration of potentially water soluble elements in the amended soils. Examination of data from the initial (T0) samples reveals that the concentrations of As, Cd, Co, Cr, Cu Ni and Zn were above the long term trigger value for irrigation waters. These exceedances occurred for MWOO 1 at application rates greater than 60 t/ha and for MWOO 2 at rates greater than 100 t/ha. Similarly, the LTVs were exceeded for surface applications of MWOO 1 at greater than 30 t/ha for MWOO 1 (and as low as 10 t/ha for Ni) and the high surface applications of MWOO 2 (50 t/ha). However, the concentrations of the elements tested decreased significantly in later soil water extracts (T2 and T3), and were close to that of the control treatments.

Analyses of the soil nutrient and heavy metal concentration data collected from soil profiles under the MWOO treated plots, reveals that there was no significant downwards movement of these elements below the initial zone of MWOO incorporation (15cm).

We assessed changes in the concentrations of potential bioavailable metal contaminants in the amended soils over time by examining metal concentrations extracted from the soils with a neutral salt solution (0.01M $CaCl_2$). Initially, the concentration of metal contaminants that were extractable in 0.01M $CaCl_2$ were higher in MWOO amended soils compared to the soils amended with the other organic materials. By the end of the trial however (T3), ageing of the MWOO and other amendments in the test soils has revealed that there is little difference in the overall metal extractability between the various materials. This is also the case when comparing metal extractability for the MWOO treatments and other current treatments, with amendments previously studied at the test site (e.g. dewatered biosolids). It is therefore unlikely that the current framework for regulating soil metal inputs from biosolids, would underestimate the risk from these same metals for sources such as MWOO and the other amendment materials tested during this trial.

Data presented shows that by applying MWOO at the ‘agronomically significant’ application rates needed to achieve an improvement in crop yield, populations of soil biota may also be affected in the short term as worm avoidance was seen for freshly applied MWOO at rates at or greater than 20 t/ha. Subsequent testing showed that ageing of the MWOO treated soils in the field had lessened these effects. It is possible that this behaviour is due to increased salinity levels following MWOO application to the soil, however it is unclear as to how worm populations would recover, once soil salinity levels were reduced, i.e. whether *in situ* worm populations would have the captivity to repopulate amended soils. It is also possible that the presence of organic contaminants (e.g. DEET), identified in the MWOO and amended soils may also have had an adverse effect on soil biota. Indeed, an additive effect of high EC, heavy metals and organic contaminants was likely thus resulting in the observed earthworm avoidance following application.

Initially, MWOO applications resulted in increased microbial activity in the amended soils. Soil microbial respiration and the capacity to cycle added N increased with increasing rates of MWOO application. At the same time, similar effects were also seen for other amendment materials, such as composted green waste. However, testing on subsequent soil samples collected as the trail progressed, particularly for the final sampling collected three years post-application, it is apparent that there has been a decline in microbial activity on the MWOO amended plots, particularly for the high rate applications (at or above 100 t/ha), which has seen a decline in the soil microbial populations’ ability to cycle applied N and has also seen reductions in soil microbial respiration to below levels seen in control soils.

Overall, the addition of MWOO to the soil surface had the greatest impact on soil contaminant and nutrient levels and this in turn was reflected in these soils also having the highest potential for offsite movement of these contaminants and plant nutrients immediately after application.

In summary, the data presented in this report does not provide support for the use of MWOO as a soil amendment in agriculture. Consistently high application rates were needed to produce positive gains in crop production (greater than 60 t/ha for incorporated MWOO), measured across three consecutive cropping cycles, but these rates also led to a legacy of metal and organic residues in amended soils, and the concentrations of some of these approach (metals) or exceed (organic pollutants) relevant regulatory or environmental thresholds for one MWOO application. Our data shows that there are potentially detrimental effects on biology at these rates of MWOO application and there appears to be some persistence of the organic contaminants applied with the MWOO. Even higher rates of application are needed to improve soil physical health (between 60 and 100 t/ha). Although similar application rates are needed with the use of other amendment materials (e.g. green waste), application of these do not contain the same levels of contaminants. Similar plant growth responses can be achieved with inorganic fertilizers without the inherent contamination risk.

# Background

This project was initiated by NSW EPA, having granted a general exemption for ‘organic outputs’ derived from municipal solid wastes (now referred to as mixed waste organic output – MWOO, NSW EPA 2014), to be used as composts or soil amendments under certain land-use scenarios including mine site rehabilitation, forestry, non-contact and broad-acre agriculture. Continuation of the general exemption is dependent on the outcome of trials examining the environmental and human health impacts of the MWOO materials. The exemption allows for the application of MWOO at rates up to 140 t/ha for mine site rehabilitation, 50 t/ha for plantation forestry and non-contact agriculture and no more than 10 t/ha for broad acre agriculture.

As part of this testing process, NSW Department of Primary Industries (NSW DPI) carried out a field trial aiming to provide information enabling the assessment of some of the potential benefits and risks of using such materials as soil amendments. At the same time, the general exemption granted by NSW EPA clearly states that any application to land of such material must not be harmful and must also be of benefit to soil health and agricultural production.

## *Potential issues to be addressed during field testing of MWOO*

### *Mixed Waste Organic Outputs - MWOO*

A range of mechanical and biological processes have been developed to deal with the ever increasing volume of solid wastes generated from urban areas. These processes often result in the production of a compost-like organic fraction that is also called ‘alternate waste technology derived organic rich fraction’ (AWT DORF) and more recently ‘alternate waste technology - mixed waste organic output tables’ (AWT-MWOO), and now just MWOO. This material contains differing amounts of various plant nutrients such as nitrogen (N) and phosphorus (P), as well as organic carbon (OC), and therefore has the potential to increase the soil concentration of these valuable components when applied as soil amendments. By recycling these elements back into the soil, application of the MWOO could result in the improvement of the physical, chemical and biological health of some soils.

However, MWOO also contains a number of contaminants, including heavy metals and organic compounds, which may be detrimental to the environment if their application is not adequately managed. For example, it is well known that soil microbial processes are integral in nutrient cycling process within the soil and wider environment as such are crucial for sustained agricultural production. At the same time, it has been well established that soil microbial function is highly susceptible to metal contamination (Brookes and McGrath 1984) and this is particularly relevant under the degraded soil conditions commonly found in parts of Australia (Broos et.al. 2007). These same soils are likely to benefit from carefully managed inputs of organic materials such as biosolids or composts and are often situated close to urban centres, particularly on the East coast of Australia, where much of these organic materials are produced (Whatmuff 2002).

European studies have identified over 200 contaminant organic chemical compounds in some municipal composts and their digestates (Brandli et.al. 2007a & 2007b; Brandli 2006, Brandli et.al. 2005) and it is thought that some of these also have the potential to cause harm to the environment, agricultural production and the human food chain, if their inputs to soil are also not carefully managed (Amlinger et.al. 2004). In addition, it is thought that when such contaminants are added to soils in combination, the toxicity of the chemical mixture may be increased above or decreased below that of the individual chemical alone, and so single chemical toxicity data may not be adequate as a basis for risk assessment for chemical mixtures. Kim et.al. (2011) found that the presence of Cu and Zn increased the persistence of glyphosate added to soils because the metals adversely affected the microbial populations responsible for the cycling of soil carbon. The issue of chemical mixture toxicity is the subject of ongoing research around the world, but has not been resolved as yet and therefore the toxicity of chemical mixtures, such as those potentially found in MWOO, cannot be accurately predicted (Kortenkamp et.al. 2009; VKM 2008; USEPA, 2000). Nonetheless, the environmental science/ ecotoxicology community is taking the potential effects of chemical mixtures quite seriously. For example, a recent Special Issue of *Science of the Total Environment* (2010, Volume 408, Issue 18) is devoted solely to the effects of chemical mixtures.

### *Local data*

Research into the use of MWOO on agricultural soils in New South Wales is limited. One trial investigated the use of biosolids-fortified MWOO and other materials in a mine site rehabilitation scenario. In this trial, growth response in eucalypt tree species was related to applied treatments (Kelly, 2007). While the soil amendments generally had a positive effect on tree growth, the effect was dependant mostly on the plant nutrient content of the amendment itself and the trial did not address potential impacts of contaminants on soil and environmental health or the potential use of these materials in broad acre agriculture. Also, the MWOO was fortified with biosolids, so any plant growth response would have been confounded by the additional nutrients supplied with the biosolids that were added to the MWOO. As a consequence, this study has only limited relevance to the use of MSW compost in agriculture as well as the impact of MWOO on soil health.

A second set of experiments involved separate pot and field trials looking at the response of radish (pot trial) as well as wheat and sorghum to MWOO (field trial) (Dorahy et.al. 2006a & 2006b). As with the mine site rehabilitation trial discussed above, these two experiments did not address contaminant issues to any great extent and the limited number of rates employed (3 only) make it difficult to extrapolate the data to other situations. The MWOO materials used here were also fortified with either pig manure or biosolids, so the data from these experiments have only limited relevance to the current situation.

Recently, the Australian mixed waste industry commissioned a study (referred to here as the AWT DORF Report), to identify the extent of organic contaminants in locally manufactured MWOO and the risk these chemicals may pose to the environment (Hyder, 2008a). The study was largely based on data published in the scientific literature as well as analyses performed on a very limited number of locally produced materials. This sampling exercise comprised a total of 12 samples which were taken from 4 AWT facilities. The AWT DORF Report identified a number of chemicals of concern (COC) that were not otherwise covered under guidelines for the land application of other organic materials such as biosolids. Although the authors of the report used this information to carry out a risk assessment for each of the COCs found in the MWOO samples, the authors acknowledged a number of deficiencies in the relevance of some of the toxicity information used and its statistical evaluation in the report.

### *Trial objectives*

It is clear therefore, that there is little relevant local information on the possible benefits or risks to the soil environment and agricultural production from applying MWOO to soils. To address this knowledge gap, NSW EPA funded the current research field trial program on the use of MWOO as a soil amendment and which had the following series of general project objectives;

- To determine rates of MWOO application to the soil that allow measurable benefits to agricultural production and soil health; through examining effects of MWOO on parameters relating to plant production, soil chemical and physical fertility and soil health;
- To compare these same beneficial effects from the added MWOO, with those following the addition of more commonly used organic amendment materials of similar origin such as garden organics (green waste), composted biosolids and animal manure;

- To determine any potentially negative effects from the application of MWOO materials on agricultural production as well as soil and environmental health; through examining effects of MWOO on parameters relating to plant production, soil chemical fertility, soil and environmental health, including the potential for off-site impacts and by,
- Comparing the agronomic and environmental benefits or risks from different methods of MWOO application; i.e. the different effects surface or incorporation of MWOO.

Once the MWOO and other treatments were applied, crop and soil responses to the added treatments were measured for a minimum of three subsequent cropping seasons (3 years), thus allowing sufficient time for treatments to ‘equilibrate’ with the soil system and therefore providing data needed to evaluate the medium-term effects of the MWOO material on the soil environment. The responses to MWOO were compared to different rates of composted green waste, composted biosolids and poultry manure, as well as traditional inorganic fertilizers.

Testing of soil and plant samples enabled us to assess any improvement that the various materials have on plant growth, while also allowing us to measure any changes in key soil properties and soil biology over time, following the addition of the treatments. We also measured the extractability behaviour of some of the chemical contaminants that were present in the MWOO material and other treatments, including the potential for them to be transferred to other parts of the soil and wider environment. Such information is currently lacking for NSW soil and climatic conditions and so the data obtained from this trial will assist regulators to ensure that MWOO is used as soil amendments in a sustainable and environmentally responsible manner.

# Materials and Methods

## Field Site – Centre for Recycled Organics in Agriculture

The field site for this project was established at the Centre for Recycled Organics in Agriculture (CROA), located on NSW Agriculture's Elizabeth Macarthur Agricultural Institute, Menangle NSW, 100 km south west of Sydney (70m AHD; 02883278E, 6224546N). This Centre is a dedicated field research facility that provides a resource for State Government agencies, the recycled organics industry and research/educational institutions to research and promote the sustainable use of recycled organic products and industrial residuals in agricultural production systems. The site is located about 30 km inland from the coast and is subjected to high summer and very low winter, night-time temperatures. Rainfall is spring/summer dominant and averages about 700 mm per year.

This trial was carried out on an area within CROA known as the Flat paddock. This area has previously been used for forage production and while it presents growing conditions of less than optimal soil chemical and physical fertility, it has also shown positive responses to the application of potentially beneficial organic and inorganic soil amendments. At the same time, previous work on this site has shown that the soil ecosystem on the Flat paddock is vulnerable to chemical contamination (Whatmuff et.al. 2005; McLaughlin et.al. 2006; Warne et.al. 2008; Heemsbergen et.al. 2010). Both of these traits are ideally suited to the objectives of this trial.

When the CROA site was first established, intensive soil and contour surveys were carried out to identify the major soil types and their distribution on the site. Following these, a detailed heterogeneity study was carried out to determine the extent of variation in soil characteristics within each soil type. This allowed for the design trial of areas that take into account the statistically verified soil heterogeneity of the site. The heterogeneity evaluation allowed for the Flat paddock to be divided into four replicate blocks, each comprising 588 plots. The general layout of the Flat paddock trial area is given in Plate 1.The resultant plot layout utilises both optimum plot size and orientation, while also minimising sampling requirements. Treatment allocation is discussed in more detail below

## Soils

The Flat paddock occupies approximately 16 ha of the CROA site and has a uniform slope (<2%). The soils at the site are a combination of grey chromosols and brown dermosols (see Plate 2) (Isbell 1996); both of which have similar chemical and physical properties, particularly in the A horizon where most plant root activity occurs. A heterogeneity study carried out prior to site establishment (data not shown), and subsequent chemical analysis of soils sampled from this area, showed little variation in key chemical properties for soils within normal plant rooting depth or A horizon (0-20 cm). Basic chemical, physical and morphological properties of this soil are described in Appendix 1 and photographic representations of the major soil types from this site is given in Plate 2. The soils are physically degraded as a result of excessive cultivation and are sodic in subsoil horizons (40 – 80 cm). The physical degradation has resulted in the loss of the original topsoil horizons and the remaining topsoil is structurally unstable and prone to dispersion and crusting when wetted. This soil responds favourably both physically and chemically to the addition of organic matter. The site has not received widespread applications of persistent herbicides or other organic chemicals.

The soil is moderately acid throughout, pH 5.6 (pH measured in 0.01M $CaCl_2$), in the A horizon to pH 6.4 in the subsoil) and has low levels of fertility and organic carbon (OC 2.1 %). The soil also has low background concentrations of cadmium (Cd; 0.05 – 0.09 mg/kg), copper (Cu 17 - 21 mg/kg) and zinc (Zn 40 – 65 mg/kg). These concentrations are well below the current Resource

Recovery Exemption Order for MWOO maximum allowable contaminant concentrations (MACC's) (NSW EPA 2014) and NSW EPA Biosolids Guidelines (NSW EPA 1997). The soil also has a low capacity to adsorb these metals onto the soil matrix (Whatmuff et.al. 2005).

**Plate 1:** Flat paddock site showing position of MWOO trial replicates.

**Plate 2.** Major soil types found on the CROA Flat paddock. Refer also to Appendix 2.

Grey Chromosol

Brown Dermosol

## Trial establishment and organic amendment treatments used

The current trial uses an area within each of the four replicate blocks as represented in Plate1. There are 37 plots per replicate, giving a total of 148 plots for the whole trial. Each plot is 5 m long by 3 m wide (15 m$^2$). Buffers between plots range from 1 to 5 m and are used to prevent cross contamination, where ploughing is carried out across the wider of the two buffer areas. Treatments within each replicate are arranged in a completely randomised block design.

All plot and buffer areas received an initial cultivation with an offset, 12 tined harrow, set to a depth of 7.5 cm, as part of the pasture/weed removal process. Further vegetation was removed after application of a glyphosate-based herbicide. As discussed below, the active ingredients from this herbicide were not detected in later chemical analysis of treated soils.

Following weed removal, all plots were cultivated separately with a rotary hoe to a depth of 15cm immediately prior to treatment application, taking care to only cultivate within each plot boundary. Appropriate amounts of each treatment material were weighed out and applied to the relevant plots, either by hand or via tractor bucket. Materials were then evenly distributed over the plot surface. Where the material was to be incorporated below the soil surface, these plots received a separate additional cultivation using a rotary cultivator to a depth of 15 cm, again taking care to only cultivate within the appropriate plot boundary. The use of the rotary hoe allowed for homogenisation of the applied treatments within the cultivation depth. This was especially important given some of the high application rates employed (see below). Such cultivation equipment is not usually employed in broad acre agriculture because of their high draught energy requirements as well as the damage they cause to soil structure, but their use in intensive horticulture is common.

Surface treatment plots did not receive a second cultivation with the rotary hoe as these treatments were designed to tests the soil response where amendments were left on the soil surface.

The treatments used and application rates are summarised in Table 1. This trial uses 2 contrasting MWOO materials (MWOO 1 and MWOO 2). The MWOO materials were sourced from the two major manufacturers of these materials within the Sydney Basin and their use is intended to provide data relevant to the range of materials that are available in NSW. The MWOO treatments are compared with a range of other readily available organic amendment materials resulting from potentially similar production conditions (i.e. composting), but from potentially different feedstock sources; a composted green waste and a composted biosolids treatment, as well as a poultry manure. The amendments are also compared to separate surface and incorporated, nil and fertilizer controls; where the fertilizer applications are equivalent to industry recommendations for the plant nutrient requirements for each test crop. Appendix 2 gives a schematic representation of the treatment allocation used for each replicate.

**Table 1:** Summary of treatments used in field trial including separate manure treatments

| | | reps | | rates | Rates of application (dry t/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Incorporated treatments** | MWOO1 | 4 | as is | 5 | 10 | 20 | | | 60 | 100 | 200 |
| | MWOO2 | 4 | as is | 5 | 10 | 20 | | | 60 | 100 | 200 |
| | Green waste | 4 | as is | 5 | 10 | 20 | | | 60 | 100 | 200 |
| | Manure | 4 | as is | 4 | 10 | 20 | | | 60 | 100 | |
| | Composted biosolids | 4 | as is | 2 | 10 | | | | 60 | | |
| | Control (cultivated) | 4 | as is | 1 | | | | | | | |
| | Control fertiliser | 4 | NPK[*] | 1 | | | | | | | |
| **Surface treatments** | MWOO1 | 4 | as is | 4 | 10 | 20 | 30 | 50 | | | |
| | MWOO2 | 4 | as is | 4 | 10 | 20 | 30 | 50 | | | |
| | Green waste | 4 | as is | 4 | 10 | 20 | 30 | 50 | | | |
| | Control (un cultivated) | 4 | as is | 1 | | | | | | | |
| | Control fertiliser | 4 | NPK[*] | 1 | | | | | | | |

[*] N = nitrogen, P = phosphorus, K = potassium

The primary experimental treatments for this trial centre on assessing plant growth and soil health for a series of rate responses using increasing rates of two MWOO materials incorporated into the soil (see Table 1). These rates ranged from 10 t/ha (current industry practice), followed by rates designed to give an agronomic response (20 - 50 t/ha), through to rates used in mine site rehabilitation and beyond (100 and 200 t/ha), (NSW EPA 2014a).

The surface application rates are also designed to encompass current industry practice, where MWOO is applied to the soil surface and not incorporated, at rates up to 10 t/ha. This was followed by rates designed to give an agronomic response (20 - 30 t/ha) and beyond (50 t/ha). Surface application treatments are not designed to mirror those for incorporation of MWOO, as the latter allows much higher rates of application. It was thought that the 30 t/ha surface application treatment would be equivalent to the 60 t/ha incorporation treatment, allowing for mixing during initial cultivation.

As with the MWOO treatments, the application rates for the comparison organic amendments, were designed to firstly reflect current grower practice and then as rates equivalent to the MWOO treatments. Exceptions to this were for biosolids, which were only included as incorporated treatments because current legislation does not permit surface applications of biosolids without incorporation, and for the manure treatments, where the maximum application rate was limited to 100 t /ha, because of the potentially high nutrient content of poultry manure, compared to all other amendment materials being tested. Plate 3 indicates the relative size of each experimental block (replicate) and how these are arranged in comparison to buffers and other plots.

**Plate 3** Typical arrangement of treatment plots showing ‘checkerboard’ of applied treatments and buffers, post treatment application (Block 4). Orange line marked on picture indicates block boundary.

Plates 4a and 4b compare surface applications of MWOO 1 and composted green waste. These clearly illustrate the visual differences between these two amendment materials and the substantial amount of materials that need to be added to achieve the 50 t/ha surface application treatments. Plate 5 shows a high rate incorporation treatment of MWOO 1 (200 t/ha). Similarly, high applications of incorporated treatments clearly revealed the presence of the amendment materials on the soil surface, compared to the surrounding, unamended soils. Once treatments had been applied, both glass and plastic contaminants were clearly visible on MWOO treatment plot surfaces (Plate 6).

**Plate 4:** Comparison of **surface applications** (50 t/ha) of (a) MWOO2 and (b) composted green waste

**Plate 5:** High rate (200 t/ha) incorporation treatment of MWOO1

**Plate 6:** Glass and plastic contaminants visible on soil surface of MWOO treatment plots

## Field crop establishment

### Calendar of field trial activities

A summary time line of major field trial activities is given in Table 2 below. Briefly, the first sampling event (soil) was commenced immediately after amendment application and is designated time T0 (April). An initial rainfall simulation experiment was also carried out at this time. The first successful crop (millet) was harvested in March of the following year and is designated time T1 (soil and crop). The next crop (wheat 1) was established in June of the same year and harvested in December (T2 soil and crop). The final crop (wheat 2) was established in May and harvested in November and is designated time T3 (T3 soil and plant).

### Millet

Persistent rain prevented the establishment of the proposed wheat crop for the winter season. Instead we established a summer forage/grain crop (millet) in November of the same year. Millet is used as a fast growing forage crop for animal production and the seed can also be harvested for use by domestic birds.

To establish the millet crop, the experimental site, including buffers and treated plots, was lightly cultivated with a tined harrow, to remove weeds and prepare the seed bed. Fertiliser (fertiliser control) was then broadcast prior to sowing. As per recommended agronomic practice, the millet (Japanese Millet [Shirohie Millet], *Echinochloa utilis*) was sown using a 10-row, Duncan renovator till seeder (combine), dragging a lightweight scarifier to further refine the seedbed. The millet was sown at a rate of 17 kg/ha in rows 15 cm apart, with seed placed into the soil at a depth of 5 cm.

After emergence, in the absence of adequate rainfall, the soil moisture was optimised using supplemental irrigation. This additional moisture was applied using an automated system of micro sprinklers that had been appropriately spaced to deliver water evenly over each plot. This system was programmed to deliver 4.5 mm of water per plot per hour. When in operation, each plot received a maximum 5 mm, every 2 days.

### Wheat

In preparation for sowing of two wheat crops, the experimental site, including buffers and treated plots, was lightly cultivated with a tined harrow, to remove weeds and prepare the seed bed. Fertiliser (fertiliser control) was broadcast prior to sowing. Subsequently, wheat (*Triticum aestivum* cv Livingston) was sown across all plots and buffer areas using a 10-row, Duncan renovator till seeder (combine), dragging a lightweight scarifier to further refine the seedbed. This variety was chosen for its tolerance of acidic soil conditions and relevance to eastern NSW wheat growing areas. Crop rows were spaced 15 cm apart and seed was placed at a depth of 4 cm. The sowing rate was 50 kg/ha, allowing for 70% germination. After emergence and in the absence of adequate rainfall, the soil moisture was optimised using supplemental irrigation. This additional moisture was applied using an automated system of micro sprinklers that had been appropriately spaced to deliver water evenly over each plot. This system was programmed to deliver 4.5 mm of water per plot per hour. When in operation, each plot received a maximum 5 mm, every 2 days. The eventual use of the supplementary irrigation occurred for between two and three months per wheat cropping season. (see Table 2)

**Table 2:** Summary time line of major field trial activities

| year | month | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013** | | | | | | | | | | | millet | millet | millet |
| | setup | | | | add materials | | | | | | | | irrigate |
| | plant | | weed removal | cultivation | | | wht abandoned | | weed removal | cultivation | Alt crop millet sown | | |
| | soil | | | | **T0** | | | | | | | | |
| | other | | | | | rain. simulation | | | | | | | |
| **2014** | | millet | millet | millet | | | wht 1 | wht 1 | wht 1 | wht 1 | wht 1 | wht 1 | wht 1 |
| | setup | irrigate | irrigate | | | | | | | irrigate | irrigate | irrigate | |
| | plant | 12 wk millet | | millet harvest | weed | cultivate | wht 1 sown | | | | | | harvest wht1 |
| | soil | | | **T1** | | | | | | | | | **T2** |
| | other | | | | rain. simulation | | | | | | | | |
| **2115** | | | | | | wht 2 | wht 2 | wht 2 | wht 2 | wht 2 | wht 2 | wht 2 | |
| | setup | | | weed | cultivate | | | | | irrigate | irrigate | | |
| | plant | | | | | wht 2 sown | | | | | | harvest wht 2 | |
| | soil | | | | | | | | | | | **T3** | |
| | other | | | | | | | | | | | | |

### Fertiliser

The plant growth response to the added amendments was compared to current agronomic practice i.e. the use of inorganic fertiliser as per crop recommendations. Therefore we used a control fertiliser treatment (CF) for both incorporated and surface applications. Each of these received applications of N, P, K and sulphur (S), as an inorganic fertiliser (see below).

Both crop types used the same fertiliser applications. Three fertilisers were used (Pivot 200, diammonium phosphate [DAP], and two subsequent topdressings of urea), giving a total N application of 143 kg/ha, 30 kg/ha total P, 31 kg/ha total K, and 24 kg/ha S.

## Sampling and analysis

All analyses were carried out at ISO 9001 and NATA accredited laboratories. A summary of the analytical tests carried out on samples collected during the trial is given in Table 3.

### Amendment materials – inorganic analyses

Preparation, extraction and analyses of these materials were carried out at the ISO17025 (NATA) accredited DPI laboratories at Wollongbar, using standard methods. The pH, electrical conductivity (EC), ammonia-N ($HN_4$) and nitrate-N ($NO_3$), nitrite-N ($NO_2$) and chloride (Cl) contents of these materials were determined on wet samples, while the remainder of the inorganic analyses were determined on oven dried samples. These samples were dried under forced draft (40°C) and finely ground to pass <0.5 mm sieve. All samples were analysed for total aluminium (Al), arsenic (As), Cd, chromium (Cr), Cu, cobalt (Co), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), Zn, calcium (Ca), magnesium (Mg), K, sodium (Na), and P by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) following extraction with microwave assisted digestion in reverse *aqua regia*. Total N and carbon (C) were determined by Dumas combustion and the forms of mineral N ($NH_4$, $NO_3$ and $NO_2$) were determined by flow injection analysis after extraction using potassium chloride ($KCl_{40}$ Blair et.al 1991). The same method was used to extract labile sulphur (S) which was then analysed by ICP-AES. Total phosphorus was analysed by flow injection (FIA) following semi-micro Kjeldahl digestion. Labile C was extracted using $KMnO_4$ (potassium permanganate), while fertiliser P value was determined using extracts including water and citrate (citrate soluble P data is presented). Subsamples of these materials were also collected at the time of application and frozen / freeze dried, and a portion submitted for the analysis of a range organic chemicals.

### Amendment materials – organic analyses

At the time of collection, all samples were freeze dried and homogenised. Subsequently, composited samples of MWOO 1 and 2, green waste, composted biosolids and poultry manure were submitted for the analysis of additional organic pollutants by gas chromatograph - mass spectroscopy (GC-MS), following extraction using the Accelerated Solvent Extraction (ASE) technique. Separate sub-samples were extracted with acetonitrile, dichloromethane and hexane. The first two extracts were used in the multi-analyte screen; the hexane extract was used in the analysis of a range of organotin compounds. MWOO products were screened for 567 pesticides and endocrine disrupting chemicals, using Agilent's Retention Time Locked database, coupled with the NIST AMDIS (Automated Mass Spectral Deconvolution and Identification System), NIST[1].

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[1] U.S. Department of Commerce Technology Administration National Institute of Standards and Technology (NIST). Standard Reference Data Program, Gaithersburg, MD 20899

Results were confirmed by back checking with the NIST 11 mass spectral database. Samples were extracted using a Dionex ASE 200 accelerated solvent extractor (Dionex Corporation, 228 Titan Way, Sunnyvale, California 94088-3603 U.S.A.).

Eight g of original amendment material was extracted in 11mL cells, whilst 30g of the soil samples were extracted in 33mL cells. Solvents used were hexane for the organotin compounds, and acetonitrile for the pesticides, plasticisers and personal care products.

Extraction conditions were; temperature, 100°C at 1,500psi with a 5 minute heating cycle, and 5 minutes static time. 30 and 40mL of extractant were used on the 11 and 33mL extraction vessels respectively. For organotin analyses, organic amendment samples were exhaustively extracted by ASE using hexane as detailed above. Sub-samples were dried and derivatised with Grignard reagent (methylmagnesium bromide, Cat #282235-100, Sigma Aldrich, Australia) to yield methyl derivatives. These were crosschecked with mass spectral libraries provided by Dr Frank David, Research Institute for Chromatography, Kortrijk, Belgium and Dr Phil Wylie, Agilent technologies, Wilmington, Delaware, USA.

Sixteen organotin compounds were screened for (e.g. Triethyltin, Tetraethyltin, Tripropyltin, Tetrapropyltin, Monobutyltin, Dibutyltin, Tributyltin, Tetrabutyltin, Monophenyltin, Diphenyltin, Triphenyltin, Tetraphenyltin, Tricyclohexyltin, Monooctyltin (MOT) and Dioctyltin (DOT), butone of the samples were positive for the compounds screened.

Gas chromatographic analyses were carried out on an Agilent 7890A, with 7693 autosampler, coupled to a 5975C mass selective detector. Briefly, 2µL of sample was injected in splitless mode at 250°C at a pressure of 6.8psi under constant pressure mode. An HP5-MS column of 30m x 250µm x 0.25µm was held at 50°C for 1 min, the temperature then ramped to 300°C at 10°C/min, where the temperature was held for a further 10min. The transfer line to the MSD was held at 300°C. A solvent delay of 3min was used, after which the instrument was run in selected ion mode, with the 29 monitored ions being monitored across the run, at a dwell o.d. 50ms.

For pesticides and endocrine disrupting chemicals, soils were extracted by ASE as detailed above. Sub-samples were analysed directly by GC-MS, as detailed below. Briefly, 1µL of sample was injected in splitless mode at 250ºC at a pressure of 17psi under constant pressure mode. An HP5-MS column of 30m x 250µm x 0.25µm was held at 70ºC for 2 min, then ramped to 150ºC at 25ºC/min, then 3ºC to 200ºC and finally 8ºC/min to 280ºC, where the temperature was held for a further 10min. The transfer line to the MSD was held at 280ºC. A solvent delay of 3min was used, after which the instrument was run in scan mode, from 35 to 600 m/z. The method was retention time locked to chlorpyrifos methyl, which was used as an internal standard in all samples. Total ion chromatograms were analysed by the AMDIS package, using “simple analysis” mode, one adjacent peak subtraction and a component width of 12. Resolution, sensitivity and peak shape were all set to medium, and the Agilent RTLPest2 library was used, with cross referencing to the NIST11 library for confirmations. External standards were used to confirm and quantify selected positive identifications.

## Plants

Early plant growth can be sensitive to excessive soil levels of plant nutrients as well as contaminants. For millet, the effects of the addition of the MWOO and other compost materials on plant growth were assessed twice during the growing season. This is because millet is grown for both grain and as a forage species. Early emergence plant growth was assessed by measuring crop height and above ground biomass in plants grown on each of the treated plots, 12 weeks after crop emergence. The 12 week sampling was used to assess early plant growth and how this may be related to the applied treatments. No measure of vegetative growth was made for either of the wheat test crops.

For both millet and wheat, the amount of grain production was measured at harvest and sub-samples of the grain were then analysed for metal contaminant and nutrient ion contents, as well as a range of feed quality parameters. Plant and grain sampling consisted of removing at least 2 x 1 m strips from each plot leaving at least two outer rows as a buffer. These two samples were combined for analysis.

Plant tissue samples were washed in deionised water and dried under forced draft at 70° C. Forage yield was calculated on both a fresh and dry weight basis. Plants were then ground to < 2 mm and stored prior to analysis. The grain was separated by hand from the seed head, dried as above, weighed, and grain yield calculated (t/ha). Unlike plant tissue samples, grain samples were dried under forced draft at 80° C. Following microwave assisted, hot acid digestion, all plant samples were analysed for total Al, As, Cd, Co, Cr, Cu, Fe, Mn, molybdenum Mo, Ni, Pb, Se, Zn, Ca, Mg, K, Na, and P by either an inductively coupled atomic emission spectrometer (ICPAES) or an inductively coupled mass spectrometer (ICPMS). Total N was also measured following Dumas combustion (LECO). Metal and plant nutrient concentrations were determined following microwave assisted, hot acid digestion of grain samples.

Grain and stock feed quality parameters including neutral digestible fibre (NDF), acid digestible fibre (ADF), crude protein (CP), ash content (ash), organic matter (OM), dry matter digestibility (DMD), dry organic matter digestibility (DOMD, were determined using Near Infrared Reflectance Spectroscopy (NIR). Metabolisable energy (ME) was calculated from the digestibility of the organic matter as a percentage of dry matter (DM).

## Soils – surface composite sampling and analyses

Surface composite samples (0-7.5 cm), were taken from each plot at the time of amendment application (T0) and from under each subsequent crop at harvest (Millet T1; first wheat crop T2; and second wheat crop T3). These consisted of 40, 1.5cm diameter cores per plot (0-7.5 cm).

These samples were split according to the specific analysis required. Subsamples designated for analysis of organic compounds as well as assessment of soil microbial function were immediately frozen ‘as is’. A portion of these were subsequently freeze-dried to preserve the nature of any volatile organic compounds that may be present. Both the frozen and freeze-dried samples were stored appropriately prior to submission for analysis or microbial testing.

Sub-samples designated for analyses of inorganic elements were dried under forced draft (40°C) and ground to pass <2 mm sieve. All samples were analysed for total Al, As, Cd, Cr, Cu, Co, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn, Ca, Mg, K, Na, and P by ICPAES following extraction with reverse *aqua regia* using microwave digestion. Low level elements were determined using ICP-MS. Soil pH was measured in 0.01M $CaCl_2$ ($pH_C$) and $pH_w$ and EC determined in a 1:5 soil water extract after Rayment and Higginson (1992). Only $pH_C$ values for soil pH will be given in this report, unless otherwise specified. Total N and C were determined on the dried soil samples following Dumas combustion and the forms of mineral N determined by flow injection analysis after extraction using potassium chloride ($KCl_{40}$). The same method was used to extract labile sulphur which was then analysed by ICP-AES. Available P in these soils was extracted following either/or the Bicarbonate (Colwell P) or Bray P methods; each method being specified where available P data is presented. Each is specified Total soil phosphorus was analysed by flow injection (FIA) following semi-micro Kjeldahl digestion. Determination of exchangeable cations in these soils was made using the barium chloride extraction method of Gilman and Sumpter (1986), followed by analyses using ICP AES. These values were used to calculate the percentage of exchangeable sodium (ESP %).

**Table 3** Summary of chemical tests carried out on soil and plant samples

| | | | | **Treatment** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Time** | **Type** | **Analysis** | **Notes** | **inc C** | **inc C fert** | **inc MWOO 1** | **inc MWOO 2** | **inc GW** | **inc Bio** | **inc Man** | **surf C 0** | **surf C fert** | **surf MWOO 1** | **surf MWOO 2** | **surf GW** |
| **0** | **Soil** | *Total inorganic* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Total Organic* | *Hi only for MWOO 2* | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | | *1:5 water extract* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *1:5 $CaCl_2$ extract* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Mineral N* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Nutrients* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Worm av.* | *All trts* | ✓ | | ✓ | ✓ | | | | | | | | |
| | | *Micro resp* | *All trts* | ✓ | | ✓ | ✓ | | | | | | | | |
| | | *SIR* | *Hi rates for surface trts* | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ |
| | | *SIN* | *Hi rates for surface trts* | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | | *Simulation* | *Hi only for MWOO 2* | ✓ | | ✓ | ✓ | | | | | ✓ | ✓ | | |
| **0.5** | **Millet** | *veg yld* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Total inorganic* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | *Feed quality* | *All trts* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **1** | **Soil** | Total inorganic | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Total Organic | Hi only for MWOO 2 | ✓ | | ✓ | ✓ | | | | | | ✓ | | |
| | | 1:5 water extract | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | 1:5 $CaCl_2$ extract | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Mineral N | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Nutrients | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Worm av. | All trts | | | | | | | | | | | | |
| | | Micro resp | All trts | ✓ | | ✓ | ✓ | | | | | | | | |
| | | SIR | Hi only for surface trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ |
| | | SIN | Hi only for surface trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | **Mill grn** | grn yld | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Total inorganic | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Feed quality | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **1.2** | | Simulation | Hi rates only | ✓ | | | ✓ | | | | | | ✓ | ✓ | |
| **2** | **Soil** | Total inorganic | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| | | Total Organic | Hi only for MWOO 2 | ✓ | | ✓ | ✓ | | | | | | ✓ | | |
| | | 1:5 water extract | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| | | 1:5 $CaCl_2$ extract | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| | | Mineral N | All trts | | | | | | | | | | | | |
| | | Nutrients | Exch cations only | ✓ | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| | | Worm av. | All trts | ✓ | | ✓ | | | | | | | | | |
| | | Micro resp | All trts | ✓ | | ✓ | ✓ | | | | | | | | |
| | | SIR | All trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ |
| | | SIN | All trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | **Wht grn** | grn yld | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Total inorganic | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | |
| | | Feed quality | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | |
| **3** | **Soil** | Total inorganic | Hi only for MWOO 2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | | Total Organic | Hi only for MWOO 2 | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | | 1:5 water extract | All inc trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | 1:5 $CaCl_2$ extract | All inc trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | Mineral N | All inc trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | Nutrients | No Kjeldahl S or P | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | Worm av. | All inc trts | | | | | | | | | | | | |
| | | Micro resp | All trts | ✓ | | ✓ | ✓ | | | | | | | | |
| | | SIR | All trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ |
| | | SIN | All trts | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |
| | | PNR | All trts | | | | | | | | | | ✓ | ✓ | |
| | **Wht grn** | grn yld | All trts | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Total inorganic | All trts | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | |
| | | Feed quality | All trts | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | |

Grn = grain; Total inorganic = Heavy metal and nutrient ions; Total organics = Benzophenone, DEHP, BPA, DBP and DEET, 1:5 soil water extract = $pH_W$ and EC, heavy metal and nutrient ions, 1:5 $CaCl_2$ extract = $pH_C$, heavy metal and nutrient ions; Mineral N = $NO_3$, $NH_4$ & $NO_2$; Nutrients = Kjeldahl S, Colwell P, Total N, TC, TOC, Kjeldahl P, Exchange Cations and CEC; Worm av. = worm avoidance; Micro Resp. = MicroResp evaluation; SIR = substrate induced respiration; SIN = substrate induced nitrification; PNR = potential nitrification rate; Simulation = rainfall simulation; veg yld = plant yield (12 week); grn yld = grain yield; Feed quality = NDF, ADF, CP, Ash, OM, DMD, DOMD and ME

Analysis of soil samples for organic chemicals was carried out as described above for the analyses of organic amendments.

An estimate of inorganic contaminant solubility was made on treated plots by measuring the metal content in solutions extracted from the soils using the same 1:5 soil water extract method as used to determine EC and $pH_w$ described above, although the EC and $pH_w$ were determined on separate extracts. This batch extraction technique involved end-over-end shaking (33 rpm) of 5g of soil with 25 ml of Milli-q deionised water for one hour. After one hour the soil/extracts were centrifuged at 1200g for 20 minutes and the supernatant filtered to <0.45 µm. Solutions were acidified with two drops of concentrated nitric acid and then stored at $4^{o}$C until analysis.

An estimate of the amounts of bioavailable soil metals was made on all treated plots by measuring the metal content in solutions extracted from the soils using 0.01M $CaCl_2$ (Houba et.al. 2000). This batch extraction technique involved end-over-end shaking (33 rpm) of 5g of soil with 25 ml of 0.01M $CaCl_2$ for four hours. After four hours, the soil/extracts were centrifuged at 1200g for 20 minutes and the supernatant filtered to <0.45 µm. The $_{pH}$ of the extracts was then determined and the solutions acidified with two drops of concentrated nitric acid. Samples were then stored at 4ºC until analysis.

## Soil profile sampling and analyses

Soil profile samples were collected from all of the incorporated MWOO 1 treatments (0, 60 and 100 t/ha) at time T3. These were taken to a depth of 90 cm. Five soil profile core samples were taken from each plot and divided into 7 depth increments; 0-7.5, 7.5-15, 15-30, 30-45, 45-60, 60-75, 75-90 cm. Each of the depth increments was compositing to form a single sample per depth increment. All soil samples were processed as per surface composites described above.

Samples collected from each of the depth increments for the 0 (control), 60 and 100 t/ha treatments were analysed for total metals following extraction with reverse *aqua regia* using microwave digestion as described above, including analyses by ICPMS for low-level Cd. Total N was determined following dumas combustion.

## Rainfall simulations

Simulations were undertaken using a professionally manufactured drip-simulator apparatus as pictured in Plate 7, and is based on the unit described by Bowyer-Bower and Burt (1989), who propose such a unit as a pragmatic means of comparing runoff generated from different soil treatments. As such, the simulator used in our experiments was done so with a view to providing relative comparisons of runoff concentrations between MWOO treatments and is not intended to reflect real landscape scale mobilisation processes.

This apparatus was designed to apply 'rainfall' as consistent-sized drips onto the soil surface from a height of approximately 1.5 m and at a rate of 40mm/hr. The rainfall events that were generated, have a ~1 in 10 year recurrence interval and is considered as a standard recurrence interval for simulation experiments. The slope of each rainfall plot was adjusted to fall between 3-5% and the aim was to collect a minimum of 2 l of runoff solution over a 2 hour period. The area impacted by the rain simulator was 0.5 $m^2$ (500mm x 1000mm). The simulations were carried out on 3 of the 4 field replicates only as the plots on block 1, (see Plate 1) were too flat to enable the generation of runoff.

The simulators were set up over the top of the plots as seen in Plate 7. Water for each simulator was provided by a feed tank designed to provide a consistent 20cm head. Once water had ponded on the plot surface (Plate 8), runoff flowed to the end of the collection area via a trough inserted into the plot. This was then funnelled into a collection vessel. Once the simulation run had been completed (2 hours), the total runoff was estimated by weighing the solution collected, and subsamples collected in polypropylene containers for later analyses of chemical elements. All samples collected were frozen prior to analyses. All components of the simulators and collection apparatus were thoroughly rinsed between simulation runs. Domestic potable drinking water was used for all rainfall simulation runs and samples of the water used for the simulations were routinely sampled and preserved for later analyses as a blank control.

Run off samples were analysed for total Al, As, Cd, Cr, Cu, Co, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn, Ca, Mg, K, Na, S and P by ICP AES following microwave-assisted extraction with reverse *aqua regia*.

Total N and C were determined on the run off solutions using FIA following persulphate digestion. Concentration of free reactive P, $NO_3$, $NH_4$ and oxidised N were also determined by FIA. Total C and total organic carbon (TOC) in the run off solutions were determined by measured the evolution of $CO_2$ following C oxidation using a TOC analyser. Concentrations of $Cl^-$ in the solutions were measured by ion chromatography.

**Plates 7 and 8**: Rainfall simulation apparatus (left) and ponding (right) of water on plot surface indicating start of runoff collection

## Soil physical properties

Soil water holding capacity (expressed here as plant available water) and bulk density, were measured on plots where amendments were incorporated into the soil, rather than via surface application. As discussed previously, these treatments had been applied to the test soils and mixed with the soil using a rotary hoe; often at rates where amendment materials were still visible, post-application. While this method of application was necessary to provide adequate mixing of the treatments and the receiving soils, it also completely altered the structure of these soils. However, as we are aiming to show treatment effects relative to each other and control soils, these tests were carried out in order to give an indication as to whether the amendments used had the potential to improve the physical characteristics of the otherwise physically degraded test soil.

Therefore, the determination of plant available soil water was carried out using ground (<2mm) samples, rather than on intact soil cores, for samples collected at T0 and T2. Soil moisture contents at a water tension of -10kPa (field capacity) and a water tension of 1.5 MPa (permanent wilting capacity) were determined on these soil samples using the pressure plate technique and plant-available soil water calculated as the difference between these two measurements (McIntyre 1974).

Bulk density (BD) was determined on undisturbed soil cores (7.5 cm diameter) at time T3. These were collected from the 0-7.5 cm depth fraction from each of the treated plots. Five replicate cores were taken from each plot. The soil was weighed in field condition, and then dried to constant weight at 105ºC, and then re-weighed. The volume of each core was determined and BD of the soil in each core was calculated as the total mass of oven dried soil divided by the core volume, namely;

$$\text{bulk density (BD)} = \frac{\text{soil dry weight (g)}}{\text{core volume (cm}^3\text{)}}$$

Porosity was calculated using the above data and using a value of 2.65 g/cm$^3$ for particle density.

## Soil biota and soil microbial testing

### Worm avoidance

We used a standardized earthworm avoidance test (ISO 17512-1 2008) to provide information on whether the composted MWOO applications has an effect on the habitat of soil animals. This test allows for the rapid determination of changes to the soil habitat and a high degree of sensitivity to applied chemicals (Hund-Rinke and Wiechering 2001). The basic premise behind the avoidance test, is that worms will avoid unfavourable (or less favourable conditions), when given a choice of habitat. The test species used was Eisenia fetida (*E. fetida*), also known as ‘tiger’ or compost worms. The only difference between the test protocol and the method we used is that, rather than using an artificial soil as specified, we opted for the field soils collected from both the experimental site and elsewhere. Control soils from the study site have been shown previously to be more appropriate than the standard soil mixture for these purposes (Van Zwieten et.al. 2004).

Three separate tests were carried out for the worm avoidance evaluation. The first experiment was carried out using a soil known to be favourable for worm habitation, to which either fresh MWOO, and material that had been stored frozen, were applied. By using this soil, we ensured that any effects seen were from the MWOO only, as the soil itself did not limit worm behaviour. The second experiment used fresh MWOO applications that were applied to soils collected from the experimental site, and the third experiment was carried out on soils collected from the experimental plots that had been amended two years previously, with increasing rates of MWOO 1. The treatments for the first two tests were prepared by adding appropriate amounts of MWOO 1 or 2 to the test soils at rates equivalent to those used in the field trial. In preparing the treatments, we assumed that 1 ha of land is equivalent to 1000 t of soil (7.5 cm thick with a bulk density of 1.33 g/cm$^2$).

Each test was replicated 5 times. Subsequently, soils were equilibrated with the applied treatments for 1 week prior to adding the worms. For this step, soil moisture was maintained at 90% maximum water holding capacity, which was previously shown to be preferred by worm populations (data not shown). The test boxes consisted of two chambers (Plate 9a), with the test material and the control soil separated by a divider, prior to addition of the worms. Once the divider was removed, ten mature worms were placed on the soil surface (Plate 9b) in the centre of each container which was lidded once the worms were observed to enter the soil (Plate 9c). The tests were housed in constant temperature room (20 ± 2 °C) which was uniformly lighted (800 lx) at a controlled light/dark cycle of between and 16 h/8 h (Plate 9d). This ensured that worms remain in the test medium throughout the test).

After 48 h exposure to the test treatments, the barrier was replaced into the container midline, and worms were counted in both the control and test soils, and percentage avoidance calculated (Plate 9e). Any occurrence of midline worms were split 50:50 between the control and test soil. The avoidance tests were carried out after the completion of suitable range finding tests as recommended in the ISO standard. These are used to determine if the worm will actually survive the experimental treatments. Mortality of more than 10% of the worms in the avoidance test invalidates the test for that treatment. An acute mortality test carried out on pure MWOO, showed no mortality when worms were exposed to 100% MWOO for up to 72 hours (data not shown). In addition, all test batches included a reference toxicant treatments (boric acid $H_3BO_3$) applied at a rate of 750 mg $H_3BO_3$ /kg soil. Boric acid has been used historically as a soil chemo sterilant and is an effective non-selective biocide. For the test to be validated, all worms should avoid the reference toxicant (boric acid) treatment.

**Plate 9 (a)** Two sided test box showing divider separating control (R) and test soil (L), **(b)** worms placed on mid line and **(c)**, perforated lid replaced. **(d)** test boxes arranged in cool room and **(e)** after 48 h soils separated and worms on each side counted

Plate 9(a)

Plate 9(b)

Plate 9(c)

Plate 9(d)

Plate 9 (e)

## Soil microbial testing

### *Substrate Induced Nitrification and Potential Nitrification Rate*

Substrate Induced Nitrification (SIN) was chosen as a relevant microbial indicator in these experiments, as the conversion of ammonium ($NH_4$) to nitrate ($NO_3$) in soil, also known as nitrification, is a key part of the soil N cycle, and the process is known to be a sensitive indicator of any adverse effects of pollution (Premi and Cornfield 1969). This test is designed to detect long-term adverse effects of a substance on the process of nitrification and is recognised as a standard ecotoxicity test method (OECD 2000), where a source of $NH_4$ is added to the test soils, and the formation $NO_3$ after 28 days incubation is then measured.

Briefly, three air dry soil samples (7g each) are wetted to 50% maximum water holding capacity (MWHC) and then incubated in darkness for 14 days at 20 ºC. Subsequently, 0.5 ml of 0.044 M $(NH_4)_2SO_4$ was added to two of the samples (duplicate) which were then incubated for another 28 d. The third sample was used to estimate the initial $NO_3$, $NH_4$ and $NO_2$ prior to the addition of the $NH_4$ substrate. The various forms of mineral N present were extracted with 1M KCl and measured by flow injection analysis ($KCl_{40}$, Blair et.al.1991). At the end of the 28 day incubation with the added $NH_4$, the samples were also analysed for the forms of mineral N after extraction with 1M KCl. The SIN was calculated as the amount of $NH_4$ substrate utilized (converted to $NO_3$) and is expressed as a percentage of the initial amount added. Analyses of these data were used to indicate if the MWOO treatments had interfered with the soil microbial nitrification processes.

However, there is a limitation with the SIN test in that it can only quantify a maximum of 100% substrate ($NH_4$) conversion to $NO_3$. This does not account for any more subtle differences that may exist between treatments, such as rate of conversion or the time taken to utilize all of the substrate. Thus, for the T3 sampling, we extended the SIN testing procedure to include the determination of the Potential Nitrification Rate (PNR), as described by Smolders et.al. (2001). This test is an extension of the SIN test described above, except that the forms of mineral N are measured instead at two incubation times after the addition of the $NH_4$ substrate; 7 and 28 days, rather than just 28 days. The initial mineral N analysis remains the same. The PNR is calculated as the slope of the $NO_3^-$ conversion relationship between the two sampling times.

### Substrate Induced Respiration

Soil microbial respiration is estimated by measuring the amount of carbon dioxide ($CO_2$) released from the soil following the decomposition of organic matter by soil microbes. It is an important indicator of soil health because it designates the level of microbial activity. Substrate-induced respiration (SIR) is the measurement of soil respiration in the presence of an added glucose substrate and is used as a quick estimate of the soil microbial response of an added substance (e.g. soil amendment). We used the SIR method to assess any effects of the MWOO on soil microbial processes, as it provides a measure of the broad respiratory functioning of soil biota, and is also a standardised soil ecotoxicity test. SIR was measured using the method outlined in OECD (2000). Briefly, after a pre-incubation of 14 days at 20 ºC in darkness at 50% MWHC, duplicate samples (10 g) of air dry soil were amended with 0.6 mL glucose solution (1.4 M), that delivered 6,000 µg C per gram soil. The soil samples were immediately transferred to sealed containers that included a $CO_2$ trap (vial with 3 ml 1M NaOH; Zibilske 1994). Each sample was incubated in darkness at 20ºC for 18 hours, after which time the $CO_2$ traps were removed and sealed. From each of these, 1 ml of the NaOH was removed and the $OH^-$ concentration determined after titration to pH 3.7 using a standardised HCl solution. SIR is expressed as the rate $CO_2$-C production per unit dry soil over that time period ($CO_2$-C µg C / g soil / hr).

### MicroResp$^{TM}$

As stated above, soil microbial respiration is used as an indicator of soil health. The MicroResp™ procedure is a microplate-based system which allows for the much more rapid (6 hr) estimation of basal soil, or substrate-induced, soil microbial respiration, and can also test the efficacy of a range of carbon sources (Campbell et.al. 2003). It has often been used as a form of soil microbial community profiling the *in situ* response to environmental events or stressors such as pollution events (e.g. Cordovil et.al. 2011; Tlili et.al. 2011). This method is intended to supplement the standard substrate-induced respiration test described above.

With the MicroResp™ technique, the $CO_2$ concentration in each test soil was calculated from the absorbance measured from the colour change in a pH sensitive indicator in each test well (cresol red, buffered in bicarbonate solution). The colour in the indicator well changes (red → yellow) when the pH decreases with absorbance of any $CO_2$ that has evolved from the test soil, either as basal respiration, or in response to an added substrate or C source. The system consists of a 96-deep well microplate plate that holds the test soil samples, a 96-well detection plate which contains the pH sensitive indicator, a seal and a metal clamp to hold the three parts firmly together. We used the generalised method of Campbell et.al. (2003), taking into account variation within and between detection plates. We also included some of the modifications suggested by Wakelin et.al. (2013) namely; the optimisation of soil moisture content (70 - 80%, data not shown), and provision of adequate replication to reduce detection variability (coefficient of variation [CoV] of < 10%, 8 reps, data not shown). Water was used as an estimation of basal respiration and the sugars used were;

- Alanine
- Arabinose,
- Citric acid,
- Fructose
- Galactose
- Glucose
- Malic acid
- Oxalic acid and
- Trehalose

These C sources were intended to represent the range of C sources that could be found under normal rhizoshphere conditions (e.g. carbohydrates, carboxylic acids and amino acids) and have been used previously in a identifying the effect of various soil chemical parameters on soil microbial community profiling (Campbell et.al. 1997; Chapman et.al. 2007 )

## Statistical methods

The trial uses a randomised complete block design with four replicates. The layout of each of the trial replicates, including the randomized allocation of treatments, is given in Appendix 2. As discussed above, this design included differing rates of five incorporated amendment materials; two MWOO products, a biosolids compost, a composted green waste, and a poultry manure, and 3 surface applied treatments; the same two MWOO products and the same composted green waste. The design allowed us to examine the effects of amendment application on soil chemistry, soil health and plant production over time using repeated measures analysis of variance (ANOVA), carried out using Genstat 18 (VSN International, 2016).

To reflect the treatment structure, the 38 degrees of freedom for treatments were orthogonally partitioned as in Table 4, with terms for the difference between incorporated vs surface treatments, then differences between products (within either incorporated or surface treatments), and finally effects of rate within each product. The rate effects within each treatment were further decomposed into linear and quadratic regression contrasts (but not presented). The treatment structure of the repeated measures ANOVA model consisted of these treatment terms, time and the interaction of each treatment term with time. The block structure was defined to be plot within replicate (replicate/plot), (corresponding to an equicorrelation repeated measures model). Where specific testing of only a subset of treatments within the overall structure was carried out, data was evaluated using a general analysis of variance using a reduced number of treatments partitioned as above. For the treatment effects discussed in the results section of this report, we have included the repeated measures ANOVA output table in the text immediately adjacent to a graphical representation of the data.

**Table 4:** Description of the orthogonal partitioning of the 38 degrees of freedom (DF) for treatment effects, as used in the repeated measures analysis of variance.

| Treatment structure term used | DF | Description |
|---|---|---|
| | | *Within treatments* |
| IncVSurf | 1 | Incorporated vs Surface treatments |
| IncVSurf/SurIncTrts | 6 | Between Incorporated treatments |
| IncVSurf/IncTrts/incMW001 | 4 | Rate effects for incorporated MW001 |
| IncVSurf/IncTrts/incMW002 | 4 | Rate effects for incorporated MW001 |
| IncVSurf/IncTrts/incGW | 4 | Rate effects for incorporated Green Waste |
| IncVSurf/IncTrts/incManure | 3 | Rate effects for incorporated Manure |
| IncVSurf/IncTrts/incCBio | 1 | Rate effects for incorporated Biosolids |
| IncVSurf/SurfTrts | 4 | Between surface treatments |
| IncVSurf/SurfTrts/surfMW001 | 3 | Rate effects for surface MW001 |
| IncVSurf/SurfTrts/surfMW002 | 3 | Rate effects for surface MW002 |
| IncVSurf/SurfTrts/surfGW | 3 | Rate effects for surface Green Waste |
| | | *Within treatments . time* |
| IncVSurf.time | 3 | Incorporated vs Surface treatments x time |
| IncVSurf/IncTrts.time | 15 | Between Incorporated treatments x time |
| IncVSurf/IncTrts/incMW001.time | 11 | Rate effects for incorporated MW001 x time |
| IncVSurf/IncTrts/incMW002.time | 12 | Rate effects for incorporated MW001 x time |
| IncVSurf/IncTrts/incGW.time | 8 | Rate effects for incorporated Green Waste x time |
| IncVSurf/IncTrts/incManure.time | 6 | Rate effects for incorporated Manure x time |
| IncVSurf/IncTrts/incCBio.time | 2 | Rate effects for incorporated Biosolids x time |
| IncVSurf/SurfTrts.time | 11 | Between surface treatments x time |
| IncVSurf/SurfTrts/surfMW001.time | 9 | Rate effects for surface MW001 x time |
| IncVSurf/SurfTrts/surfMW002.time | 6 | Rate effects for surface MW002 x time |
| IncVSurf/SurfTrts/surfGW.time | 3 | Rate effects for surface Green Waste x time |

In most cases, a logarithmic or square root transformation was required to remove or reduce mean-variance heterogeneity (where a logarithmic transformation was applied and zeros were present, a log(x+c) was used, where c was half the minimum non-zero value). Residual diagnostics (fitted vs residual, QQ normal, half normal, residuals histogram) were examined to check the ANOVA assumptions.

A least significant difference (l.s.d.) is provided to compare differences in treatment means at the 5% ($p<0.05$) level of significance. In most cases, an l.s.d. for each sample time (i.e. T0, T1, T2 or T3) is presented, along with the appropriate trt x time l.s.d. for the repeated measures model. Where the data set had been transformed to satisfy the assumptions of statistical inference associated with meeting the criteria of a normally distributed data set, the l.s.d obtained from the transformed data is included in either data tables or with a graphical representation of the data.

Where appropriate, regression models are fitted to of each individual sample point, with regression coefficient ($R^2$) included as an indication of goodness of fit at $p \leq 0.05$. A range of regression models were fitted to describe specific data relationships, following the fitting of a range of simple equations to the data using curve fitting software (TableCurve 2D, Systat Software)  Regression techniques used are indicated in text, depending on the data being examined. The range includes, linear and non-linear regression, multiple linear regression, and groups regression for the linear and non-linear, time based-data.

For the profile data, the REML directive in Genstat was used to fit each model, with fixed effects being treatment by depth and the random effects were replicate (and plot for the equi-correlation model). Several different functions were fitted to account for correlations in the residuals between measurements on successive depths for the same plot (specified using the VSTRUCTURE directive for plot by depth). These were, in increasing order of complexity, the equicorrelation, autoregressive order 1 (AR1), AR1 with heterogeneous variances by depth, and antedependence order 1 models. Comparison of deviances from each indicated that, for most responses, the AR1 with heterogeneous variances was the most parsimonious model.

In addition, the data generated using the MicroResp procedure was also evaluated using an additional multivariate technique, known as canonical variate analysis, also found in Genstat. This statistical test presents a way of summarising the differences between treatment groups (i.e. the respiration response to 9 different C sources for the soils tested).

Given the nature of the trial design that we used, the repeated measures ANOVA procedure often resulted in the identification of multiple significant treatment effects, including differences with rates of application, between treatments, and over time. In the interests of brevity, we have therefore endeavoured to summarize these effects by only discussing the most pertinent of these results during the main body of this report. For more information, we have submitted the full set of repeated measures ANOVA output tables in an electronic supplementary information file along with this report.

# Results and Discussion

## Analyses of amendment materials

Selected inorganic chemical analysis of the amendment materials used in the trial is presented in Table 5. In addition, preliminary chemical analysis of the two MWOO materials provided by NSW EPA, prior to trial establishment, can be found in Appendix 3.

A comparison of the inorganic chemical concentrations across the range of amendments used in this trial (Table 5), reveal differences between the materials used. High EC levels were found in the two MWOO materials and the poultry manure, compared to the composted biosolids and green waste, and this trend was also seen for the concentrations of Cl measured. As expected, the poultry manure had the highest concentrations of plant nutrient elements N and P, while concentrations of these in the two MWOO materials were greater than or similar to those in the green waste and composted biosolids. The two MWOO materials had higher concentrations of the heavy metal contaminants Cd, Cu, Ni, Pb and Zn, compared to the green waste compost, composted biosolids and poultry manure. A review by McLaughlin et.al. (2000) identified Cd, Cu and Zn, as the heavy metal contaminants most likely to impact on soil health and agricultural production, if their input into soils were not carefully managed. The concentrations of inorganic components measured in the two MWOO products are consistent with data cited by Smith (2009) and Dorahy et.al. (2009). The MWOO 1 material complies with the NSW EPA Mixed Waste Order (Table 1, NSW EPA 2014b), however the MWOO 2 material has high concentrations of Cr, Cu and Pb, which would make it suitable for mine site rehabilitation only. The other materials (green waste, composted biosolids and poultry manure, have contaminant concentrations which would allow them the ‘B’ contaminant grade, according to NSW EPA guidelines for biosolids application to agricultural soils (NSW EPA 1997). Materials must be graded as C or better for use in agriculture.

Data for the analysis of the organic chemical contaminants found in the two MWOO materials used prior to application can also be found in Appendix 3. This analysis found that there were significant concentrations of phthalates, particularly Bis-2-ethyl hexyl phthalate (DEHP), found in both MWOO materials, as well as some phenols and some PAH’s including naphthalene. These data are consistent with data presented through an AWT industry report on MWOO composts in Australia (Hyder Consulting 2008a). It should be noted that DEHP has been identified as a chemical of concern by the AWT industry. Table 6 lists the range of additional pesticide and endocrine disrupting chemicals found in the MWOO materials applied during this field trial. The concentrations of BBP and DBP are consistent with concentrations reported by Brandli et.al. (2005; 2007), who listed a range of persistent organic pollutants (POP’s) measured in source separated compost.

**Table 5:** Selected inorganic chemical properties of the amendment materials tested during this trial

| Parameter | | MWOO1 | MWOO2 | Green waste | Composted biosolid | Poultry manure |
|---|---|---|---|---|---|---|
| **EC** | dS/m | 7.6 | 4.6 | 0.98 | 1.3 | 8.1 |
| **$pH_W$** | pH units | 8.3 | 8.7 | 8.6 | 7.5 | 8.5 |
| **Chloride (Cl)** | mg/kg | 6700 | 4000 | 710 | 900 | 3900 |
| **Total Nitrogen (TN)** | % | 2.1 | 1.3 | 1.6 | 0.83 | 3.1 |
| **Ammonia-N ($NH_4$)** | mg/kg | 880 | 250 | 17 | 6.6 | 1400 |
| **Nitrate-N ($NO_3$)** | mg/kg | 52 | 300 | 6.7 | 8.7 | 960 |
| **Nitrite-N ($NO_2$)** | mg/kg | 2.0 | 8.3 | 0.94 | 0.42 | 120 |
| **Total Organic Carbon (TOC)** | % | 24 | 18 | 24 | 12 | 24 |
| **Total Phosphorus (TP)** | mg/kg | 5900 | 3600 | 3300 | 7400 | 19000 |
| **Available Phosphorus** | mg/kg | 5200 | 3100 | 2700 | 6700 | 18000 |
| **KCl extractable sulphur (S)** | mg/kg | 1400 | 1100 | 77 | 650 | 3600 |
| **PPOC** | g C/kg | 4.4 | 4.3 | 9 | 5 | 7.9 |
| **Total elements (by ICP)** | | | | | | |
| **Aluminium (Al)** | % | 1.7 | 1.3 | 1.2 | 1.9 | 1.3 |
| **Arsenic (As)** | mg/kg | 5.5 | ND | 9.5 | 5.2 | ND |
| **Boron (B)** | mg/kg | 32 | 26 | 29 | 18 | 33 |
| **Calcium (Ca)** | % | 3.4 | 2.6 | 1.9 | 1.3 | 5 |
| **Cadmium (Cd)** | mg/kg | 2.0 | 4.2 | 0.82 | 0.3 | ND |
| **Cobalt (Co)** | mg/kg | 6.1 | 8.2 | 5.3 | 7.1 | 7 |
| **Chromium (Cr)** | mg/kg | 82 | 100 | 61 | 130 | 23 |
| **Copper (Cu)** | mg/kg | 260 | 380 | 67 | 110 | 120 |
| **Iron (Fe)** | % | 1.4 | 1.6 | 1.2 | 2.6 | 0.91 |
| **Potassium (K)** | % | 1 | 0.68 | 1 | 0.62 | 2.4 |
| **Magnesium (Mg)** | % | 0.31 | 0.21 | 0.38 | 0.42 | 0.9 |
| **Manganese (Mn)** | mg/kg | 350 | 440 | 320 | 290 | 850 |
| **Molybdenum (Mo)** | mg/kg | 3.1 | 5 | 1.9 | 2 | 9.8 |
| **Sodium (Na)** | % | 0.68 | 0.67 | 0.18 | 0.16 | 0.56 |
| **Nickel (Ni)** | mg/kg | 41 | 40 | 12 | 23 | 14 |
| **Lead (Pb)** | mg/kg | 220 | 280 | 66 | 48 | 4.8 |
| **Sulphur (S)** | % | 0.45 | 0.28 | 0.26 | 0.25 | 0.66 |
| **Zinc (Zn)** | mg/kg | 700 | 600 | 240 | 220 | 570 |

EC = electrical conductivity; $pH_W$ = pH water; Cl = water soluble chloride (EC, $pH_W$ & Cl measured in 1:5 soil water extract); TN = total nitrogen following dumas combustion; $NO_3$, $NH_4$, $NO_2$ = Ammonia, nitrate and nitrite measure following KCL extraction; TOC = total organic carbon measured following Dumas combustion; TP = total phosphorus analysed by flow injection (FIA) following semi-micro Kjeldahl digestion. Available P = citrate soluble P; KCl extractable = S extracted using KCl; PPOC = Labile carbon – (Potassium permanganate Oxidisable Carbon), Total elements, Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, and Zn = elements extracted by microwave assisted digestion in reverse *aqua regia*; ND = not detected.

The DEHP concentrations found in the MWOO materials used in our trials are higher than those reported for compost by Brandli et.al. (2007; 0.28 mg/kg), and higher than the median value reported for biosolids (e.g. 110 mg/kg reported by Smith 2009 and 15 mg/kg reported by Rigby et.al. 2015). The concentration of BPA in both MWOO materials appears to be high. Concentrations of BPA in biosolids were reported to range between <0.03 and 1.47 mg/kg (Langdon et.al. 2011), and while the leaching of this compound from municipal waste landfill has been reported (Paxeus 2000; Yamamoto et.al. 2001), we could not find concentrations reported for composts or MWOO in the scientific literature. The presence of N,N-Diethyl-m-toluamide [DEET] has been reported at concentrations of between 0.5 and 3 µg/L in wastewater (e.g. Aronson et.al. 2011; Weeks et.al. 2011), but again, little information could be found describing the presence of DEET in MWOO or composted green waste.

| CAS | Name | Quantity (mg/kg) | |
|---|---|---|---|
| | | **MWOO 1** | **MWOO 2** |
| 131-11-3 | Dimethylphthalate [DMP] | 0.6 | - |
| 134-62-3 | N,N-Diethyl-m-toluamide [DEET] | 11.3 | 18.9 |
| 119-61-9 | Benzophenone | 4.7 | 4.4 |
| 84-74-2 | Di-n-butylphthalate [DBP] | 4.8 | 4.0 |
| 80-05-7 | Bisphenol A [BPA] | 563.3 | 7,313.7 |
| 85-68-7 | Butyl benzyl phthalate [BBP] | 0.2 | - |
| 82657-04-3 | Bifenthrin | 0.7 | 1.4 |
| 117-81-7 | Bis(2-ethylhexyl)phthalate [DEHP] | 302.3 | 291.7 |

- =not detected

**Table 6:** Quantities of additional organic analytes found in the MWOO amendment materials tested during this trial

Analysis of the composited samples of green waste, composted biosolids and poultry manure, for the additional organic pollutants discussed earlier, showed either below detection or trace quantities of these same organic pollutants (data not shown). Therefore soils treated with these materials were not analysed for these compounds.

## Effects of amendments on soil properties

### Soil pH

The effect of increasing rates of amendment addition on soil pH is illustrated in Figure 1. Data is presented for soil sampled at times T0 (immediately after application), and three years later (T3). The ANOVA output tables for this data are given in Tables 4a (Standard ANOVA) and Table 4b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

The ANOVA output tables presented in Table 7a and 7b reveal multiple significant treatment effects of amendment application on soil pH; including application rate effects within treatments, differences between different amendment materials, and changes in these effects over time.

In summary, application of each of the amendments resulted in an immediate increase in soil pH for all treatments, compared to those of the control treatments (Figure 1). Soil pH increased with increasing rates of amendment application, with the maximum increase (nearly 3 pH units) seen for the 200 (t/ha) incorporation of MWOO (1 and 2), the 100 t/ha incorporation treatment for manure and the 50 t/ha surface applications of MWOO (1 and 2). Soil pH increased to a lesser extent with green waste and composted biosolids, compared to similar applications of MWOO and poultry manure. Similar effects (i.e. pH increase) have been seen in short-term greenhouse incubation studies where there has been no leaching of mineralised N (Dudley et.al. 1986; Whalen et.al. 2000).

The monitoring of the soil pH of the treated plots during subsequent sampling times during this trial is important, as soil pH also influences the solubility of inorganic contaminants. Over time, the post-application increase in soil pH was not as evident for the MWOO and manure amended soils, with the pH of these treatments declining by around 0.5 pH units over the period T0 – T3. The decrease in pH over the same period was less for green waste and composted biosolids amended soils. However, the pH of all treatments remained higher than those of the control treatments.

More often than not, long-term application of both biosolids (Dowdy et.al. 1991; Barbaric et.al. 1997), and animal manures (Chang et.al. 1990; Tyson and Cabrera 1993) leads to an eventual decrease in soil pH. The decrease in soil pH, from their initial rise on the treated plots over the time period T0 to T3, was not unexpected. The decrease in soil pH over time in the amended plots was probably a result of $NO_3$ production by soil micro-organisms (from $NH_3$), where protons ($H^+$) are released into the soil solution. The decomposition of labile organic matter may also contribute to changes in soil pH, where $H^+$ ions in the soil solution are consumed during the microbial breakdown of the organic matter (Ritchie and Dowling 1985). It is expected that the pH of these plots will decrease further over time.

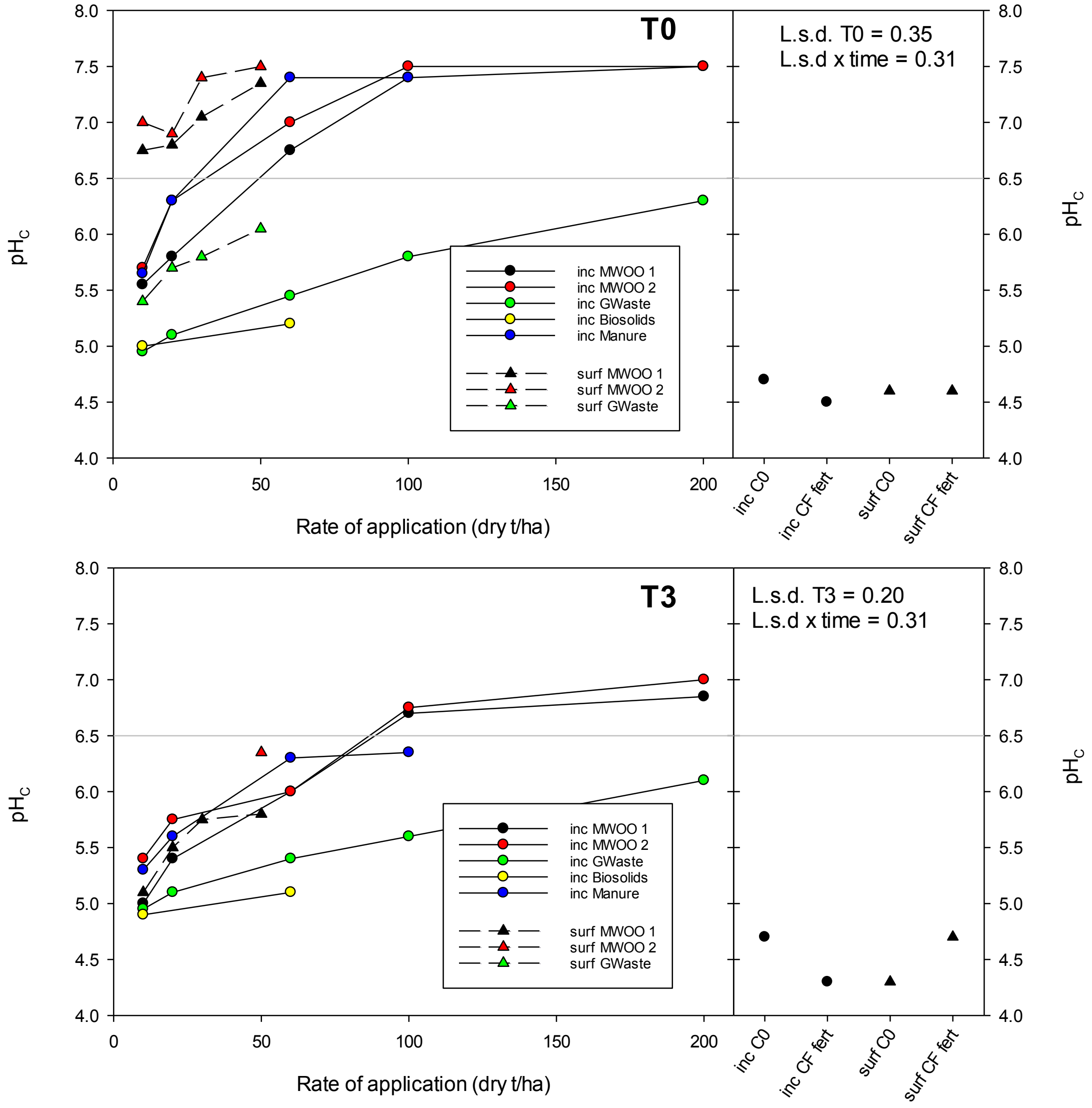


**Figure 1:** Changes in soil pH over time (T0 and T3) with increasing rates of either incorporated and surface applied MWOO1 and MWOO 2, compared to applications of green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

**Table 7a:** ANOVA output table for pH

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.34 | 0.45 | 5.02 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 356.28 | 9.90 | 110.91 | <.001 |
| Residual | 108 | | 9.64 | 0.09 | 2.37 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 29.23 | 9.74 | 259.23 | <.001 |
| trtID.time | 79 | -29 | 21.48 | 0.27 | 7.23 | <.001 |
| Residual | 246 | -87 | 9.25 | 0.04 | | |
| Total | 475 | -116 | 377.31 | | | |

**Table 7b:** Repeated measures ANOVA output table for pH

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.34 | 0.45 | 5.02 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.90 | 0.90 | 10.04 | 0 |
| IncVSurf.IncTrts | 6 | | 121.71 | 20.28 | 227.33 | <.001 |
| IncVSurf.SurfTrts | 4 | | 96.34 | 24.08 | 269.92 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 43.54 | 10.88 | 121.99 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 35.14 | 8.79 | 98.46 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 18.60 | 4.65 | 52.12 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 18.04 | 6.01 | 67.38 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.64 | 0.64 | 7.14 | 0.01 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 7.06 | 2.35 | 26.38 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 7.74 | 2.58 | 28.9 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 4.55 | 1.52 | 16.99 | <.001 |
| Residual | 108 | | 9.64 | 0.09 | 2.37 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 36.91 | 12.30 | 327.33 | <.001 |
| IncVSurf.time | 3 | | 7.05 | 2.35 | 62.52 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 7.06 | 0.47 | 12.52 | <.001 |
| IncVSurf.SurfTrts.time | 10 | -2 | 6.56 | 0.66 | 17.46 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.30 | 0.03 | 0.68 | 0.78 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.59 | 0.07 | 1.98 | 0.05 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.20 | 0.02 | 0.65 | 0.73 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 1.29 | 0.22 | 5.74 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.00 | 0.00 | 0.05 | 0.95 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 1.03 | 0.11 | 3.05 | 0 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.56 | 0.19 | 4.97 | 0 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.10 | 0.03 | 0.85 | 0.47 |
| Residual | 246 | -87 | 9.25 | 0.04 | | |
| Total | 475 | -116 | 377.31 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Soil electrical conductivity

The effect of increasing rates of amendment addition on soil EC is illustrated in Figure 2. The ANOVA output tables for this data are given in Tables 8a (Standard ANOVA) and Table 8b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

Soil EC is a measure of the electrical conductivity of soluble ions in solution, and as the concentration of these ions increases, so does the soil EC. A high soil EC can result in decreases in plant growth, with a value of 0.63 dS/m (630 µS/cm) (in the 1:5 soil: water extract), often used as an indicator above which reduced plant growth may result in tolerant plant species. Sensitive plant species may have yields affected at much lower levels of salinity, with values <0.1 dS/m in the 1:5 soil water extract, resulting in yield reductions for sensitive crops grown in soils with moderate clay contents (Shaw 2005).

The ANOVA output tables presented in Table 8a and Table 8b reveal multiple significant treatment effects of amendment application on soil EC; including application rate effects within treatments, differences between different amendment materials, and changes in these effects over time. From an examination of the data in Figure 2 and the ANOVA output tables given Table 5a and 5b, it can

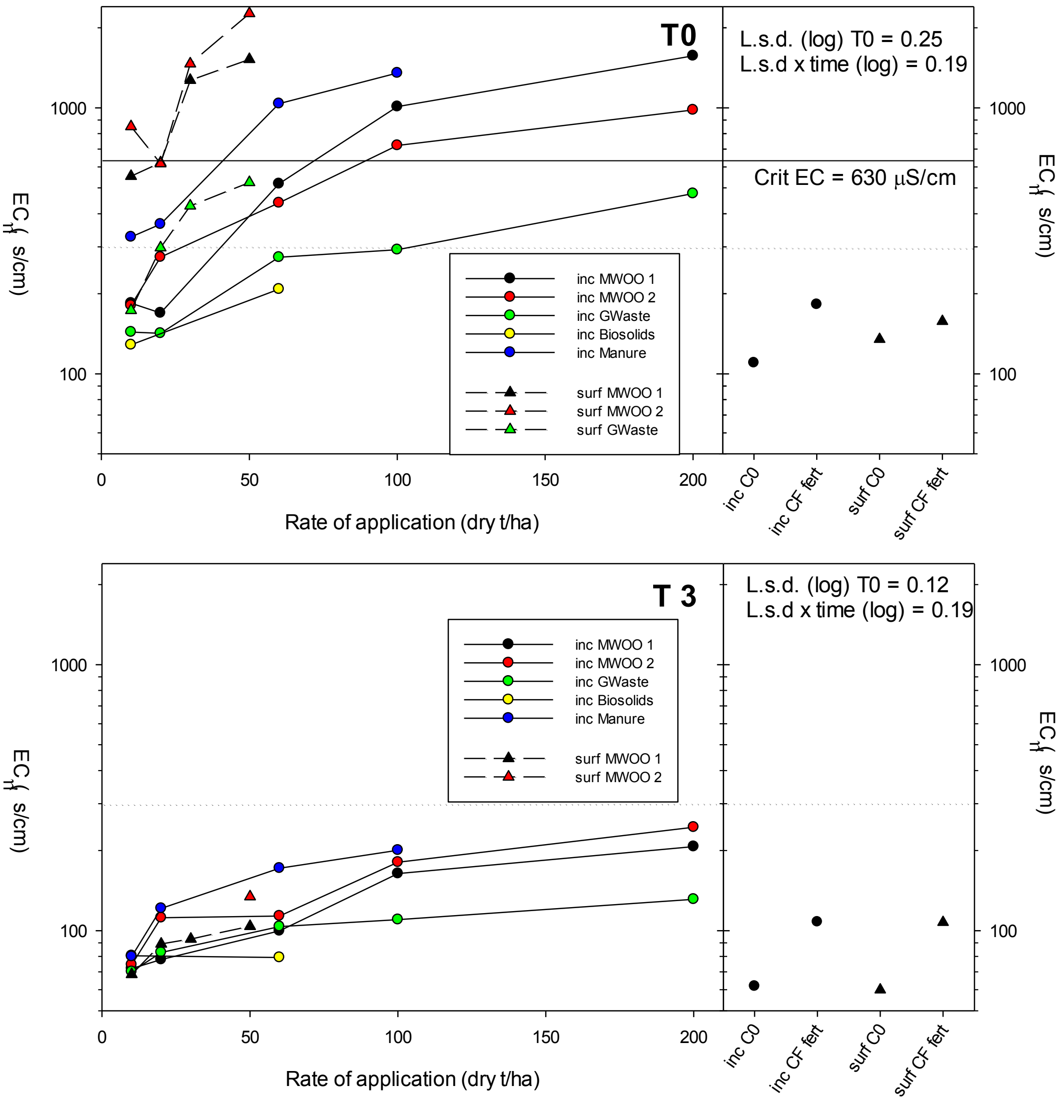


**Figure 2**: Changes in soil EC (measured in a 1:5 soil water extract) over time (T0 and T3) with increasing rates of either incorporated and surface applied MWOO1 and MWOO 2, compared to applications of green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Critical value for EC, (Crit EC), above which yield in tolerant plants, may become adversely affected is indicated (630 µS/cm).

**Table 8a:** ANOVA output table for 1:5 soil water extract electrical conductivity (EC)

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.17 | 0.39 | 11.52 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 23.91 | 0.66 | 19.63 | <.001 |
| Residual | 108 | | 3.66 | 0.03 | 2.41 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 26.85 | 8.95 | 636.67 | <.001 |
| trtID.time | 79 | -29 | 8.75 | 0.11 | 7.88 | <.001 |
| Residual | 246 | -87 | 3.46 | 0.01 | | |
| Total | 475 | -116 | 58.32 | | | |

**Table 8b:** Repeated measures ANOVA output table for EC

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.17 | 0.39 | 11.52 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.14 | 0.14 | 4.09 | 0.046 |
| IncVSurf.IncTrts | 6 | | 5.52 | 0.92 | 27.2 | <.001 |
| IncVSurf.SurfTrts | 4 | | 3.60 | 0.90 | 26.57 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 3.97 | 0.99 | 29.32 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 3.80 | 0.95 | 28.04 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 1.42 | 0.35 | 10.46 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 2.33 | 0.78 | 22.95 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.09 | 0.09 | 2.54 | 0.114 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.09 | 0.36 | 10.71 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 1.68 | 0.56 | 16.58 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.83 | 0.28 | 8.14 | <.001 |
| Residual | 108 | | 3.66 | 0.03 | 2.41 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 32.90 | 10.97 | 780.07 | <.001 |
| IncVSurf.time | 3 | | 2.28 | 0.76 | 54.15 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 1.98 | 0.13 | 9.38 | <.001 |
| IncVSurf.SurfTrts.time | 10 | -2 | 4.15 | 0.41 | 29.5 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.81 | 0.07 | 4.79 | <.001 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.12 | 0.01 | 1.04 | 0.41 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.12 | 0.02 | 1.07 | 0.383 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.19 | 0.03 | 2.24 | 0.04 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.04 | 0.02 | 1.58 | 0.209 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.25 | 0.03 | 1.96 | 0.044 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.09 | 0.03 | 2.24 | 0.085 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.09 | 0.03 | 2.04 | 0.109 |
| Residual | 246 | -87 | 3.46 | 0.01 | | |
| Total | 475 | -116 | 58.32 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

be seen that the initial application of all amendments (pre-irrigation or cropping activities), raised the soil EC above that of the control and control fertilizer treatments, and that EC increased with increasing application of all amendments. For incorporated treatments, rates above 20 t/ha were need to increase soil EC above the control, although lower rates had the same result for poultry manure. For surface applied treatments, MWOO applications increased the soil EC above the control for all treatments. The EC for some of these exceeded the critical salinity threshold, particularly for incorporated MWOO and manure applied at rates greater than 60 t/ha, and for surface applied MWOO applied at rates greater than 30 t/ha. Generally, applications of green waste and composted biosolids has a smaller effect on soil EC compared to MWOO and poultry manure, while surface applications had a larger impact on soil EC compared to incorporation of the amendments. However, it can also be seen from Figure 2 that this was only a transient affect, as EC levels have declined over time as the soluble salts have been removed from the upper part of the test soils, as a result of rainfall and irrigation associated with the cropping carried out during the trial. By time T3, the soil EC had declined significantly until only the highest rates of MWOO and poultry manure were significantly higher than the EC measured in the control and control fertilizer treatments.

## Soil fertility and plant nutrient elements

For this report, we have grouped the discussion of the inorganic, non-heavy metal elements, under the heading of ‘soil fertility and plant nutrients‘.

The average concentration of soil fertility and nutrient elements measured in the amended soils is given in Appendices 4a (T0 sampling), 4b (T1 sampling) and 4c (T2 sampling). These elements were not measured in the T3 soils. These parameters include total S, total and plant available P (Colwell P), total and mineral N ($NH_4$ and $NO_3$), TOC, as well as CEC and exchangeable cations. These Appendices also include the least significant difference (l.s.d.) for each parameter at the 5% probability level ($p<0.05$). Table 5 also lists the nutrient elements found in the amendments prior to application. It is not unexpected that soil nutrient concentrations would increase when the materials were applied to the trial soils and that this increase would vary between the different nutrient and amendments used. Also as expected, the concentrations of these elements increase with application rate.

### *Soil cation exchange capacity*

The effect of increasing rates of amendment addition on soil CEC is illustrated in Figure 3. The ANOVA output tables for this data are given in Tables 9a (Standard ANOVA) and Table 9b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

Soil CEC gives an indication of the potential of the soil to hold plant nutrients, by estimating the capacity of the soil to retain cationic elements. As such, CEC influences soil structural stability, nutrient availability, soil pH and the soils’ ability to moderate reactions to fertiliser and ameliorant inputs. Soils with high CEC typically have a high clay and organic matter content. These soils are considered to be more fertile, as they can hold more plant nutrients. Sandy soils typically have a lower CEC and require more frequent fertilizer applications. (Hazleton and Murphy 2007)

Amendment application increased the CEC of soils where application exceeded 20 t/ha (Figure 3) and CEC increased with increasing application rates. The application of MWOO resulted in higher soil CEC compared to composted biosolids and green waste and was comparatively higher following surface application. These results are expected as it is well known that organic matter has a higher CEC, compared to most of the inorganic components in the solid phase (McBride 2000).

The control soils at this site are considered to have a low CEC (6-12 cmol(+)/kg, Hazelton and Murphy 2007). High rates of incorporated MWOO (greater than 60 t/ha) and composted green waste (200 t/ha), increased the soil CEC into the high range (25-40 cmol(+)/kg), while the application of composted biosolids had little significant effect of soil CEC (Appendix 3a). Likewise, surface applications of both MWOO (greater than 20 t/ha) and composted green waste (greater than 30 t/ha) also increased soil CEC to levels considered to in the high CEC range.

Over time (T0 to T3), the soil CEC generally decreased for all amendments. Whalen et.al. (2000) attributed a loss in CEC, post-manure application, to the breakdown and loss of labile and reactive C, which would otherwise contribute to higher soil CEC levels. Soil CEC remained above control levels for incorporated MWOO, manure and green waste treatments, at rates greater than 50 t/ha.

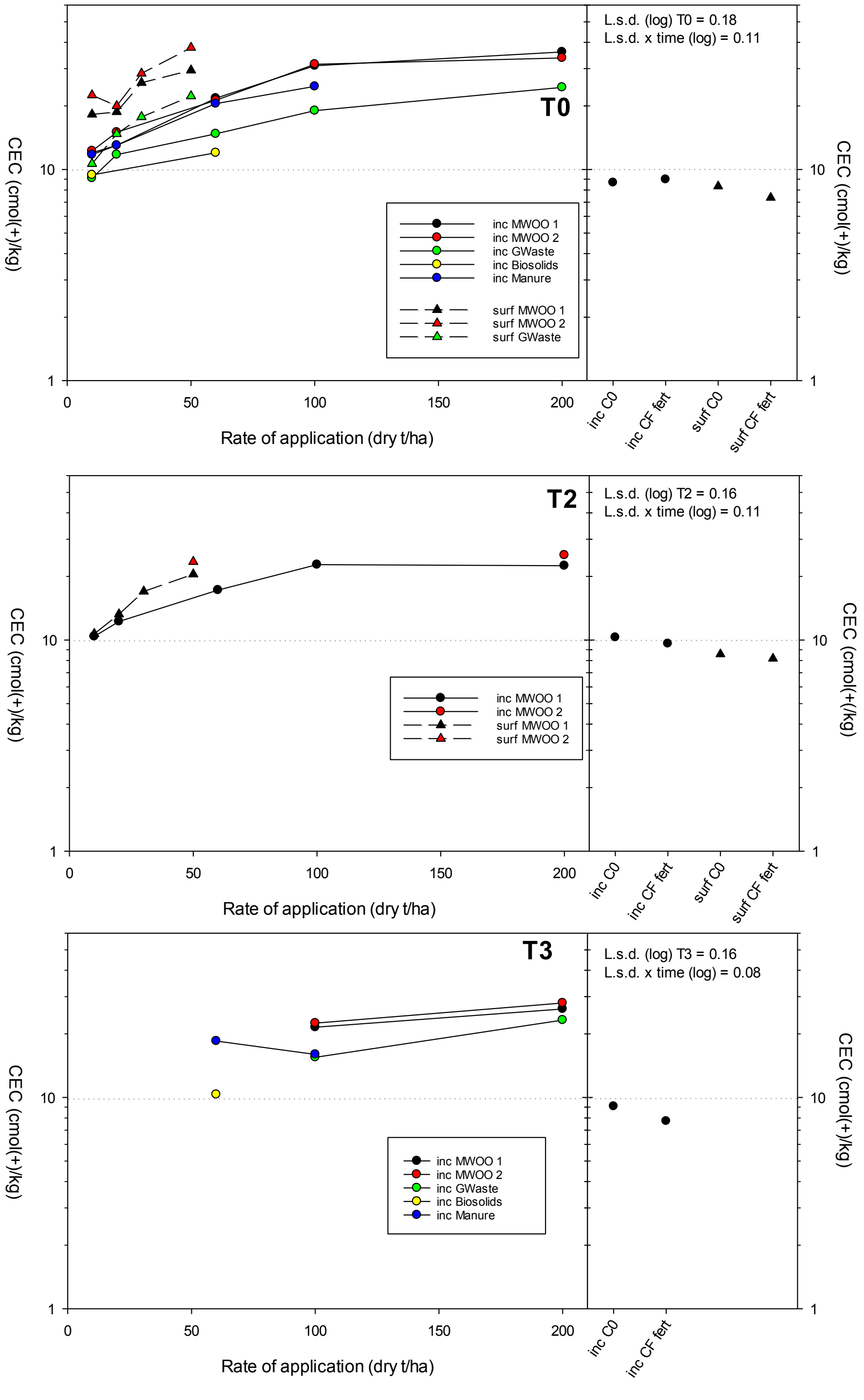


**Figure 3:** Changes in soil cation exchange capacity (CEC) over time (T0, T1 and T2) with increasing rates of MWOO compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated on x-axis for each treatment.

**Table 9a:** ANOVA output table for soil CEC

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.07 | 0.02 | 1.57 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 15.92 | 0.44 | 29.86 | <.001 |
| Residual | 108 | | 1.60 | 0.01 | 4.43 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 0.76 | 0.25 | 75.56 | <.001 |
| trtID.time | 60 | -48 | 0.64 | 0.01 | 3.19 | <.001 |
| Residual | 189 | -144 | 0.63 | 0.00 | | |
| Total | 399 | -192 | 14.63 | | | |

**Table 9b:** Repeated measures ANOVA output table for CEC

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.07 | 0.02 | 1.57 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.00 | 0.00 | 0.2 | 0.655 |
| IncVSurf.IncTrts | 6 | | 3.58 | 0.60 | 40.23 | <.001 |
| IncVSurf.SurfTrts | 4 | | 3.54 | 0.88 | 59.67 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 2.02 | 0.51 | 34.1 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 2.15 | 0.54 | 36.24 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 1.61 | 0.40 | 27.19 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 0.79 | 0.26 | 17.88 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.07 | 0.07 | 4.67 | 0.033 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.66 | 0.22 | 14.83 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 0.75 | 0.25 | 16.86 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.69 | 0.23 | 15.53 | <.001 |
| Residual | 108 | | 1.60 | 0.01 | 4.43 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 1.16 | 0.39 | 115.64 | <.001 |
| IncVSurf.time | 2 | -1 | 0.07 | 0.03 | 10.45 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.18 | 0.01 | 3.65 | <.001 |
| IncVSurf.SurfTrts.time | 7 | -5 | 0.24 | 0.03 | 10.32 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 9 | -3 | 0.05 | 0.01 | 1.81 | 0.07 |
| IncVSurf.IncTrts.incMW002.time | 5 | -7 | 0.03 | 0.01 | 1.68 | 0.142 |
| IncVSurf.IncTrts.incGW.time | 5 | -7 | 0.02 | 0.00 | 0.99 | 0.425 |
| IncVSurf.IncTrts.incManure.time | 4 | -5 | 0.07 | 0.02 | 4.99 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 1 | -2 | 0.00 | 0.00 | 0.17 | 0.683 |
| IncVSurf.SurfTrts.surfMW001.time | 6 | -3 | 0.02 | 0.00 | 1.09 | 0.37 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.01 | 0.00 | 1.15 | 0.33 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.01 | 0.00 | 1.25 | 0.294 |
| Residual | 189 | -144 | 0.63 | 0.00 | | |
| Total | 399 | -192 | 14.63 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Total and plant available (Colwell) soil phosphorus*

The effect of increasing rates of amendment addition on total soil P, at time T0, is illustrated in Figure 4. The ANOVA output tables for this data are given in Tables 10a (Standard ANOVA) and Table 10b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Total P in the amended soils increased when amendments were applied and increased with increasing application rate. These increases reflect the P content of the amendment materials (see Table 5).

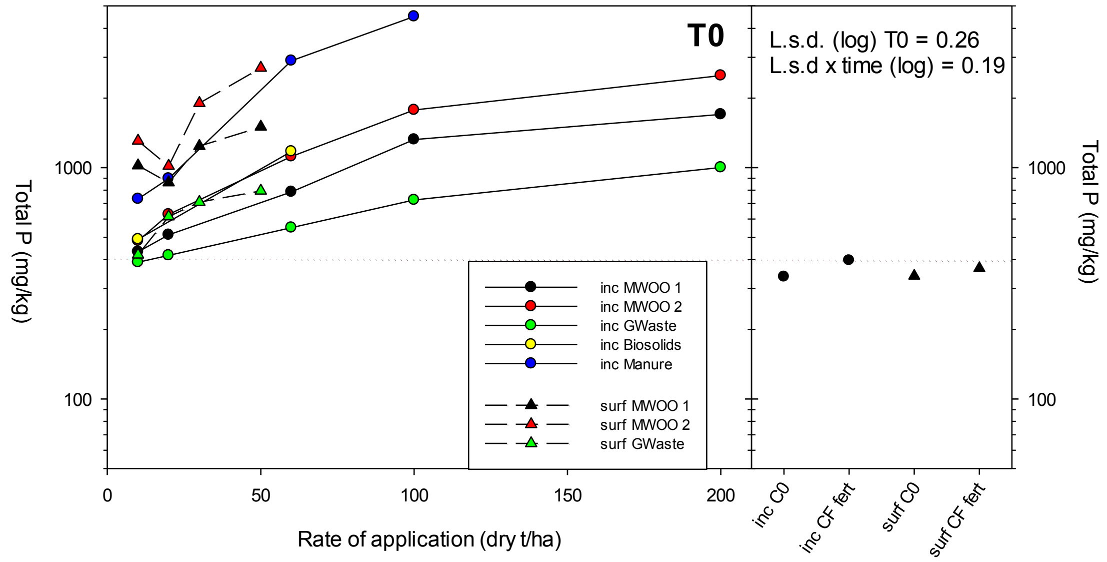


**Figure 4:** Increases in total soil P (T0) with increasing rates of MWOO compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated on x-axis for each treatment.

For all amendments, total soil P concentrations were increased above the control for rates above 10 t/ha. Soil P concentrations for surface applications of MWOO and green waste were significantly higher than equivalent incorporated treatments. Manure amendments added the most P to the test soils. For the incorporated MWOO treatments, a 100 t/ha application raised the total soil P concentration to over 1300 mg/kg (MWOO 1) and more than 1700 mg/kg for MWOO 2. A manure application of 60 t/ha raised soil P concentrations to over 1100 mg/kg. Surface applied MWOO increased soil P concentrations to values above 1000 mg/kg for applications as low as 10 t/ha. There was no significant effect of time on total soil P concentrations as illustrated in the repeated measures output table shown in Table 10b.

**Table 10a:** ANOVA output table for total soil P

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.52 | 0.17 | 5.31 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 39.78 | 1.10 | 33.6 | <.001 |
| Residual | 108 | | 3.55 | 0.03 | 2.31 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 2 | -1 | 0.76 | 0.38 | 26.67 | <.001 |
| trtID.time | 50 | -58 | 1.04 | 0.02 | 1.46 | 0.041 |
| Residual | 156 | -177 | 2.22 | 0.01 | | |
| Total | 355 | -236 | 30.49 | | | |

**Table 10b:** Repeated measures ANOVA output table for total soil P

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.52 | 0.17 | 5.31 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.60 | 0.60 | 18.14 | <.001 |
| IncVSurf.IncTrts | 6 | | 11.36 | 1.89 | 57.6 | <.001 |
| IncVSurf.SurfTrts | 4 | | 5.99 | 1.50 | 45.57 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 4.09 | 1.02 | 31.09 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 5.38 | 1.34 | 40.89 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 1.60 | 0.40 | 12.16 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 6.70 | 2.23 | 67.94 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 1.05 | 1.05 | 31.82 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.41 | 0.14 | 4.2 | 0.007 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 1.97 | 0.66 | 20 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.53 | 0.18 | 5.35 | 0.002 |
| Residual | 108 | | 3.55 | 0.03 | 2.31 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 2 | -1 | 1.11 | 0.55 | 38.89 | <.001 |
| IncVSurf.time | 2 | -1 | 0.29 | 0.15 | 10.22 | <.001 |
| IncVSurf.IncTrts.time | 9 | -9 | 0.21 | 0.02 | 1.65 | 0.105 |
| IncVSurf.SurfTrts.time | 7 | -5 | 0.27 | 0.04 | 2.67 | 0.012 |
| IncVSurf.IncTrts.incMW001.time | 8 | -4 | 0.02 | 0.00 | 0.17 | 0.994 |
| IncVSurf.IncTrts.incMW002.time | 4 | -8 | 0.03 | 0.01 | 0.6 | 0.666 |
| IncVSurf.IncTrts.incGW.time | 4 | -8 | 0.01 | 0.00 | 0.11 | 0.979 |
| IncVSurf.IncTrts.incManure.time | 3 | -6 | 0.07 | 0.02 | 1.66 | 0.179 |
| IncVSurf.IncTrts.incCBio.time | 1 | -2 | 0.00 | 0.00 | 0.07 | 0.794 |
| IncVSurf.SurfTrts.surfMW001.time | 6 | -3 | 0.18 | 0.03 | 2.14 | 0.052 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.04 | 0.01 | 1.04 | 0.376 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.02 | 0.01 | 0.49 | 0.692 |
| Residual | 156 | -177 | 2.22 | 0.01 | | |
| Total | 355 | -236 | 30.49 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Similar trends were also seen in the soil concentrations of plant-available P (Colwell P) as illustrated in Figure 5. The ANOVA output tables for this data are given in Tables 11a (Standard ANOVA) and Table 11b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

Colwell P concentrations increased with increasing rates of amendment application. These concentrations were raised above those of the control soil for incorporation of MWOO 2 and composted biosolids at rates above 10 t/ha and for all surface applied amendments. Rates above 20 t/ha were needed to raise Colwell P concentrations above those of the control for MWOO 2 and green waste. Colwell P concentrations were increased from <20 mg/kg in the control soils, to > 240 mg/kg for a 100 t/ha application of MWOO1 and to > 350 mg/kg for MWOO2 applied at the same rate. A 60 t/ha application raised Colwell P concentrations to above 100 mg/kg and 150 mg/kg, for the MWOO 1 and MWOO 2 materials, respectively. Further examination of the data in Figure 4 shows that there has been little significant change in the concentrations of available soil P in the three years post-application and these concentrations remain high for application rates of MWOO and manure above 60 t/ha. The only treatment that showed a change (decrease) in Colwell P over time, was for the poultry manure (Figure 5).

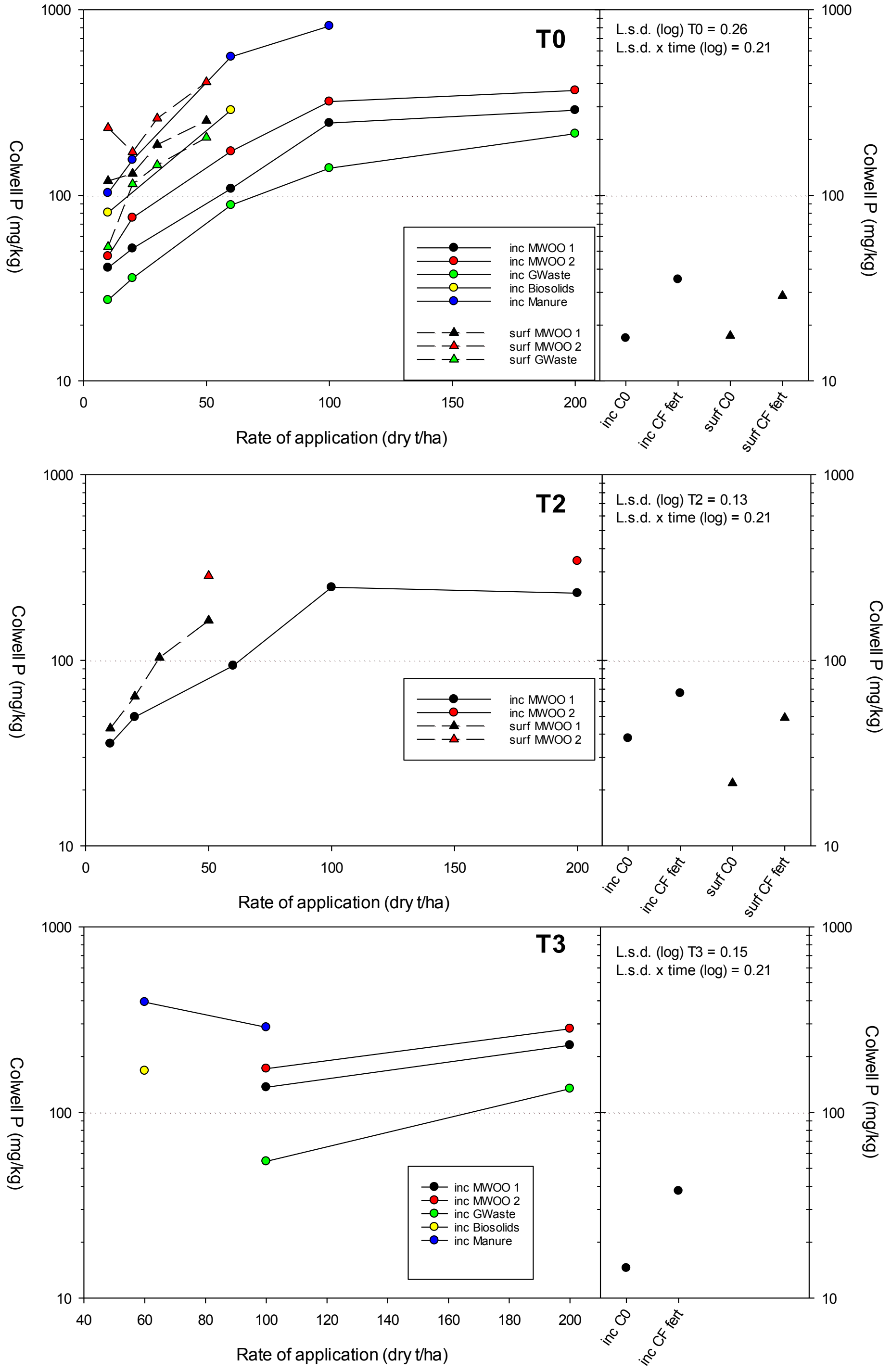


**Figure 5:** Changes in Colwell P over time (T0, T2 and T3) with increasing rates of MWOO compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated on x-axis for each treatment.

**Table 11a:** ANOVA output table for Colwell P

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.14 | 0.05 | 0.97 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 81.42 | 2.26 | 46.7 | <.001 |
| Residual | 108 | | 5.23 | 0.05 | 3.21 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 3.50 | 1.17 | 77.26 | <.001 |
| trtID.time | 60 | -48 | 3.36 | 0.06 | 3.71 | <.001 |
| Residual | 189 | -144 | 2.86 | 0.02 | | |
| Total | 399 | -192 | 70.93 | | | |

**Table 11b:** Repeated measures ANOVA output table for Colwell P

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.14 | 0.05 | 0.97 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 1.47 | 1.47 | 30.34 | <.001 |
| IncVSurf.IncTrts | 6 | | 24.31 | 4.05 | 83.66 | <.001 |
| IncVSurf.SurfTrts | 4 | | 12.78 | 3.19 | 65.95 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 9.28 | 2.32 | 47.92 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 10.16 | 2.54 | 52.45 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 8.06 | 2.02 | 41.61 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 7.24 | 2.41 | 49.81 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 2.62 | 2.62 | 54 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 2.24 | 0.75 | 15.42 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 2.53 | 0.84 | 17.42 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 2.38 | 0.79 | 16.39 | <.001 |
| Residual | 108 | | 5.23 | 0.05 | 3.21 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 4.76 | 1.59 | 104.99 | <.001 |
| IncVSurf.time | 2 | -1 | 0.80 | 0.40 | 26.44 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.91 | 0.06 | 4.03 | <.001 |
| IncVSurf.SurfTrts.time | 7 | -5 | 0.81 | 0.12 | 7.66 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 9 | -3 | 0.13 | 0.01 | 0.94 | 0.489 |
| IncVSurf.IncTrts.incMW002.time | 5 | -7 | 0.08 | 0.02 | 1.02 | 0.404 |
| IncVSurf.IncTrts.incGW.time | 5 | -7 | 0.10 | 0.02 | 1.36 | 0.242 |
| IncVSurf.IncTrts.incManure.time | 4 | -5 | 0.33 | 0.08 | 5.49 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 1 | -2 | 0.00 | 0.00 | 0.13 | 0.715 |
| IncVSurf.SurfTrts.surfMW001.time | 6 | -3 | 0.14 | 0.02 | 1.6 | 0.15 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.13 | 0.04 | 2.88 | 0.037 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.07 | 0.02 | 1.5 | 0.215 |
| Residual | 189 | -144 | 2.86 | 0.02 | | |
| Total | 399 | -192 | 70.93 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Even in high plant nutrient demand systems like dairy pastures, Colwell P concentrations in soils of 60-80 (mg P / kg soil) are adequate for pasture growth; [see link below for current industry recommendations] (http://fertsmart.dairyingfortomorrow.com.au/wp-content/uploads/2013/06/5.00203-NSW-PKS-Agronomic-ranges-V2-June13.pdf)

This level of plant available P is exceeded at incorporated MWOO application rates greater than 20 t/ha (greater than 10 for manure), and all MWOO surface applications.

Anything above these concentrations in the soil will provide no agronomic response and will simply increase the concentration of P in surface runoff (M$^{c}$Dowell et.al. 2003; Dougherty et.al 2011) that can contribute to eutrophication of waterways. Industry best-practice guidelines discourage the application of more P (or N) on soils where you already have high nutrient status (Burkitt et.al 2010; and references cited within). This risk was examined further in the results of the rainfall simulation experiments discussed below.

### *Soil nitrogen*

The effect of increasing rates of amendment addition on total soil N is illustrated in Figure 6. The ANOVA output tables for this data are given in Tables 12a (Standard ANOVA) and Table 12b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

Soil concentrations of total N increased significantly with the application of all amendments. Total soil N concentrations in the amended soils exceed the control at rates of application above 10 t/ha for MWOO, green waste and composted biosolids, and at 10 t/ha for the poultry manure amended soil.

Concentrations of total N in soil greater than 1,500 mg/kg (0.15 %) are considered to be in the medium range and concentrations above 5,000 mg/kg (0.5%) are considered to be very high (Hazelton and Murphy 2007). Total N concentrations in the medium range were reached with the incorporation of amendments at rates of between 20 and 60 t/ha for the MWOO, composted green waste and composted biosolids treatments, and with as little as 10 t/ha for the poultry manure treatment. Incorporated treatment application rates above 60 t/ha, for MWOO 1 and MWOO 2 and for the poultry manure, pushed N concentrations into the high range and for the green waste treatment at an application of 200 t/ha.

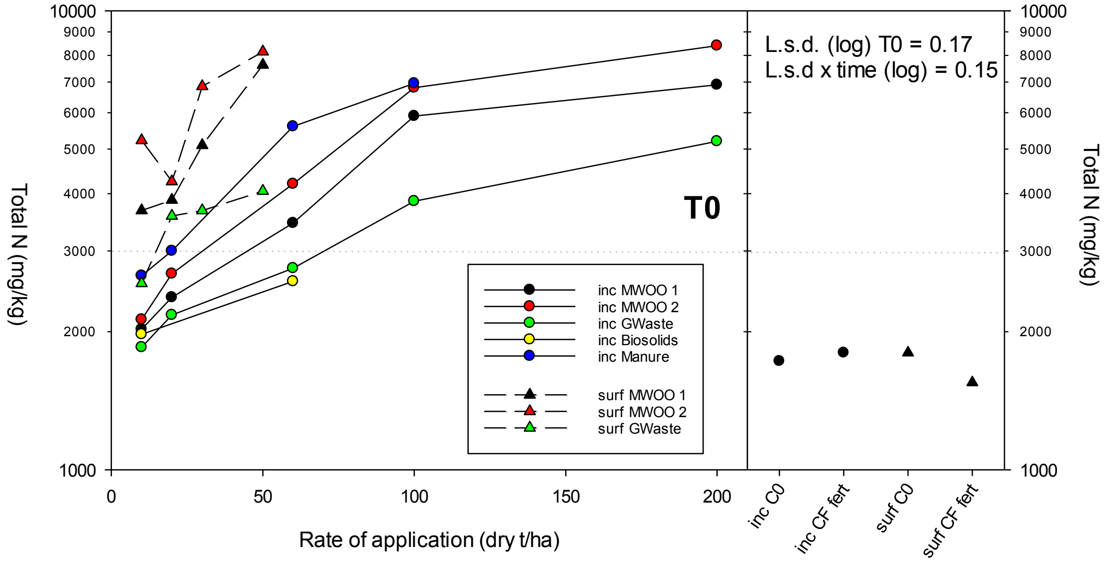


**Figure 6:** Increases in total soil N (T0) with increasing rates of MWOO compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated on x-axis for each treatment.

For surface application treatments, application rates of 10 t/ha resulted in medium soil N concentrations, and reached the high range with applications above 30 t/ha, for the MWOO 1 and

MWOO 2 treatments. No surface application of green waste elevated total soil N concentrations into the high range.

**Table 12a:** ANOVA output table for Total soil N

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.34 | 0.11 | 4.97 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 17.85 | 0.50 | 21.76 | <.001 |
| Residual | 108 | | 2.46 | 0.02 | 3.09 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 1.08 | 0.36 | 48.97 | <.001 |
| trtID.time | 60 | -48 | 1.02 | 0.02 | 2.31 | <.001 |
| Residual | 189 | -144 | 1.39 | 0.01 | | |
| Total | 399 | -192 | 17.77 | | | |

**Table 12b:** Repeated measures ANOVA output table for Colwell P

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.34 | 0.11 | 4.97 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.00 | 0.00 | 0.06 | 0.808 |
| IncVSurf.IncTrts | 6 | | 2.96 | 0.49 | 21.66 | <.001 |
| IncVSurf.SurfTrts | 4 | | 2.87 | 0.72 | 31.49 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 2.88 | 0.72 | 31.57 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 3.81 | 0.95 | 41.78 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 1.83 | 0.46 | 20.1 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 1.63 | 0.54 | 23.9 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.09 | 0.09 | 3.97 | 0.049 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.72 | 0.24 | 10.54 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 0.89 | 0.30 | 13.07 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.36 | 0.12 | 5.24 | 0.002 |
| Residual | 108 | | 2.46 | 0.02 | 3.09 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 1.58 | 0.53 | 71.35 | <.001 |
| IncVSurf.time | 2 | -1 | 0.20 | 0.10 | 13.67 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.33 | 0.02 | 2.96 | <.001 |
| IncVSurf.SurfTrts.time | 7 | -5 | 0.32 | 0.05 | 6.17 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 9 | -3 | 0.04 | 0.00 | 0.66 | 0.745 |
| IncVSurf.IncTrts.incMW002.time | 5 | -7 | 0.04 | 0.01 | 1.2 | 0.309 |
| IncVSurf.IncTrts.incGW.time | 5 | -7 | 0.01 | 0.00 | 0.38 | 0.86 |
| IncVSurf.IncTrts.incManure.time | 4 | -5 | 0.10 | 0.02 | 3.25 | 0.013 |
| IncVSurf.IncTrts.incCBio.time | 1 | -2 | 0.00 | 0.00 | 0.06 | 0.804 |
| IncVSurf.SurfTrts.surfMW001.time | 6 | -3 | 0.02 | 0.00 | 0.44 | 0.852 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.05 | 0.02 | 2.27 | 0.081 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.02 | 0.01 | 0.79 | 0.502 |
| Residual | 189 | -144 | 1.39 | 0.01 | | |
| Total | 399 | -192 | 17.77 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Soil total organic carbon*

The effect of increasing rates of amendment addition on TOC is illustrated in Figure 7. The ANOVA output tables for this data are given in Tables 13a (Standard ANOVA) and Table 13b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

All of the amendment materials contain significant quantities of total organic carbon (TOC), which is a desirable input into impoverished soils (see Table 5). As with other nutrient parameters discussed above, the measured concentrations of TOC increased with the application of all amendments and increased with increasing application rates.

For the T0 sampling, soil TOC concentrations increased markedly with the incorporation of the MWOO, composted green waste and manure amendments, although these concentrations were not significantly greater than control concentrations until rates of application exceeded 60 t/ha for MWOO 1 and MWOO 2, green waste and the poultry manure treatment. TOC concentrations were 4-fold higher at an MWOO application of 200 t/ha and 3.5-fold higher for an equivalent composted green waste application. The concentrations of TOC in the composted biosolids treatments were not significantly different from control concentrations.

For surface application treatments, a 10 t/ha application of MWOO 1, MWOO 2 and green waste, increased soil TOC concentrations above the control level. A surface 50 t/ha application of MWOO 1 resulted in a greater than 5-fold increase in soil TOC, while a similar rate of application of composted green waste resulted in a 3-fold increase in soil TOC.

Analysis of the data for the T2 and T3 sample times shows that there has been a significant drop in soil TOC, post-amendment application (Figure 7 and Table 13b). Although still higher than control TOC concentrations, the TOC concentrations in MWOO and green waste amended soils has dropped by almost 30% at the high application rates, and is more than 50% lower in the poultry manure treatments. Clemente et.al. (2006) found that the organic matter present in a compost amended soil was more resistant to degradation than that amended with fresh cow manure, because there was less easily degradable C in the compost material. This finding may explain why the drop in TOC for manure treatments was larger than for other amendments.

The decrease in soil TOC is also significant for the surface applied treatments of MWOO 1 and MWOO 2, where for the 50 t/ha applications, the soil TOC level had dropped by 50% of the initial TOC content by time T2. While some of the observed decrease in TOC in the surface applied treatments could be attributed to soil mixing associated with crop establishment activities such as cultivation, there is an obvious difference in TOC persistence between surface and incorporated treatments (Table 13b) and there appears to be a much higher rate of TOC degradation seen in the surface applied treatments than normally reported for mature composts (e.g. Bernal et.al. 1998). It is also possible that the breakdown of TOC in the surface applied materials may be accelerated due to exposure to sunlight (UV) and other environmental factors such as wider differences in temperature.

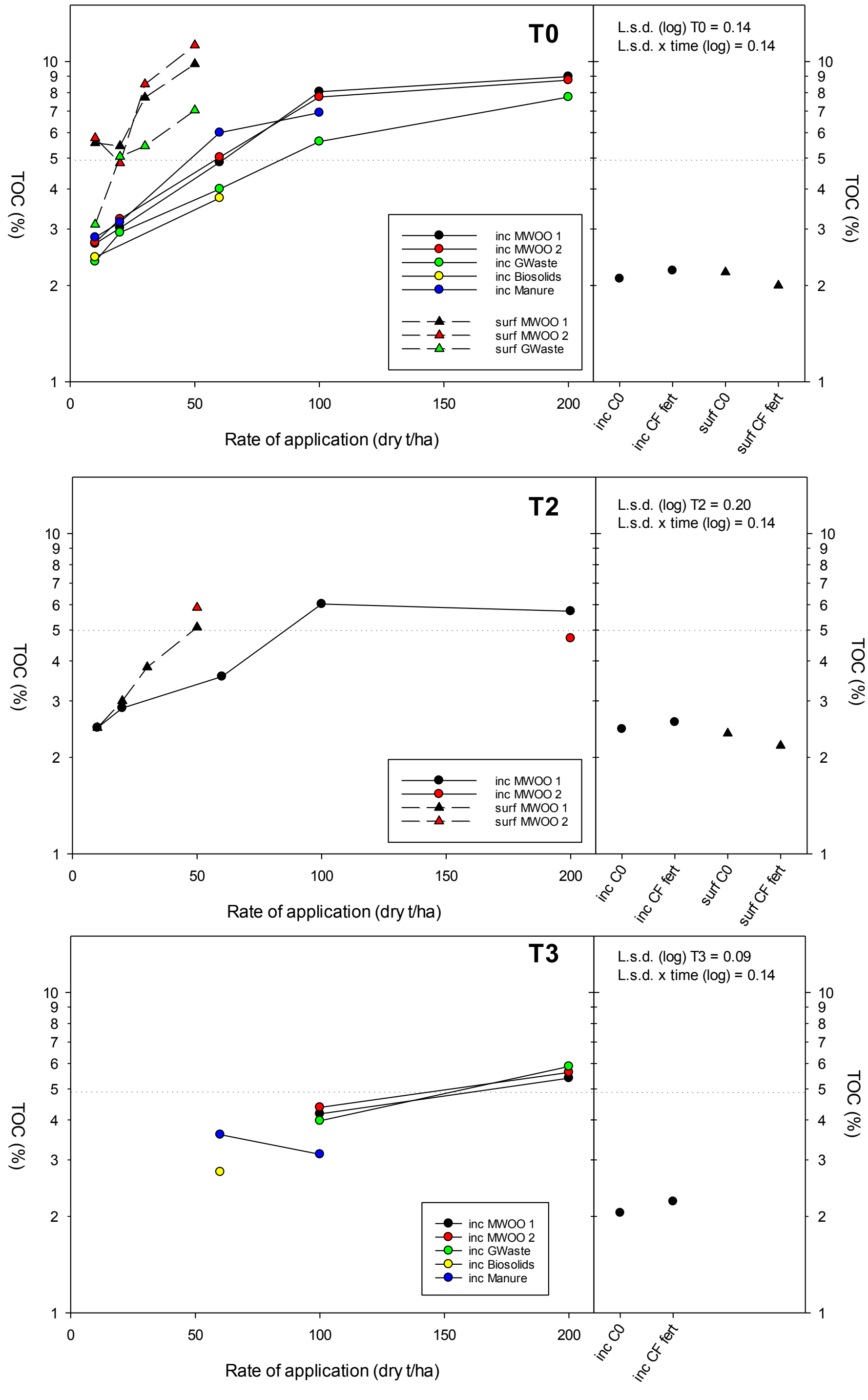


**Figure 7:** Changes in soil TOC over time (T0, T2 and T3) with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

**Table 13a:** ANOVA output table for TOC

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.33 | 0.11 | 5.04 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 16.03 | 0.45 | 20.52 | <.001 |
| Residual | 108 | | 2.34 | 0.02 | 3.15 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 2.38 | 0.79 | 115.33 | <.001 |
| trtID.time | 60 | -48 | 1.43 | 0.02 | 3.46 | <.001 |
| Residual | 189 | -144 | 1.30 | 0.01 | | |
| Total | 399 | -192 | 17.35 | | | |

**Table 13b:** Repeated measures ANOVA output table for TOC

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.33 | 0.11 | 5.04 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.27 | 0.27 | 12.65 | <.001 |
| IncVSurf.IncTrts | 6 | | 1.97 | 0.33 | 15.14 | <.001 |
| IncVSurf.SurfTrts | 4 | | 2.63 | 0.66 | 30.28 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 2.54 | 0.63 | 29.21 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 2.86 | 0.72 | 32.98 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 2.21 | 0.55 | 25.48 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 1.25 | 0.42 | 19.16 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.19 | 0.19 | 8.94 | 0.003 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.82 | 0.27 | 12.52 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 1.20 | 0.40 | 18.36 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.77 | 0.26 | 11.85 | <.001 |
| Residual | 108 | | 2.34 | 0.02 | 3.15 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 3.47 | 1.16 | 168 | <.001 |
| IncVSurf.time | 2 | -1 | 0.31 | 0.16 | 22.57 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.89 | 0.06 | 8.59 | <.001 |
| IncVSurf.SurfTrts.time | 7 | -5 | 0.40 | 0.06 | 8.32 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 9 | -3 | 0.06 | 0.01 | 1.04 | 0.409 |
| IncVSurf.IncTrts.incMW002.time | 5 | -7 | 0.05 | 0.01 | 1.43 | 0.214 |
| IncVSurf.IncTrts.incGW.time | 5 | -7 | 0.03 | 0.01 | 0.78 | 0.562 |
| IncVSurf.IncTrts.incManure.time | 4 | -5 | 0.07 | 0.02 | 2.7 | 0.032 |
| IncVSurf.IncTrts.incCBio.time | 1 | -2 | 0.00 | 0.00 | 0.48 | 0.49 |
| IncVSurf.SurfTrts.surfMW001.time | 6 | -3 | 0.03 | 0.01 | 0.78 | 0.589 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.02 | 0.01 | 0.95 | 0.42 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.02 | 0.01 | 0.98 | 0.404 |
| Residual | 189 | -144 | 1.30 | 0.01 | | |
| Total | 399 | -192 | 17.35 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Soil contaminants - heavy metals

### *Total soil metals*

Total soil metal concentrations for time T0 are presented in Table 14. Also included with this data is the l.s.d. (trt x time) for each metal at $p<0.05$ following repeated measures analysis of variance, as well as the MACC for each element (NSW EPA 2014a). Soil metal concentrations measured in at all sampling times (T0, T1, T2 and T3) are given in Appendices 5a (T0), 5b (T1), 5c (T2) and 5d (T3).

The metal concentrations found in the amendments has been discussed earlier in this report (Table 5), where it was shown that MWOO materials contained significant amounts of Cd (2.6 – 3.4 mg/kg), Cu (82 – 100 mg/kg), Pb (220 – 280 mg/kg) and Zn (600 - 700 mg/kg); concentrations that are generally greater than, those in the other amendment materials evaluated in this trial (see Table 5). It is therefore not unexpected that soil metal concentrations would increase when the materials were applied to the trial soils and that this increase would vary between the different metals and amendments used. Also as expected, metals concentrations increased with application rate.

Following application, soil metal concentrations were below the Resource Recovery Exemption Order for MWOO maximum allowable contaminant concentrations (MACC's) (NSW EPA 2014a), for all metals applied with green waste, composted biosolids and poultry manure treated soils, even where these were applied at rates up to 200 t/ha for the composted green waste amendment.

For the MWOO treatments at application rates up to 200 t/ha (incorporated), and 50 t/ha (surface applied), concentrations of Cr, Ni and Pb were below the corresponding MACC value. However, the MACCs were exceeded for Cd (Figure 8), Cu (Figure 9) and Zn (Figure 10). These three contaminant elements have been identified as having the greatest potential to adversely impact food production or soil health, following the application of various amendments, including compost and biosolids (McLaughlin et.al. 2000). Hence, our discussion on metal contaminants will focus mainly on these three heavy metal elements.

The effect of increasing rates of amendment addition on soil Cd concentration is illustrated in Figure 8. The ANOVA output tables for this data are given in Tables 15a (Standard ANOVA) and Table 15b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

Data presented from the initial T0 sampling show that soil concentrations of Cd increased above those of the control soils, with increasing rates of MWOO 1, MWOO 2 and green waste application, although this effect was not significant for the composted biosolids and the poultry manure treatments. Surface applied treatments had a greater impact on soil Cd concentrations than for incorporated treatments, as the amendment materials had not been mixed with the soil, but rather the amendments had been left on the soil surface. Total Cd concentrations measured in MWOO treated soils (Figure 8) for the incorporated 60 t/ha application raised the soil Cd concentration to between 40% (MWOO 2) and 62% (MWOO 1) of the Cd MACC (see Figure 8). The Cd MACC was exceeded at rates of 100 t/ha (140%) for MWOO 1 and at 200 t/ha (105%) for MWOO 2. For surface applied treatments, the application needed to raise soil Cd above the Cd MACC were lower; 30 t/ha for MWOO 1 (108%) and 50 t/ha MWOO 2 (124%).

Further analysis of the data presented in Figure 8 and Table 15b (and Appendices 5a, 5b and 5c), show that soil Cd concentrations have declined in the top 7.5 cm of the plots during period since the amendments were first applied to the soil (T0 to T3). Measured soil concentrations of Cd were significantly lower for incorporated MWOO 1 and MWOO 2 applied at rates above 20 t/ha and are now below the Cd MACC for all incorporated treatments. For the surface applied MWOO 1 and MWOO 2, the decline in soil Cd in the top 7.5 cm is more pronounced and concentrations for all application rates (10 – 50 t/ha), are now consistent with the Cd concentrations measured in the incorporation treatments (Figure 8). There were no significant changes in soil Cd over time for the biosolids and poultry manure treatments and only at the highest rates for green waste application.

**Table 14:** Average (T0) soil heavy metal concentrations (mg/kg) following application of amendments to the treatment plots. Included also are the l.s.d. values (in bold type) for each metal following analysis of variance at p<0.05. Included is the soil maximum allowable contaminant concentration (MACC) for each metal as per NSW EPA Resource Recovery Exemption for MWOO (NSW EPA 12014). MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.

| **Application, treatment and rate** | **Cd** | **Cr** | **Cu** | **Ni** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|
| | | | **mg/kg** | | | |
| inc C 0 | 0.08 | 15.3 | 14.2 | 7.5 | 16.0 | 21.7 |
| inc CF fert | 0.09 | 17.8 | 16.0 | 7.6 | 18.2 | 21.3 |
| inc MWOO1 10 | 0.19 | 16.5 | 24.9 | 8.6 | 24.2 | 40.2 |
| inc MWOO1 20 | 0.26 | 17.9 | 29.6 | 8.5 | 29.4 | 52.1 |
| inc MWOO1 60 | 0.62 | 23.8 | 78.3 | 12.2 | 63.0 | 117.2 |
| inc MWOO1 100 | 1.41 | 31.3 | 134.9 | 16.8 | 113.7 | 241.2 |
| inc MWOO1 200 | 1.43 | 31.1 | 158.3 | 21.0 | 128.6 | 275.3 |
| inc MWOO2 10 | 0.15 | 17.6 | 24.2 | 9.1 | 23.9 | 45.7 |
| inc MWOO2 20 | 0.24 | 19.6 | 32.4 | 10.7 | 31.2 | 68.2 |
| inc MWOO2 60 | 0.40 | 22.9 | 50.8 | 12.4 | 45.8 | 124.1 |
| inc MWOO2 100 | 0.87 | 25.9 | 100.8 | 19.0 | 83.7 | 264.1 |
| inc MWOO2 200 | 1.05 | 27.3 | 117.9 | 20.5 | 102.7 | 325.8 |
| inc GW 10 | 0.10 | 20.8 | 15.4 | 9.9 | 17.2 | 23.1 |
| inc GW 20 | 0.09 | 23.3 | 17.4 | 12.7 | 17.4 | 26.5 |
| inc GW 60 | 0.13 | 18.5 | 18.2 | 9.2 | 18.9 | 36.4 |
| inc GW 100 | 0.15 | 21.0 | 22.8 | 11.3 | 23.7 | 49.8 |
| inc GW 200 | 0.47 | 24.8 | 32.2 | 11.5 | 30.5 | 84.6 |
| inc Bio 10 | 0.10 | 21.3 | 19.4 | 11.5 | 16.4 | 28.3 |
| inc Bio 60 | 0.13 | 20.2 | 29.1 | 11.9 | 19.4 | 43.3 |
| inc Man 10 | 0.08 | 18.5 | 19.1 | 10.8 | 14.4 | 37.9 |
| inc Man 20 | 0.08 | 21.5 | 21.5 | 12.1 | 16.5 | 46.8 |
| inc Man 60 | 0.09 | 18.4 | 36.3 | 10.9 | 13.5 | 124.3 |
| inc Man 100 | 0.09 | 22.8 | 44.6 | 13.6 | 15.0 | 157.0 |
| surf C 0 | 0.07 | 17.7 | 14.8 | 8.0 | 18.3 | 21.1 |
| surf CF fert | 0.08 | 18.1 | 14.5 | 7.7 | 18.0 | 21.2 |
| surf MWOO1 10 | 0.76 | 24.3 | 74.9 | 12.2 | 64.7 | 134.4 |
| surf MWOO1 20 | 0.61 | 21.6 | 71.0 | 11.9 | 65.2 | 133.4 |
| surf MWOO1 30 | 1.08 | 28.8 | 128.2 | 15.5 | 99.9 | 210.7 |
| surf MWOO1 50 | 1.40 | 29.0 | 147.2 | 17.9 | 126.2 | 265.4 |
| surf MWOO2 10 | 0.63 | 38.9 | 78.6 | 21.3 | 70.4 | 203.0 |
| surf MWOO2 20 | 0.39 | 31.6 | 50.7 | 18.4 | 43.1 | 123.6 |
| surf MWOO2 30 | 0.77 | 23.1 | 98.4 | 16.7 | 79.4 | 257.4 |
| surf MWOO2 50 | 1.24 | 35.8 | 144.9 | 27.9 | 109.8 | 374.4 |
| surf GW 10 | 0.11 | 17.9 | 17.1 | 9.1 | 18.1 | 31.4 |
| surf GW 20 | 0.15 | 17.7 | 21.6 | 9.7 | 20.4 | 44.5 |
| surf GW 30 | 0.18 | 20.1 | 22.5 | 9.8 | 23.3 | 51.5 |
| surf GW 50 | 0.22 | 22.1 | 33.4 | 11.3 | 29.4 | 69.8 |
| **MACC (NSW EPA 2014[*])** | **1** | **100** | **100** | **60** | **150** | **200** |
| *trans* | ***log*** | ***none*** | ***log*** | ***sqrt*** | ***log*** | ***log*** |
| ***l.s.d. trt x time*** | ***0.22*** | ***15.5*** | ***0.18*** | ***0.61*** | ***0.15*** | ***0.19*** |

[*] Table 2, Maximum allowable soil contaminant concentration for non-contact and broad acre agriculture, NSW EPA 2014

It is likely that the reduction in measured soil metal concentrations is a result of repeated mixing (particularly for surface treatments), associated with seed bed preparation and crop cultivation activities. Vision of the high rate incorporation treatment s (Plate 5) and surface treatments (Plates 4a and 4b), reveal large amounts of the MWOO material initially remaining on the soil surface, only to be further mixed and incorporated with the underlying soil with subsequent cropping activities.

Potential subsurface movement of contaminants was assessed at time T3 and is discussed in some detail elsewhere in this report

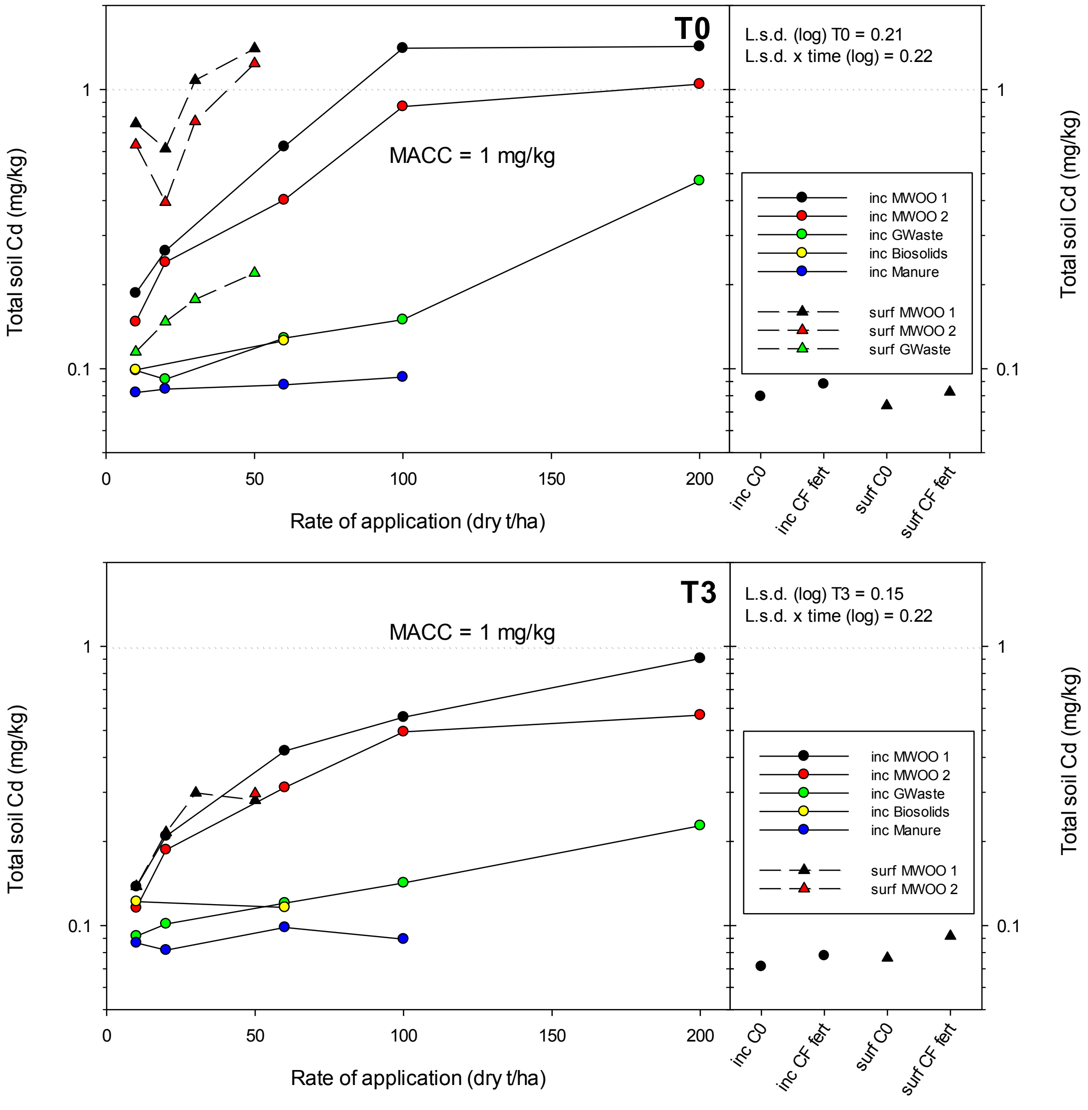


**Figure 8:** Total soil Cd concentrations resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Critical maximum allowable soil contaminant concentration for non-contact and broad acre agriculture (MACC = 1 mg Cd /kg soil, NSW EPA 2014) indicated on Figure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser.

**Table 15a:** ANOVA output table for Total soil Cd

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.24 | 0.41 | 10.42 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 74.22 | 2.06 | 52.15 | <.001 |
| Residual | 108 | | 4.27 | 0.04 | 2.06 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 2.52 | 0.84 | 43.69 | <.001 |
| trtID.time | 79 | -29 | 4.51 | 0.06 | 2.97 | <.001 |
| Residual | 246 | -87 | 4.72 | 0.02 | | |
| Total | 475 | -116 | 81.98 | | | |

**Table 15b:** Repeated measures ANOVA output table for Total Soil Cd

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.24 | 0.41 | 10.42 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.51 | 0.51 | 12.82 | <.001 |
| IncVSurf.IncTrts | 6 | | 31.49 | 5.25 | 132.74 | <.001 |
| IncVSurf.SurfTrts | 4 | | 19.79 | 4.95 | 125.14 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 9.45 | 2.36 | 59.76 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 6.93 | 1.73 | 43.85 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 2.57 | 0.64 | 16.25 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 0.03 | 0.01 | 0.28 | 0.839 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.05 | 0.05 | 1.3 | 0.257 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.93 | 0.64 | 16.31 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 2.01 | 0.67 | 16.94 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.61 | 0.20 | 5.18 | 0.002 |
| Residual | 108 | | 4.27 | 0.04 | 2.06 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 3.83 | 1.28 | 66.56 | <.001 |
| IncVSurf.time | 3 | | 2.30 | 0.77 | 39.93 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.62 | 0.04 | 2.16 | 0.008 |
| IncVSurf.SurfTrts.time | 10 | -2 | 1.40 | 0.14 | 7.29 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.30 | 0.03 | 1.3 | 0.217 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.15 | 0.02 | 0.97 | 0.46 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.13 | 0.02 | 0.82 | 0.583 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.07 | 0.01 | 0.59 | 0.737 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.03 | 0.01 | 0.65 | 0.522 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.57 | 0.06 | 3.29 | <.001 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.09 | 0.03 | 1.51 | 0.213 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.01 | 0.00 | 0.25 | 0.858 |
| Residual | 246 | -87 | 4.72 | 0.02 | | |
| Total | 475 | -116 | 81.98 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

The effect of increasing rates of amendment addition on soil Cu is illustrated in Figure 9. The ANOVA output tables for this data are given in Tables 16a (Standard ANOVA) and Table 16b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

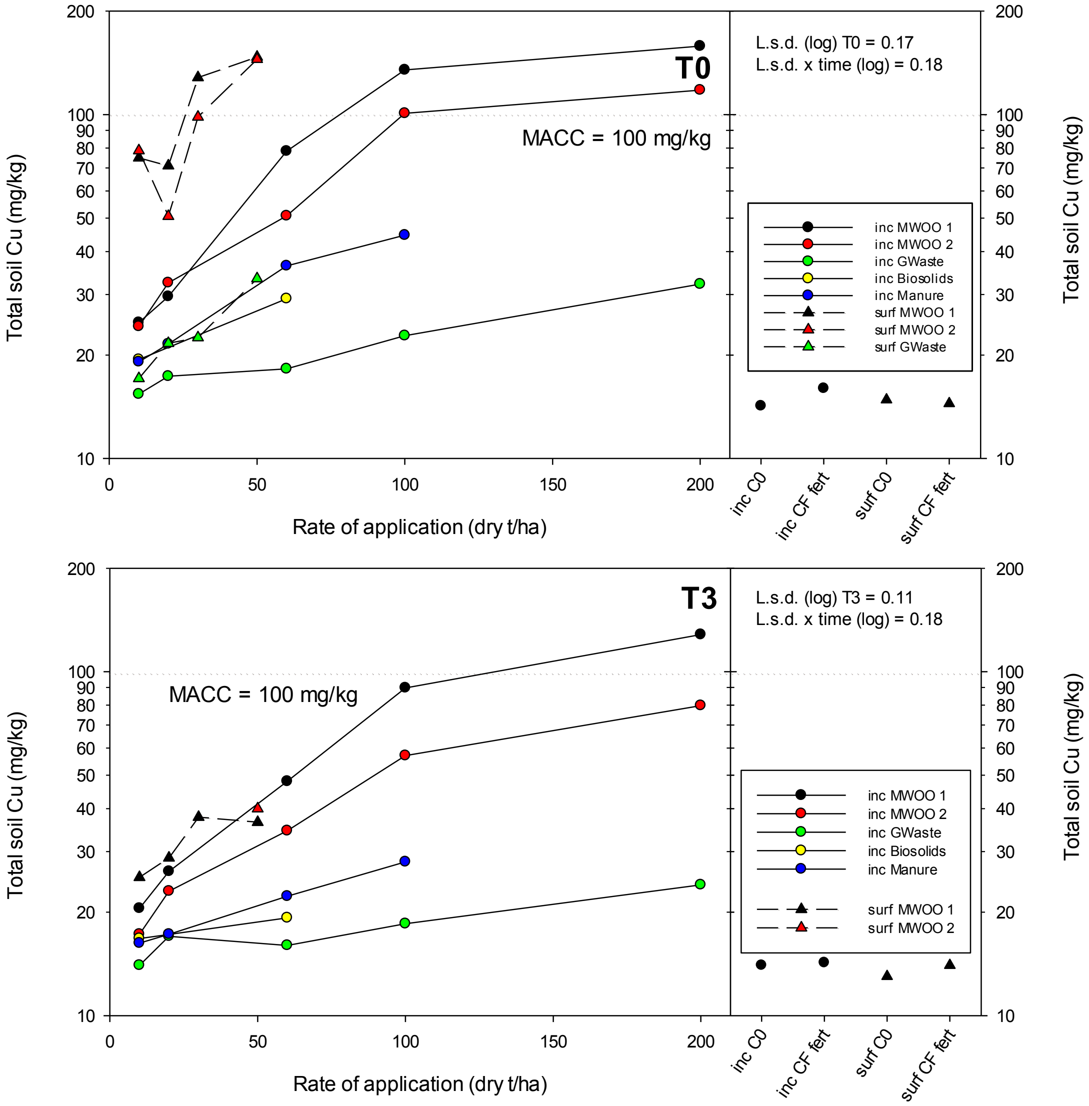


**Figure 9:** Total soil Cu concentrations resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Critical maximum allowable soil contaminant concentration for non-contact and broad acre agriculture (MACC = 100 mg Cu /kg soil, NSW EPA 2014) indicated on Figure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser.

Data presented from the initial T0 sampling show that soil concentrations of Cu increased above those of the control soils, with increasing application rates of MWOO 1, MWOO 2, green waste, composted biosolids and poultry manure. Surface applied treatments had a greater impact on soil Cu concentrations than for incorporated treatments, as the amendment materials had not been mixed with the soil, but rather the amendments had been left on the soil surface.

For Cu (Figure 9), a 60 t/ha incorporation application of MWOO resulted an increase of soil Cu of between 50% (MWOO 1) and 78% (MWOO 2) of the Cu MACC, and this limit was exceeded at application rates above 100 t/ha for both MWOO materials. Similar to Cd, the soil Cu MACC was

**Table 16a:** ANOVA output table for Total soil Cu

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.24 | 0.08 | 2.97 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 50.02 | 1.39 | 52.38 | <.001 |
| Residual | 108 | | 2.87 | 0.03 | 1.83 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 2.96 | 0.99 | 67.91 | <.001 |
| trtID.time | 79 | -29 | 2.88 | 0.04 | 2.51 | <.001 |
| Residual | 245 | -88 | 3.56 | 0.01 | | |
| Total | 474 | -117 | 54.94 | | | |

**Table 16b:** Repeated measures ANOVA output table for Total Soil Cu

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.24 | 0.08 | 2.97 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.03 | 0.03 | 1.28 | 0.26 |
| IncVSurf.IncTrts | 6 | | 17.71 | 2.95 | 111.25 | <.001 |
| IncVSurf.SurfTrts | 4 | | 14.18 | 3.55 | 133.65 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 8.26 | 2.07 | 77.86 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 5.16 | 1.29 | 48.6 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 0.68 | 0.17 | 6.43 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 1.01 | 0.34 | 12.74 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.16 | 0.16 | 5.93 | 0.017 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.52 | 0.51 | 19.08 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 2.01 | 0.67 | 25.3 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.40 | 0.13 | 4.99 | 0.003 |
| Residual | 108 | | 2.87 | 0.03 | 1.83 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 4.21 | 1.40 | 96.72 | <.001 |
| IncVSurf.time | 3 | | 1.43 | 0.48 | 32.72 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.26 | 0.02 | 1.18 | 0.287 |
| IncVSurf.SurfTrts.time | 10 | -2 | 0.88 | 0.09 | 6.07 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.38 | 0.03 | 2.21 | 0.012 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.10 | 0.01 | 0.9 | 0.52 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.02 | 0.00 | 0.17 | 0.994 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.05 | 0.01 | 0.54 | 0.777 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.02 | 0.01 | 0.61 | 0.547 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.36 | 0.04 | 2.73 | 0.005 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.09 | 0.03 | 2.09 | 0.103 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.02 | 0.01 | 0.4 | 0.754 |
| Residual | 245 | -88 | 3.56 | 0.01 | | |
| Total | 474 | -117 | 54.94 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

exceeded at much lower application rates for the surface treatments; 30 t/ha for MWOO1 (135% above the MACC) and 50 t/ha for MWOO 2 (144% Above the MACC). No application of green waste, composted biosolids or poultry manure exceeded the MACC for Cu.

Further analysis of the data presented in Figure 9 and Table 16b (and Appendices 5a, 5b and 5c), show that soil Cu concentrations have declined in the top 7.5 cm of the plots during period since the amendments were first applied to the soil (T0 to T3). Measured soil concentrations of Cu were significantly lower for incorporated MWOO 1 and MWOO 2 applied at rates above 60 t/ha and are now below the Cu MACC for all incorporated treatments, except for the 200 t/ha MWOO 1. For the surface applied MWOO 1 and MWOO 2, the decline in soil Cu in the top 7.5 cm is more pronounced and concentrations for all application rates (10 – 50 t/ha), are now consistent with the incorporation treatments (Figure 9). There were also declines in soil Cu over time for the green waste, biosolids and poultry manure treatments.

Again, we suggest that the reduction in measured soil metal concentrations, particularly for those in the surface applied MWOO treatments, is a result of repeated associated with seed bed preparation and crop cultivation activities.

The effect of increasing rates of amendment addition on soil Zn is illustrated in Figure 10. The ANOVA output tables for this data are given in Tables 17a (Standard ANOVA) and Table 17b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

As with Cd and Cu discussed above, data presented from the initial T0 sampling show that soil concentrations of Zn increased above those of the control soils and increased with increasing application rates of MWOO 1, MWOO 2, green waste and poultry manure, but that this increase was not as significant for the composted biosolids treatment (Table 12b). Surface applied treatments had a greater impact on soil Zn concentrations than for incorporated treatments, as the amendment materials had not been mixed with the soil, but rather the amendments had been left on the soil surface.

Total Zn concentrations measured in MWOO treated soils (Figure 10) for the incorporated 60 t/ha application raised the soil Zn concentration to between 60% (MWOO 1) and 62% (MWOO 2) of the Zn MACC (see Figure 10). The Zn MACC was exceeded at rates of 100 t/ha (120%) for MWOO 1 (130%) for MWOO 2. For surface applied treatments, the application needed to raise soil Zn concentrations above the Zn MACC were lower; 30 t/ha for MWOO 1 (105%) and 30 t/ha MWOO 2 (130%).

Further analysis of the data presented in Figure 10 and Table 17b, show that soil Zn concentrations have declined in the top 7.5 cm of the plots during period since the amendments were first applied to the soil (T0 to T3). Measured soil concentrations of Zn were significantly lower for incorporated MWOO 1 and MWOO 2 applied at rates above 60 t/ha and are now below the Zn MACC for the 100 t/ha incorporated treatments, but remain above the Zn MACC for the 200 t/ha applications of both MWOO 1 and MWOO 2. For the surface applied MWOO 1 and MWOO 2, the decline in soil Zn in the top 7.5 cm is more pronounced and concentrations for all application rates (10 – 50 t/ha), are now consistent with the incorporation treatments (Figure 10). There were also significant decreases in soil Zn over time for the incorporated green waste, biosolids and poultry manure treatments.

Again, we suggest that the reduction in measured soil metal concentrations, particularly for those in the surface applied MWOO treatments, is a result of repeated associated with seed bed preparation and crop cultivation activities.

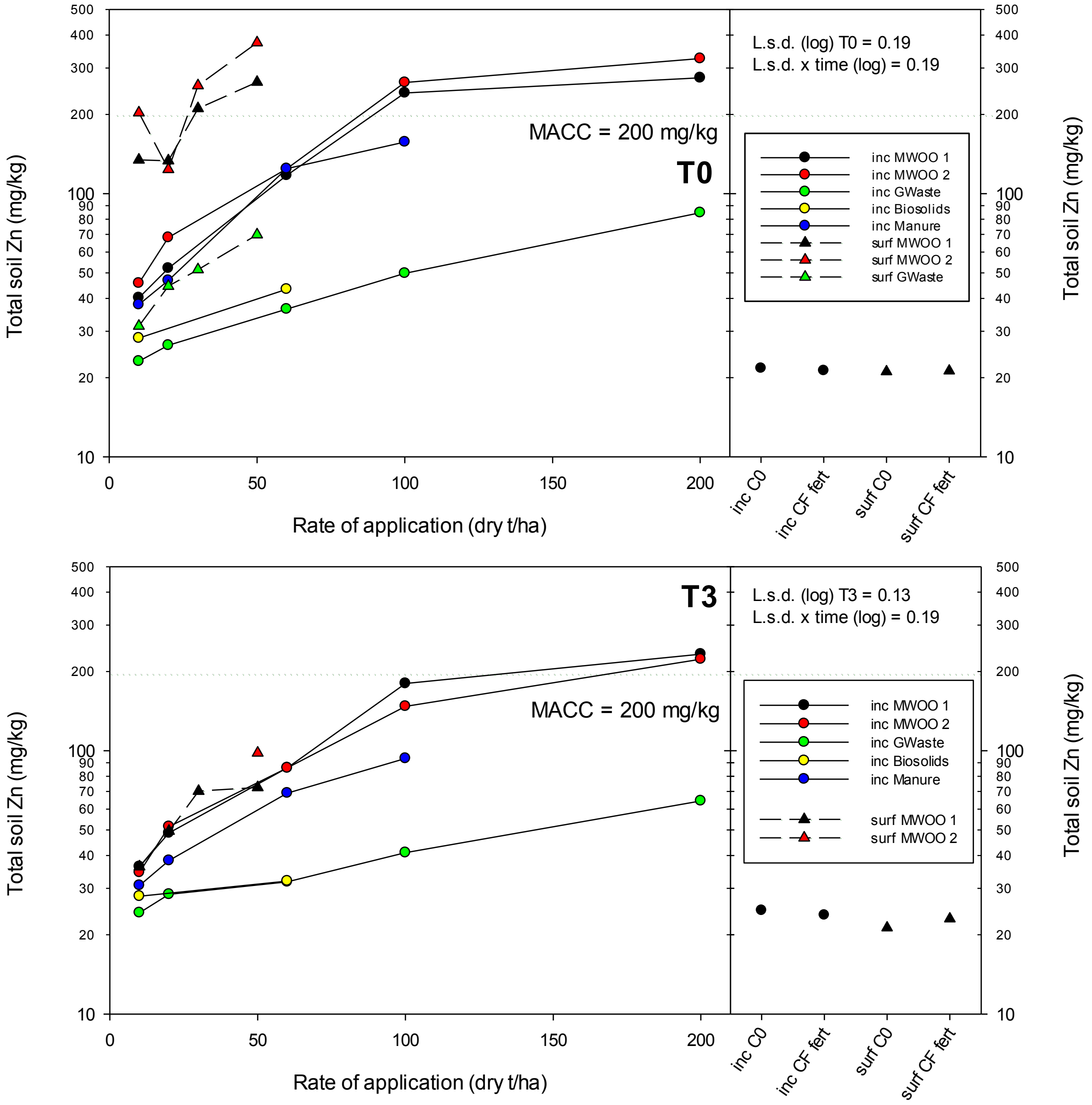


**Figure 10:** Total soil Zn concentrations resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Critical maximum allowable soil contaminant concentration for non-contact and broad acre agriculture (MACC = 200 mg Zn /kg soil, NSW EPA 2014) indicated on Figure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser.

**Table 17a:** ANOVA output table for Total soil Zn

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.32 | 0.44 | 11.64 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 68.17 | 1.89 | 49.94 | <.001 |
| Residual | 108 | | 4.09 | 0.04 | 3.17 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 3.03 | 1.01 | 84.43 | <.001 |
| trtID.time | 79 | -29 | 3.10 | 0.04 | 3.28 | <.001 |
| Residual | 246 | -87 | 2.94 | 0.01 | | |
| Total | 475 | -116 | 71.81 | | | |

**Table 17b:** Repeated measures ANOVA output table for Total Soil Zn

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.32 | 0.44 | 11.64 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.11 | 0.11 | 3 | 0.086 |
| IncVSurf.IncTrts | 6 | | 22.17 | 3.70 | 97.46 | <.001 |
| IncVSurf.SurfTrts | 4 | | 17.26 | 4.32 | 113.8 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 9.24 | 2.31 | 60.91 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 7.56 | 1.89 | 49.82 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 2.55 | 0.64 | 16.8 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 3.60 | 1.20 | 31.63 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.18 | 0.18 | 4.77 | 0.031 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.93 | 0.64 | 16.98 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 2.93 | 0.98 | 25.75 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.87 | 0.29 | 7.61 | <.001 |
| Residual | 108 | | 4.09 | 0.04 | 3.17 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 4.39 | 1.46 | 122.23 | <.001 |
| IncVSurf.time | 3 | | 1.81 | 0.60 | 50.5 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 0.33 | 0.02 | 1.86 | 0.028 |
| IncVSurf.SurfTrts.time | 10 | -2 | 1.30 | 0.13 | 10.88 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.11 | 0.01 | 0.74 | 0.715 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.11 | 0.01 | 1.1 | 0.364 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.04 | 0.00 | 0.41 | 0.914 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.09 | 0.02 | 1.27 | 0.273 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.02 | 0.01 | 0.78 | 0.458 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.27 | 0.03 | 2.5 | 0.009 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.14 | 0.05 | 3.78 | 0.011 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.00 | 0.00 | 0.09 | 0.968 |
| Residual | 246 | -87 | 2.94 | 0.01 | | |
| Total | 475 | -116 | 71.81 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Metal contaminant extractability using 0.01 M $CaCl_2$ extracts*

Total soil metal concentrations by themselves, may have only limited usefulness in assessing metal risk to the soil ecosystem, due to the large effect of soil type in moderating metal toxicity (McLaughlin et.al. 2000). Various soil extracts have been used to assess soil metal bioavailability (for reviews see Beckett 1989; National Research Council 2003). Extraction of soil metals with neutral salts such as $CaCl_2$ (e.g. Mench et.al.1994, Houba et.al. 2000), has gained popularity as an estimator of metal bioavailability in soils as amounts of soil metals extracted are often well correlated with measured biological responses such as plant uptake, or microbial activity. At the same time, the amounts extracted using these methods can also be used to give an estimation of the soil's ability to partition various metal elements between the soil solution (bioavailable), and the soil solid phase (unavailable), thus giving an indication of whether any potentially adverse impacts on the soil and environment are reduced over time or as a result of treatment application to the soil e.g. following a shift in soil pH. Therefore, we used $CaCl_2$ extracts to estimate the amounts of potentially bioavailable metals in amended soils and to also allow some insight as to whether the amounts found in this bioavailable fraction alter with time.

Generally, the concentrations of Ca-extractable metals increased initially with the application of the various amendments used in this trial and increased with increasing application rate. Concentrations of Ca-extractable metals were often higher than those in control soils and these were initially different for different amendment materials. Over time, the concentrations of Ca-extractable metal decreased.

The effect of increasing rates of amendment addition on the Ca-extractability of soil Cd is illustrated in Figure 11. The ANOVA output tables for this data are given in Tables 18a (Standard ANOVA) and Table 18b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Data is presented for the T0 and T3 sampling times.

Initially, the concentrations of Ca-extractable Cd increased with increasing rates of MWOO 1 application and ranged between 0.001 and 0.021 (mg/kg). Concentrations were lower in the MWOO 2 amended soils. Conversely, concentrations of Ca-extractable Cd decreased with increasing applications of incorporated green waste, manure and composted biosolids and concentrations were lower than control soils for these treatments. Surface applied MWOO 1 and MWOO 2 resulted in higher amounts of Ca-extractable Cd (4.4- fold higher), than the incorporated treatments, but were only just significantly different from the control soils.

In contrast, the data presented in Figure 11 also shows that the by the time of the T3 sampling, concentrations of Ca-extractable Cd have decreased. The decrease was seen for all amendments, incorporated and surface applied, except for the composted biosolids treatment, for which no significant change was measured (see also Table Figure 18b). By the time of the T3 sampling (Figure 11), there is no difference between incorporated and surface treatments, and that Cd extractability decreases with increasing rates of MWOO application.

It has often been reported that the soil application of organic amendments such as biosolids, is followed by an immediate increase in soil metal concentrations including a 'flush' of bioavailable or easily extractable metals (Wallan and Beckett 1979; Logan et.al.1997), which is then followed by a reduction in metal availability (Chaney 1990). It is widely reported that soil metal bioavailability decreases with time following application (Dalloway 1995). Similar relationships have been seen with biosolids application (Chaney 1990) and could in part be due to the pH increase observed in these plots as discussed earlier in this report.

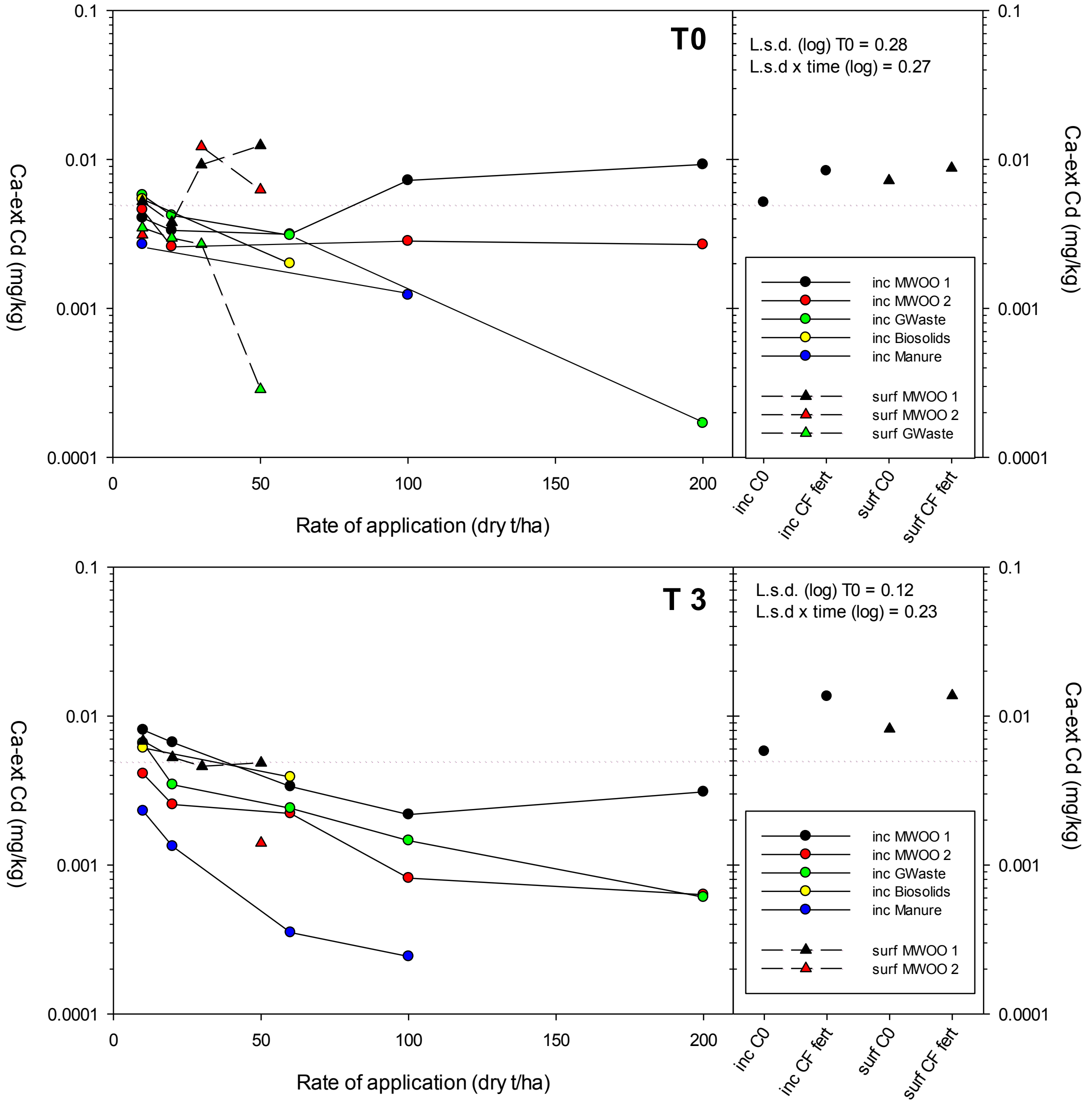


**Figure 11:** Changes in the $CaCl_2$-extractability of Cd over time (T0 to T3) resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser.

**Table 18a:** ANOVA output table for Ca extractable Cd

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.60 | 0.87 | 12.18 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 87.56 | 2.43 | 34.23 | <.001 |
| Residual | 98 | -10 | 6.96 | 0.07 | 2.64 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 2.94 | 0.98 | 36.34 | <.001 |
| trtID.time | 68 | -40 | 11.29 | 0.17 | 6.16 | <.001 |
| Residual | 181 | -152 | 4.88 | 0.03 | | |
| Total | 389 | -202 | 72.35 | | | |

**Table 18b:** Repeated measures ANOVA output table for Ca extractable Cd

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.59 | 0.86 | 12.17 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 4.00 | 4.00 | 56.29 | <.001 |
| IncVSurf.IncTrts | 6 | | 24.77 | 4.13 | 58.11 | <.001 |
| IncVSurf.SurfTrts | 4 | | 11.29 | 2.82 | 39.73 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 1.49 | 0.37 | 5.24 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 2.36 | 0.59 | 8.29 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 12.16 | 3.04 | 42.8 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 10.46 | 3.49 | 49.07 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.87 | 0.87 | 12.26 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.19 | 0.06 | 0.88 | 0.454 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 1.83 | 0.61 | 8.57 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 9.38 | 3.13 | 43.99 | <.001 |
| Residual | 98 | -10 | 6.96 | 0.07 | 2.64 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 3.40 | 1.13 | 42.03 | <.001 |
| IncVSurf.time | 3 | | 0.50 | 0.17 | 6.16 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 2.77 | 0.18 | 6.84 | <.001 |
| IncVSurf.SurfTrts.time | 10 | -2 | 2.44 | 0.24 | 9.06 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 2.38 | 0.20 | 7.36 | <.001 |
| IncVSurf.IncTrts.incMW002.time | 4 | -8 | 0.66 | 0.16 | 6.12 | <.001 |
| IncVSurf.IncTrts.incGW.time | 6 | -6 | 0.94 | 0.16 | 5.8 | <.001 |
| IncVSurf.IncTrts.incManure.time | 3 | -6 | 1.16 | 0.39 | 14.31 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.05 | 0.03 | 0.94 | 0.394 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 1.13 | 0.13 | 4.66 | <.001 |
| IncVSurf.SurfTrts.surfMW002.time | 1 | -8 | 0.30 | 0.30 | 11.13 | 0.001 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.49 | 0.16 | 6.08 | <.001 |
| Residual | 181 | -152 | 4.88 | 0.03 | | |
| Total | 389 | -202 | 72.35241 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Typically, because of their transient nature, amounts extracted by the $CaCl_2$ extract can be meaningless in isolation, unless they are related to a biological process, or to some other relevant measure (Houba et.al. 2000). In our case, by expressing the amounts of each metal element extracted as a proportion of total amount in the soil (i.e. Ca-extractable Cd / Total soil Cd, %), we can gain some more insight as to whether the metals are becoming increasingly adsorbed (less bioavailable) over time, as well as allowing us to compare the response from other amendment materials.

Initially, the proportion of total soil Cd extracted by 0.01M $CaCl_2$ ranged between 0.04% and 18% across all the amended and control soils. Increasing rates of amendment application resulted in a decreasing proportion of Ca-extractable Cd, for both the incorporated and surface treatments. The proportion of extractable Cd in the amended soils was always lower than those in the control soils.

For the T3 sampling, a similar range was seen for the Cd extractability (0.06% – 24%), compared to the T0 sampling. At time T3, the proportion of total soil Cd extracted by 0.01 M $CaCl_2$ did not differ between significantly between amendment materials, except at the highest rates of application (above 100 t/ha). However, Cd-extractability also decreased over time at these higher application rates, compared to the earlier T0 sampling.

The importance of pH on the bioavailability of heavy metals have been consistently reported in the scientific literature, especially for Cd and Zn, (e.g. Anderson and Nilsson 1974; Logan and Chaney 1983; Keens 1984; Dalloway 1995; Schmidt 1997). As soil pH declines, metal solubility increases (Lindsay 1979) and metals become more bioavailable (Sanders et.al. 1986; Smith 1994). The capacity of soils to adsorb metals is often pH-dependent, particularly for variable charge clays, oxide minerals and organic complexes, and adsorption increases with increased soil pH Soil pH also influences the formation of precipitates on or near soil mineral surfaces, as well as the desorption of metals from the solid to solution phase (Brümmer et.al. 1983; Christensen 1984; Hamon et.al. 2002). Adsorption of metals by organic matter in soils is also pH dependent and dissolution of soil organic matter increases with increasing pH (Christensen and Christensen 2000; Evans et.al.1995).

Consistent with the scientific literature, soil pH had an important influence on extractability of Cd in the amended soils in this trial. We carried out a multiple linear regression analysis using soil pH, total soil Cd (log) and time as fitted terms. This model accounted for 88% of variation ($p<0.001$) in the extractability of Cd across all amendment materials and the T0 and T3 samplings. The regression output for analysis is given in Appendix 6a.

In order to assess if there were any significant differences between the overall extractability of the applied Cd applied across all amendments, we plotted the relationship between soil pH and the amount of Cd extracted by $CaCl_2$ for each of the sample times, using data from all amendments (Figure 12). To accompany these plots we carried out a multiple-nonlinear, groups regression analysis, using time as an explanatory variable. This model fitted a three term exponential function to the data and tested if the data could be best described by a single curve or a series of curves. The output for this analysis is given in Appendix 6d.

The non-linear groups regression analysis of the Cd extractability data shows that the Cd-extractability – pH relationship is best described by a single curve and this model accounted for almost 85% of the variation in the data across all years and amendment treatments (Appendix 6d). In other words, Cd extractability was similar for all of the amendments tested, and this consistency in extractability did not change over time.

The effect of increasing rates of amendment addition on the Ca-extractability of soil Cu is illustrated in Figure 13. The ANOVA output tables for this data are given in Tables 19a (Standard ANOVA) and Table 19b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Data is presented for the T0 and T3 sampling times.

The concentrations of Ca-extractable Cu increased with increasing rates of MWOO application and ranged between 0.03 and 5.7 (mg/kg). Surface applied MWOO resulted in equivalent or higher amounts of Ca-extractable Cu (1.7- fold higher), than the equivalent incorporated treatments. Ca-extractable Cu concentrations were similar to control concentrations for composted biosolids and green waste amended soils. Unlike Cd, the concentration of Ca-extractable Cu did not decrease with increasing rates of application (Table 19b).

The data presented in Figure 13 shows that the concentrations of Ca-extractable Cu have decreased in the three years since MWOO application (T3) and this reduction in concentration was significant for the MWOO 1 and MWOO 2 (incorporated and surface applied) and poultry manure, but less so for green waste or composted biosolids. By the time of the T3 sampling, there was little difference in Cu-extractability between the green waste, composted biosolids and poultry manure treatments, and the MWOO 1 and MWOO 2 treatment differed from the former only at rates greater than 60 t/ha, where Cu-extractability increases slightly with increasing rates of MWOO application.

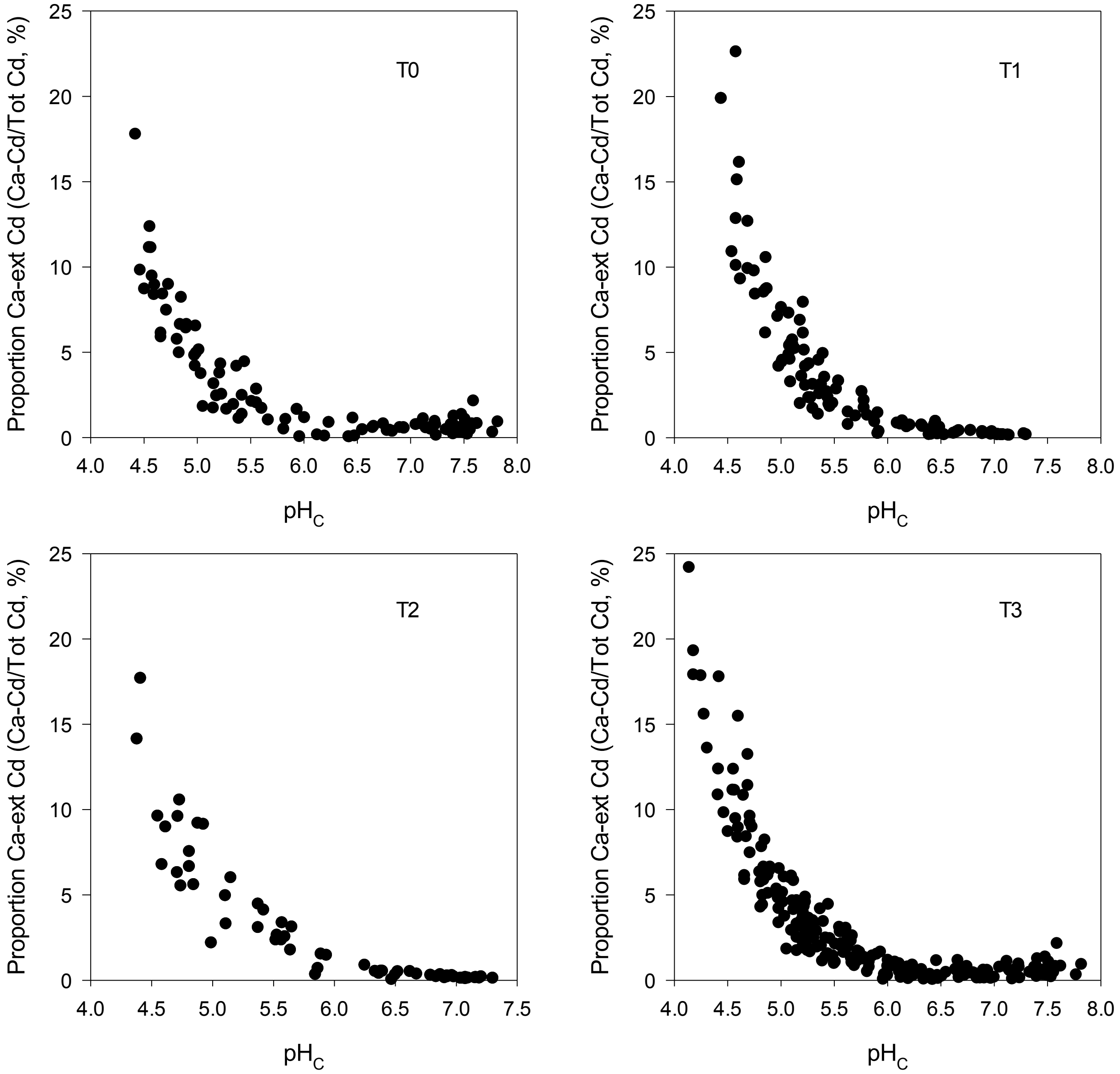


**Figure 12:** The effect of time on the relationship between soil pH and the proportion of Ca-extractable Cd (Ca-ext Cd / Tot Cd, %) for soils treated with a range of organic amendments; MWOO, composted green waste, composted biosolids and poultry manure and sampled over three years (T0 – T3). The data has been presented separately for each year in order to compare Cd extractability between the different amendment materials and changes in this extractability over time.

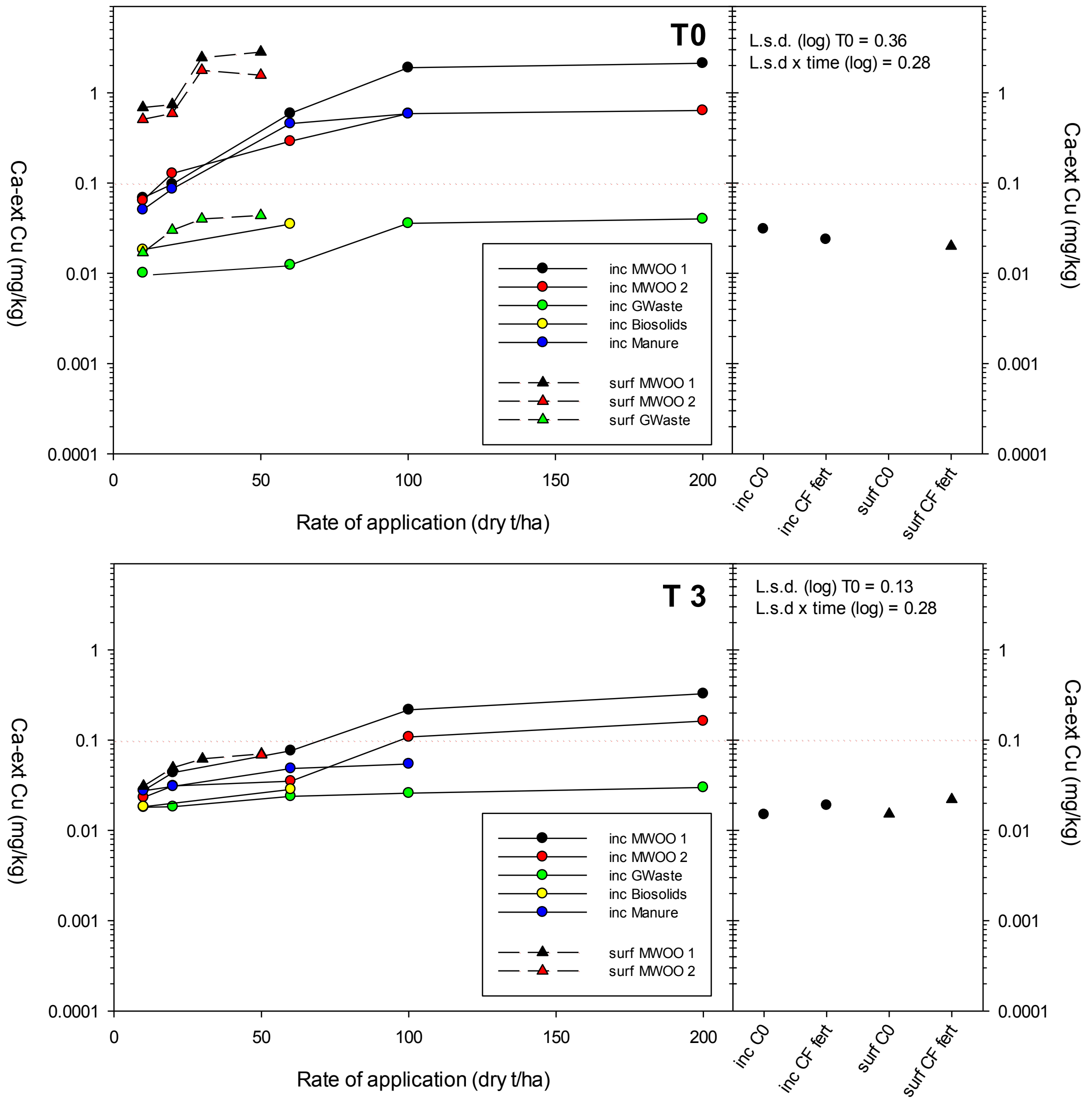


**Figure 13:** Changes in the $CaCl_2$-extractability of Cu over time (T0 to T3) resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser.

**Table 19a:** ANOVA output table for Ca extractable Cu

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.47 | 0.16 | 2.23 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 150.43 | 4.18 | 59.38 | <.001 |
| Residual | 108 | | 7.60 | 0.07 | 2.08 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 28.81 | 9.60 | 283.28 | <.001 |
| trtID.time | 77 | -31 | 21.85 | 0.28 | 8.37 | <.001 |
| Residual | 226 | -107 | 7.66 | 0.03 | | |
| Total | 453 | -138 | 171.25 | | | |

**Table 19b:** Repeated measures ANOVA output table for Ca extractable Cu

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.47 | 0.16 | 2.23 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.19 | 0.19 | 2.68 | 0.105 |
| IncVSurf.IncTrts | 6 | | 58.03 | 9.67 | 137.44 | <.001 |
| IncVSurf.SurfTrts | 4 | | 53.08 | 13.27 | 188.59 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 18.22 | 4.55 | 64.72 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 11.02 | 2.75 | 39.14 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 2.38 | 0.60 | 8.46 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 5.14 | 1.71 | 24.33 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.57 | 0.57 | 8.08 | 0.005 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 4.00 | 1.33 | 18.94 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 5.81 | 1.94 | 27.52 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 1.42 | 0.47 | 6.75 | <.001 |
| Residual | 108 | | 7.60 | 0.07 | 2.08 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 35.25 | 11.75 | 346.63 | <.001 |
| IncVSurf.time | 3 | | 9.55 | 3.18 | 93.88 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 6.59 | 0.44 | 12.96 | <.001 |
| IncVSurf.SurfTrts.time | 9 | -3 | 6.46 | 0.72 | 21.18 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.93 | 0.08 | 2.28 | 0.009 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.53 | 0.07 | 1.97 | 0.051 |
| IncVSurf.IncTrts.incGW.time | 7 | -5 | 1.08 | 0.15 | 4.53 | <.001 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.95 | 0.16 | 4.65 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.03 | 0.02 | 0.48 | 0.618 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.68 | 0.08 | 2.22 | 0.022 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.16 | 0.05 | 1.62 | 0.185 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.08 | 0.03 | 0.81 | 0.489 |
| Residual | 226 | -107 | 7.66 | 0.03 | | |
| Total | 453 | -138 | 171.25 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

This increase in extractable-Cu with increasing MWOO application rates could in part be due to the release of higher amounts of organically bound Cu at higher MWOO application rates. It is generally recognised that the organic constituents in soils form both soluble and insoluble compounds with metal cations, particularly Cd and Cu (Stevenson 1994; Alloway 1995). However, the contribution of soil organic matter (SOM) to solid-phase adsorption decreases at neutral to alkaline pH. This is more due to the dissolution of SOM at high pH, which can also contribute to increases in dissolved species in solution. Therefore as the pH of the amended soils increases (Figure 1), organically-bound Cu tends to be released into soil solution and is thus extracted by 0.01M $CaCl_2$.

For Cu, the proportion of total soil Cd extracted by 0.01M $CaCl_2$ ranged between 0.02% and 3.4% across all the materials tested, but dropped significantly for the T3 sampling (0.05% – 0.31%). As with the MWOO material, the proportion of total soil Cu extracted by 0.01 M $CaCl_2$ over time did not differ between amendment materials, except at the highest rates (above 100 t/ha). The influence of pH on this relationship is not as important as for Cd. We carried out a multiple linear regression analysis using soil pH, total soil Cu (log) and time as fitted terms and accounted for 72% of variation ($p<0.001$) in the extractability of Cu across all amendment materials and the T0 and T3 samplings. The regression output for analysis is given in Appendix 6b.

In order to assess if there were any significant differences between the overall extractability of the applied Cu applied across all amendments, we plotted the relationship between soil pH and the amount of Cu extracted by $CaCl_2$ for each of the sample times, using data from all amendments (Figure 14). To accompany these plots we carried out a multiple-nonlinear, groups regression analysis, using time as an explanatory variable. This model fitted a three term exponential function to the data and tested if the data could be best described by a single curve or a series of curves. The output for this analysis is given in Appendix 6e.

The non-linear groups regression analysis of the Cu extractability data shows that the Cu-extractability – pH relationship is best described by separate curves based on the different sampling times. This model accounted for 72% of the variation in the data across all years and amendment treatments (Appendix 6e). In other words, Cu-extractability was similar for all of the amendments tested, but this relationship between Cu-extractability and pH changed over time (Figure 14).

The effect of increasing rates of amendment addition on the Ca-extractability of soil Zn is illustrated in Figure 15. The ANOVA output tables for this data are given in Tables 20a (Standard ANOVA) and Table 20b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

The concentrations of Ca-extractable Zn increased with increasing rates of MWOO 1, MWOO 2 and manure application and ranged between 0.07 (mg/kg) and 6.1 (mg/kg). Concentrations of Ca-extractable Zn did not decrease with increasing rates of biosolids application and decreased to concentrations below those in the control soils following the application of green waste. The application of MWOO 1 and MWOO 2 to the soil surface resulted in higher amounts of Ca-extractable Zn (2.4- fold higher), than the incorporated treatments, while surface applications of green waste reduced Ca-extractable Zn concentrations to below those of the control soils.

Further examination of the data presented in Figure 15 and Table 20b, reveals that the concentrations of Ca-extractable Zn have decreased in the three years since amendment application for the MWOO and manure treated soils, and that this decrease is more pronounced with increasing rates of application. The concentrations of Ca-extractable Zn in the green waste and biosolids amended soils have not changed over time. Figure 15 also shows that there is now no difference between incorporated and surface treatments in terms of the concentrations of Ca-extractable Zn.

Initially, the proportion of total soil Zn extracted by 0.01M $CaCl_2$ ranged between 0.03% and 3.4% across all the materials tested, and these concentrations were not significantly different from the extractability of Zn in the control soils. A similar range in Zn-extractability was seen for the T3 sampling (0.04% – 7%). However by the time of the T3 sampling, Zn-extractability as a proportion of total soil Zn, is now lower than control concentrations and this effect is more significant at higher application rates of MWOO 1 and MWOO 2 and has remained unchanged for the green waste amend soils. The proportion of total soil Zn applied with the biosolids and green waste treatments were not significantly different during the T0 to T3 time period. For surface treatments, there was a slight decrease in the proportion of Ca-extractable Zn seen at the high rate application (50 t/ha) for both MWOO 1 and MWOO 2.

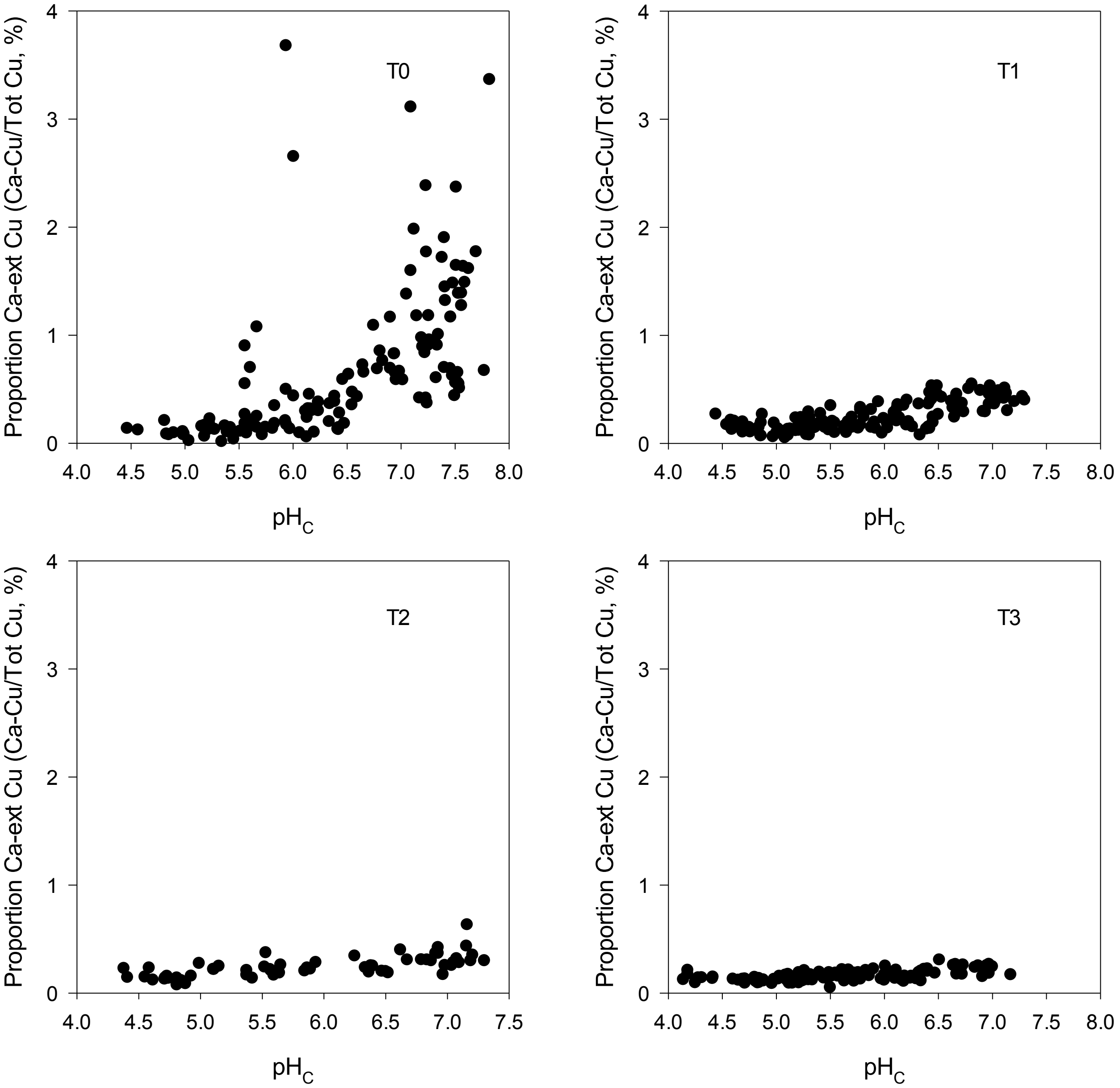


**Figure 14:** The effect of time on the relationship between soil pH and the proportion of Ca-extractable Cu (Ca-ext Cu / Tot Cu, %) for soils treated with a range of organic amendments; MWOO, composted green waste, composted biosolids and poultry manure and sampled over three years (T0 – T3). The data has been presented separately for each year in order to compare Cu extractability between the different amendment materials and changes in this extractability over time.

By using multiple regression analysis of these data, we are able to show that changes in soil pH have had an important influence on the changes in Zn extractability over time (see Appendix 6C). The regression model used only soil pH, total soil Zn (log) and time as fitted terms and accounted for over 80% variation in the examining the proportion of total Zn (log) across all amendments and sampling times.

In order to assess if there were any significant differences between the overall extractability of the applied Zn applied across all amendments, we plotted the relationship between soil pH and the amount of Zn extracted by $CaCl_2$ for each of the sample times, using data from all amendments (Figure 16). To accompany these plots we carried out a multiple, nonlinear, groups regression analysis, using time as an explanatory variable. This model fitted a three term exponential function to the data and tested if the data could be best described by a single curve or a series of curves. The output for this analysis is given in Appendix 6f.

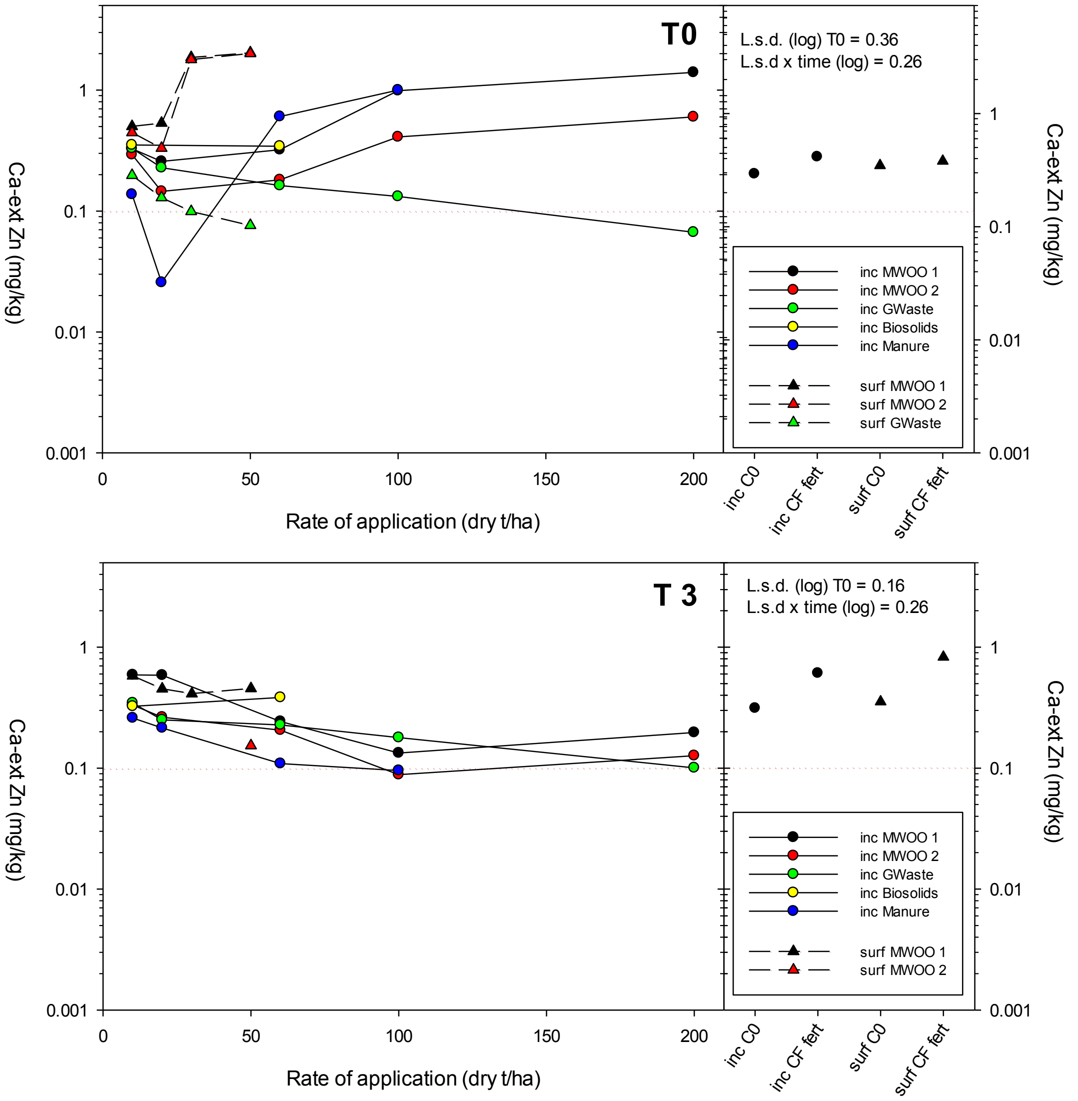


**Figure 15:** Changes in the $CaCl_2$-extractability of Zn over time (T0 to T3) resulting from soils being amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure) L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser

**Table 20a:** ANOVA output table for Ca extractable Zn

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.20 | 0.40 | 7.69 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 24.72 | 0.69 | 13.2 | <.001 |
| Residual | 108 | | 5.62 | 0.05 | 1.74 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 1.28 | 0.43 | 14.3 | <.001 |
| trtID.time | 87 | -21 | 22.76 | 0.26 | 8.77 | <.001 |
| Residual | 266 | -67 | 7.94 | 0.03 | | |
| Total | 503 | -88 | 54.73 | | | |

**Table 20b:** Repeated measures ANOVA output table for Ca extractable Zn

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.20 | 0.40 | 7.69 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.02 | 0.02 | 0.35 | 0.553 |
| IncVSurf.IncTrts | 6 | | 6.16 | 1.03 | 19.74 | <.001 |
| IncVSurf.SurfTrts | 4 | | 12.22 | 3.05 | 58.69 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 1.18 | 0.30 | 5.67 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 0.36 | 0.09 | 1.74 | 0.146 |
| IncVSurf.IncTrts.incGW | 4 | | 2.94 | 0.73 | 14.12 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 1.29 | 0.43 | 8.25 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.00 | 0.00 | 0.07 | 0.789 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.52 | 0.17 | 3.32 | 0.023 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 0.72 | 0.24 | 4.6 | 0.005 |
| IncVSurf.SurfTrts.surfGW | 3 | | 1.18 | 0.39 | 7.55 | <.001 |
| Residual | 108 | | 5.62 | 0.05 | 1.74 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 1.72 | 0.57 | 19.25 | <.001 |
| IncVSurf.time | 3 | | 1.21 | 0.40 | 13.58 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 2.42 | 0.16 | 5.41 | <.001 |
| IncVSurf.SurfTrts.time | 11 | -1 | 5.58 | 0.51 | 16.99 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 3.09 | 0.26 | 8.64 | <.001 |
| IncVSurf.IncTrts.incMW002.time | 12 | | 2.87 | 0.24 | 8.01 | <.001 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.11 | 0.01 | 0.45 | 0.887 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 5.43 | 0.90 | 30.33 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.01 | 0.00 | 0.1 | 0.909 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 1.48 | 0.16 | 5.52 | <.001 |
| IncVSurf.SurfTrts.surfMW002.time | 6 | -3 | 1.94 | 0.32 | 10.85 | <.001 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.06 | 0.02 | 0.65 | 0.582 |
| Residual | 266 | -67 | 7.94 | 0.03 | | |
| Total | 503 | -88 | 54.73 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

The non-linear groups regression analysis of the Zn-extractability data shows that the Zn-extractability – pH relationship can be described by a single curve and this model accounted for 78% of the variation in the data across all years and amendment treatments (Appendix 6f). A second model for this relationship is also presented in Appendix 6f, which fits separate curves to the data based on sampling time, but this more complex model only accounted for an extra 5% of the variation in Zn extractability. In practical terms therefore, Zn extractability was essentially similar for all of the amendments tested, and this consistency in extractability did not change, for sample times after T0.

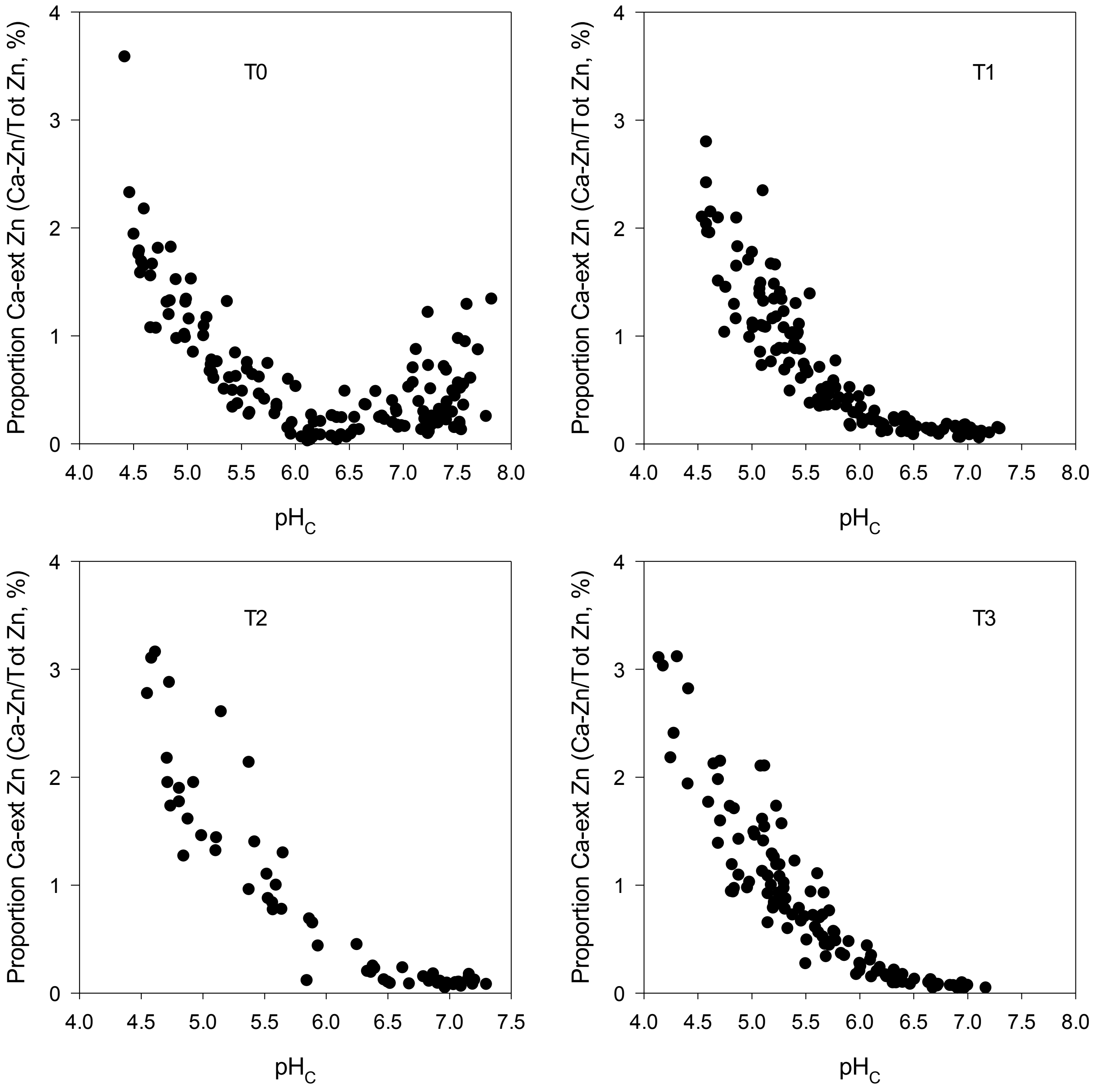


**Figure 16:** The effect of time on the relationship between soil pH and the proportion of Ca-extractable Zn (Ca-ext Zn / Tot Zn, %) for soils treated with a range of organic amendments; MWOO, composted green waste, composted biosolids and poultry manure and sampled over three years (T0 – T3). The data has been presented separately for each year in order to compare Zn extractability between the different amendment materials and changes in this extractability over time.

## *Metal contaminant extractability – comparison between a range of organic amendments including dewatered biosolids*

In the previous section it was shown that there was little difference in the proportion of extractable metals between the various amendments, other than some changes (decreases) immediately following their application to the test soil. Using this information, we are able to group the amendments together, in terms of the proportion of total metal that is extractable using a $CaCl_2$ extract..

Similar comparisons can also be made between metal extractability for the range of different organic amendments used in this trial, with data generated for materials such as soluble metal salts and dewatered biosolids, studied previously at the same site. This comparison may allow us to assess if current guidelines regulating the use of MWOO onto soils, which were based on risk assessments developed for biosolids (NSW EPA 1997), are indeed appropriate for MWOO and other organic amendments.

The metal salts and dewatered biosolids were applied to other plots at the current trial site during a previous study as described by M$^{C}$Laughlin et.al. (2006), Warne et.al. (2008) and Heemsbergen et.al. (2010), as part of the Australian, National Biosolids Research Program (NBRP). See M$^{c}$Laughlin et.al. 2007, for more details. In summary, the previous studies compared the effects of metal contaminants (Cd, Cu and Zn) between those applied as inorganic metal salts and those applied with dewatered biosolids, for a range of soil types across Australia, all using similar methodology. The dose-response relationships to the applied metals were assessed for a range of endpoints and the data pooled to provide a risk assessment based on critical soil properties. It is appropriate therefore, that we compare data from the current trial with those from these previous studies carried out at the same site, given that the site setup and methodology was essentially the same, including the use of the $CaCl_2$ procedure for extracting 'bioavailable' soil metals. We have used linear regression with groups to formalise this comparison.

Figure 17 presents a comparison of the concentrations of Ca-extractable Cd found in the organic amendment treated soils used during this trial for the T0 and T3 samplings, with that of dewatered biosolids, as well as an inorganic Cd-salt.

The proportion of soil Cd extracted using 0.01M $CaCl_2$ was lower on the amendment and biosolids amended soils compared to those treated with the Cd-salt. A comparison of the T0 and T3 data in Figure 17 shows that, despite the initial higher concentrations of extractable Cd found in the high rate MWOO treatments, ageing of treatments in these soils (T0 – T3), has reduced the extractability of Cd and to concentrations no greater than that of dewatered biosolids. The groups regression analysis of the Ca-extractable Cd data shows that for time T0, the data set is best described by separate relationships for the Cd-salt and MWOO 1 and the other amendments as a second group. This model, although significant at $p<0.001$, only accounted for just under 50 % of the variation in extractable Cd for all Cd sources (salt, MWOO and other amendments). For time T3, Cd-extractability in the MWOO, and manure treated soils had decreased as discussed previously, and are now similar to or below that of dewatered biosolids. The groups regression for time T3 accounted for a much higher percentage of variation in the Ca-extract data (88%), and while the relationship indicates three separate groups for this data; Cd salt as the first group, MWOO and dewatered biosolids as the second, and the other amendments as a third group with lower Cd-extractability, Cd-extractability of the MWOO and other amendments was no higher than that of the dewatered biosolids.

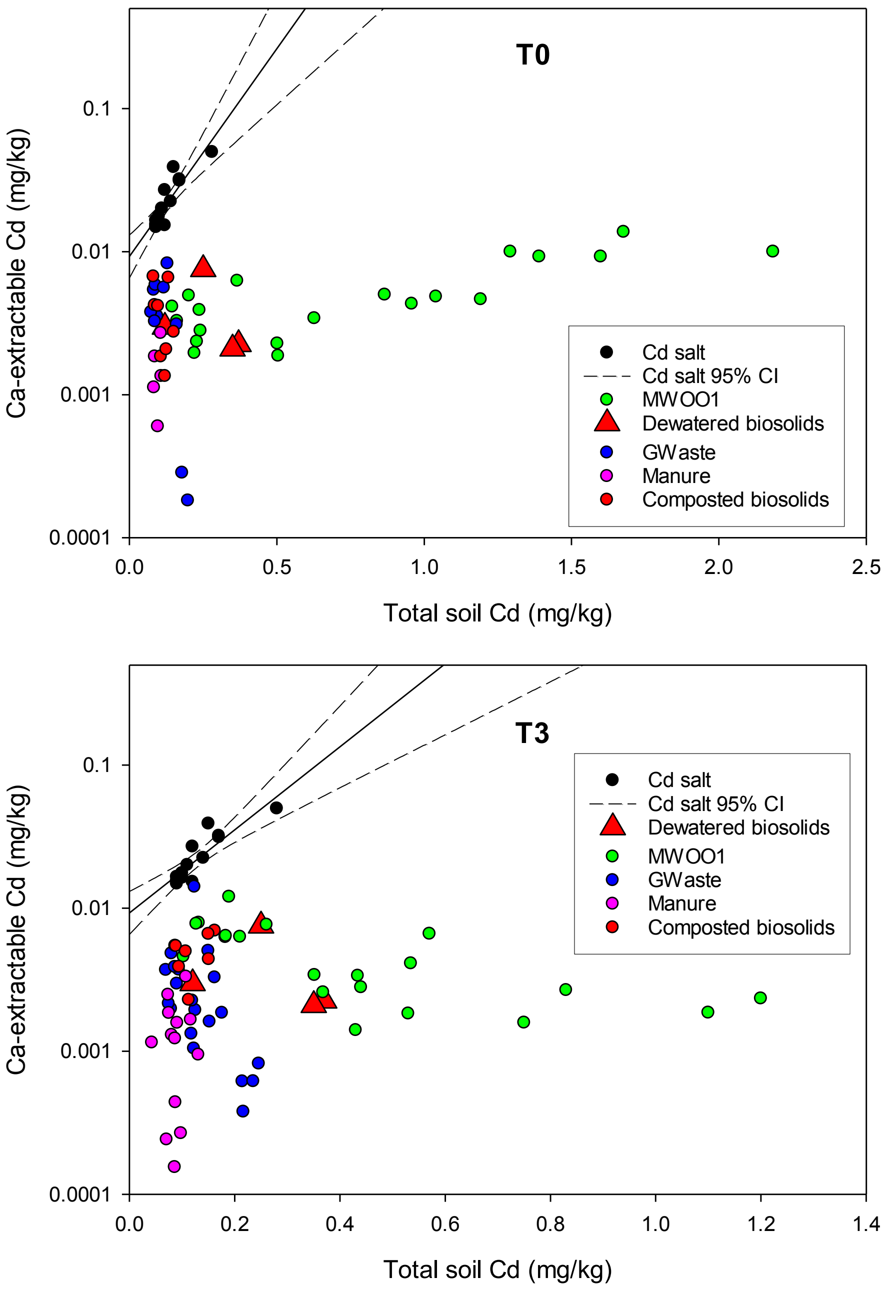
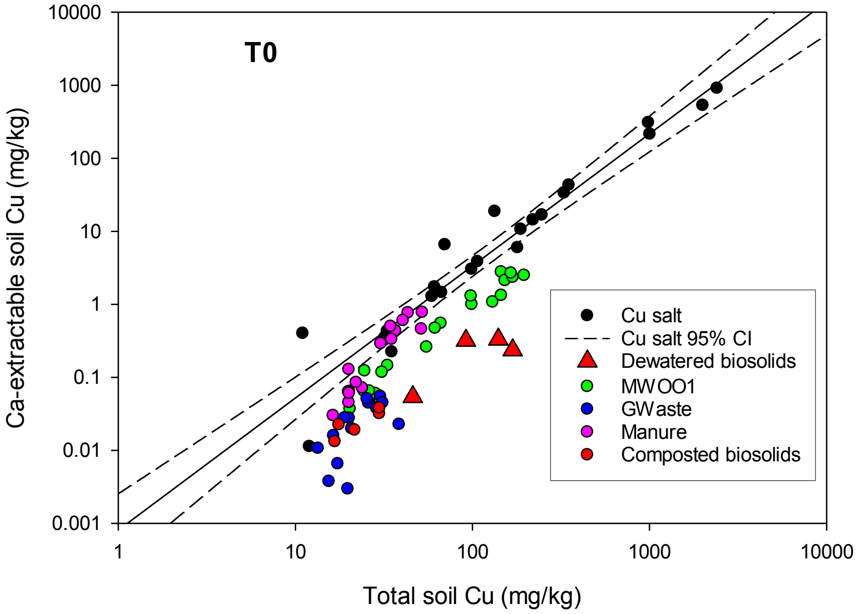


**Figure 17:** A comparison of Cd-extractability determined for a range of organic amendments and an inorganic Cd-salt, all applied at various times to the plots on the trial site. Amendments include; dewatered and lime-amended biosolids, MWOO 1 and MWOO 2, composted green waste, poultry manure and composted biosolids. Regression line and 95% confidence intervals indicate spread of data for Cd metal-salt benchmark. Data for the Cd salt and dewatered biosolids treatments from samples collected during a previous study. Data for the MWOO 1, GWaste (green waste), manure (poultry manure) and composted biosolids treatments originated from the current trial.

Figure 18 presents a comparison of the concentrations of Ca-extract Cu found in the organic amendment treated soils used during this trial for the T0 and T3 samplings, with that of dewatered biosolids, as well as an inorganic Cu-salt. The proportion of soil Cu extracted using 0.01M $CaCl_2$ was lower for the amendment and biosolids amended soils, compared to those treated with the Cu-salt. However, a comparison of the T0 and T3 data in Figure 18 shows that the initial extractability of Cu in the MWOO and manure treated plots, was higher than for comparative biosolids application. Despite this, concentrations of extractable-Cu in the aged soils (T0 – T3), has reduced to concentrations that are not distinguishable from dewatered biosolids.



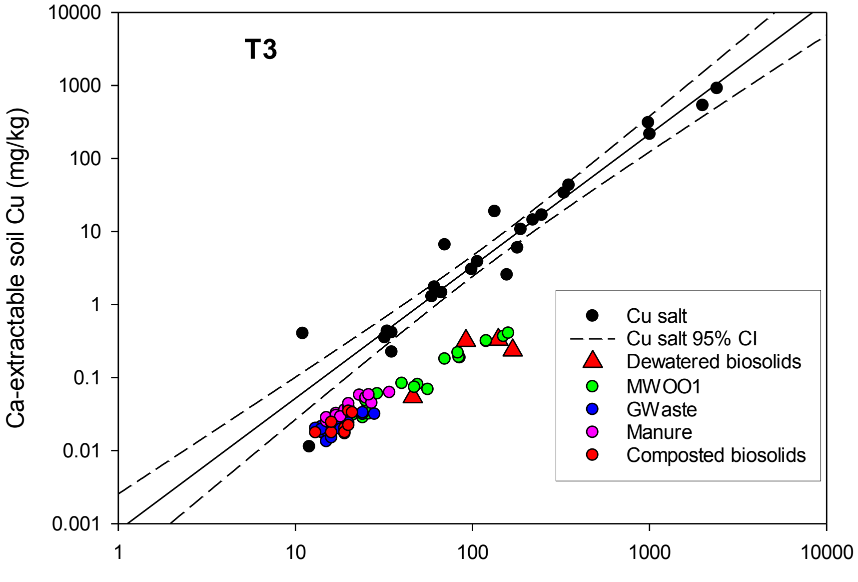


**Figure 18:** A comparison of Cu-extractability determined for a range of organic amendments and an inorganic Cu-salt, all applied at various times to the plots on the trial site. Amendments include; dewatered and lime-amended biosolids, MWOO 1 and MWOO 2, composted green waste, poultry manure and composted biosolids. Regression line and 95% confidence intervals indicate spread of data for Cu metal-salt benchmark. Data for the Cu salt and dewatered biosolids treatments from samples collected during a previous study. Data for the MWOO 1, GWaste (green waste), manure (poultry manure) and composted biosolids treatments originated from the current trial.

The groups regression analysis of the Ca-extractable Cu data shows that for time T0, the data set is best described by separate parallel relationships for the Cu-salt, MWOO 1 and manure as a second group and the other amendments, including dewatered biosolids as a third group. This model was significant at $p<0.001$ and accounted for just under 93 % of the variation in extractable-Cu for all Cu sources (salt, MWOO and other amendments). For time T3, Cu-extractability in the MWOO, and manure treated soils has decreased, and is now similar to, or below that, of dewatered biosolids. The groups regression for time T3 accounted for a slightly higher percentage of variation in the Ca extractability data (95%), and while the relationship indicates two separate parallel groups for this data; Cu salt as the first group, MWOO, dewatered biosolids, poultry manure and the other amendments as a second group with similar Cu-extractability, Cu-extractability of the MWOO and other amendments was no higher than the dewatered biosolids at time T3.

Figure 19 presents a comparison of the concentrations of Ca-extractable Zn found in the organic amendment treated soils used during this trial for the T0 and T3 samplings, with that of dewatered biosolids, as well as an inorganic Zn-salt.

The proportion of soil Zn extracted using 0.01M $CaCl_2$ was always lower on the amendment and biosolids amended soils compared to those treated with the Zn-salt. In addition, the data in Figure 19 shows that Zn-extractability for the amendments used in the current trial (MWOO, composted green waste, poultry manure and composted biosolids), is lower than that of dewatered biosolids.

The groups regression analysis of the Ca-extractable Zn data shows that for time T0, the data set is best described by three separate relationships; one for the Zn-salt, and the other two for the dewatered biosolids, MWOO and other amendments. This model was significant at $p<0.001$ and accounted for just under 91 % of the variation in extractable-Zn for all Zn sources (salt, MWOO and other amendments). As discussed previously, for time T3, Zn-extractability in the MWOO treated soils had decreased, and is now similar to, or below that, of dewatered biosolids. The groups regression for time T3 accounted for a slightly higher percentage of variation in the Ca-extract data (96%), and while the relationship still indicates three separate groups for this data; Zn salt as the first group, dewatered biosolids as the second group, MWOO, composted biosolids, poultry manure and the other amendments as a third group with similar Zn-extractability, Zn-extractability of the MWOO and other amendments was lower than the dewatered biosolids at time T3.

Smith (2009) has reviewed the scientific literature on the bioavailability of metal contaminants in composts and concluded that the actual composting process itself serves to reduce metal extractability by increasing the level of organic-complexation of some metal contaminants. While this may be important for elements with an affinity for organic matter such as Cu (Alloway 1995), this process is less important for Zn (Lindsay 1979). It is unclear therefore, why Zn extractability is lower for the current treatments compared to that of the dewatered biosolids reported previously, although the source of the Zn in the current materials (feedstock), may have made the Zn less extractable (Epstein 2003).

The above comparison of metal-extractability between MWOO treatments and other amendments used in the current trial, with that of amendments studied previously at the same site (e.g. dewatered biosolids), shows that there is little difference in metal-extractability between the various amendments, once the initial, post-application ‘flush’ of highly labile metals has subsided. It is therefore unlikely that the current framework for regulating soil metal inputs from biosolids would underestimate the risk from these same metals, for sources such as MWOO and the other amendment materials tested during this trial.

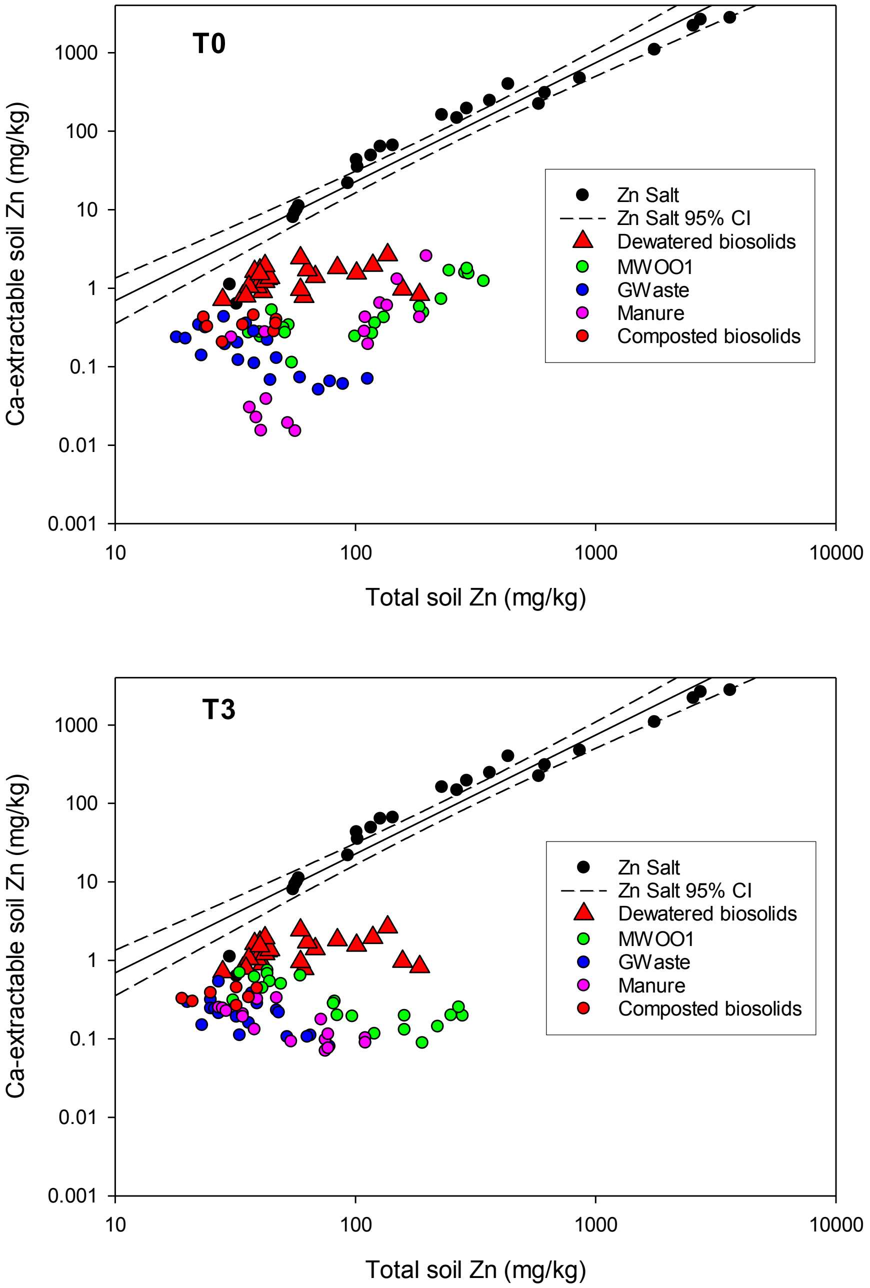


**Figure 19:** A comparison of Zn extractability determined for a range of organic amendments and an inorganic Zn-salt, all applied at various times to the plots on the trial site. Amendments include; dewatered and lime-amended biosolids, MWOO 1 and MWOO 2, composted green waste, poultry manure and composted biosolids. Regression line and 95% confidence intervals indicate spread of data for Zn metal-salt benchmark. Data for the Zn-salt and dewatered biosolids treatments from samples collected during a previous study. Data for the MWOO 1, GWaste (green waste), manure (poultry manure) and composted biosolids treatments originated from the current trial.

## Soil Contaminants – organic chemicals

Of the eight pesticide and endocrine disrupting chemicals found in the MWOO materials used in this trial (see Table 6), only 5 were subsequently detected in the MWOO amended soils; Benzophenone (CAS 119-61-9), Bis(2-ethylhexyl)phthalate (DEHP; CAS 117-81-7), Bisphenol A (BPA, CAS 80-07-7), Di-n-butylphthalate (DBP, CAS 84-74-2) and N,N-Diethyl-m-toluamide (DEET, CAS 134-62-3). All of the chemicals listed are associated with plastic manufacture and breakdown (Teuten et.al. 2009), except for N,N-Diethyl-m-toluamide (DEET), which is an insect repellent. Compounds such as Bisphenol A [BPA- 2,2-(4,40-dihydroxydiphenyl)propane] and phthalates (Di-n-butylphthalate [DBP] and Bis(2-ethylhexyl)phthalate [DEHP]), are among additives and monomers released from plastic in the environment and are often present in landfill leachate (e.g. Yamamoto et.al. 2001; Fromme et.al. 2002; Asakura et al. 2004). The soil concentrations of each of these analytes found in the MWOO treated plots are discussed below (see also Appendix 7).

### Benzophenone

Benzophenone (BP), or diphenyl ketone, is used as an additive in plastics, household cleaning products, and UV light stabilising products (Careghini et.al. 2015). This class of chemicals can have an adverse effect on reproduction and hormonal function; an action known collectively as endocrine disruption. These chemicals can enter the environment via solid-waste landfill (Kim and Choi 2014), but are considered to be highly insoluble in water and strongly adsorbed to the soil solid phase (USEPA 1994). Benzophenones have been shown to biodegrade in water, but there is limited evidence available from studies on soil, excepting that degradation half-life is dependent on the monomer of BP being tested (Gago-Ferrero et.al. 2012). A search of the scientific literature did not reveal an ecological Investigation limit (EIL) for BP in soil.

The effect of increasing rates of amendment addition and time (T0 – T3), on the soil concentrations of BP is illustrated in Figure 20. The ANOVA output tables for this data are given in Tables 21a (Standard ANOVA) and Table 21b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in this figure is the l.s.d. indicating significance at $p< 0.05$ for the interaction between treatment and time. The soil concentration of BP ranged between 0.03 (mg/kg) and 0.53 (mg/kg) for the T0 sampling.

Soil BP concentrations increased with increasing rates of MWOO application, and were proportionally higher for the surface treatments. The concentrations of BP in amended soils were similar for both MWOO 1 and 2, at the highest rate of application (Table 21b). In subsequent years (Figure 20), it can be seen the BP concentrations in the amended soils decreased by up to 88% for the 50 t/ha surface application of MWOO 2, although this degradation was slower for the same surface application of MWOO 1 (22%). Benzophenone is still detectable in a number of treatments, three years after the initial application.

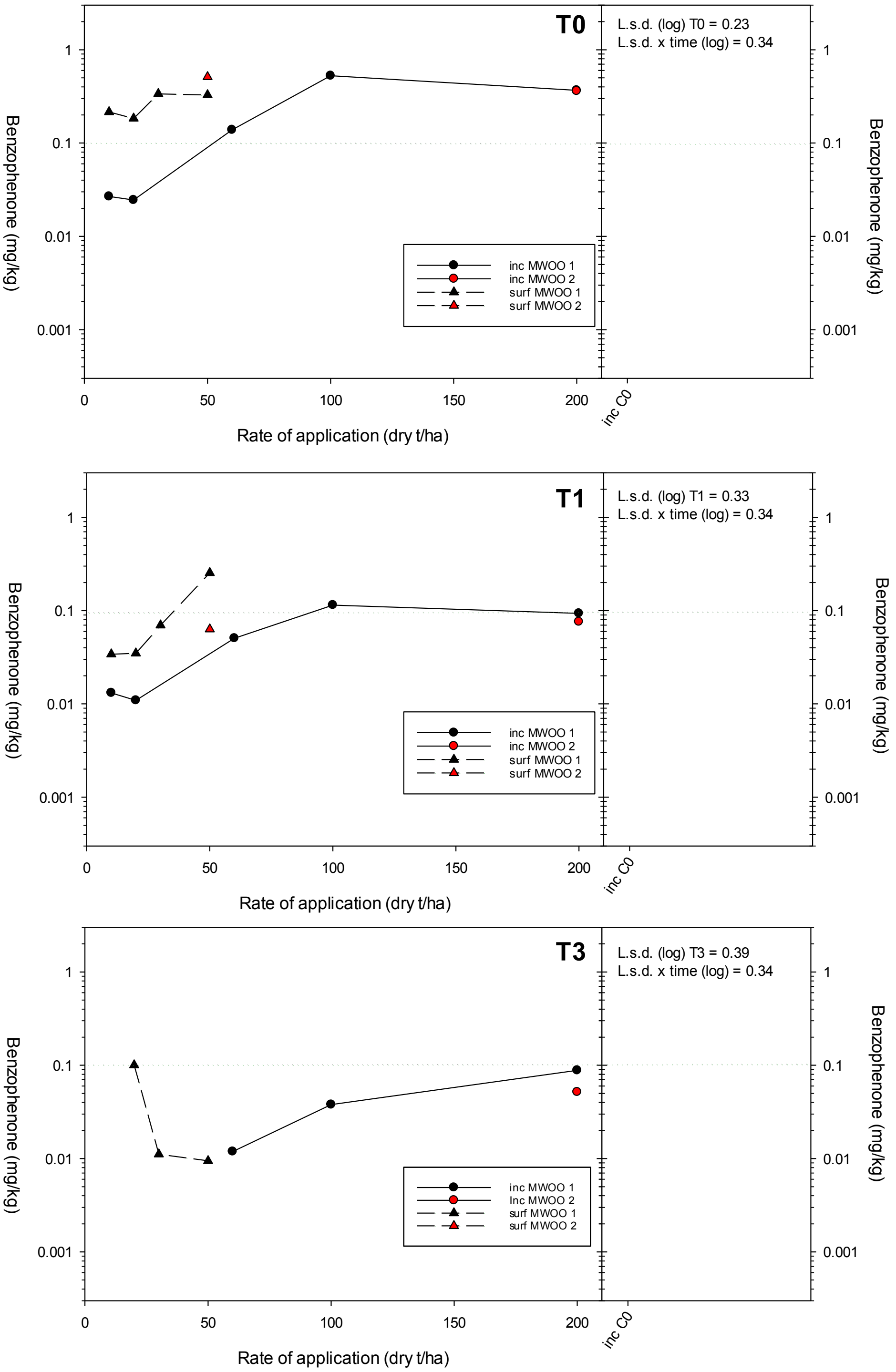


**Figure 20:** Average total soil benzophenone concentrations resulting from soils being amended with increasing rates of incorporated or surface applied MWOO1 and MWOO 2. The soils were sampled soon after treatment application (T0), and again at the end of the first (T1), and third cropping seasons (T3); spanning a total of three years post-application. L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control.

**Table 21a:** ANOVA output table for Total soil Benzophenone

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.54 | 0.18 | 1.83 | |
| repf.plotf stratum | | | | | | |
| trtID | 11 | -25 | 55.29 | 5.03 | 50.68 | <.001 |
| Residual | 28 | -80 | 2.78 | 0.10 | 2.29 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 81.04 | 27.01 | 624.23 | <.001 |
| trtID.time | 24 | -84 | 8.15 | 0.34 | 7.85 | <.001 |
| Residual | 50 | -283 | 2.16 | 0.04 | | |
| Total | 119 | -472 | 32.42 | | | |

**Table 21b:** Repeated measures ANOVA output table for Total soil Benzophenone

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.54 | 0.18 | 1.83 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 1.36 | 1.36 | 13.69 | <.001 |
| IncVSurf.IncTrts | 2 | -4 | 34.55 | 17.28 | 174.2 | <.001 |
| IncVSurf.SurfTrts | 1 | -3 | 1.23 | 1.23 | 12.38 | 0.002 |
| IncVSurf.IncTrts.incMW001 | 4 | | 17.07 | 4.27 | 43.02 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.80 | 0.27 | 2.7 | 0.065 |
| Residual | 28 | -80 | 2.78 | 0.10 | 2.29 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 85.39 | 28.46 | 657.71 | <.001 |
| IncVSurf.time | 3 | | 2.49 | 0.83 | 19.15 | <.001 |
| IncVSurf.IncTrts.time | 3 | -15 | 1.92 | 0.64 | 14.82 | <.001 |
| IncVSurf.SurfTrts.time | 2 | -10 | 0.83 | 0.41 | 9.56 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 9 | -3 | 1.30 | 0.14 | 3.33 | 0.003 |
| IncVSurf.SurfTrts.surfMW001.time | 7 | -2 | 4.83 | 0.69 | 15.93 | <.001 |
| Residual | 50 | -283 | 2.16 | 0.04 | | |
| Total | 119 | -472 | 32.42 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Bis(2-ethylhexyl)phthalate*

Bis(2-ethylhexyl)phthalate (DEHP), is one of the phthalate plasticizers used in the manufacture of flexible PVC (Tueten et.al. 2009). As with BP, phthalates as a class of chemicals, can have an adverse effect on reproduction and hormonal function; an action known collectively as endocrine disruption.. The release of DEHP may take place during the useable life of the plastic or after its disposal (Teuten et.al. 2009), and considerable amounts have been found in the leachate from municipal solid-waste landfill sites (Yamamoto et.al. 2001). A review of literature on residence of DEHP in soil shows that the half-lives for DEHP range from 14 to 200 days (Hyder Consulting 2008b; EU 2006). The same authors have suggested a tentative environmental investigation level (EIL) for DEHP be set at 57 (mg/kg). In a study carried out to inform regulation in the Netherlands, van Wezel et.al. (2000) proposed an environmental risk limit (ERL) for DEHP in soil of 1 mg/kg fresh soil. Smith (2009) considered DEHP to be significant organic chemical to be found in biosolids and that its dynamics in soil required further investigation, particularly where there is potential exposure to grazing livestock from surface applications of biosolids to agricultural soils. Likewise, Cartwright et.al. (2000), considered DEHP to be the most persistent of the phthalates in the soil environment. As discussed earlier, concentrations of DEHP in the MWOO materials tested in our trial are of a higher concentration than the median value quoted by Smith (2009).

The effect of increasing rates of amendment addition and time (T0 – T3), on the soil concentrations of DEHP, is illustrated in Figure 21. The ANOVA output tables for this data are given in Tables 22a (Standard ANOVA) and Table 22b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in this figure is the l.s.d. indicating significance at $p< 0.05$ for the interaction between treatment and time. The soil concentration of DEHP ranged between 1.5 (mg/kg) and 83.9 (mg/kg) for the T0 sampling. Soil DEHP concentrations increased with increasing rates of MWOO application, and were highest for the surface application treatments. Concentrations exceeded the proposed Hyder ERL for incorporation applications at rates above 60 t/ha, and for most of the surface application treatments. All rates exceeded the ERL's proposed by van Wezel et.al. (2009). In subsequent years (Figure 21), it can be seen the DEHP concentrations in the amended soils decreased by up to 97% for the 50 t/ha surface application of MWOO 2, although this degradation was not always consistent across treatments (Table 30b). DEHP is still detectable in a number of treatments, with an average concentration across all treated soils of 4.1 mg/kg, three years after the initial application.

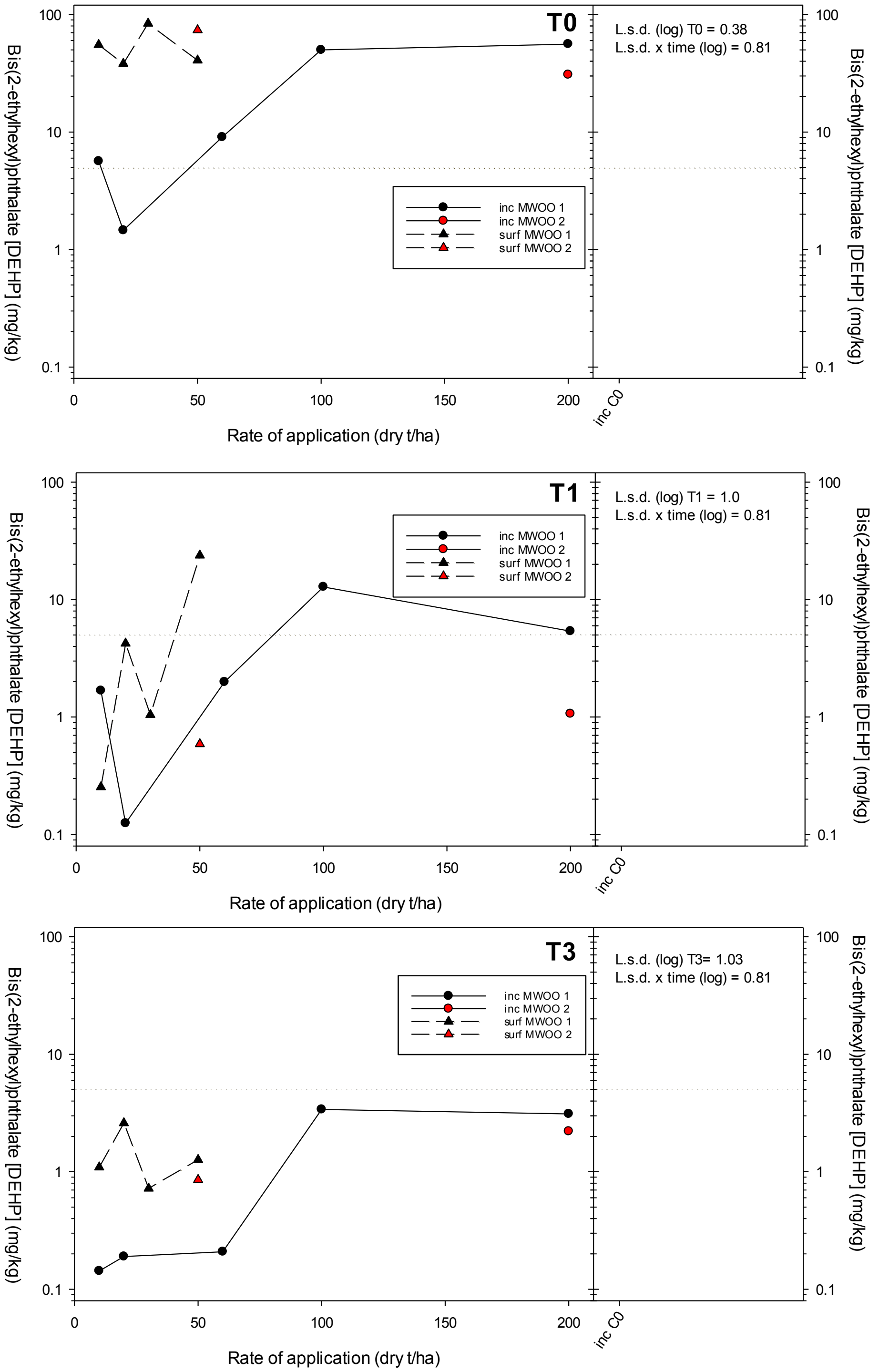


**Figure 21:** Average total soil Bis(2-ethylhexyl)phthalate (DEHP) concentrations resulting from soils being amended with increasing rates of incorporated or surface applied MWOO1 and MWOO 2. The soils were sampled soon after treatment application (T0), and again at the end of the first (T1) and third cropping seasons (T3); spanning a total of three years post-application. L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control.

**Table 22a:** ANOVA output table for Total soil Bis-2-ethylhexyl-phthalate [DEHP]

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.70 | 0.57 | 1.7 | |
| repf.plotf stratum | | | | | | |
| trtID | 11 | -25 | 27.21 | 2.47 | 7.42 | <.001 |
| Residual | 31 | -77 | 10.34 | 0.33 | 1 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 191.24 | 63.75 | 191.71 | <.001 |
| trtID.time | 31 | -77 | 15.93 | 0.51 | 1.54 | 0.067 |
| Residual | 72 | -261 | 23.94 | 0.33 | | |
| Total | 151 | -440 | 120.28 | | | |

**Table 22b:** Repeated measures ANOVA output table for Total soil Bis-2-ethylhexyl-phthalate [DEHP]

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.70 | 0.57 | 1.69 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 1.90 | 1.90 | 5.71 | 0.023 |
| IncVSurf.IncTrts | 2 | -4 | 5.34 | 2.67 | 8 | 0.002 |
| IncVSurf.SurfTrts | 1 | -3 | 1.33 | 1.33 | 3.97 | 0.055 |
| IncVSurf.IncTrts.incMW001 | 4 | | 17.55 | 4.39 | 13.15 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 3.36 | 1.12 | 3.36 | 0.031 |
| Residual | 31 | -77 | 10.34 | 0.33 | 1 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 211.01 | 70.34 | 211.53 | <.001 |
| IncVSurf.time | 3 | | 8.35 | 2.78 | 8.37 | <.001 |
| IncVSurf.IncTrts.time | 4 | -14 | 1.35 | 0.34 | 1.01 | 0.407 |
| IncVSurf.SurfTrts.time | 3 | -9 | 2.73 | 0.91 | 2.74 | 0.05 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 7.07 | 0.59 | 1.77 | 0.069 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 4.96 | 0.55 | 1.66 | 0.115 |
| Residual | 72 | -261 | 23.94 | 0.33 | | |
| Total | 151 | -440 | 120.28 | | | |

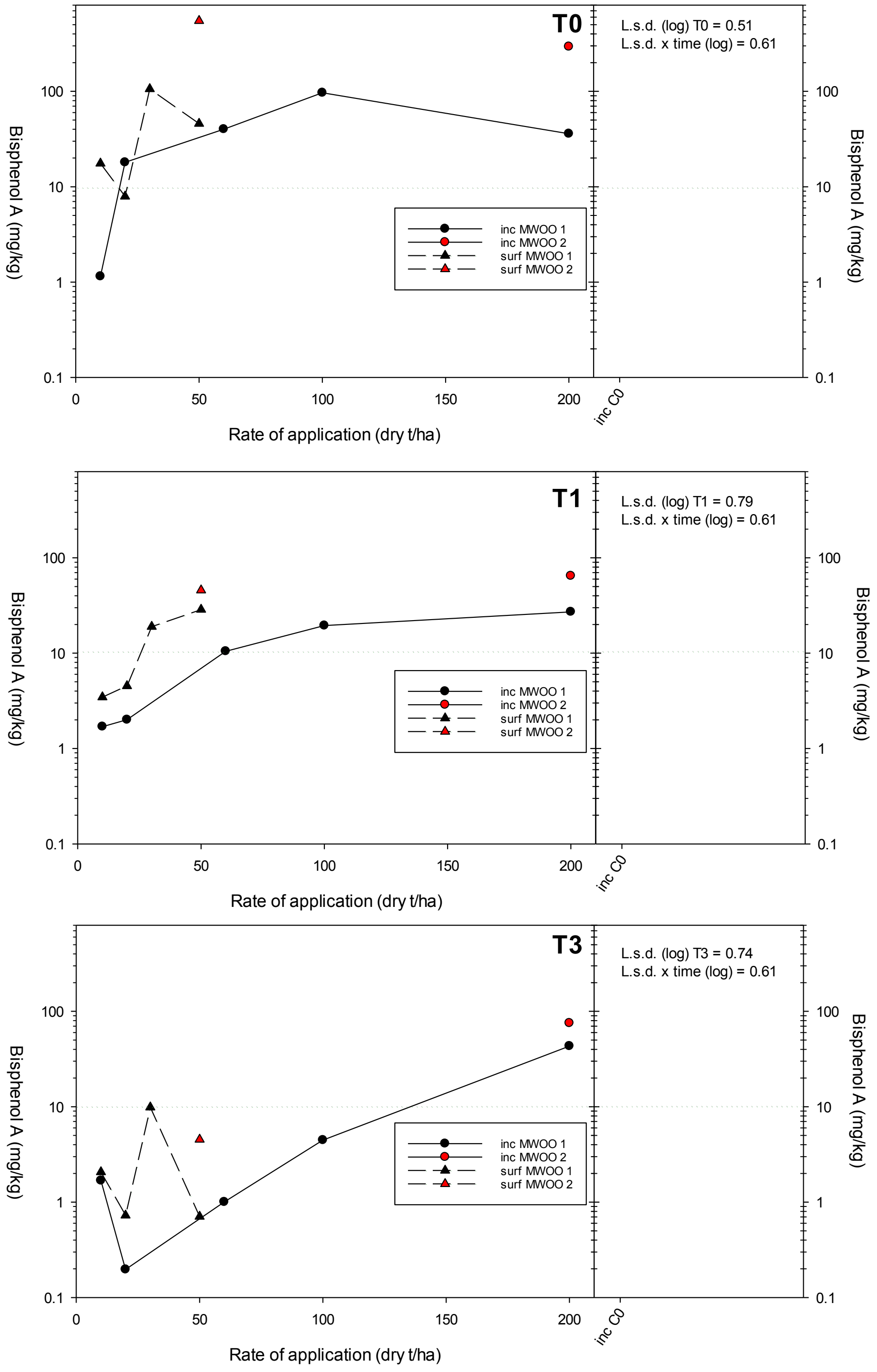
d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Bisphenol A*

Bisphenol A (BPA) is used in the manufacture of polycarbonates and as a plasticizer, stabilizer, and antioxidant in other plastics such as PVC and has been seen to readily leach into the aquatic environment (Yamamoto and Yasuhara 1999). As with BP and DEHP, BPA has been shown to have an adverse effect on reproduction and hormonal function as endocrine disruptors at low dose exposure to aquatic species (Oehlmann et.al. 2009). Fent et.al. (2003) reported that BPA is rapidly adsorbed once applied to the soil with half-lives ranging from 1-7 days (Ying and Kookana 2005; Xu et.al. 2009) and up to 37.5 days (Careghini et.al. 2015). Bisphenol A is not expected to be persistent in the soil environment (Michalowicz 2014). There have not been many studies on the impact of BPA on soil health and so it is difficult to find an ERL for this compound. Lemos et.al. (2010) found that for some soil invertebrates (woodlice), the lowest observed effect concentration (LOEC) was 10 mg/kg, although this level was highly dependent on the life cycle stage of the organism.

The effect of increasing rates of amendment addition and time (T0 – T3), on the soil concentrations of Bisphenol A, is illustrated in Figure 22. The ANOVA output tables for this data are given in Tables 23a (Standard ANOVA) and Table 23b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in Figure 22 is the l.s.d. indicating significance at $p< 0.05$ for the interaction between treatment and time. The soil concentration of BPA ranged between 1.2 mg/kg and 548 mg/kg for the T0 sampling. Soil BPA concentrations increased with increasing rates of MWOO application, and were highest for the high rate incorporation and surface application treatments. Given that the concentrations of BPA differed between the two MWOO materials (Table 6), it is not unexpected that the high rate MWOO 2 applications had the highest soil concentrations of BPA.

In subsequent years (T1 to T3), BPA concentrations in the amended soils decreased by up to 92% for the 50 t/ha surface application of MWOO 2 (548 mg/kg down to 4.6 mg/kg Appendix 7), although this degradation was not always consistent across treatments. After the initial (T0-T1) drop in soil concentrations, the degradation of BPA has slowed (Figure 22), and is still detectable in a number of treatments at time T3, with concentrations ranging between 0.2 mg/kg and 75 mg/kg, with an average concentration across all treated soils of 13 mg/kg, three years after the initial application.



**Figures 22:** Average total soil Bisphenol A concentrations resulting from soils being amended with increasing rates of incorporated or surface applied MWOO1 and MWOO 2. The soils were sampled soon after treatment application (T0), and again at the end of the first (T1) and third cropping seasons (T3); spanning a total of three years post-application. L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control.

**Table 23a:** ANOVA output table for Total soil Bisphenol A

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 8.08 | 2.69 | 14.26 | |
| repf.plotf stratum | | | | | | |
| trtID | 11 | -25 | 64.47 | 5.86 | 31.04 | <.001 |
| Residual | 31 | -77 | 5.85 | 0.19 | 0.99 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 117.07 | 39.02 | 204.43 | <.001 |
| trtID.time | 30 | -78 | 20.03 | 0.67 | 3.5 | <.001 |
| Residual | 85 | -248 | 16.23 | 0.19 | | |
| Total | 163 | -428 | 118.83 | | | |

**Table 23b:** Repeated measures ANOVA output table for Total soil Bisphenol A

Variate: tresp

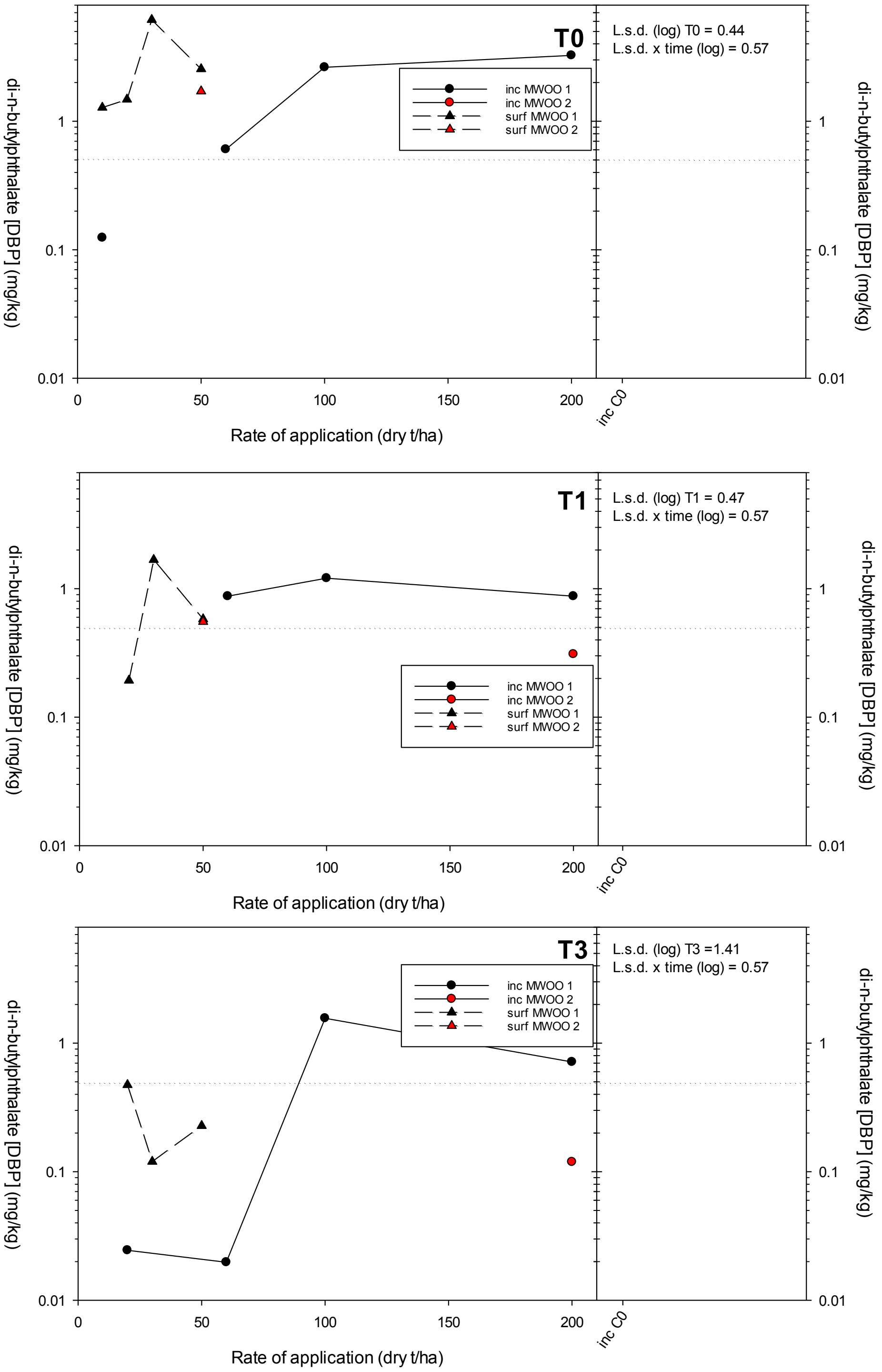
| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 8.08 | 2.69 | 14.27 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 1.89 | 1.89 | 10.01 | 0.003 |
| IncVSurf.IncTrts | 2 | -4 | 63.43 | 31.72 | 167.96 | <.001 |
| IncVSurf.SurfTrts | 1 | -3 | 15.61 | 15.61 | 82.65 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 27.40 | 6.85 | 36.28 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 6.22 | 2.07 | 10.98 | <.001 |
| Residual | 31 | -77 | 5.85 | 0.19 | 0.99 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 105.30 | 35.10 | 183.86 | <.001 |
| IncVSurf.time | 3 | | 11.92 | 3.97 | 20.81 | <.001 |
| IncVSurf.IncTrts.time | 4 | -14 | 3.48 | 0.87 | 4.55 | 0.002 |
| IncVSurf.SurfTrts.time | 3 | -9 | 3.49 | 1.16 | 6.09 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 11 | -1 | 10.77 | 0.98 | 5.13 | <.001 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 4.97 | 0.55 | 2.89 | 0.005 |
| Residual | 85 | -248 | 16.23 | 0.19 | | |
| Total | 163 | -428 | 118.83 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *Dibutylphthalate*

Dibutylphthalate (DBP) is another plasticizer thought to be moderately bound to the soil matrix (Jensen et.al. 2001). Inman et.al. (1984) reported a half-life for DBP in soil of less than 90 days. Ma et.al. (2016), have found effects on soil organisms such as earthworms for DBP concentrations as low as 2.5 mg/kg and a reduction in juvenile moulting in collembolans has been found at concentrations as low as 1 mg/kg (Jensen et.al. 2001). van Wezel et.al. (2000) propose a soil ERL for DBP of 0.7 mg/kg fresh soil.

The effect of increasing rates of amendment addition and time (T0 – T3), on the soil concentrations of DBP, is illustrated in Figure 23. The ANOVA output tables for this data are given in Tables 24a (Standard ANOVA) and Table 24b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in Figure 23 is the l.s.d. indicating significance at $p < 0.05$ for the interaction between treatment and time. The soil concentration of DBP ranged between below detection and up to 6.2 mg/kg for the T0 sampling. Soil BDP concentrations increased with increasing rates of MWOO 1 application, and were highest for the high rate incorporation and surface application treatments. There was no significant difference between the two MWOO materials, either for surface applications, or following incorporation into the test soils. (Table 24b). In subsequent years (Figure 23), it can be seen the BDP concentrations in the amended soils decreased by up to 77% for the 50 t/ha surface application of MWOO 1, although this degradation not always consistent across treatments. After the drop in soil concentrations, the degradation of BDP has slowed (Figure 23), and is still detectable in a number of treatments at time T3, with concentrations ranging up to 1.6 mg/kg, with an average concentration across all treated soils of 0.3 mg/kg, three years after the initial application.



L.s.d. (log) T0 = 0.44
L.s.d. x time (log) = 0.57

L.s.d. (log) T1 = 0.47
L.s.d. x time (log) = 0.57

L.s.d. (log) T3 =1.41
L.s.d. x time (log) = 0.57

**Figure 23:** Average total soil Di-n-butylphthalate (DBP) concentrations resulting from soils being amended with increasing rates of incorporated or surface applied MWOO1 and MWOO 2. The soils were sampled soon after treatment application (T0), and again at the end of the first (T1) and third cropping seasons (T3); spanning a total of three years post-application. L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control.

**Table 34a:** ANOVA output table for Total soil Di-n-butylphthalate [DBP]

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.81 | 0.94 | 2.74 | |
| repf.plotf stratum | | | | | | |
| trtID | 10 | -26 | 40.61 | 4.06 | 11.89 | <.001 |
| Residual | 21 | -87 | 7.17 | 0.34 | 3.4 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 76.12 | 25.37 | 252.6 | <.001 |
| trtID.time | 19 | -89 | 12.79 | 0.67 | 6.7 | <.001 |
| Residual | 28 | -305 | 2.81 | 0.10 | | |
| Total | 84 | -507 | 35.41 | | | |

**Table 34b:** Repeated measures ANOVA output table for Total soil Di-n-butylphthalate [DBP]

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.81 | 0.94 | 2.74 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 16.63 | 16.63 | 48.7 | <.001 |
| IncVSurf.IncTrts | 1 | -5 | 0.06 | 0.06 | 0.17 | 0.682 |
| IncVSurf.SurfTrts | 1 | -3 | 1.56 | 1.56 | 4.58 | 0.044 |
| IncVSurf.IncTrts.incMW001 | 4 | | 34.47 | 8.62 | 25.23 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.74 | 0.58 | 1.69 | 0.199 |
| Residual | 21 | -87 | 7.17 | 0.34 | 3.4 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 67.94 | 22.65 | 225.45 | <.001 |
| IncVSurf.time | 3 | | 6.62 | 2.21 | 21.96 | <.001 |
| IncVSurf.IncTrts.time | 3 | -15 | 1.90 | 0.63 | 6.3 | 0.002 |
| IncVSurf.SurfTrts.time | 2 | -10 | 2.03 | 1.01 | 10.09 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 6 | -6 | 6.72 | 1.12 | 11.15 | <.001 |
| IncVSurf.SurfTrts.surfMW001.time | 5 | -4 | 3.47 | 0.70 | 6.92 | <.001 |
| Residual | 28 | -305 | 2.81 | 0.10 | | |
| Total | 84 | -507 | 35.41 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

### *N,N-Diethyl-m-toluamide*

N,N-Diethyl-m-toluamide (DEET) is an active ingredient of insect repellents that have been used by humans for 30 years. It has also been used as a solvent for polymer manufacture. It is thought that its main route to the environment is via the application of wastewater or biosolids. In a paper summarizing the environmental fate of DEET, Weeks et.al. (2012), report a soil half-life for DEET of 10 to 35 days and this chemical is not considered to be persistent in the soil environment. While DEET has been found to be toxic to aquatic organisms, we could find no studies reporting toxicity to soil-based organisms and DEET is considered to pose a low environmental hazard.

The effect of increasing rates of amendment addition and time (T0 – T3), on the soil concentrations of DBP, is illustrated in Figure 24. The ANOVA output tables for this data are given in Tables 25a (Standard ANOVA) and Table 25b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in Figure 24 is the l.s.d. indicating significance at $p< 0.05$ for the interaction between treatment and time. The soil concentration of DEET ranged from below detection and up to 1.3 mg/kg for the T0 sampling. Soil DEET concentrations increased with increasing rates of MWOO 1 application, and were highest for the high rate incorporation treatments. There was no significant difference between the two MWOO materials for either incorporated of surface applied material. In subsequent years (Figure 24), it can be seen the DEET concentrations in the amended soils decreased by up to 93% for the 50 t/ha surface application of MWOO 2, although this degradation not always consistent across treatments. By the time of the final sampling at time T3, DEET concentrations dropped to a maximum of 0.18 mg/kg, with an average concentration across all treated soils of 0.05 mg/kg, three years after the initial application.

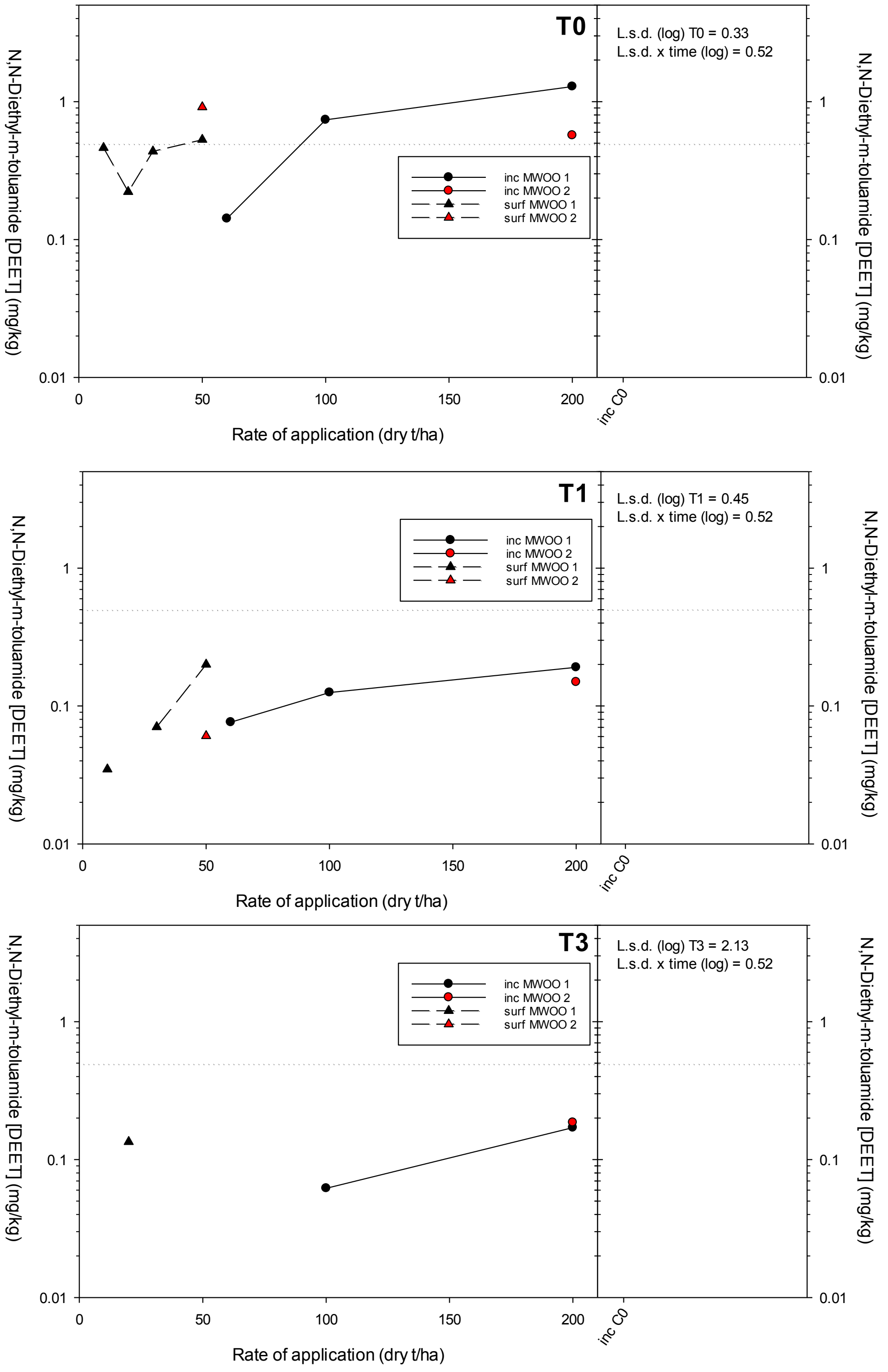


**Figure 24:** Average total soil N,N-Diethyl-m-toluamide (DEET) concentrations resulting from soils being amended with increasing rates of incorporated or surface applied MWOO1 and MWOO 2. The soils were sampled soon after treatment application (T0), and again at the end of the first (T1) and third cropping seasons (T3); spanning a total of three years post-application. L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control.

**Table 25a:** ANOVA output table for Total soil N,N-Diethyl-m-toluamide [DEET]

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.99 | 1.00 | 4.83 | |
| repf.plotf stratum | | | | | | |
| trtID | 8 | -28 | 4.76 | 0.60 | 2.89 | 0.023 |
| Residual | 22 | -86 | 4.54 | 0.21 | 1.9 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 46.55 | 15.52 | 142.87 | <.001 |
| trtID.time | 17 | -91 | 2.55 | 0.15 | 1.38 | 0.247 |
| Residual | 19 | -314 | 2.06 | 0.11 | | |
| Total | 72 | -519 | 14.93 | | | |

**Table 25b:** Repeated measures ANOVA output table for Total soil N,N-Diethyl-m-toluamide [DEET]

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 2.99 | 1.00 | 4.83 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 1.35 | 1.35 | 6.53 | 0.018 |
| IncVSurf.IncTrts | 1 | -5 | 0.24 | 0.24 | 1.17 | 0.292 |
| IncVSurf.SurfTrts | 1 | -3 | 0.57 | 0.57 | 2.77 | 0.11 |
| IncVSurf.IncTrts.incMW001 | 2 | -2 | 4.18 | 2.09 | 10.14 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 2.12 | 0.71 | 3.43 | 0.035 |
| Residual | 22 | -86 | 4.54 | 0.21 | 1.9 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 50.04 | 16.68 | 153.6 | <.001 |
| IncVSurf.time | 3 | | 3.46 | 1.15 | 10.63 | <.001 |
| IncVSurf.IncTrts.time | 3 | -15 | 3.34 | 1.11 | 10.24 | <.001 |
| IncVSurf.SurfTrts.time | 2 | -10 | 0.90 | 0.45 | 4.16 | 0.032 |
| IncVSurf.IncTrts.incMW001.time | 5 | -7 | 0.65 | 0.13 | 1.2 | 0.348 |
| IncVSurf.SurfTrts.surfMW001.time | 4 | -5 | 0.15 | 0.04 | 0.35 | 0.843 |
| Residual | 19 | -314 | 2.06 | 0.11 | | |
| Total | 72 | -519 | 14.93 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Effects of amendments on soil physical fertility

### *Plant available soil water, soil bulk density and soil porosity*

The application of organic amendments, including materials such as composted wastes and biosolids, have been shown to improve soil physical properties in degraded soils (Aggelides and Londra 2000). Biosolids have been shown to improve soil moisture content (Epstein et.al., 1976), soil water retention capacity (Gupta et al., 1977), and total porosity and pore size distribution (Kladivko and Nelson, 1979); while similar effects have been seen following the application of composts (e.g. Pagliai et.al., 1981). Both Aggelides and Londra (2000) and Diacono and Montemurro (2009) stress that extent of these effects are proportional to the rates, and frequency of amendment application. Chan et.al. (2008), concluded that compost applications improved the aggregate stability of a degraded soil, but only after applications exceeded 120 t/ha.

Both plant available soil water and bulk density, were measured on plots where amendments were incorporated into the soil, rather than via surface application. To provide adequate mixing of the amendment materials, some of which were applied at rates up to 200 t/ha, the incorporation of treatments was carried out using a rotary hoe, and in doing so, this procedure completely altered the structure of these soils. Nonetheless, we are still able to highlight treatment effects on key soil physical properties, relative to the unamended control soils.

The amount of plant available soil water was calculated as the difference between the measured field capacity and permanent wilting point, soil water contents. Figure 25 shows the effect of increasing amendment application on the levels of plant-available soil water. Data is included for soils collected at times T0 and T2 and the Figure also includes the l.s.d. for the time x treatment interaction, indicating statistical significance ($p<0.05$). Higher levels of plant available water are considered indicative of a soil environment less prone to water stress.

For the initial (T0) sampling, the amount of plant available soil water was higher than for control soils for rates of MWOO application greater than 60 t/ha and for the highest application of green waste (200 t/ha). Applications of biosolids or manure did not increase levels of plant available soil water to above those of the control. The increase in levels in plant available soil water had persisted by the time of the T2 sampling (Figure 25) and rates of MWOO application above 60 t/ha increased the levels of plant available water above those of the control.

Figure 26 shows the effect of increasing applications of MWOO 1 and high rate only applications of MWOO 2 (200 t/ha), composted green waste (100 t/ha), composted biosolids (60 t/ha) and poultry manure (100 t/ha), on soil bulk density and calculated total soil porosity, where reductions in soil bulk density and/or increases in soil porosity can lead to better root penetration, improved soil aeration and potentially improved drainage conditions.

Data is presented for soils collected at time T3 and the Figure also includes the l.s.d. for the treatment effect on both bulk density and soil porosity, indicating statistical significance ($p<0.05$). The data presented in Figure 26 shows that there was a statistically significant decrease in soil bulk density, but only for high rates of MWOO 1 (10 % for 100 t/ha and 17% for 200 t/ha), MWOO 2 (8% for 200 t/ha), and manure application (5% for 100 t/ha). Application of other amendments did not result in a statistically significant decrease in soil bulk density. The decreases in soil bulk presented above are mirrored by increases in soil porosity as presented in Figure 26. Soil porosity increased above levels in the control soil, but again, only for the highest rates of MWOO application (5% for 100 t/ha, and 7% for 200 t/ha).

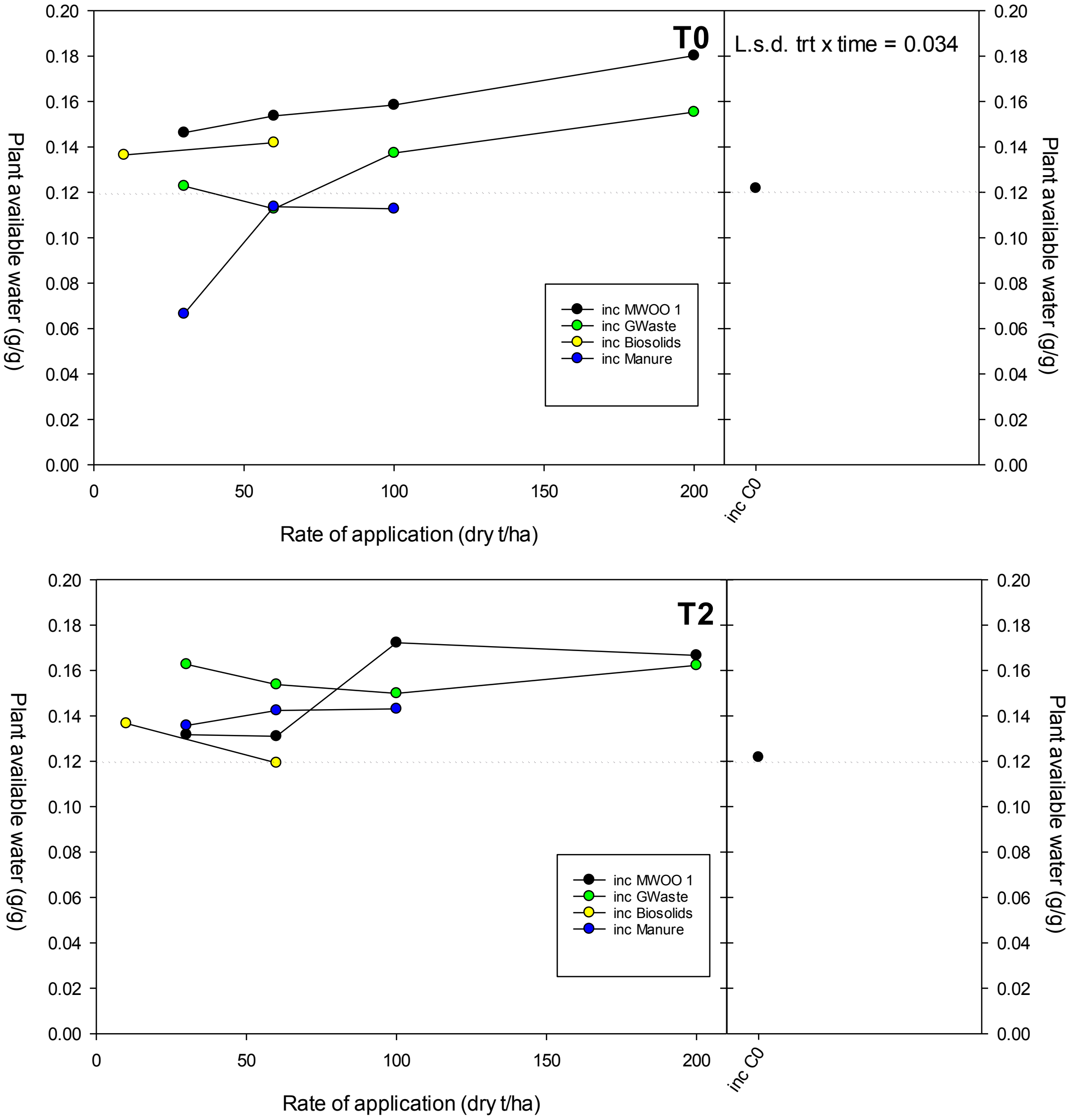


**Figure 25**: The effect of increasing rates of incorporated MWOO1, compared to increasing applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure), on the quantity of plant available soil water. Data is presented for soils sampled at time T0 and T2. L.s.d. indicates significance at $p < 0.05$ for the interaction between treatments and time. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; CO = control; Inc = incorporated treatments; surf = surface applied; C0 = control; CF fert = control fertiliser

Lindsay and Logan (1998) observed increases in moisture retention and decreases in bulk density, in soils receiving sewage sludge, four years post application, and attributed these results to increased concentrations of soil organic carbon, which in turn created more water adsorbing surfaces and diluted the mineral components in receiving soils. Similar conclusions were drawn by Khaleel et.al. (1981) who analysed data from field applications of a range of organic amendments, including domestic waste and poultry manure, for both short and long-term studies. Mamo et.al. (2000) studied the effects of two MWOO materials on soil water and soil water stress and how these influenced the yield of irrigated corn. Although water retention curves for amended soils showed that addition of the MWOO increased the water holding capacity in these soils, increases in the amount of plant available water were not significant and were further compromised by increased salinity levels in the field soils. Given that TOC concentrations in the amended soils have dropped by up to 30 % for the incorporated MWOO and green waste treatments, and by up to 50

% in the surface applied MWOO treatments, it is likely that the measured improvements in soil physical fertility may not persist. However Chan et.al. (2011), found that the beneficial effects of compost application on vegetable production, persisted in some cases for up to five successive crops, post compost application.

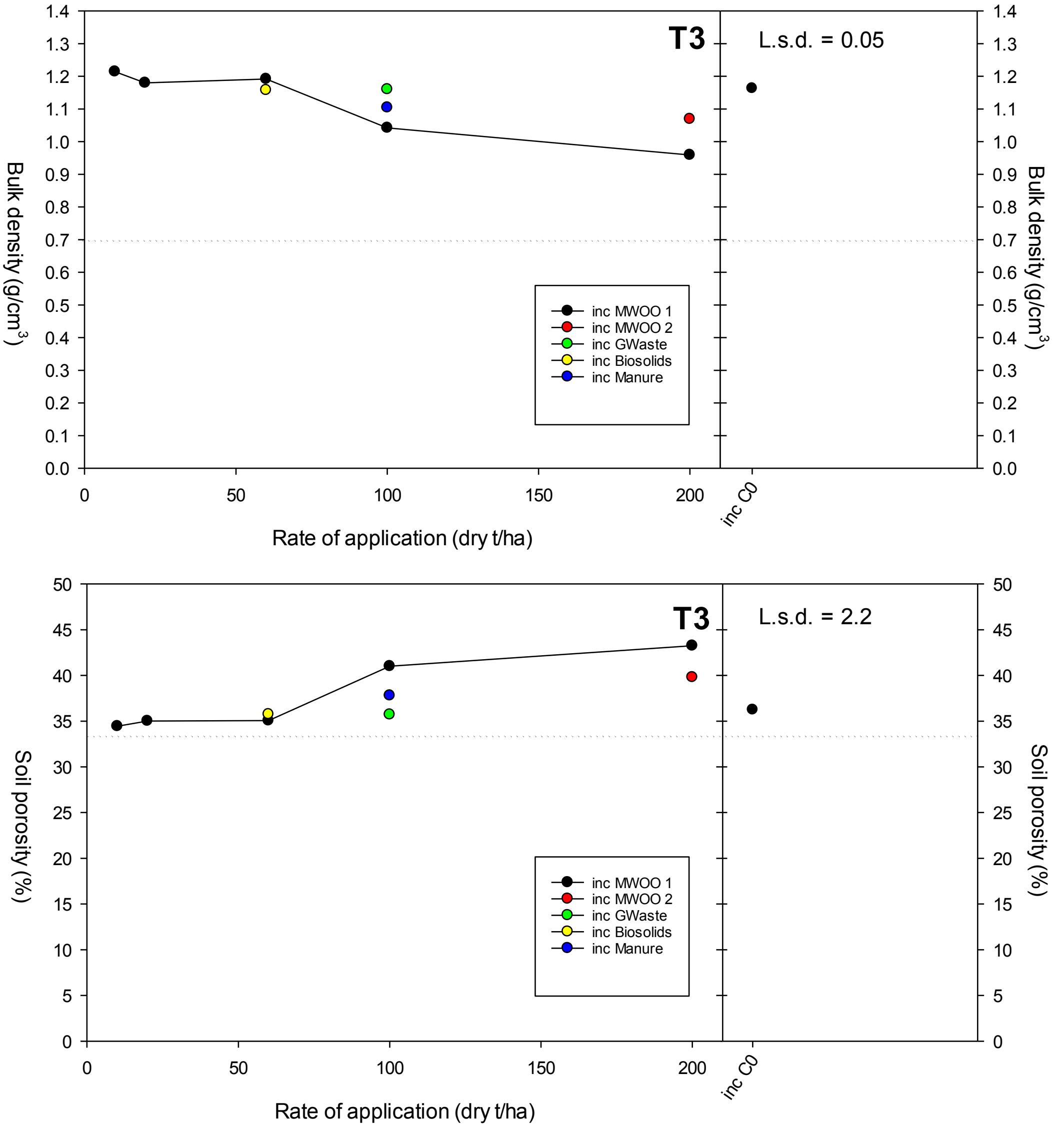


**Figure 26**: The effect of increasing rates of incorporated MWOO1, and high rates of MWOO 2, composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure), on soil bulk density (g/cm$^3$) and calculated soil porosity (%). Data is presented for soils sampled at time T3. L.s.d. indicates significance at p< 0.05 for the interaction between treatments. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; CO = control; Inc = incorporated treatments

# Effects of amendments on plant growth, metal uptake and product quality

## Growing conditions

A summary calendar of field trial activities is given in Table 2. Monthly growing conditions (rainfall, maximum and minimum temperature) that occurred during the field trial are presented in Appendix 8 which also includes long-term district climate averages. For the first year of the trial (T0 – T1, 2013), rainfall at the site exceeded monthly averages for June (160 mm compared to the June average of 67 mm) and November (106 mm compared to the November average of 76mm). The wet conditions in June prevented the establishment of the first crop (wheat), and millet was grown instead (October 2013 – late March 2014). A drier than average late summer was corrected by supplemental irrigation during this period (see Table 2).

For the second year of the trial (2014), the late winter months were again wetter than average (135 mm compared to the August average of 42mm). It was also noted that for July in particular, the minimum temperatures was lower than average, and there were 18 frost days on site for the period June to July. The frost was seen to impact on the emerging wheat crop at the site which had been planted in late June 2014. Some general bird damage was noted at grain harvest.

The third growing season, 2015, saw average weather conditions prevailing for most of the growing season, preceded by above average rainfall for April (195 mm compared to the April average of 68 mm). There were some frost events prior to seedling emergence and while the crop was planted late May 2015, late winter frosts did not affect plant growth. Only limited supplemental irrigation (September and October Table 2) was needed.

## Millet dry matter and grain yield

The effect of increasing rates of amendment addition on 12-week millet dry matter yield (DM) is illustrated in Figure 27. The ANOVA output tables for this data are given in Tables 26a (Standard ANOVA) and Table 26b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Plant growth (Plate 10) generally responded positively to the incorporation or surface applications of the amendment materials but few of these responses were statistically different from the control soils (Figure 30, Table 26b).

**Plate 10:** Early millet vegetative growth, 2 weeks prior to DM sampling. Wooden pegs indicate the individual plot boundaries (plot size = 5m x 3 m).

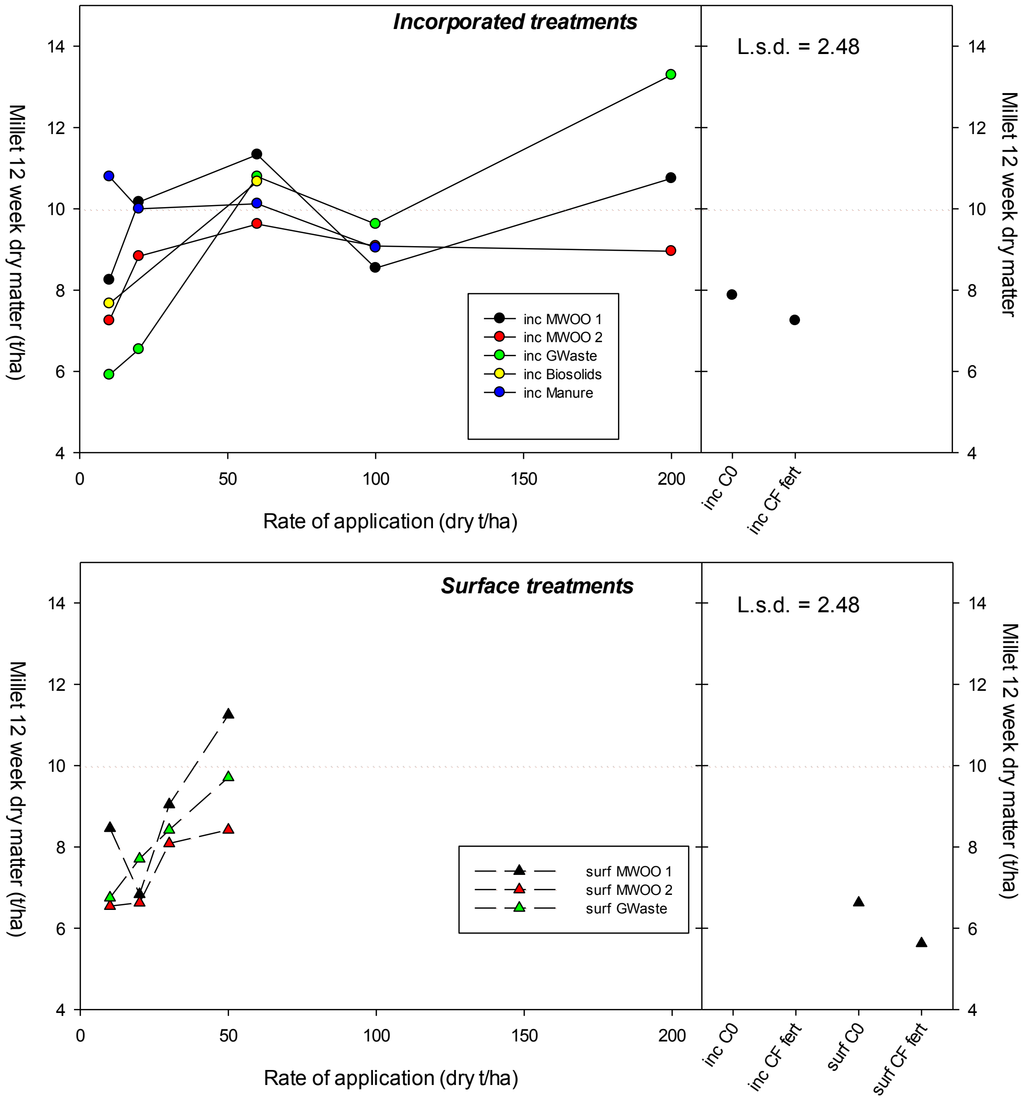


**Figure 27:** Average dry matter yield for millet plants sample 12 weeks after planting. Plants were grown on soils amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2 compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

Dry matter yields ranged between 4 and 18 t DM /ha and did not always increase with increasing application rate, except for the incorporated green waste, and surface applied MWOO 1 (Table 26b). Applications of MWOO 1 of more than 60 t/ha resulted in DM production exceeding control levels. No MWOO 2 treatment increased DM yield to above those of the control soil. Similar results were seen for DM yield for the green waste and the composted biosolids treatments, where applications above 60 t /ha exceeded control levels.

Increasing application of manure resulted in decreasing yields. The reason for the reduction of yield with manure application could be that the poultry manure used had not stabilised at the time of application and had very high concentrations of $NH_4$. Subsequently, amended soils had $NH_4$ concentrations up to 600 mg/kg for the highest manure applications (Appendix 4a), and these in combination with the wet soil conditions described above, would likely have resulted in the persistence of these high $NH_4$ concentrations for some time (Handreck and Black 2010). Similar toxicity following manure application is common where high application rates are applied, especially where this coincides with low temperatures and wet soil conditions (Handreck and Black 2010). These authors recommend applications of no more than 4-5 t/ha for a single application of poultry manure, which is far exceeded by the rates used in this trial. Soil $NH_4$ concentrations had dropped by the time of the T1 sampling to less than 100 mg/kg for the highest manure application (100 t/ha, Appendix 4b).

**Table 26a:** ANOVA output table for millet 12-week dry matter yield

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 5.77 | 1.92 | 0.61 | |
| repf.*Units* stratum | | | | | |
| trtID | 36 | 442.31 | 12.29 | 3.92 | <.001 |
| Residual | 108 | 338.38 | 3.13 | | |
| Total | 147 | 786.46 | | | |

**Table 26b:** Repeated measures ANOVA output table for millet 12-week dry matter yield

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 5.77 | 1.92 | 0.61 | |
| repf.*Units* stratum | | | | | |
| IncVSurf | 1 | 65.39 | 65.39 | 20.87 | <.001 |
| IncVSurf.IncTrts | 6 | 43.59 | 7.26 | 2.32 | 0.038 |
| IncVSurf.SurfTrts | 4 | 47.70 | 11.93 | 3.81 | 0.006 |
| IncVSurf.IncTrts.incMW001 | 4 | 29.49 | 7.37 | 2.35 | 0.058 |
| IncVSurf.IncTrts.incMW002 | 4 | 12.71 | 3.18 | 1.01 | 0.404 |
| IncVSurf.IncTrts.incGW | 4 | 149.19 | 37.30 | 11.9 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | 6.24 | 2.08 | 0.66 | 0.576 |
| IncVSurf.IncTrts.incCBio | 1 | 18.00 | 18.00 | 5.75 | 0.018 |
| IncVSurf.SurfTrts.surfMW001 | 3 | 40.04 | 13.35 | 4.26 | 0.007 |
| IncVSurf.SurfTrts.surfMW002 | 3 | 11.35 | 3.78 | 1.21 | 0.311 |
| IncVSurf.SurfTrts.surfGW | 3 | 18.62 | 6.21 | 1.98 | 0.121 |
| Residual | 108 | 338.38 | 3.13 | | |
| Total | 147 | 786.46 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

For surface applications of the amendments (Figure 27, Table 26b), only the 50 t/ha application of MWOO 1 and 50 t/ha application of green waste, resulted in a statistically higher plant DM yield in plants grown on treated soils, compared to the control treatment.

The effect of increasing rates of amendment addition on millet grain yield is illustrated in Figure 28. The ANOVA output tables for this data are given in Tables 27a (Standard ANOVA) and Table 27b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Any positive gains in plant DM yield were not translated into grain yield which did not respond to the application of the of the amendment materials for both incorporated and surface application treatments (Figure 28 and Tables 27a and 27b).

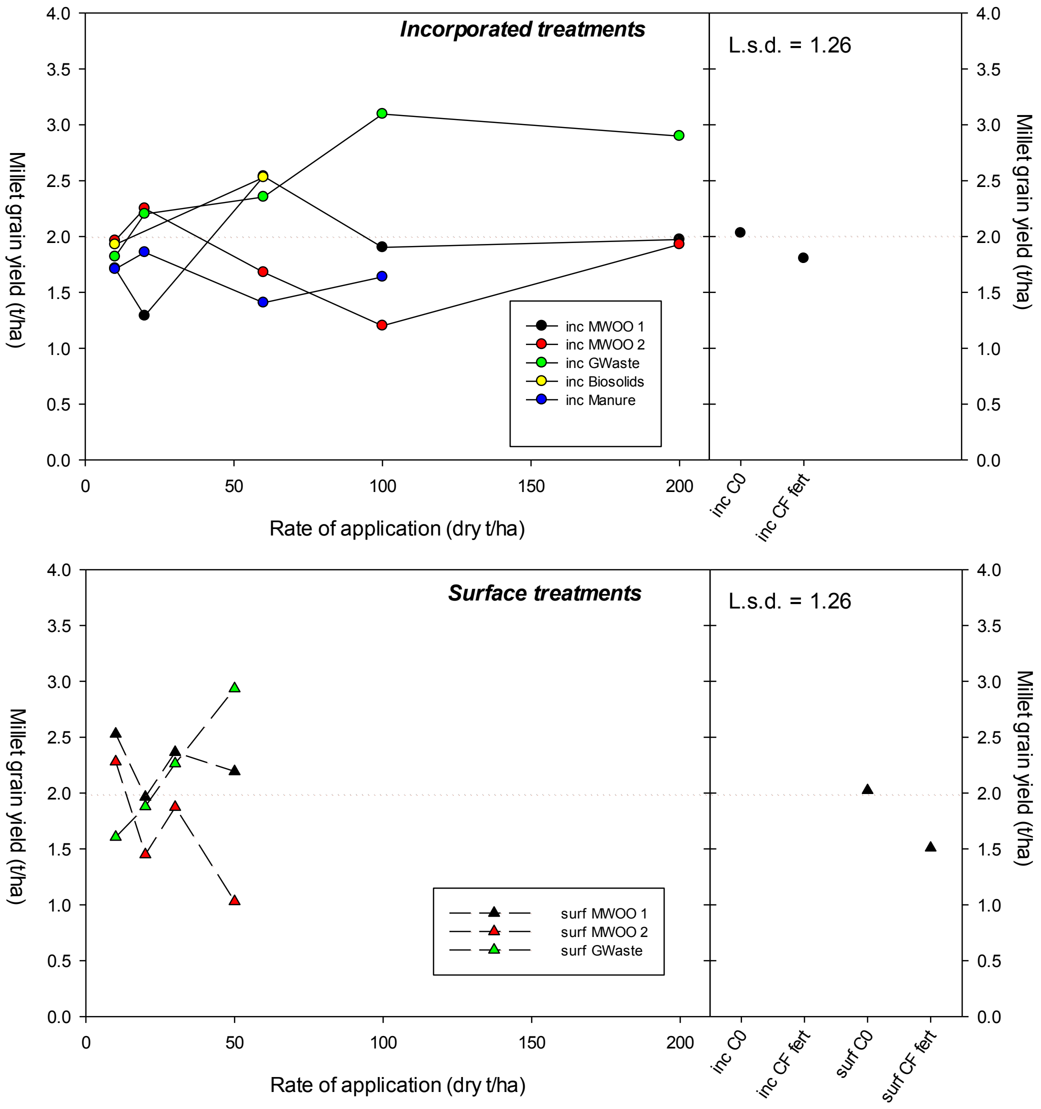


**Figure 28:** Average grain yield for millet sampled at harvest. Plants were grown on soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

Grain yields ranged between 1 and 3.5 t/ha. No application of MWOO, green waste, composted biosolids or manure, either incorporated or surface applied, resulted in grain yield exceeding control treatments (Table 27b).

**Table 27a:** ANOVA output table for millet grain yield

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 9.79 | 3.26 | 4.03 | |
| repf.*Units* stratum | | | | | | |
| trtID | 36 | | 31.87 | 0.89 | 1.09 | 0.353 |
| Residual | 107 | -1 | 86.55 | 0.81 | | |
| Total | 146 | -1 | 128.07 | | | |

**Table 27b:** Repeated measures ANOVA output table for millet grain yield

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 9.79 | 3.26 | 4.03 | |
| repf.*Units* stratum | | | | | | |
| IncVSurf | 1 | | 0.00 | 0.00 | 0 | 0.989 |
| IncVSurf.IncTrts | 6 | | 8.06 | 1.34 | 1.66 | 0.138 |
| IncVSurf.SurfTrts | 4 | | 4.40 | 1.10 | 1.36 | 0.252 |
| IncVSurf.IncTrts.incMW001 | 4 | | 3.27 | 0.82 | 1.01 | 0.405 |
| IncVSurf.IncTrts.incMW002 | 4 | | 2.48 | 0.62 | 0.77 | 0.55 |
| IncVSurf.IncTrts.incGW | 4 | | 4.34 | 1.09 | 1.34 | 0.259 |
| IncVSurf.IncTrts.incManure | 3 | | 0.43 | 0.14 | 0.18 | 0.913 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.72 | 0.72 | 0.89 | 0.347 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.70 | 0.23 | 0.29 | 0.834 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 3.48 | 1.16 | 1.44 | 0.236 |
| IncVSurf.SurfTrts.surfGW | 3 | | 3.98 | 1.33 | 1.64 | 0.184 |
| Residual | 107 | -1 | 86.55 | 0.81 | | |
| Total | 146 | -1 | 128.07 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Wheat grain yield

The effect of increasing rates of amendment addition on wheat grain yield for the first (T2) and second (T3) wheat crops is illustrated in Figure 29. The ANOVA output tables for this data are given in Tables 28a (Standard ANOVA) and Table 28b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

For the first wheat crop (T2), plant growth (Plate 11) generally responded positively to the incorporated amendment materials but less so to the surface application of these materials (Table 28b). Grain yields range from 1.1 t/ha for the unfertilized control, to 6.5 t/ha for the highest application (200 t/ha) of MWOO 1. Overall, these yields are quite high compared the National (1.8 t/ha), and NSW (2.1 t/ha), average yields as cited for the 2012-2013 season by the Australian Bureau of Statistics (ABS 2013), and reflect the intensive nature of the experimental trial setup including the provision of supplemental irrigation.

Grain yield generally increased with application rate for all incorporated amendments except the composted biosolids and manure treatments. Surface application rate had less of an effect on yield, except for MWOO 2, where increasing applications resulted in statistically significant increases in grain yield (Table 28b). For the MWOO 1 and 2 incorporation treatments, applications greater than 60 t/ha resulted in grain yields exceeding control and control fertilizer levels ($p<0.05$).

The data presented in Figure 29 also shows that a surface application of greater than 20 t/ha application for MWOO 1 and greater than 30 t/ha for MWOO 2, resulted grain yields that were statistically greater than plants grown on the control treatment.

**Plate 11:** First (T2) wheat crop at flowering (left) and just prior to grain harvest (right). Wooden pegs indicate the individual plot boundaries (plot size = 5m x 3 m).

These are compared to the other incorporation treatments such as green waste, which required applications greater than 60 t/ha to exceed control treatment yields and manure applications as low as 10 t/ha, which also resulted in yield greater than control levels. No biosolids applications (incorporated at 10 and 60 t/ha) raised wheat grain yields above the control. These results contrast with data from the previous crop (millet), which showed that no applications of any of the amendments raised grain yields above control levels, either when the material was incorporated below the soil surface, or for surface applications.

Growing conditions were not limiting for the second wheat crop (T3), compared to the T2 crop, which suffered severe frost damage during early growth and bird damage at grain filling. These improved growing conditions were reflected by an average increase in grain yield across all control and amendment treatments of 31% (Figure 29). For the second crop, plant growth responded positively to the amendment materials. Grain yields range between 3 t/ha for the unfertilized control, to 7.5 t/h for the highest application (100 t/ha) of manure. Once again, these yields are quite high compared to average yields cited for the 2012-2013 season by the Australian Bureau of Statistics (ABS 2013).

For the MWOO 1 and 2 incorporation treatments, applications greater 60 t/ha resulted in grain yields exceeding control levels ($p<0.05$). No incorporated green waste of composted biosolids treatments resulted in wheat yields that were statistically different from the unamended control. However, all poultry manure treatments (10 to 100 t/ha) resulted in grain yield greater than the unamended control.

The data presented in Figure 29 also shows that a surface application of greater than 20 t/ha application for MWOO 1 and 30 t/ha for MWOO 2, resulted grain in yields that were statistically greater than plants grown on the control treatment. Surface applications of GW at rates greater 20 t/ha, increased grain yield to greater than the unfertilized control.

These results contrast with data from the previous crop (millet), which showed that the manure treatments did not boost crop production, probably because the material had not stabilised at the time of application and had very high concentrations of $NH_4$. The composted green waste treatments continue to have a beneficial effect on production for surface application treatments. It should also be noted that after three years, the composted biosolids treatments are no longer having a positive influence on grain yield compared to the unfertilized control. Only two amendment treatments (incorporated MWOO 1 at 200 t/ha and 100 t/ha poultry manure), resulted in grain yields greater than the fertilizer control.

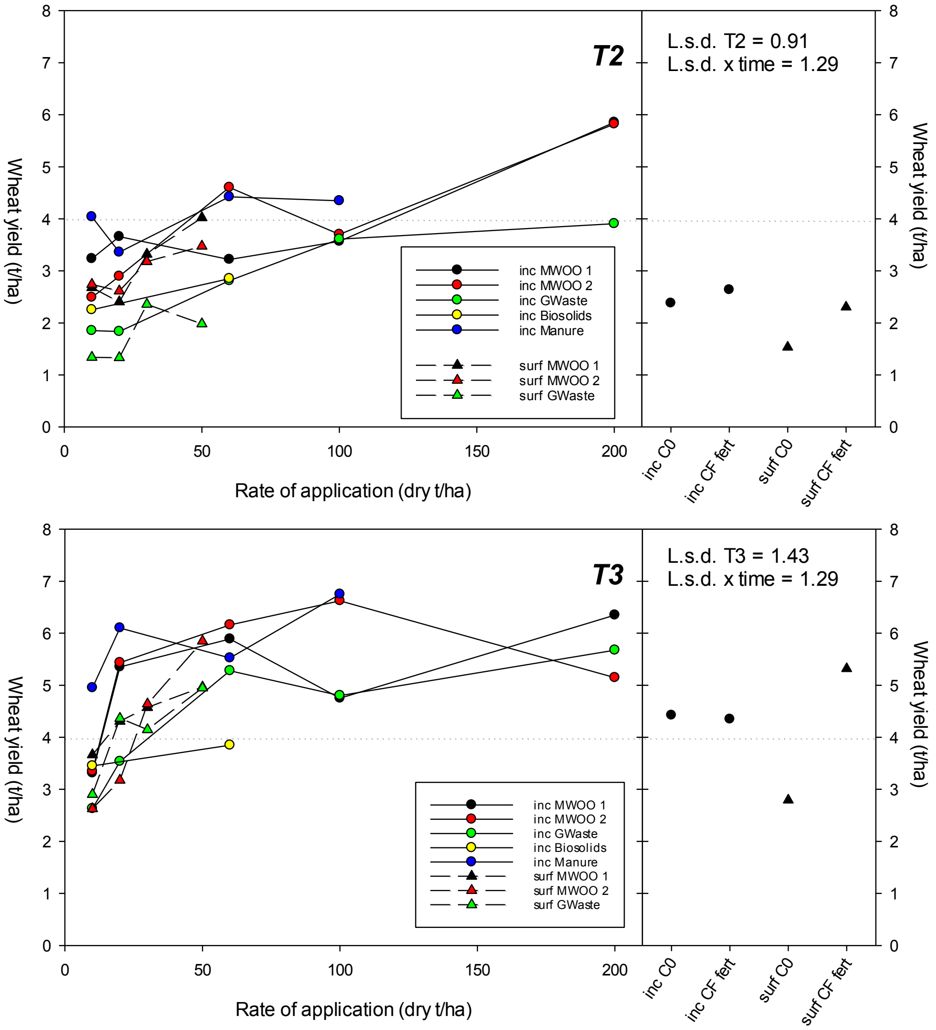


**Figure 29:** Average grain yields for plants harvested from the first (T2) and second (T3) wheat crops. Plants were grown on soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p < 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 28a:** ANOVA output table for wheat grain yield

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 27.54 | 9.18 | 9.39 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 325.18 | 9.03 | 9.24 | <.001 |
| Residual | 105 | -3 | 102.60 | 0.98 | 1.35 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 188.90 | 188.90 | 261.21 | <.001 |
| trtID.time | 36 | | 60.82 | 1.69 | 2.34 | <.001 |
| Residual | 78 | -33 | 56.41 | 0.72 | | |
| Total | 259 | -36 | 612.61 | | | |

**Table 28b:** Repeated measures ANOVA output table for wheat grain yield

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 27.54 | 9.18 | 9.39 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 46.55 | 46.55 | 47.64 | <.001 |
| IncVSurf.IncTrts | 6 | | 89.20 | 14.87 | 15.22 | <.001 |
| IncVSurf.SurfTrts | 4 | | 30.06 | 7.52 | 7.69 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 38.05 | 9.51 | 9.74 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 38.72 | 9.68 | 9.91 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 40.02 | 10.00 | 10.24 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 4.91 | 1.64 | 1.67 | 0.177 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.76 | 0.76 | 0.78 | 0.379 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 8.79 | 2.93 | 3 | 0.034 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 20.04 | 6.68 | 6.84 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 8.06 | 2.69 | 2.75 | 0.046 |
| Residual | 105 | -3 | 102.60 | 0.98 | 1.35 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 188.90 | 188.90 | 261.21 | <.001 |
| IncVSurf.time | 1 | | 0.27 | 0.27 | 0.37 | 0.542 |
| IncVSurf.IncTrts.time | 6 | | 4.65 | 0.77 | 1.07 | 0.387 |
| IncVSurf.SurfTrts.time | 4 | | 12.53 | 3.13 | 4.33 | 0.003 |
| IncVSurf.IncTrts.incMW001.time | 4 | | 6.80 | 1.70 | 2.35 | 0.061 |
| IncVSurf.IncTrts.incMW002.time | 4 | | 16.48 | 4.12 | 5.7 | <.001 |
| IncVSurf.IncTrts.incGW.time | 4 | | 3.65 | 0.91 | 1.26 | 0.293 |
| IncVSurf.IncTrts.incManure.time | 3 | | 5.06 | 1.69 | 2.33 | 0.081 |
| IncVSurf.IncTrts.incCBio.time | 1 | | 0.01 | 0.01 | 0.01 | 0.926 |
| IncVSurf.SurfTrts.surfMW001.time | 3 | | 0.16 | 0.05 | 0.07 | 0.975 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | | 7.44 | 2.48 | 3.43 | 0.021 |
| IncVSurf.SurfTrts.surfGW.time | 3 | | 3.77 | 1.26 | 1.74 | 0.166 |
| Residual | 78 | -33 | 56.41 | 0.72 | | |
| Total | 259 | -36 | 612.61 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Plant uptake of nutrients and metal contaminants

### *Millet*

The millet crop was sampled for vegetative growth 12 weeks after planting, and these samples were then analysed for metal contaminant and nutrient elements. All plant uptake data are expressed on a dry weight basis. These data (treatment means) are presented in Appendix 10a for the incorporation treatments and Appendix 10b for the surface application treatments. The concentration of a number of the nutrient and metal elements tested in the millet herbage increased with increases in application rate (e.g. Cr, Cu, Fe, K, N, P, S and Zn and Cl; see Appendix 6a and 6b), although these increases were not consistent across all amendments. At no stage did heavy metal accumulation in millet leaves reach a level where toxicity and subsequent yield loss may have been expected.

The effect of increasing rates of amendment addition on millet leaf Zn is illustrated in Figure 30. The ANOVA output tables for this data are given in Tables 29a (Standard ANOVA) and Table 29b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Millet leaf Zn ranged from 33 mg/kg in the control plants, up to 81 mg/kg for the highest rate of incorporated MWOO 1 (200 t/ha).

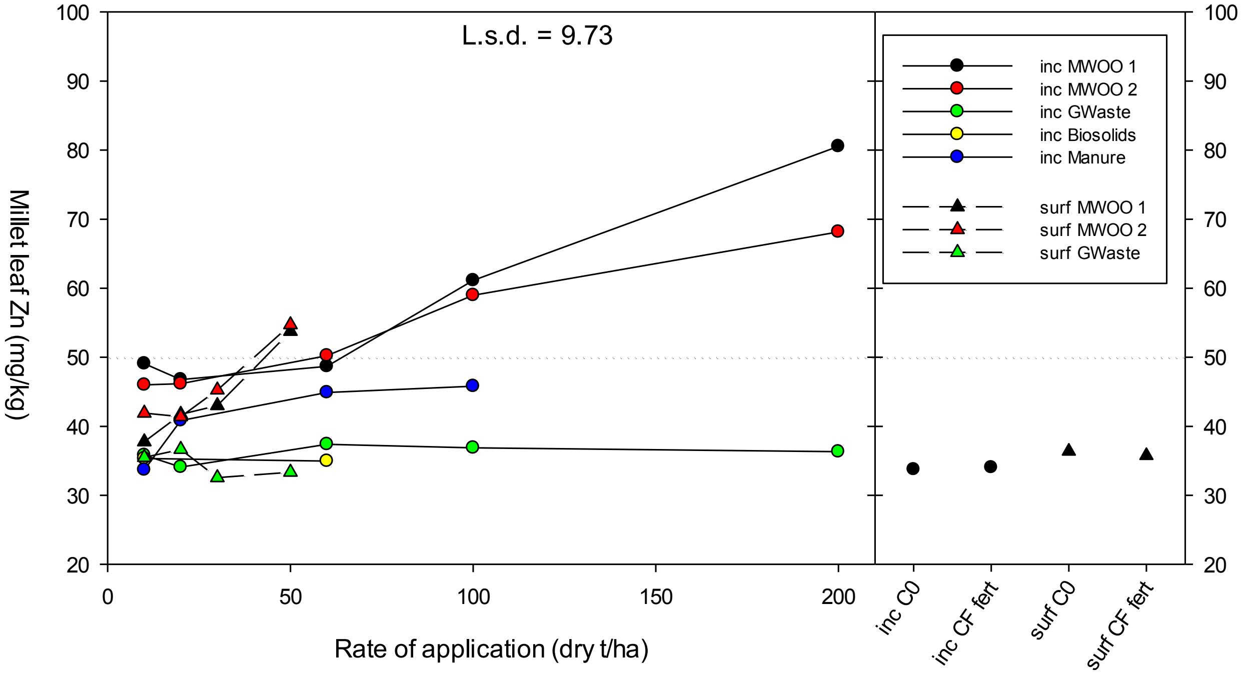


**Figure 30:** Average millet leaf Zn values for plants sampled after 12 weeks growth. Plants were grown on soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 29a:** ANOVA output table for millet leaf Zn

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 744.45 | 248.15 | 5.15 | |
| repf.*Units* stratum | | | | | |
| trtID | 36 | 16367.37 | 454.65 | 9.43 | <.001 |
| Residual | 108 | 5206.17 | 48.21 | | |
| Total | 147 | 22317.99 | | | |

**Table 29b:** Repeated measures ANOVA output table for millet leaf Zn

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 744.45 | 248.15 | 5.15 | |
| repf.*Units* stratum | | | | | |
| IncVSurf | 1 | 705.76 | 705.76 | 14.64 | <.001 |
| IncVSurf.IncTrts | 6 | 8141 | 1356.83 | 28.15 | <.001 |
| IncVSurf.SurfTrts | 4 | 1384.27 | 346.07 | 7.18 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | 3228.15 | 807.04 | 16.74 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | 1456.99 | 364.25 | 7.56 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | 25.94 | 6.48 | 0.13 | 0.969 |
| IncVSurf.IncTrts.incManure | 3 | 365.37 | 121.79 | 2.53 | 0.061 |
| IncVSurf.IncTrts.incCBio | 1 | 0.25 | 0.25 | 0.01 | 0.943 |
| IncVSurf.SurfTrts.surfMW001 | 3 | 560.69 | 186.9 | 3.88 | 0.011 |
| IncVSurf.SurfTrts.surfMW002 | 3 | 456.31 | 152.1 | 3.16 | 0.028 |
| IncVSurf.SurfTrts.surfGW | 3 | 42.64 | 14.21 | 0.29 | 0.829 |
| Residual | 108 | 5206.17 | 48.21 | | |
| Total | 147 | 22317.99 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

The concentration of Zn in millet leaves exceeded those in the control for all rates of incorporated MWOO 1 and MWOO 2, and for poultry manure applied at rates above 60 t/ha. This was also the case for surface applied MWOO at rates above 30 t/ha for the surface applied MWOO 1 and MWOO 2. No applications of either green waste or composted biosolids, resulted in leaf Zn concentrations exceeding those in the control treatment plants.

While the Zn concentrations increased significantly above the control with increasing rates of application of MWOO 1, MWOO 2, the maximum Zn level of 80.5 mg/kg found in the high rate MWOO 1 application (200 t/ha) is less than the lower critical limit for Zn in plants (100 mg/kg), above which a yield reduction (phytotoxicity) may occur in sensitive plants (Kabata Pendias and Pendias, 1984). However, it should be noted that Zn accumulation was generally highest in plants grown in the MWOO treated soils compared to other amendments such as composted green waste.

The effect of increasing rates of amendment addition on millet leaf N is illustrated in Figure 31, where average N concentrations are compared across all of the incorporation and surface application treatments. The ANOVA output tables for this data are given in Tables 30a (Standard ANOVA) and Table 30b (Repeated measures ANOVA for orthogonally partitioned treatment structure). A leaf concentration of around 2% N is considered adequate for millet (Reuter and Robinson 1997). As with Zn, increasing rates of MWOO 1. MWOO 2 and poultry manure application, generally resulted in increased leaf N concentrations compared to the unfertilised control. For the surface applied treatments, increasing rates of MWOO 2 resulted in increasing leaf N concentrations, while the opposite was seen for surface applied green waste, where concentrations decreased with increasing green waste applications.

Leaf N concentrations exceeded those of the unamended control for both MWOO 1 and MWOO 2 applications above 60 t/ha, for manure applications above 20 t/ha, but not for any green waste or biosolids treatments. Leaf N concentrations were not above the control for any surface treatments. However, when comparing leaf N concentrations in plants grown on the *fertiliser* control to those in plants grown on compost treated plots, only those grown on the highest incorporation application rate of MWOO 2 (200 t/ha) and manure (60 and 100 t/ha) and none of the surface applications, exceeded the fertiliser control level.

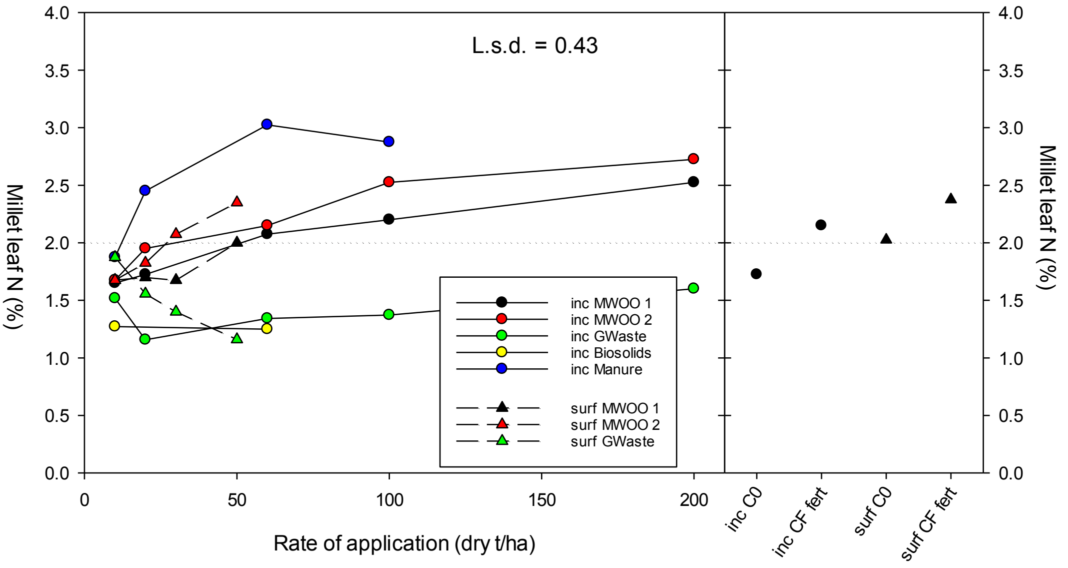


**Figure 31:** Average millet leaf N (%) values for plants sampled after 12 weeks growth. Plants were grown on soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 30a:** ANOVA output table for millet leaf N

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 6.22 | 2.07 | 22.42 | |
| repf.*Units* stratum | | | | | |
| trtID | 36 | 32.77 | 0.91 | 9.84 | <.001 |
| Residual | 108 | 9.99 | 0.09 | | |
| Total | 147 | 48.98 | | | |

**Table 30b:** Repeated measures ANOVA output table for millet leaf N

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 6.22 | 2.07 | 22.42 | |
| repf.*Units* stratum | | | | | |
| IncVSurf | 1 | 0.65 | 0.65 | 7 | 0.009 |
| IncVSurf.IncTrts | 6 | 17.58 | 2.93 | 31.68 | <.001 |
| IncVSurf.SurfTrts | 4 | 3.52 | 0.88 | 9.52 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | 2.05 | 0.51 | 5.55 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | 2.89 | 0.72 | 7.8 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | 0.47 | 0.12 | 1.26 | 0.29 |
| IncVSurf.IncTrts.incManure | 3 | 3.19 | 1.06 | 11.49 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | 0.00 | 0.00 | 0.01 | 0.917 |
| IncVSurf.SurfTrts.surfMW001 | 3 | 0.30 | 0.10 | 1.09 | 0.357 |
| IncVSurf.SurfTrts.surfMW002 | 3 | 1.05 | 0.35 | 3.79 | 0.012 |
| IncVSurf.SurfTrts.surfGW | 3 | 1.08 | 0.36 | 3.89 | 0.011 |
| Residual | 108 | 9.99 | 0.09 | | |
| Total | 147 | 48.98 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Millet grain was also harvested (Plate 12) from each of the test treatments, and as with the leaf samples, the grain samples were analysed for metal contaminant and nutrient elements. Part of this analysis also included an assessment for a range of stock feed quality parameters and although these are mostly applicable to silage, they can also be used to indicate the effect or treatments on the nutrient quality of the harvested grain. These data (treatment means) are presented in Appendix 10a for the inorganic elements and Appendix 10b for the feed quality parameters.

**Plate 12:** Late stage millet growth where seed heads are ripening (~ 50%), less than 2 weeks prior to grain harvest. Compared to early plant growth shown in Plate 10, plot boundary pegs are now obscured by the growing crop.

Generally, the accumulation of nutrient and metal elements in millet grain was less responsive to the rate of amendment application, compared to the millet leaf tissue discussed above. Even so, a number of the nutrient and metal elements tested in the millet grain increased with increases in application rate (e.g. Ca, K, N, P, S and Zn; see Appendix 10a and 10b), although once again, these increases were not consistent across all amendments. At no stage did heavy metal accumulation in millet grain reach a level where food safety was compromised and the level all the metals in the millet grain were within the normal range expected in plant tissue. Accumulation of metals was generally highest in the MWOO and poultry manure treated plots.

The effect of increasing rates of amendment addition on millet grain Zn is illustrated in Figure 32, where average Zn concentrations are compared across all of the incorporation and surface application treatments. The ANOVA output tables for this data are given in Tables 31a (Standard ANOVA) and Table 31b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

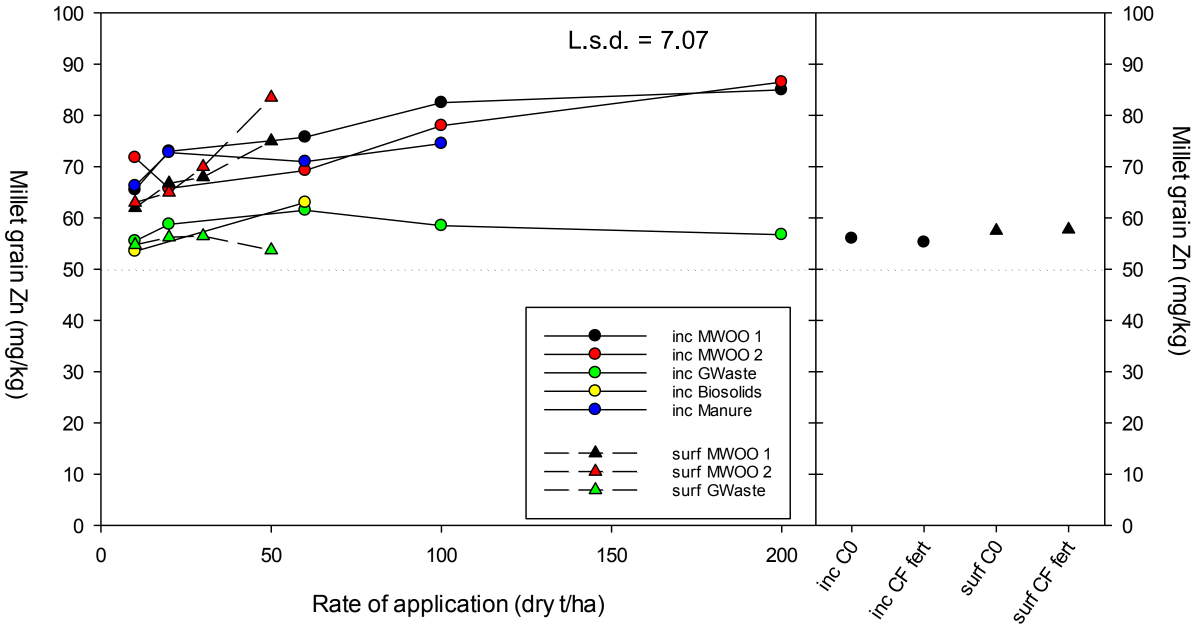


**Figure 32:** The effect of amendments on average concentrations of Zn found in millet grain. Plants were grown on soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 31a:** ANOVA output table for millet grain Zn

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 997.68 | 332.56 | 13.08 | |
| repf.*Units* stratum | | | | | |
| trtID | 36 | 13078.77 | 363.3 | 14.29 | <.001 |
| Residual | 108 | 2745.82 | 25.42 | | |
| Total | 147 | 16822.27 | | | |

**Table 31b:** Repeated measures ANOVA output table for millet grain Zn

Variate: tresp

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| repf stratum | 3 | 997.68 | 332.56 | 13.08 | |
| repf.*Units* stratum | | | | | |
| IncVSurf | 1 | 587.88 | 587.88 | 23.12 | <.001 |
| IncVSurf.IncTrts | 6 | 6229.05 | 1038.18 | 40.83 | <.001 |
| IncVSurf.SurfTrts | 4 | 2419.96 | 604.99 | 23.8 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | 967.8 | 241.95 | 9.52 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | 1070.5 | 267.62 | 10.53 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | 82.7 | 20.67 | 0.81 | 0.519 |
| IncVSurf.IncTrts.incManure | 3 | 151.25 | 50.42 | 1.98 | 0.121 |
| IncVSurf.IncTrts.incCBio | 1 | 180.5 | 180.5 | 7.1 | 0.009 |
| IncVSurf.SurfTrts.surfMW001 | 3 | 346.19 | 115.4 | 4.54 | 0.005 |
| IncVSurf.SurfTrts.surfMW002 | 3 | 1022.75 | 340.92 | 13.41 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | 20.19 | 6.73 | 0.26 | 0.851 |
| Residual | 108 | 2745.82 | 25.42 | | |
| Total | 147 | 16822.27 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Millet grain Zn concentrations increased with increasing rate of application for MWOO 1, MWOO 2 and composted biosolids, but not for green waste or poultry manure (Table 31b). Millet grain Zn concentrations increased to concentrations above those found in the control samples at all rates of incorporated MWOO 1 and MWOO 2, for surface MWOO treatments greater than 10 t/ha, and for all manure treatments. There was no effect of composted green waste application on the accumulation of Zn in millet grain (Table 31b).

An examination of the feed quality data presented in Appendix 10b suggests that the quality of the millet grain improved where sufficient rates of the amendments were applied to the soils. Dry matter (DM %) contents were not influenced by treatment application but were high for all treatments and this reflects the fact that they are related to millet grain which has a higher DM content than leaves. The concentrations of digestible fibre (%NDF and %ADF), in the grain were all in the high quality range and generally decreased with application rate for all treatments (i.e. less fibre and therefore higher digestibility). Crude protein (CP) concentrations in the grain increased with the application of MWOO and manure only, although these were not significantly different to the CP concentrations in grain from control treatment, where application rates were below 100 t/ha for MWOO and 60 t/ha for manure treated soils. Surface applications of MWOO only resulted in raised CP concentrations in the millet grain at rates of 50 t/ha. The amount of metabolisable energy (ME) in the millet grain increased with amendment treatments, once they were applied at sufficient application rates. For millet grain sampled from incorporated MWOO (1 and 2), the ME was greater than grain from the control and control fertiliser treatments at rates of application at 60 t/ha or above, and at rates of between 30 and 50 t/ha for the surface application treatments. Similarly for incorporated composted green waste, biosolids and manure, an application of 60 t/ha and above, increased the ME of the millet grain to levels above grain sampled from the control and control fertiliser treatments.

### *Wheat*

Samples of wheat grain were collected in December 2014, for the first (T2) and December 2015, for the second (T3) wheat crops, and then analysed for metal contaminant and nutrient elements. Treatment means for wheat grain chemical analyses are presented in Appendix 11a (first wheat crop) and in Appendix 12a (second crop). All analyses are expressed on a dry weight basis. Chemical analyses were only carried out on wheat grain harvested from the control and MWOO treated plots (high rate for MWOO2) as indicated in Table 3.

A number of the nutrient and metal elements tested for in the wheat grain increased in concentration with increases in application rate (e.g. Ca, Cd, Fe, N, P, S and Zn), although these increases were not consistent across all amendments. As an example, the effect of increasing rates of MWOO addition on wheat grain Cd is illustrated in Figure 33, where average Cd concentrations are compared across all of the incorporation and surface application for MWOO 1, and high rate treatments for MWOO 2. The ANOVA output tables for this data are given in Tables 32a (Standard ANOVA) and Table 32b (Repeated measures ANOVA for orthogonally partitioned treatment structure).

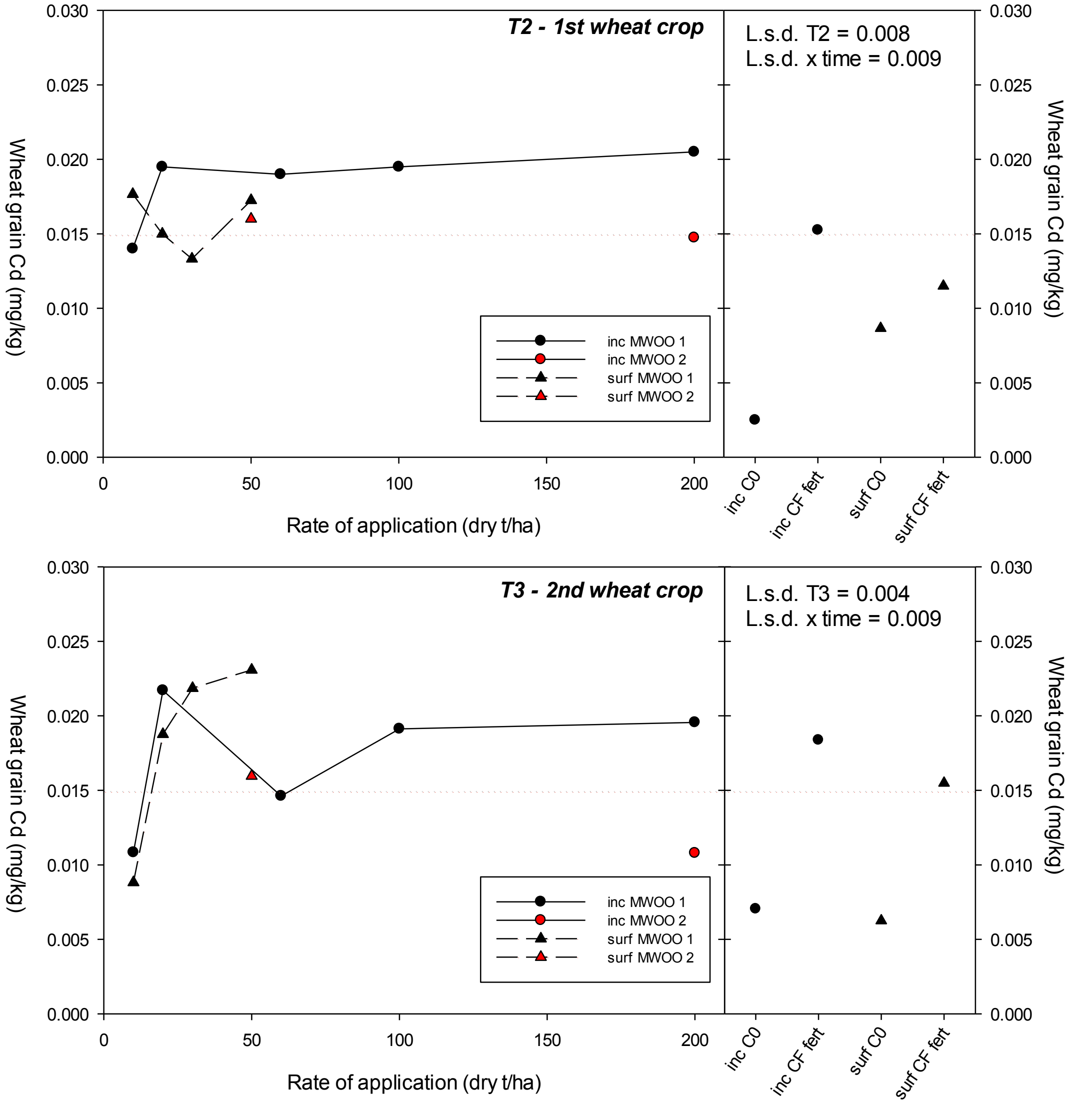


**Figure 33:** The effect of amendments on average concentrations of Cd found in wheat grain. Data is presented for plants grown on soils amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, for the 1st (T2 – wht 1) and 2nd (T3 – wht 2) wheat crops. L.s.d. indicates significance at $p< 0.05$, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control, CF fert = control fertiliser.

For the first wheat crop, the concentration of Cd in wheat grain increased above control concentrations with increases in application rate for MWOO 1 and for the 200 t/ha application of MWOO 2. Similar patterns were seen in the second wheat crop, although Cd concentrations in the samples taken from surface applied MWOO 1, showed a slight increase over time (Table 32b). For both crops, the highest concentrations of grain Cd were found in surface application treatments. At no stage did heavy metal accumulation in wheat grain reach a concentration where food safety was compromised, including for Cd, which only accumulated to less than 50% of the Australian Cd food standard of 1 mg/kg (dry weight (DWT)(FSANZ 2005). The concentrations of all the metals in the grain were within the normal range expected in plant tissue (Reuter and Robinson 1997).

**Table 32a:** ANOVA output table for wheat grain Cd

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.95E-04 | 6.49E-05 | 1.74 | |
| repf.plotf stratum | | | | | | |
| trtID | 15 | -21 | 3.12E-03 | 2.08E-04 | 5.58 | <.001 |
| Residual | 42 | -66 | 1.57E-03 | 3.73E-05 | 1.04 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 5.63E-05 | 5.63E-05 | 1.58 | 0.218 |
| trtID.time | 14 | -22 | 5.42E-04 | 3.87E-05 | 1.08 | 0.406 |
| Residual | 33 | -78 | 1.18E-03 | 3.57E-05 | | |
| Total | 108 | -187 | 5.21E-03 | | | |

**Table 32b:** Repeated measures ANOVA output table for wheat grain Cd

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 1.95E-04 | 6.49E-05 | 1.74 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 3.84E-04 | 3.84E-04 | 10.29 | 0.003 |
| IncVSurf.IncTrts | 3 | -3 | 1.04E-03 | 3.48E-04 | 9.33 | <.001 |
| IncVSurf.SurfTrts | 3 | -1 | 1.27E-03 | 4.23E-04 | 11.33 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 5.22E-04 | 1.30E-04 | 3.49 | 0.015 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 2.66E-04 | 8.87E-05 | 2.38 | 0.083 |
| IncVSurf.SurfTrts.surfMW002 | 1 | -2 | 5.25E-04 | | | |
| Residual | 42 | -66 | 1.57E-03 | 3.73E-05 | 1.04 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 3.30E-07 | 3.30E-07 | 0.01 | 0.924 |
| IncVSurf.time | 1 | | 2.60E-04 | 2.60E-04 | 7.28 | 0.011 |
| IncVSurf.IncTrts.time | 3 | -3 | 1.22E-04 | 4.06E-05 | 1.14 | 0.349 |
| IncVSurf.SurfTrts.time | 3 | -1 | 2.83E-05 | 9.42E-06 | 0.26 | 0.851 |
| IncVSurf.IncTrts.incMW001.time | 4 | | 4.57E-05 | 1.14E-05 | 0.32 | 0.862 |
| IncVSurf.SurfTrts.surfMW001.time | 3 | | 3.58E-04 | 1.19E-04 | 3.34 | 0.031 |
| Residual | 33 | -78 | 1.18E-03 | 3.57E-05 | | |
| Total | 108 | -187 | 5.21E-03 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Treatment averages for wheat grain quality data is presented for the first crop in Appendix 11b and for the second crop in Appendix 12b. Quality parameters, such as CP concentrations, grain weight, hardness and colour are used to grade wheat when it has been harvested, and this will determine the price farmers get for this product. The top grade classification for Australian wheat is termed ‘prime hard’ and has a minimum crude protein requirement of 13%. Grain quality parameters such as CP are influenced not only by the genetic disposition shown by specific varieties, but also by soil properties, including the presence and availability of plant nutrients such as N and P.

The effect of increasing rates of MWOO addition on wheat grain CP is illustrated in Figure 34, where average CP concentrations are compared across all of the incorporation and surface application for MWOO 1, and high rate treatments for MWOO 2. The ANOVA output tables for this data are given in Tables 33a (Standard ANOVA) and Table 33b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Examination of this data suggests that the quality of the wheat grain in crop 1 was improved above those of the control treatments, where sufficient rates of the amendments were applied to the soils (Figure 34). While CP concentrations increased with increasing application of MWOO up to 200 t/ha, these were not significantly different from the control treatment for all but the 200 t/ha MWOO 2 treatment. All grain CP concentrations were in the prime hard category for the first crop. Furthermore, grain weights generally dropped as application rates of the MWOO material increased (data not shown), and so it is not likely that MWOO application resulted in improved grain quality above that seen using conventional fertiliser practice.

There was a greater difference seen between control and MWOO 1 and MWOO 2 treatments for the better yielding, second crop (Figure 34), where CP concentrations exceeded the control treatment for incorporation rates greater than 60 t/ha for MWOO 1 and for the 200 t/ha MWOO 2 treatment. However, none of the CP concentrations in the MWOO treatments exceeded the fertilizer control treatment. Surface applications of MWOO had no impact on CP concentrations for the second crop.

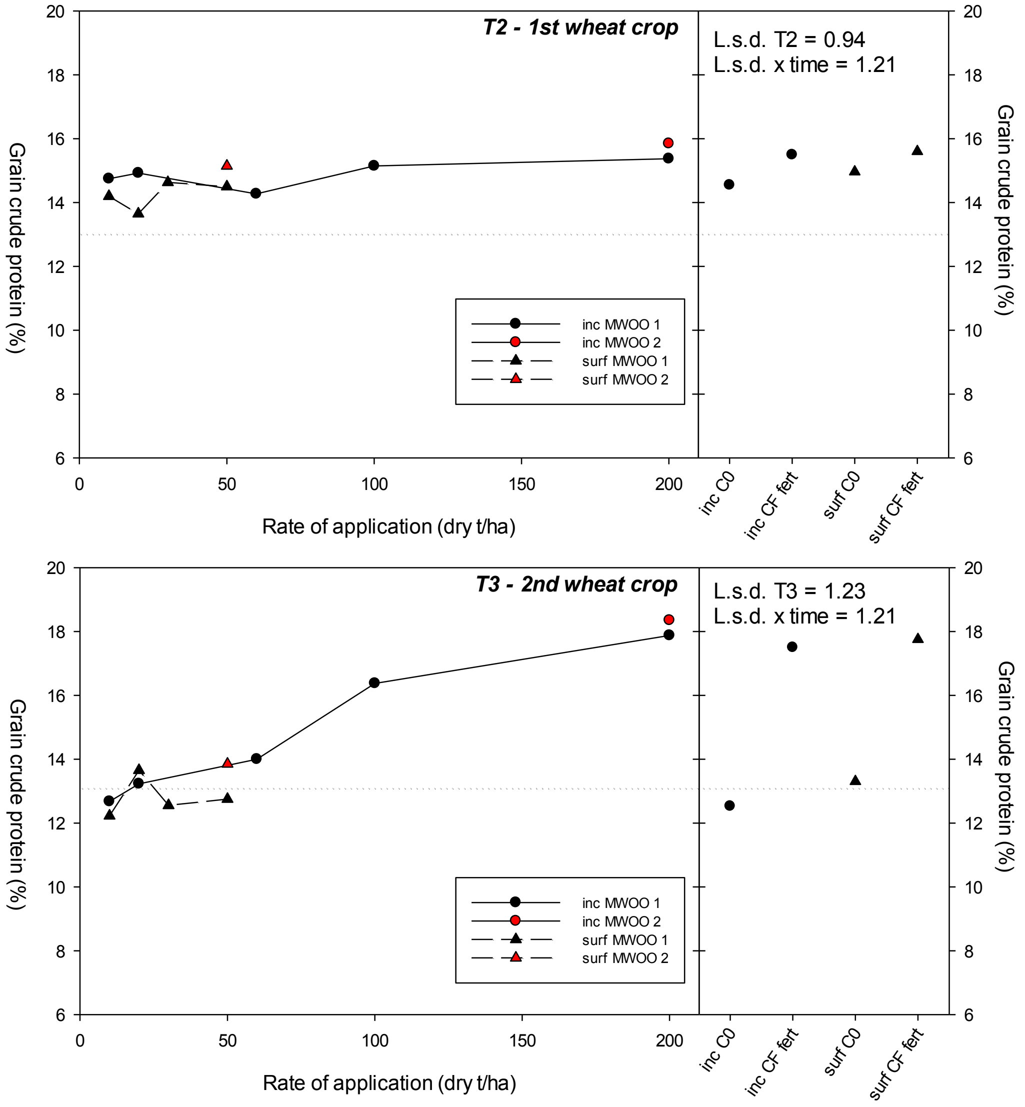


**Figure 34**: Average crude protein contents (%) for wheat grain harvested from the experimental plots. Data is presented for plants grown on soils amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2, for the 1st (T2 – wht 1) and 2nd (T3 – wht 2) wheat crops. L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 33a:** ANOVA output table for wheat grain crude protein

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 44.17 | 14.72 | 16.55 | |
| repf.plotf stratum | | | | | | |
| trtID | 15 | -21 | 230.83 | 15.39 | 17.3 | <.001 |
| Residual | 42 | -66 | 37.37 | 0.89 | 1.53 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 1.44 | 1.44 | 2.47 | 0.125 |
| trtID.time | 14 | -22 | 91.57 | 6.54 | 11.22 | <.001 |
| Residual | 33 | -78 | 19.23 | 0.58 | | |
| Total | 108 | -187 | 374.64 | | | |

**Table 33b:** Repeated measures ANOVA output table for wheat grain crude protein

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 44.17 | 14.72 | 16.55 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 139.72 | 139.72 | 157.05 | <.001 |
| IncVSurf.IncTrts | 3 | -3 | 162.65 | 54.22 | 60.94 | <.001 |
| IncVSurf.SurfTrts | 3 | -1 | 66.96 | 22.32 | 25.09 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 52.25 | 13.06 | 14.68 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 1.26 | 0.42 | 0.47 | 0.704 |
| IncVSurf.SurfTrts.surfMW002 | 1 | -2 | 5.13 | | | |
| Residual | 42 | -66 | 37.37 | 0.89 | 1.53 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 1 | | 11.03 | 11.03 | 18.92 | <.001 |
| IncVSurf.time | 1 | | 57.29 | 57.29 | 98.31 | <.001 |
| IncVSurf.IncTrts.time | 3 | -3 | 44.52 | 14.84 | 25.47 | <.001 |
| IncVSurf.SurfTrts.time | 3 | -1 | 26.64 | 8.88 | 15.24 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 4 | | 29.02 | 7.26 | 12.45 | <.001 |
| IncVSurf.SurfTrts.surfMW001.time | 3 | | 5.30 | 1.77 | 3.03 | 0.043 |
| Residual | 33 | -78 | 19.23 | 0.58 | | |
| Total | 108 | -187 | 374.64 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## The potential for mobility and off-site movement of metal contaminants and other elements

## Rainfall simulations: the effect of amendments on the volume and chemical composition of run off

Different methods of treating applied MWOO, e.g. retention on surface vs incorporation, are hypothesised to lead to differences in the potential loss in surface runoff and consequent environmental risks such that material retained on the surface be more exposure to losses. We used simulated rainfall to investigate relative differences in the potential for offsite movement of applied materials and constituents. There is a wide range of rainfall simulators used for such investigations all of which provide artefacts of scale, raindrop kinetic energy and intensity which will provide a range or biases in the results (Sharpley and Kleinman 2003). Nevertheless, rainfall simulation has and continues to be widely used to understand both processes of mobilisation of particulates and solutes and for examination of relative differences in the concentrations and quantities of these particulates and solutes that are mobilised. Dougherty et.al. (2008) concluded that that small-scale, high-intensity rainfall simulation provides a useful tool for studying treatment effects, while Bowyer-Bower and Burt (1989), also indicated that such experiments were particularly useful in simulating soil surface conditions which is of relevance to studying the differences between surface and incorporated applications of MWOO. We used the rainfall simulation techniques described by Bowyer-Bower and Burt (1989) to investigate relative differences in mobilisation of solutes. We chose these methods based on a compromise between realism of rainfall/drop characteristics and the need for replication to provide statistically robust data.

The rainfall simulation experiments for T0 were carried out on the MWOO 1 (all rates, incorporation and surface treatments) and MWOO 2 (200 t/ha, incorporation surface treatments) and associated control plots only. For the T1 runoff experiments, this treatment range was narrowed even further to include the high rate MWOO1 and 2 treatments only (see Table 3).

### *Initial run off volume (T0)*

Amending soils with materials such as biosolids and composted green wastes have been shown to improve soil physical properties such as infiltration (Tsadilas et.al. 2005) resulting in reduced runoff (Joshua et.al. 1998; Rostagno and Sosebee, 2001).

Figure 35 compares the average runoff volumes at time T0, following all rates of MWOO 1 and highest rates of MWOO 2 applications to the soil (200 t/ha incorporated and 50 t/ha surface). Volumes are compared for both incorporated and surface applications of MWOO 1 and also include control and unamended treatments. Run off volumes ranged between 10.9 L and 29.1 L and were greatest on control or untreated plots. Run off volumes decreased with increasing application rate for both incorporated and surface applied MWOO 1. However, run off volumes were only significantly lower ($p<0.05$) than the controls for incorporation rates of 200 t/ha for MWOO 1 and MWOO 2, and for the 50 t/ha surface applications for both MWOO 1 and MWOO 2. The rest of the incorporation MWOO application rates (10, 20, 60 and 100 t/ha) were not statistically different from the control. Similarly, surface applications up to 30 t/ha did not reduce run off below control levels.

Joshua et.al. (1998) examined run off during a biosolids field trial. They attributed the measured reduction in surface runoff to the surface protection, increased infiltration and soil water holding capacity and increased hydraulic resistance to surface flow from increased surface roughness. Similarly, Li et.al. (2014) found that the simple presence of leaf litter was sufficient to reduce run off in a forest ecosystem.

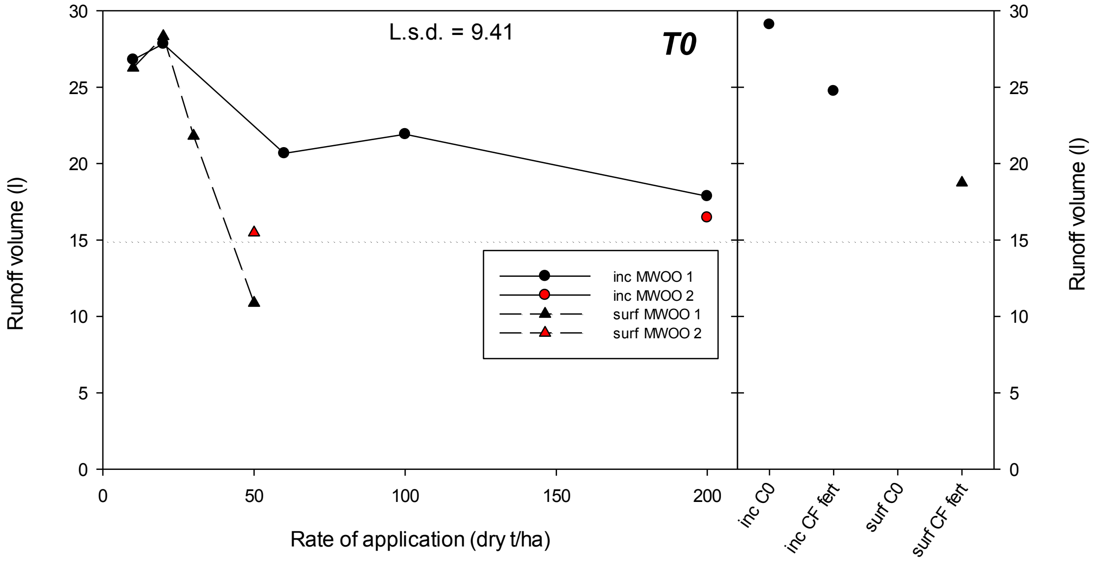


**Figure 35:** The effect of MWOO application on run off volume collected from treated soils following a simulated rainfall event. Data is presented for soils amended with increasing rates of either incorporated or surface applied MWOO1 and MWOO 2 compared to control treatments. L.s.d. indicates significance at p< 0.05. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

## *Initial runoff composition (T0)*

Data for the inorganic chemical analysis of runoff collected at time T0 is presented in Appendix 13a for the time T1 in Appendix 13b. These are for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2 compared to control treatments. L.s.d. (transformed where appropriate) for each element is included and indicates significance at p< 0.05.

Examination of the runoff data presented in Appendices 13a and 13b reveals that, of the suite of heavy metal elements measured in the run off samples, MWOO application had an influence on As, Cd, Cr, Cu, Mo, Ni, Pb, and Zn, all of which significantly increased in concentration in the MWOO treatment run off solutions compared to the control treatment. The highest concentration of these was for the surface application treatments.

For example, the concentration of Cu measured in the run off solutions is presented in Figure 36. The concentration of Cu in run off increased with increasing applications of MWOO, for both incorporated and surface treatments. However, these Cu concentrations were not significantly greater than the control except for rates above 100 t/ha for incorporated MWOO1 and for surface applications above 30 t/ha.

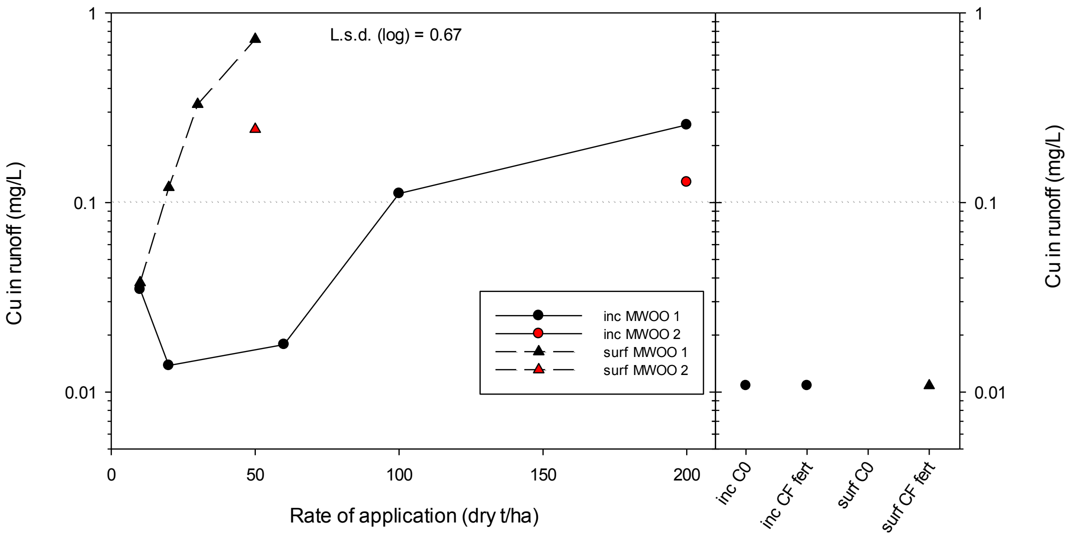


**Figure 36:** The effect of MWOO application on average Cu concentration in run off collected from treated soils following a simulated rainfall event. Data is presented for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to control treatments. L.s.d. indicates significance at p< 0.05. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

Of the nutrient elements and compounds analysed for in the run off samples, MWOO influenced the concentration of Total N, total and reactive P, Cl, $SO_4$ and soluble TOC. As with the metal elements discussed above, the concentrations of the nutrient elements in run off solution increased with increasing rates of MWOO application, and were also higher in surface treatments compared to where MWOO was incorporated. This is illustrated in Figure 37 for total N and Figure 38 for Total P. The concentration of total N in run off increased with increasing applications of MWOO for both incorporated and surface treatments and was highest in surface treatments. There was no difference in the concentration of total N in run off between MWOO 1 and MWOO 2. The concentrations of total N was greater than that of the control for incorporation of MWOO 1 at rates of application above 60 t/ha and for surface applications above 20 t/ha.

The concentrations of P in runoff increased with application rate and were higher for the surface treatments compared to the control (Figure 38). At modest rates of incorporated and surface MWOO 1 and 2 there was no significant increase in total P concentrations relative to the controls (incorporated MWOO 1 below 100 t/ha, and surface applied MWOO 1 below 30 t/ha). However the 200 t/ha of incorporated MWOO 1 and 2, as well as 30 and 50 t/ha of surface applied MWOO 1 and 2 treatments, all resulted in significantly higher concentrations of P in runoff, than either of the respective controls.

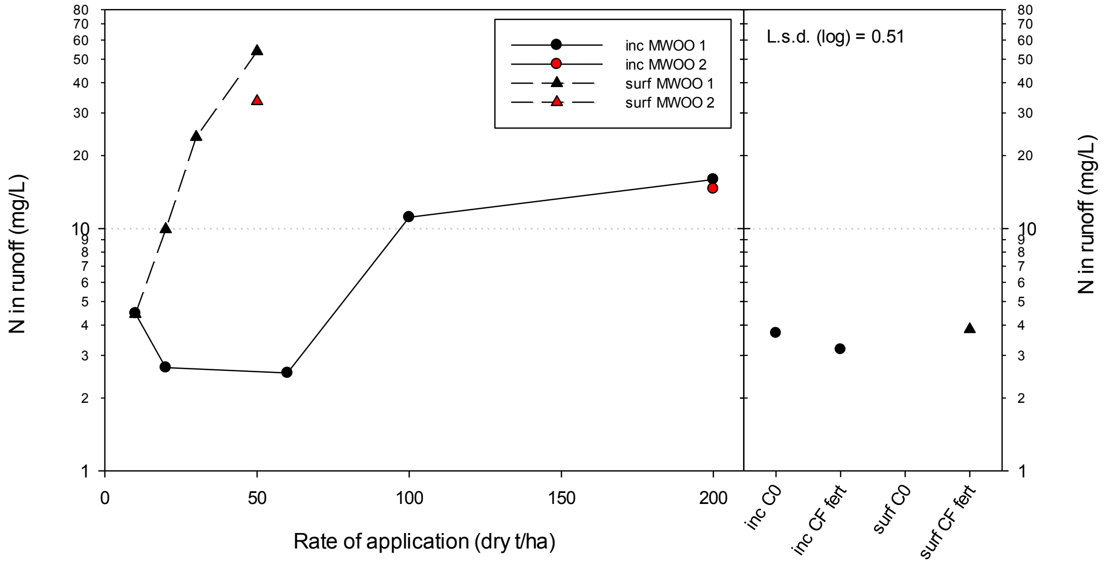


**Figure 37:** The effect of MWOO application on average N concentration in run off collected from treated soils following a simulated rainfall event. Data is presented for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to control treatments. L.s.d. indicates significance at p< 0.05. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

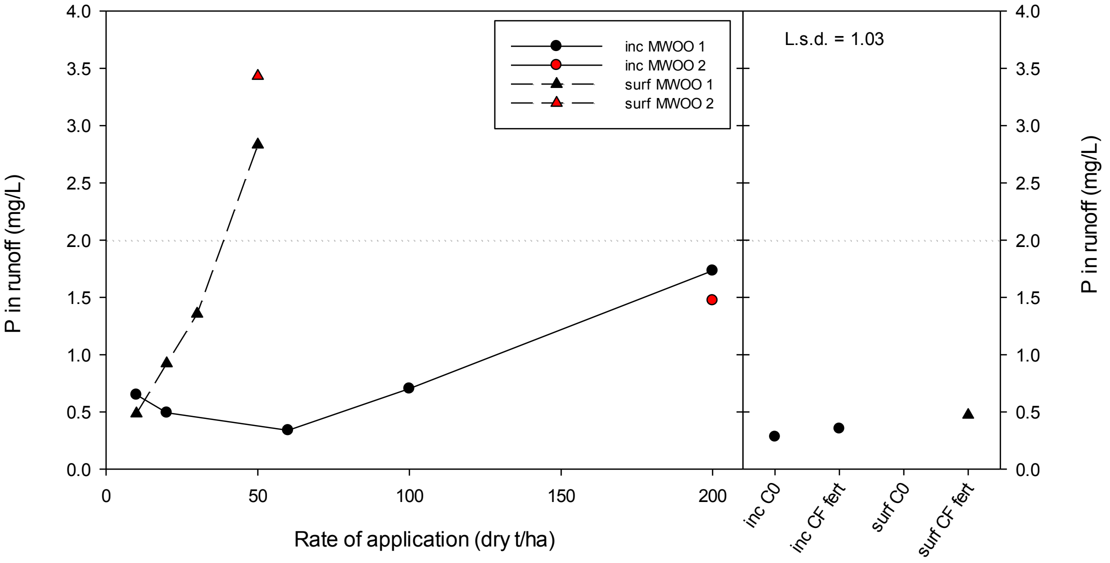


**Figure 38:** The effect of MWOO application on average Total P concentration in run off collected from treated soils following a simulated rainfall event. Data is presented for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to control treatments. L.s.d. indicates significance at p< 0.05. Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

## *Accounting for volume differences in total element loading in run off*

As discussed above, there were differences in the total run off volumes for different application rates and application scenarios (incorporated and surface). In assessing the extent of any off site risk posed by the mobilisation of MWOO contaminants and nutrient elements, the differences in volume must be accounted for. Therefore, for each of the elements tested, we calculated the actual run off loading, expressed as the weight of element lost in runoff, based on treatment specific volumes (data not shown). In actuality, analysis of the data generated through this process still indicated that the greatest potential risk from contaminant run off was from the surface treated plots; even though these treatments had a reduced run off volume compared to control and incorporated treatments.

For example, the effect of MWOO application on the overall Cu load removed in run off from the MWOO treated plots is given in Figure 39. Total Cu removed increased with application rate for both incorporated and surface applied MWOO. However, the amount of Cu removed was only significantly higher than the control for the surface applied treatments at application rates above 20 t/ha and this was for MWOO 1 not MWOO 2. Even though the surface application plots had reduced volumes of run off compared to the incorporation treatments (Figure 35), the much higher Cu concentration in the surface treatment solutions more than compensated for the reduced volume, and the total amount of Cu lost from the surface treatments was significantly higher than for the incorporated treatments.

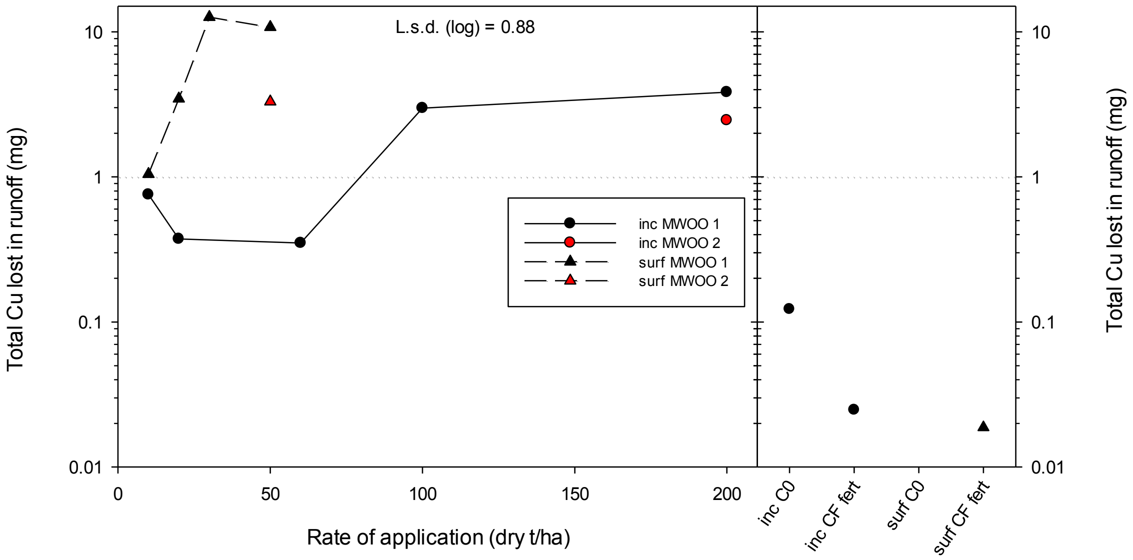


**Figure 39:** The effect of MWOO application on average total Cu load (mg) removed with run off, accounting for differences in run off volume. Run off was collected from treated soils following a simulated rainfall event. Data is presented for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2 compared to control treatments. L.s.d. indicates significance at p< 0.05. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

## *Changes in run off volume and element concentrations over time*

A second series of rainfall simulation experiments was carried out at time T1 (See Table 2). Only the high rate MWOO1 and MWOO2 treatments were sampled at this time, however this still allowed us to assess changes in run off volume and chemical composition over time.

For the T1 sampling, total run off volumes generated during the rainfall simulations decreased for the incorporation treatments compared to the T0 experiments, but were similar for both the T0 and T1 experiments carried out on the surface application treatments (data not shown). Comparison of element concentrations determined in run off solutions generated during the T1 experiments (Appendix 13b) with those found in the earlier T0 solutions (Appendix 13a), reveal a marked decrease in the solution concentration for most elements over time between T0 and T1. These decreases were more pronounced for the surface application treatments.

For example, with Cd (Figure 40), there was a more than 10-fold decrease in the Cd concentration in the 50 t/ha, surface MWOO 1 treatment and a two to three-fold decrease for the incorporated MWOO applied at 200 t/ha. However, by the time of the T1 run off sampling, the concentration of Cd was greater than that measured in control samples for only for the 200 t/ha incorporation of MWOO 2. This decrease was significant for the both MWOO 1 and MWOO 2.

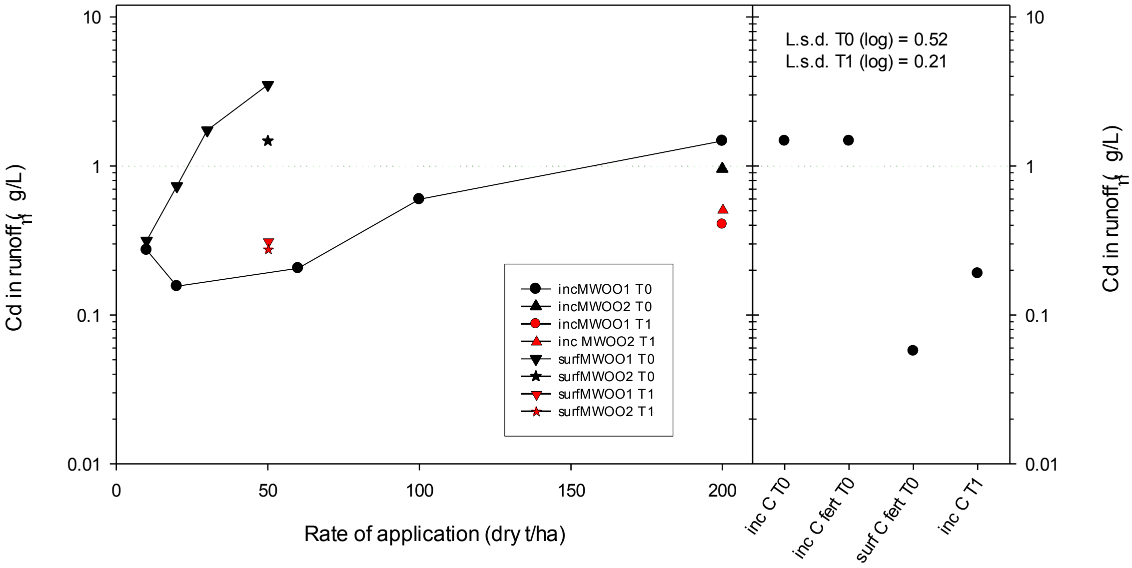


**Figure 40:** Changes over time in the average Cd concentration in run off collected from MWOO treated soils following a simulated rainfall event repeated at time T0 and T1. Data is presented for soils amended with increasing rates of either incorporated, or surface applied MWOO1 and MWOO 2, compared to control treatments. L.s.d. indicates significance at $p < 0.05$. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

For Zn sampled at T1 (Figure 41), there was an almost 10-fold decease in Zn concentrations for the surface application of MWOO 1, applied at 50 t/ha and this reduction was for both MWOO materials. By T1, there was no significant difference between Zn concentrations in run off samples collected from either the high rate surface of incorporation MWOO treatments.

As reported previously, Joshua et.al. (1998) found that high applications of biosolids reduced the overall volume of runoff form amended plots and increased the retention of rainfall. The same study found that, despite an initial spike in metal contaminant concentrations in the runoff solutions immediately following biosolids application, once the applied treatments had stabilised, runoff concentrations were found to be low. Similar effects on runoff loads were reported by Kelling et.al. (1977).

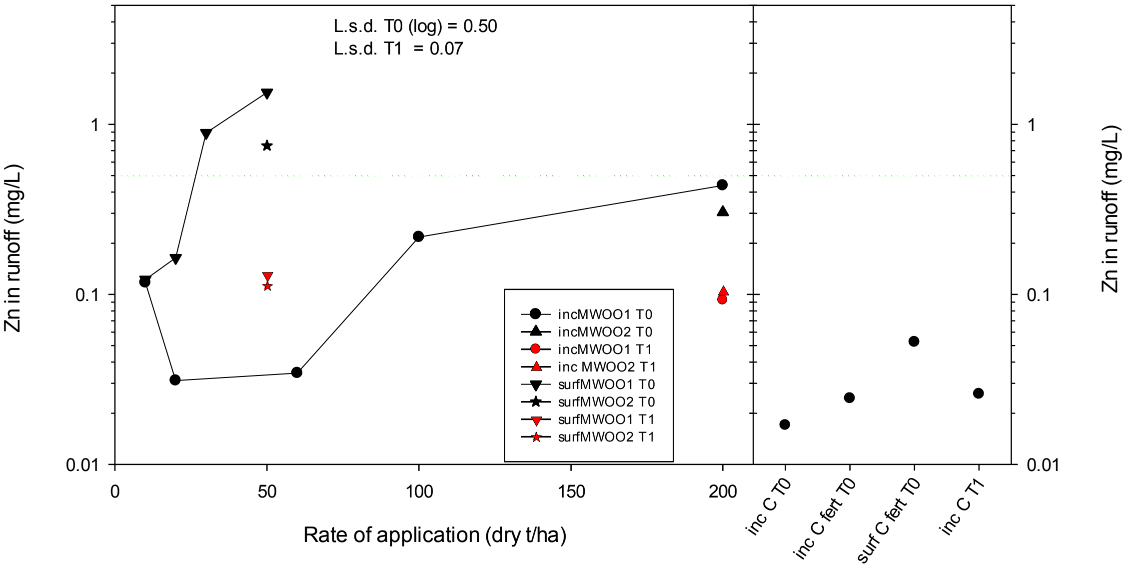


**Figure 41**: Changes over time in the average total Zn concentration in run off collected from MWOO treated soils following a simulated rainfall event repeated at time T0 and T1. Data is presented for soils amended with increasing rates of either incorporated or surface MWOO1 and MWOO 2 compared to control treatments. L.s.d. indicates significance at $p< 0.05$. Inc = incorporated treatments; surf = surface applied; C = control; CF fert = control fertiliser. Application rates (dry t/ha) indicated for each treatment represented in the Figure.

## Using batch extractions to assess the potential for offsite movement of contaminants

As discussed above, two sets of runoff experiments were completed at the time of the T0 and T1 soil samplings. Unfortunately, the rainfall simulation procedure is very laborious, and not conducive to being carried out on a large number of experimental treatments. Concurrent to the run off experiments, we carried out batch extractions of ‘water soluble’ elements using a 1:5 soil water extract procedure as described earlier. This procedure included filtering (0.45 µm) of the extracts and acidification of the filtrates, prior to storage and analysis.

A range of methods have been used to collect soil solution (Litaor 1988). Soil solution is not the same as a soil suspension (Nolan et.al. 2003) extracted by some chemical reagent such as water (Li and Shuman 1997), or dilute salt extract (Almas et.al. 2000). Techniques such as immiscible displacement with a dense liquid (Elkhatib et.al.1986), centrifugation of near-saturated soil samples (Thibault and Sheppard 1992), and the use of inert porous samplers inserted into wetted soil (Knight et.al. 1992), have all been used to ‘estimate’ the soil solution with varying degrees of success. However, Meers et.al. (2006) indicated the possibility artefacts caused by metal complexation for some specific elements, with the use of Rhizon soil solution samplers. Therefore, it is clear that each method still produces an operationally defined sample, which must be kept in mind when analysing their contents. Direct measurement of the various chemical species and complexes in the soil solution is not possible and therefore, any method used to isolate or extract the soil solution will significantly alter its chemistry. Thus our understanding of soil solution chemistry is based on examination of an operationally separated medium.

He et.al (2015) examined the relationship between a 1:5 soil water extract and a saturated paste extract for examining the sodium adsorption ratio of soils. They varied the 1:5 extract in the way the soil water suspension was mixed by stirring, shaking or pre wetting samples for 24 hours. Although the data using these methods were highly correlated, different mixing methods produced different results, thought to be based on differences in mechanical action. Grathwohl and Susset (2009) concluded that laboratory batch tests overestimated effluent concentrations compared to percolation extraction, while Lackovic et.al. (1997) considered a range of leaching and batch tests to be highly conservative in their ability to estimate contaminant mobility in soils but nonetheless viewed them as estimating metal mobility under a 'worst case' scenario.

Therefore, considering the operationally defined nature of these extractions, we have used the 1:5 soil water extract to estimate amendment and time effects, on the concentration of 'water-soluble' elements in the treated soils. As a guide only, we have attempted to put these element concentrations into an environment context by aligning them with irrigation water quality guideline limits specified in Australian and New Zealand Environment Conservation Council (ANZECC) water quality guidelines. This document recommends trigger values for each element based on the proposed frequency of irrigation. For the purposes of this data comparison, we chose to use the long term trigger value (LTV) as an appropriate standard. It is recognised that the date we have generated would represent a worst case scenario.

Measurement of nutrient elements and metal contaminants in the 1:5 soil water extracts showed similar trends in their apparent solubility to those seen in the run off experiments; where the concentrations of contaminants extracted using batch techniques, also decreased with time. Further consideration of these data has shown that contaminant concentrations measured in both the batch extraction, and run off solutions, are highly correlated, although the concentrations in the batch extraction samples are much higher than in runoff solutions, possible due to the to the added mechanical action used in the batch method as discussed above. Appendix 14a, Appendix 14b and Appendix 14c give correlations between batch and runoff concentrations of Cd, Cu and Zn, respectively. Data for the 1:5 soil water extract carried out on the MWOO treated plots is given in Appendix 15a for T0, Appendix 15b for T1, Appendix 15c for T2 and Appendix 15d for T3. Where appropriate, the irrigation water quality LTV values for each metal are included in these Appendices and these have been adjusted to align with the dilutions used in the preparation of the 1:5 soil water extract (i.e. fives time dilution).

The effect of increasing rates of amendment addition and time (T0 – T3), on the concentration of Cu measured in the 1:5 soil water extracts, is illustrated in Figure 42. The ANOVA output tables for this data are given in Tables 34a (Standard ANOVA) and Table 34b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in Figure 42 is the l.s.d. indicating significance at $p < 0.05$ for the interaction between treatment and time.

The concentration of Cu in the 1:5 extracts increased with application rate of all amendments (Table 34b), although this increase was less significant for the T3 sampling. Concentrations appeared to plateau at MWOO 1 and MWOO 2 application rates above 100 t/ha (incorporated) and 30 t/ha for surface applied MWOO 1 and MWOO 2. Similar plateaus in Cu concentrations were seen for green waste (applications greater than 100 t/ha) and poultry manure (greater than 60 t/ha). Overall, the concentration of Cu in the 1:5 soil water extract was highest in the MWOO amended soils compared to composted biosolids, green waste and was comparable to the concentrations measured after amendment with poultry manure. The measured Cu concentrations exceeded those of the control for incorporated MWOO 1 and MWOO 2 applied at rates above 60 t/ha and for surface applied MWOO 1 at rates above 10 t/ha, or above 20 t/ha for MWOO 2. The Cu concentrations in the 1:5 soil water extracts for all other amendments were not significantly different from those of the control.

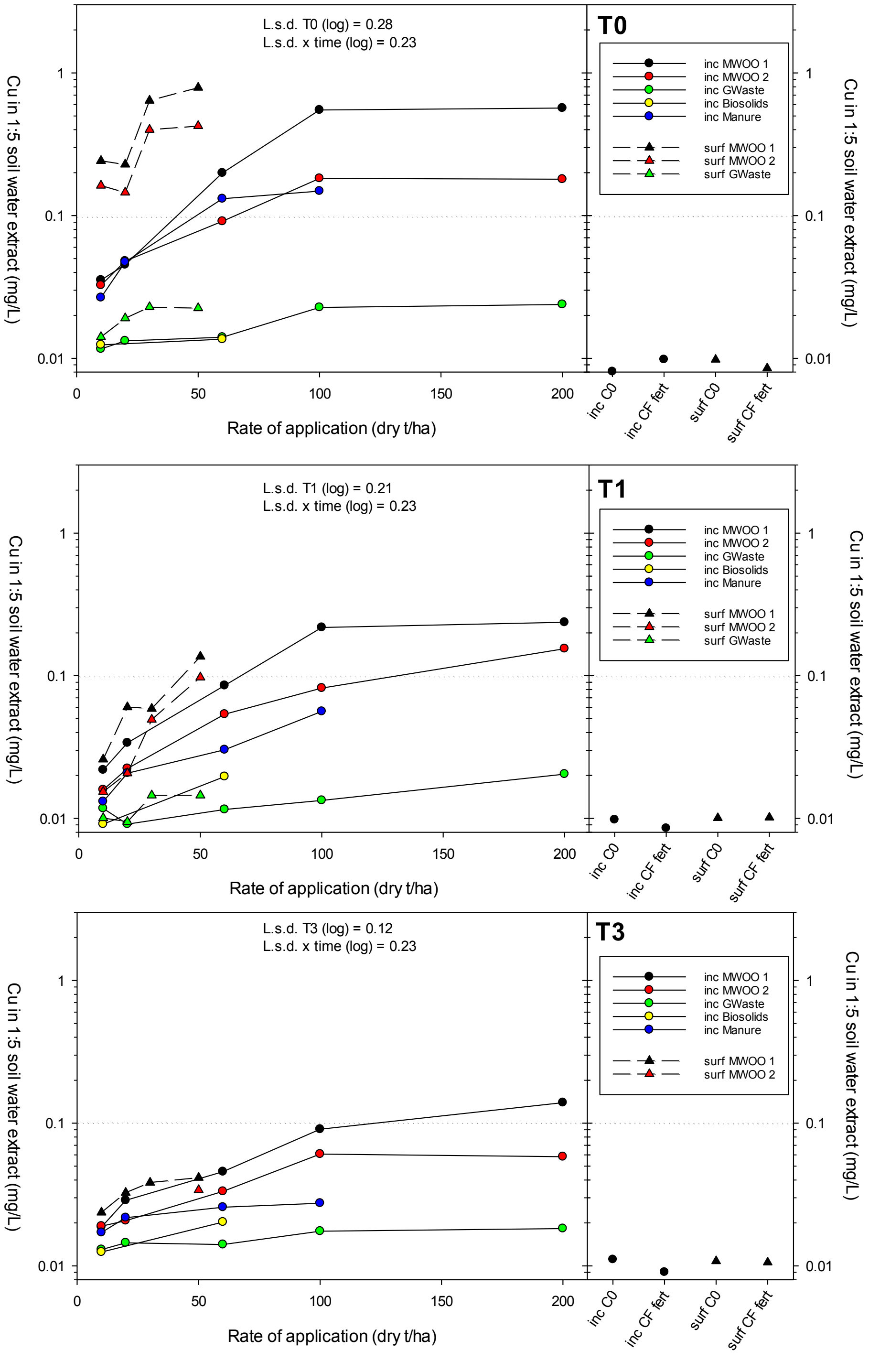


**Figure 42:** Changes in the water extractability of Cu over time (1:5 soil water extract), for either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 34a:** ANOVA output table for Cu in 1:5 soil water extracts

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.37 | 0.12 | 2.74 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 98.92 | 2.75 | 61.91 | <.001 |
| Residual | 108 | | 4.79 | 0.04 | 1.96 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 12.38 | 4.13 | 181.98 | <.001 |
| trtID.time | 79 | -29 | 14.43 | 0.18 | 8.06 | <.001 |
| Residual | 245 | -88 | 5.55 | 0.02 | | |
| Total | 474 | -117 | 118.55 | | | |

**Table 34b:** Repeated measures ANOVA output table for Cu in 1:5 soil water extracts

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.37 | 0.12 | 2.74 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 0.36 | 0.36 | 8.01 | 0.006 |
| IncVSurf.IncTrts | 6 | | 37.60 | 6.27 | 141.2 | <.001 |
| IncVSurf.SurfTrts | 4 | | 35.39 | 8.85 | 199.38 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 12.37 | 3.09 | 69.66 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 6.60 | 1.65 | 37.21 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 0.67 | 0.17 | 3.79 | 0.006 |
| IncVSurf.IncTrts.incManure | 3 | | 2.84 | 0.95 | 21.32 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 0.27 | 0.27 | 6.14 | 0.015 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 2.24 | 0.75 | 16.82 | <.001 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 3.66 | 1.22 | 27.53 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 0.40 | 0.13 | 3.03 | 0.033 |
| Residual | 108 | | 4.79 | 0.04 | 1.96 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 15.70 | 5.23 | 230.81 | <.001 |
| IncVSurf.time | 3 | | 4.50 | 1.50 | 66.12 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 3.15 | 0.21 | 9.26 | <.001 |
| IncVSurf.SurfTrts.time | 10 | -2 | 6.30 | 0.63 | 27.78 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.65 | 0.05 | 2.39 | 0.006 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.37 | 0.05 | 2.06 | 0.04 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.11 | 0.01 | 0.6 | 0.777 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.58 | 0.10 | 4.25 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.09 | 0.04 | 1.96 | 0.142 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.46 | 0.05 | 2.25 | 0.02 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.08 | 0.03 | 1.24 | 0.295 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.04 | 0.01 | 0.54 | 0.655 |
| Residual | 245 | -88 | 5.55 | 0.02 | | |
| Total | 474 | -117 | 118.55 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

Comparison of element concentrations in the 1:5 soil water extracts reveal a marked decrease in concentrations over time (T0 to T3 samplings, compare data in Appendix 15a for T0, Appendix 15b for T1, Appendix 15c for T2 and Appendix 15d for T3). For example, it can be seen from Figure 42, that by the time of the T3 sampling, Cu concentrations in the soil water extracts have decreased to the point where there is little significant difference in concentration between the amended soils and the controls, and only for the highest rates of MWOO 1 (100 and 200 t/ha), do the Cu concentrations differ from the control.

Similar trends were seen for other elements, for example P. The effect of increasing rates of amendment addition and time (T0 – T3), on the concentration of P measured in the 1:5 soil water extracts, is illustrated in Figure 43. The ANOVA output tables for this data are given in Tables 35a (Standard ANOVA) and Table 35b (Repeated measures ANOVA for orthogonally partitioned treatment structure). Also included in Figure 43 is the l.s.d. indicating significance at $p< 0.05$ for the interaction between treatment and time.

The concentration of P in the 1:5 extracts increased with application rate for all amendments at time T0 (Table 35b), although this increase was less significant for the T3 sampling. As with Cu, concentrations of P in the extracts appeared to plateau at MWOO 1 and MWOO 2 application rates above 100 t/ha (incorporated) but this plateau effect was not as evident for surface applied MWOO. Similar plateaus in P concentrations were not seen for poultry manure application where P concentrations continued to rise with increasing rates of application. Overall, the concentration of P in the 1:5 soil water extract was highest in the poultry manure amended soils compared to MWOO and the other amendments. The concentration of P in green waste was comparable to the concentrations measured after amendment with MWOO. At time T0, the measured P concentrations exceeded those of the control for incorporated MWOO 1 and MWOO 2 applied at rates above 20 t/ha and for all surface applied MWOO, all incorporated poultry manure treatments, and for composted biosolids and green waste applied at rates exceeding 20 t/ha.

By the time of the T3 sampling (Figure 43), P concentrations in the soil water extracts have decreased, but this decrease was not as significant as seen for Cu. The concentration of P in the soil water extracts still show an increase with increased rate of amendment application and are still highest for the poultry amended soils. The concentration of P in the amended soils exceed the control concentrations for incorporation of MWOO 1 and MWOO 2, green waste and composted biosolids, at rates above 60 t/ha, and for all rates of poultry manure application.

As discussed earlier, the application of organic amendments is often followed by an immediate ‘flush’ of easily extractable metals and nutrient elements in the amended soils (e.g. Wallan and Beckett 1979). This ‘flush’ is then followed by a reduction in extractability over time following application to the soil (Alloway 1995). Our data is consistent with these findings. Sawhney et.al. (1994) reported that leaching of metal contaminants from municipal solid waste compost was generally low, and decreased over time following an initial spike in leachate metal concentrations.

Of the elements tested, the concentrations of As, Cd, Co, Cr, Cu Ni and Zn were above the irrigation LTV for the T0 sampling, when the LTVs were adjusted to take into account the dilution (5x) used in the 1:5 soil water extract. The rates of MWOO application where these exceedances occurred were for the high incorporation rates of MWOO 1 (greater than 60 t/ha) and greater than 100 t/h for MWOO 2 (Ni). Similarly, the LTVs were exceeded for surface applications of MWOO 1 greater than 30 t/ha for MWOO 1 (10 t/ha for Ni) and the high surface applications of MWOO 2 (50 t/ha).

By the time of the T1 sampling, only Cu and Ni concentrations in the 1:5 soil water extracts exceeded the LTV for these elements, again at high MWOO application rates and especially for surface application. Soil water extract element concentrations measured in samples taken at T2 and T3 were all below the relevant LTV.

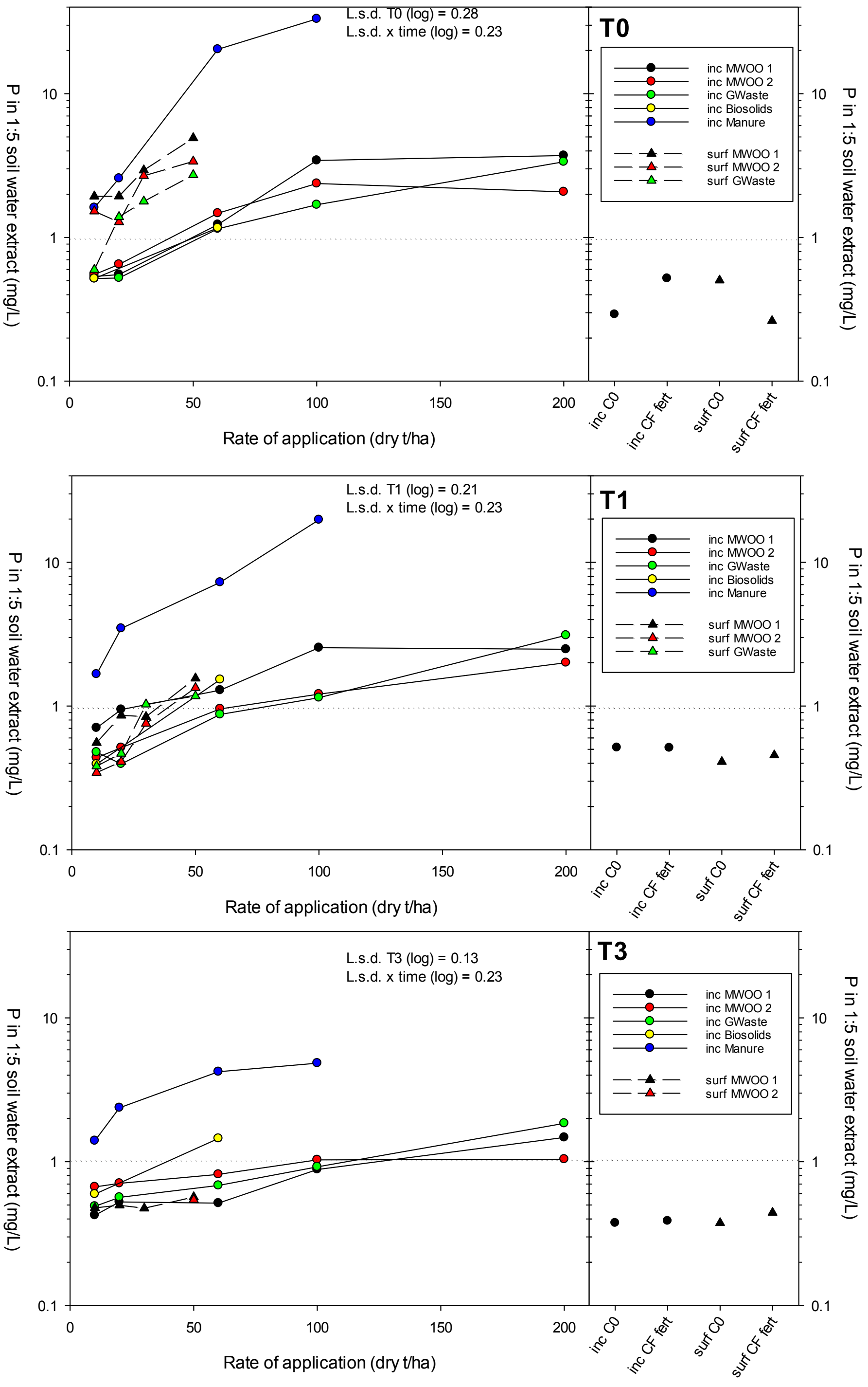


**Figure 43:** Changes in the water extractability of P over time (1:5 soil water extract), for either incorporated, or surface applied MWOO1 and MWOO 2, compared to applications of composted green waste (GWaste), composted biosolids (Biosolids) and poultry manure (Manure). L.s.d. indicates significance at p< 0.05, following repeated measures analysis of variance taking into account the orthogonal partitioning of the treatment structure. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control; CF fert = control fertiliser.

**Table 35a:** ANOVA output table for P in 1:5 soil water extracts

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.27 | 0.09 | 1.77 | |
| repf.plotf stratum | | | | | | |
| trtID | 36 | | 67.41 | 1.87 | 36.8 | <.001 |
| Residual | 108 | | 5.49 | 0.05 | 2.77 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 6.13 | 2.04 | 111.11 | <.001 |
| trtID.time | 79 | -29 | 8.91 | 0.11 | 6.13 | <.001 |
| Residual | 246 | -87 | 4.53 | 0.02 | | |
| Total | 475 | -116 | 75.84 | | | |

**Table 35b:** Repeated measures ANOVA output table for P in 1:5 soil water extracts

Variate: tresp

| Source of variation | d.f. | (m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|---|
| repf stratum | 3 | | 0.27 | 0.09 | 1.77 | |
| repf.plotf stratum | | | | | | |
| IncVSurf | 1 | | 5.66 | 5.66 | 111.34 | <.001 |
| IncVSurf.IncTrts | 6 | | 31.13 | 5.19 | 101.96 | <.001 |
| IncVSurf.SurfTrts | 4 | | 3.19 | 0.80 | 15.69 | <.001 |
| IncVSurf.IncTrts.incMW001 | 4 | | 4.58 | 1.15 | 22.53 | <.001 |
| IncVSurf.IncTrts.incMW002 | 4 | | 2.79 | 0.70 | 13.69 | <.001 |
| IncVSurf.IncTrts.incGW | 4 | | 6.17 | 1.54 | 30.34 | <.001 |
| IncVSurf.IncTrts.incManure | 3 | | 8.97 | 2.99 | 58.75 | <.001 |
| IncVSurf.IncTrts.incCBio | 1 | | 1.53 | 1.53 | 30.05 | <.001 |
| IncVSurf.SurfTrts.surfMW001 | 3 | | 0.77 | 0.26 | 5.03 | 0.003 |
| IncVSurf.SurfTrts.surfMW002 | 3 | | 2.01 | 0.67 | 13.17 | <.001 |
| IncVSurf.SurfTrts.surfGW | 3 | | 2.64 | 0.88 | 17.32 | <.001 |
| Residual | 108 | | 5.49 | 0.05 | 2.77 | |
| repf.plotf.*Units* stratum | | | | | | |
| time | 3 | | 7.75 | 2.58 | 140.38 | <.001 |
| IncVSurf.time | 3 | | 2.61 | 0.87 | 47.36 | <.001 |
| IncVSurf.IncTrts.time | 15 | -3 | 1.75 | 0.12 | 6.32 | <.001 |
| IncVSurf.SurfTrts.time | 10 | -2 | 2.51 | 0.25 | 13.65 | <.001 |
| IncVSurf.IncTrts.incMW001.time | 12 | | 0.57 | 0.05 | 2.57 | 0.003 |
| IncVSurf.IncTrts.incMW002.time | 8 | -4 | 0.49 | 0.06 | 3.34 | 0.001 |
| IncVSurf.IncTrts.incGW.time | 8 | -4 | 0.27 | 0.03 | 1.84 | 0.071 |
| IncVSurf.IncTrts.incManure.time | 6 | -3 | 0.93 | 0.15 | 8.39 | <.001 |
| IncVSurf.IncTrts.incCBio.time | 2 | -1 | 0.07 | 0.04 | 1.94 | 0.146 |
| IncVSurf.SurfTrts.surfMW001.time | 9 | | 0.23 | 0.03 | 1.41 | 0.185 |
| IncVSurf.SurfTrts.surfMW002.time | 3 | -6 | 0.07 | 0.02 | 1.27 | 0.287 |
| IncVSurf.SurfTrts.surfGW.time | 3 | -6 | 0.11 | 0.04 | 1.94 | 0.124 |
| Residual | 246 | -87 | 4.53 | 0.02 | | |
| Total | 475 | -116 | 75.84 | | | |

d.f. = degrees of freedom; (m.v.) = changes in degrees of freedom due to missing values; s.s = sum of squares; m.s. = mean square; v.r. = variance ration; F pr. = F test probability

## Evaluation of downward movement of inorganic contaminants - profile sampling

Any evaluation of environmental risks associated with MWOO application to soils must also include an evaluation of the potential for contaminant mobility down through the soil profile. So far, we have discussed the potential for offsite movement of contaminants using both standard batch extraction tests as well as measuring run off collected following simulated rainfall on selected experimental plots. We also sampled the soil profile of selected high rate MWOO 1 treated plots (control, 60 and 100 t/ha) to a depth of 90 cm. Average total soil metal and nutrient concentrations at increasing depths down the soil profile are given in Appendix 16.

Analyses of the soil nutrient and heavy metal concentration data collected from soil profiles under the MWOO treated plots, reveals that there was no significant ($p<0.05$) downwards movement of these elements below the initial zone of MWOO incorporation (15cm).

For nutrient elements, this is illustrated for N (Figure 44) and P (Figure 45). Nitrogen is considered to be a mobile element in soils (Joshua et.al. 2001). Statistical analysis of these data using the autoregressive order 1 model (AR1), showed a highly significant interaction between treatment and depth for N ($P=0.003$) but not for P. Neither of these elements was seen to migrate down the soil profile, despite relatively high concentrations of N and P being measured in runoff waters and in soil water extracts.

Similar trends were seen for heavy metal contaminants such as Pb (Figure 46) and Zn (Figure 47), where, although the surface soil concentrations of these elements were elevated following the application of MWOO, there is no evidence of their migration below the zone of MWOO incorporation. Statistical analysis of these data using the autoregressive order 1 model (AR1), showed a highly significant interaction between treatment and depth for both Pb ($P=0.002$) and for Zn ($P<0.001$).

Similar results have been found for municipal solid waste and municipal solid waste-biosolids compost (Breslin 1999) and municipal solid waste compost (Kaschi et.al. 2002), where metal contaminants applied with the amendment materials, remained in the upper soil layers.

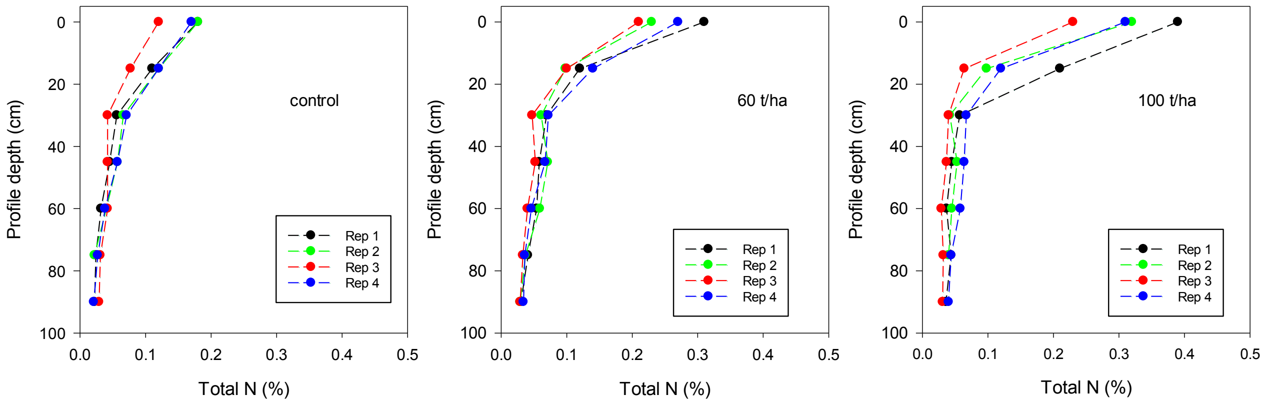


**Figure 44:** The concentration of total soil N (%) for each treatment replicate, measured in depth profile samples collected from control and MWOO 1 treated plots (60 and 100 t/ha), at time T3. Depth increments are for the mid-point of each sample.

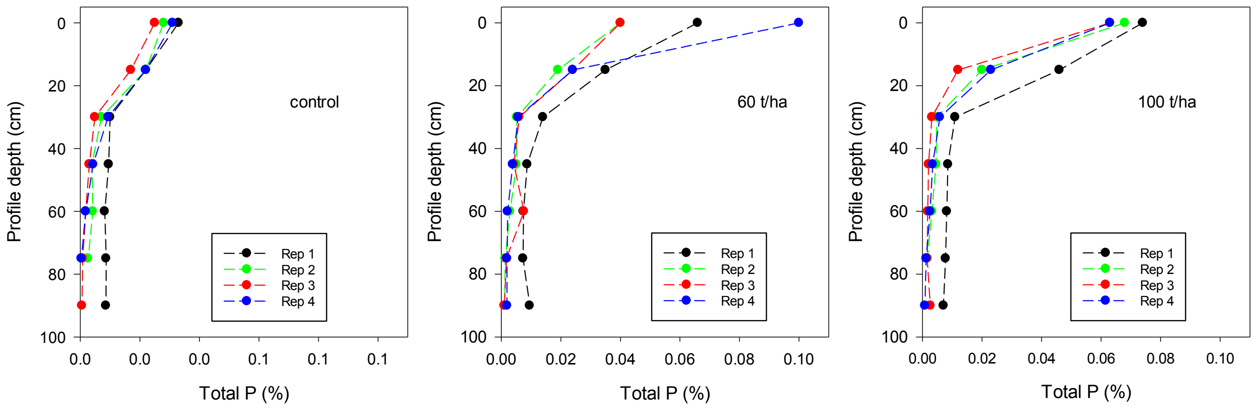


**Figure 45:** The concentration of total soil P (%) for each treatment replicate, measured in depth profile samples collected from control and MWOO 1 treated plots (60 and 100 t/ha), at time T3. Depth increments are for the mid-point of each sample.

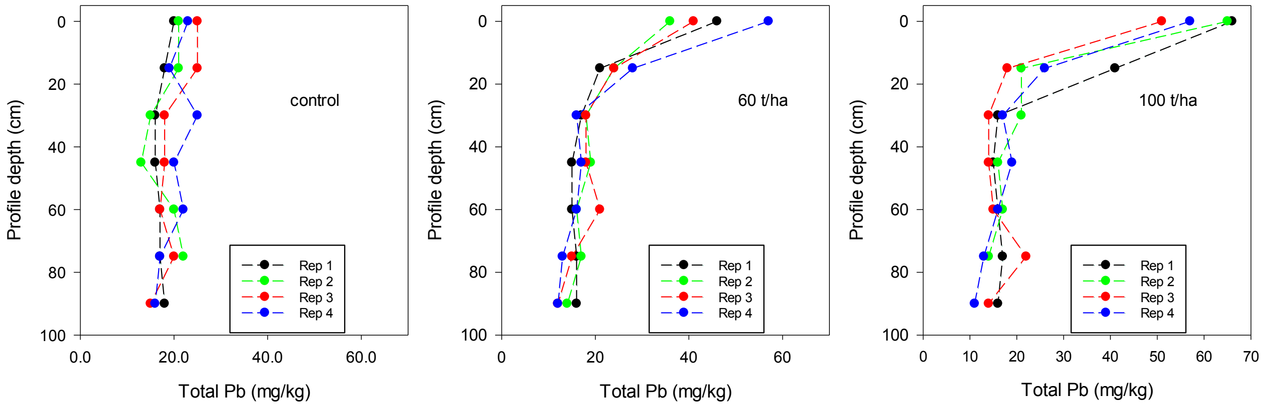


**Figure 46:** The concentration of total soil Pb (mg/kg) for each treatment replicate, measured in depth profile samples collected from control and MWOO 1 treated plots (60 and 100 t/ha), at time T3. Depth increments are for the mid-point of each sample.

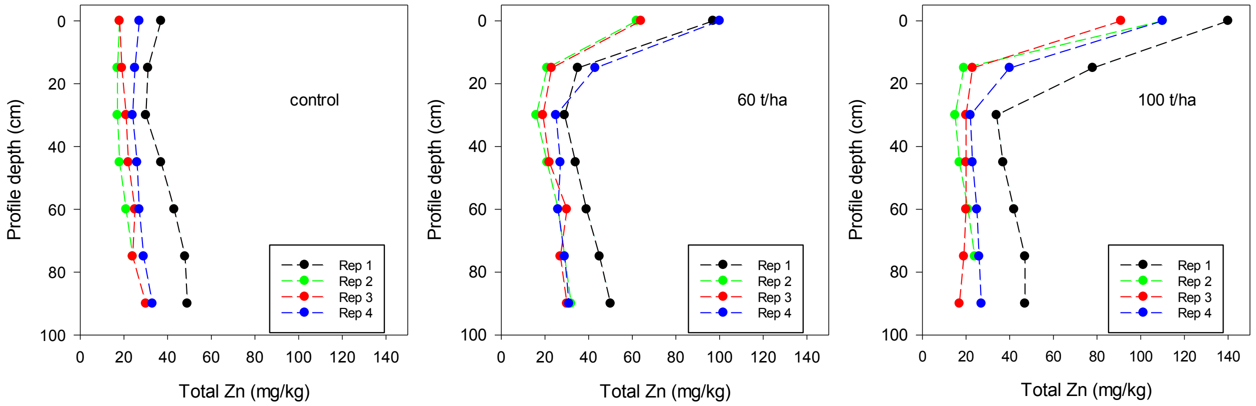


**Figure 47:** The concentration of total soil Zn (mg/kg) for each treatment replicate, measured in depth profile samples collected from control and MWOO 1 treated plots (60 and 100 t/ha), at time T3. Depth increments are for the mid-point of each sample.

## Effects of amendments on soil biota and soil microbial health

### Earthworm avoidance

Atruso et.al. (2011) found that earthworms were attracted to biosolids applied at low rates but avoided treatments where large amounts had been applied, whereas Moreira et.al. (2008) reported no avoidance behaviour when worms were exposed to biosolids or biosolids-composts. Marques et.al. (2009) successfully used earthworm avoidance behaviour as a screening tool for herbicides in soils.

We carried out an initial experiment comparing worm avoidance behaviour between the two MWOO sources, and found that there was no difference in worm behaviour in animals exposed to the different materials (data no shown). We therefore continued the worm testing using MWOO 1 for all subsequent experiments. Figure 48 illustrates trends in worm avoidance behaviour to freshly applied MWOO 1 at rates equivalent to those used in the field experiments. For the fresh MWOO 1 treatments, the worms showing avoidance behaviour for a 20 t/ha application (40% avoidance), and complete avoidance was seen at all rates above 20 t/ha.

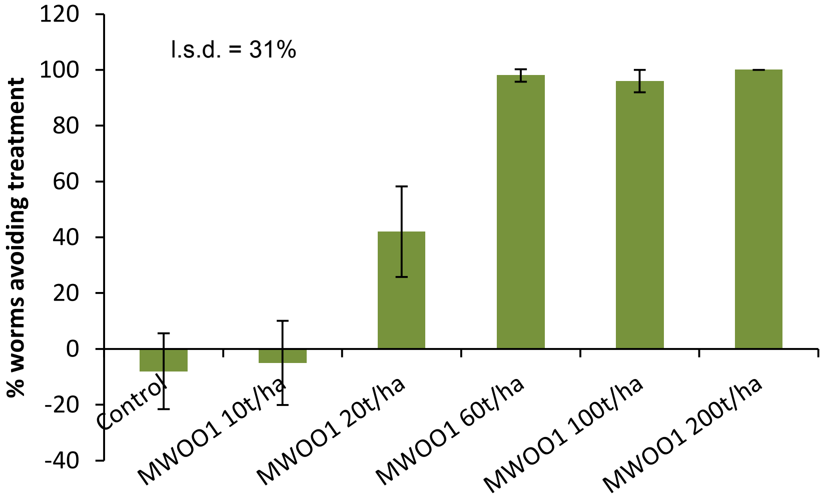


**Figure 48** The effect of increasing rates of freshly applied MWOO 1(2 weeks), on worm avoidance behaviour, compared to the control test soil. Positive range indicates avoidance of treatment, while negative range indicates preference for test treatments. Responses in the range ± 20% represent no avoidance or preference. L.s.d. indicates significance at $p< 0.05$ and s.e.d. (standard error of the difference between means) at same level of significance.

Figure 49 illustrates trends in worm avoidance behaviour to treated soils collected from the field site that had MWOO1 applied, two years previously. These data show that after two years 'ageing' under field conditions, there was no longer any worm avoidance observed for the MWOO treated soils, and worms showed no preference for either the control or treated soils.

It was discussed above that initial application of all MWOO amendments temporarily raised the soil EC up to levels that occasionally exceeded the critical salinity threshold for plant growth. Subsequent to this, the EC levels were seen to decline by the time of the second sampling period (T1), as the soluble salts had been removed from the upper part of the soil profile and thus the component of the soil profile tested, i.e. the 0-10 cm increment. As it is well known that worms are sensitive to high levels of soil salinity, we carried out an avoidance experiment that matched salinity levels measured in MWOO amended soils, with those from an inorganic source of soluble salts; namely NaCl.

Figure 50 illustrates trends in worm avoidance behaviour to salinity levels equivalent to those found in freshly-MWOO amended soils, compared to control and reference toxicant treatments. While the avoidance behaviour in the salt-based EC soils was slightly less than seen for the equivalent amount of applied MWOO, the worms nonetheless also showed strong avoidance behaviour when exposed to artificially elevated levels of soil salinity, and so it is possible that the increased soil salinity from soluble salts applied with the MWOO, contributed to the observed worm avoidance behaviour. It is also possible that some of the contaminants added with the MWOO may also have contributed to worm avoidance in the freshly amended soils.

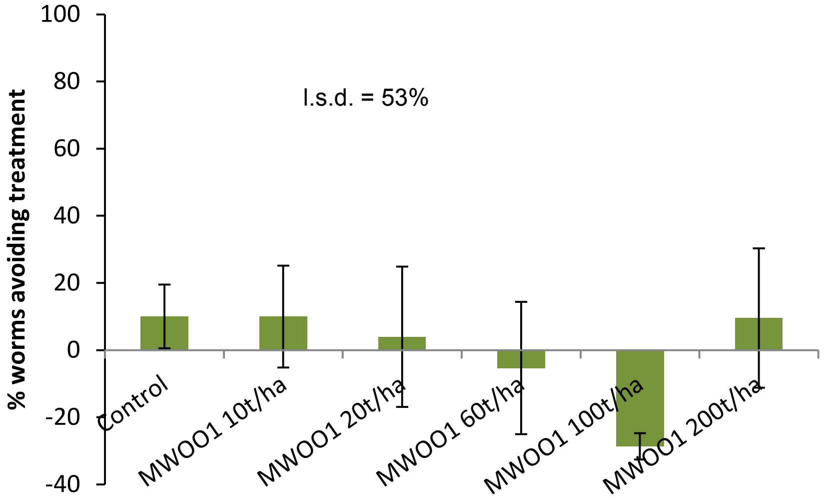


**Figure 49:** The ageing effect on worm avoidance behaviour from increasing rates MWOO 1 added to soils 2 years prior to testing (T2), compared to the control test soil. Positive range indicates avoidance of treatment, while negative range indicates preference for test treatments. Responses in the range ± 20% represent no avoidance or preference. L.s.d. indicates significance at p< 0.05 and s.e.d. (standard error of the difference between means) at same level of significance.

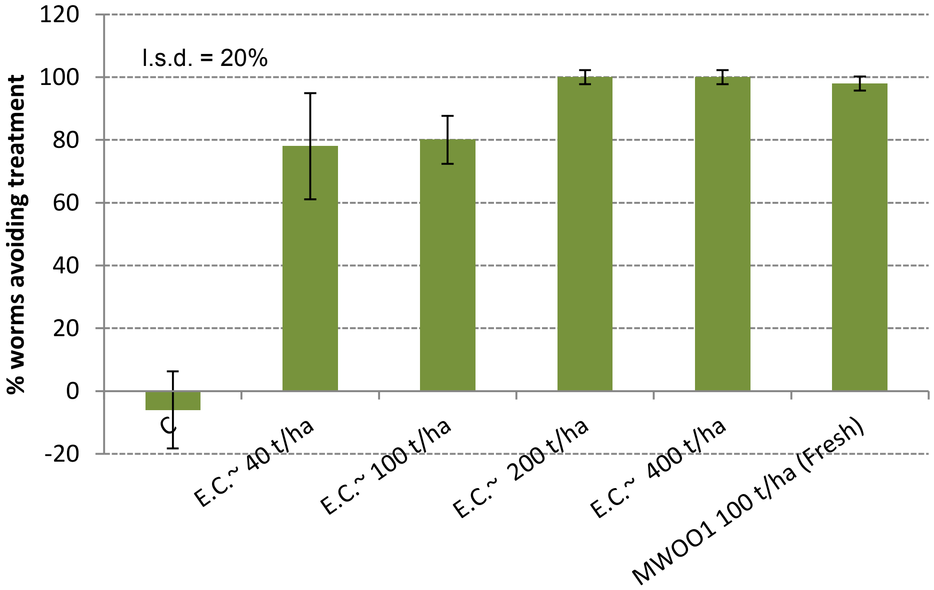


**Figure 50:** The comparative effect of increased soil salinity levels equivalent to applications of freshly applied MWOO on worm avoidance behaviour compared to control and reference toxicant treatments. Positive range indicates avoidance of treatment, while negative range indicates preference for test treatments. Responses in the range ± 20% represent no avoidance or preference. L.s.d. indicates significance at p<0.05 and s.e.d. (standard error of the difference between means) at same level of significance.

These data are consistent with the findings of Owojori and Reinecke (2009), who found up to 50% avoidance for soil salinity levels equivalent to an EC of 0.26 dS/m; an EC level which is close to that measured in soils freshly amended with MWOO at a rate of 20 t/ha (Data not shown). Under field conditions, it has been observed that earthworms will move into deeper soils layers to avoid environmental stressors such as drought (Chan and Barchia (2007). However, if the soluble salts or contaminants applied with the MWOO also moves downward with infiltering water, this behaviour may not be protective enough, and so field populations may be at risk. It has also been found that the presence of some of the organic compounds associated with MWOO, for example DEET (see above), can also lead to avoidance behaviour in in vertebrates such as leaches (Vongsombath et.al. 2011)

## Soil microbial function - Substrate Induced Nitrification (SIN)

Soil microbial populations are often viewed as being highly sensitive to contaminants and soil pollution, and in particular, the soil microbial populations' ability to cycle atmospheric N (e.g. M$^c$Grath et.al. 1988). The SIN test assesses potential effects on this microbial function in soil.

Figure 51 shows the effect of increasing amounts of both MWOO 1 and MWOO 2, on substrate-induced nitrification (SIN), by the indigenous soil microbial populations. The soils were sampled from the treated plots at times T0, T1, T2 and T3 (zero, 1, 2 and 3 years post-application). The SIN is expressed as the percentage of substrate ($NH_4$) used after a 7 day pre-incubation followed by a 28-day incubation with the substrate. A SIN value of 100% indicates no adverse effect on soil microbial function as the soil microbial population is able to mineralise all of the added $NH_4$ to $NO_{3-}$N. Toxicity or stress on the soil microbial population is indicated by a decrease in the SIN value, below that of the control.

There was some temporal variation in the SIN data, however microbial SIN increased with additions of MWOO (Figure 51) above control levels, and all of the added substrate was utilized at rates exceeding 10 t/ha. For surface MWOO treatments however, there does appear to be some reduction in SIN over time (Figure 51).

Background SIN values for the soil at the trial site have been reported previously (Broos et.al. 2007). This study examined the microbial response to metal contamination across 12 Australian soil types. The Flat Paddock soil, where the current work was carried out, was at the low end of background microbial activity (including SIN), compared to the other soils tested by Broos et.al. (2007). In a previous study carried out at the site evaluating the impact of biosolids on soil properties (Whatmuff et.al. 2005), indigenous microbial populations did not readily assimilate the applied amendment materials, which at times caused some reduction in overall microbial activity. Similar effects may have occurred post application of MWOO, especially for high rate treatments, which are also accompanied by increased loads of metal and organic contaminants.

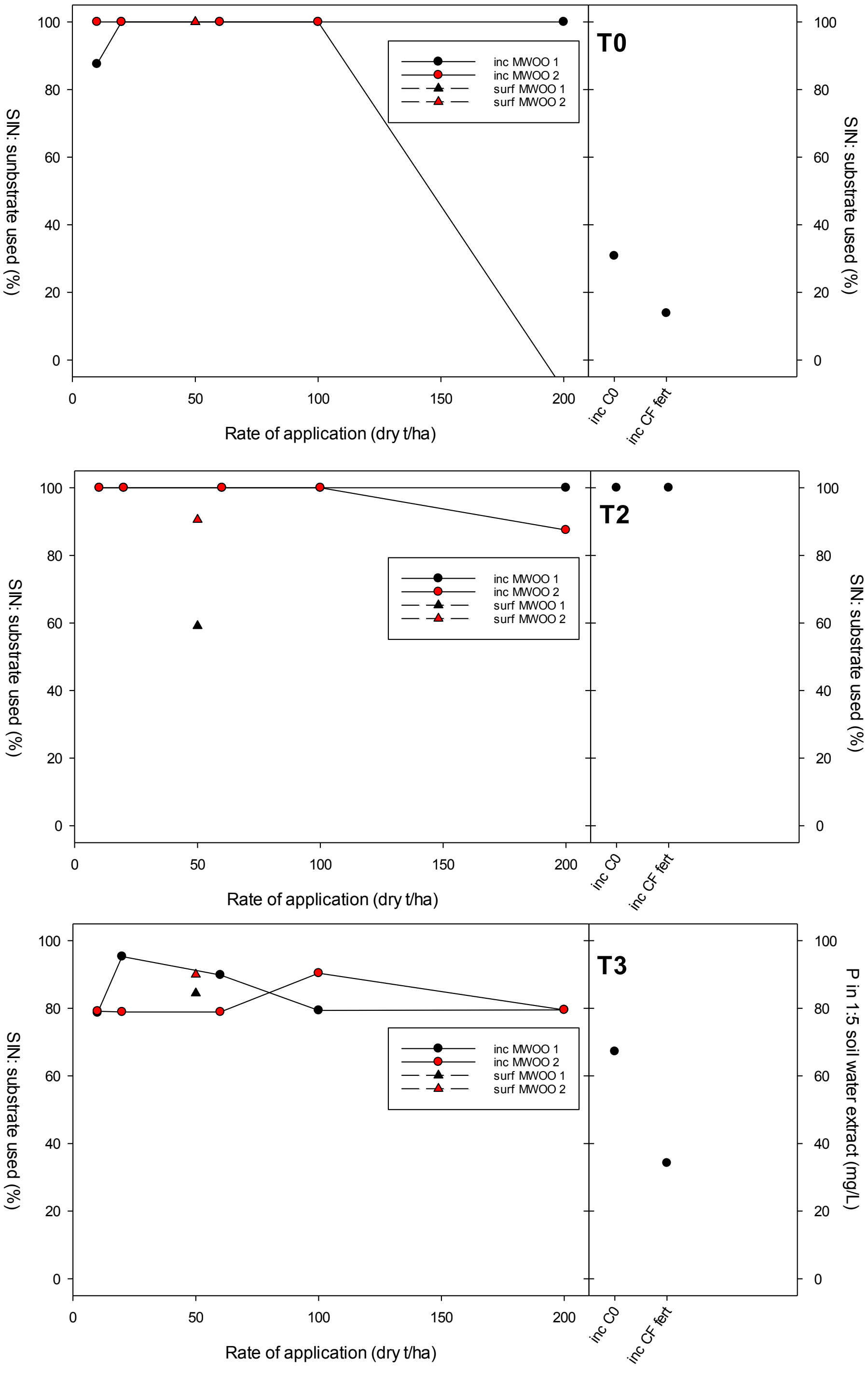


**Figure 51**: The effect of increasing rates of incorporated and surface applied MWOO 1 and MWOO 2 on soil microbial substrate induced nitrification (SIN) for soils sampled at time T0, T1, T2 and T3 (zero, 1, 2 and 3 years post-application) compared to control and control fertilizer treatments. Data are expressed as the percentage (%) substrate used. Inc = incorporated treatments; surf = surface applied; CO = control, CF fert = control fertilizer.

## Soil microbial function – potential nitrification rate (PNR)

Using the current methodology, the SIN test can only evaluate the use of the added substrate (% of substrate used), with any amount above 100% being substrate-limited, and this can be viewed as a limitation of the SIN method. The Potential Nitrification Rate test (PNR) overcomes the limitation of the added substrate (Smolders et.al. 2001). The PNR test is also thought to be a more sensitive assay for the detection of environmental toxicity (Broos et.al. 2005). Therefore we carried out the PNR on T3 soil samples, in an attempt to provide a more sensitive indicator of nitrification of $NH_4$. PNR is expressed as mg N (as $NO_3$) produced / kg soil / day.

Figure 52 presents the data for the PNR test carried out on the T3 soils. Analyses of these data show that for 200 t/ha MWOO 1 and MWOO 2 treatments, there was a significant reduction in PNR. The PNR values ranged between 2.9 (mg N /kg /d) for the 10 t/ha MWOO treatment, to -0.97 (mg N /kg /d) for the MWOO 1 200 t/ha treatment; the latter representing a 1.6 fold drop in PNR compared to the control soil.

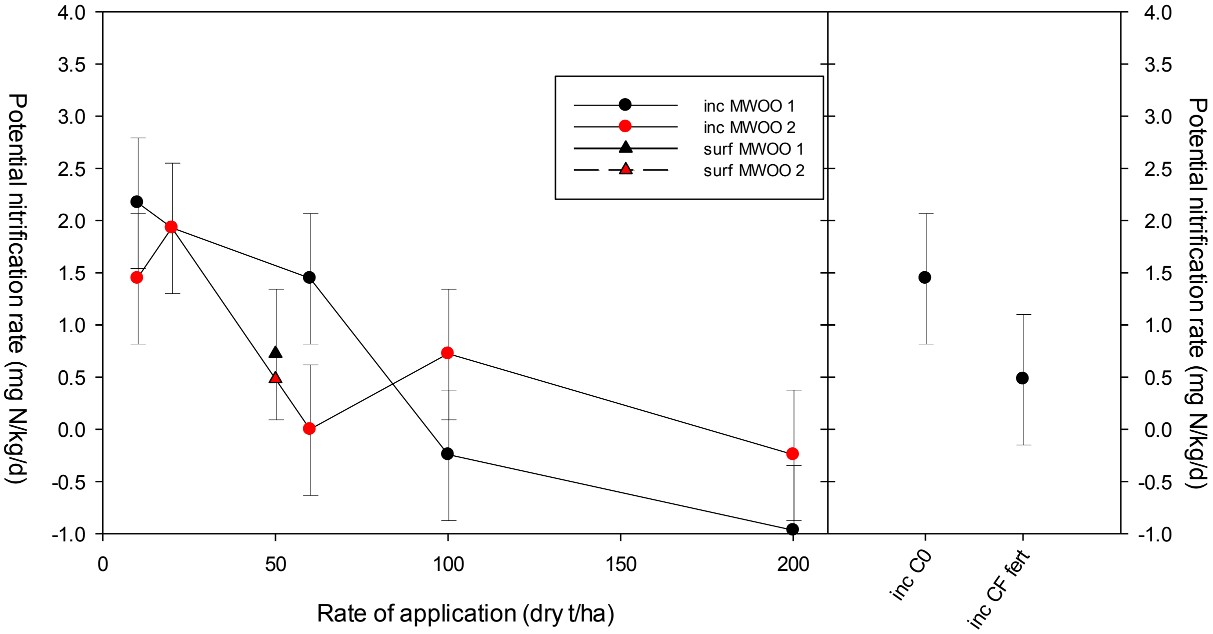


**Figure 52**: The effect of increasing rates of incorporated and surface applied MWOO 1 and MWOO 2 on the potential nitrification rate (PNR) for soils sampled at time T3,(3 years post-application) compared to control and control fertilizer treatments. Data are expressed as the rate of $NH_3$ substrate used per kg soil per day. Error bars indicate s.e.d. (standard error of the difference between means) at $p < 0.05$. Inc = incorporated treatments; surf = surface applied; CO = control, CF fert = control fertilizer.

Several studies have reported a drop in PNR in response to adverse soil conditions. Soil PNR decreased by 50% in response to increasing Cu additions to three different soils (Mertens et.al. 2010) and to Zn in a range of long-term contaminated soils (Mertens et.al. 2006). Smolders et.al. (2001) reported a drop of up to 44% in the PNR in the metal contaminated soils studied.

## Soil microbial function –Substrate Induced Respiration (SIR)

Table 46 lists the average SIR data ($CO_2$-C evolved [mg/g/hr]**)** for each rate of the incorporated MWOO 1 and MWOO 2 materials, sampled from the treatment soils at times T0, T1 and T2 (zero, 1 and 2 years post-application). The SIR test allows us to assess if toxicity or stress on the soil microbial population is occurring and is indicated by a decrease in SIR compared to the control.

Trends observed for the SIR response to the added MWOO are also given in Figure 53, which also includes the SIR response to green waste applied at 200 t/ha for comparison. Although there was some temporal variation in the SIR data, soil microbial respiration increased in all treatments post-MWOO application, when compared to the control treatments. Generally there was less microbial activity in the soils treated with MWOO2 (Figure 53) compared to those receiving MWOO1 at time T0 (47% less), as well as time T1 (48% less). It can also be seen that there is a slight, but significant decrease in microbial respiration, after the addition of the substrate for the higher rate treatments receiving MWOO1, for the T3 sampling. Included also in Figure 53 is the SIR response to added GW compost (100 t/ha), which shows that rates of microbial respiration in the GW treatment was as high, or higher than that in MWOO treatments.

**Table 36:** Treatment averages for $CO_2$-C evolved during the Substrate Induced Respiration tests (SIN) carried out on MWOO and control soils collected at times T0, T1 and T2.

| | **SIR - $CO_2$-C evolved (mg/g/hr)** | | |
|---|---|---|---|
| | T0 | T1 | T2 |
| Inc C | 2.89 | 1.36 | 3.43 |
| Inc CF | | 0.98 | 3.77 |
| Inc MWOO 1 20t | 4.71 | 9.90 | 5.79 |
| Inc MWOO 1 60t | 10.15 | 6.78 | 10.02 |
| Inc MWOO 1 100t | 9.17 | 6.81 | 8.44 |
| Inc MWOO 1 200t | 12.56 | 10.56 | 8.43 |
| Inc MWOO 2 20t | 9.37 | 7.41 | 6.47 |
| Inc MWOO 2 60t | 6.00 | 5.62 | 7.88 |
| Inc MWOO 2 100t | 8.79 | 5.91 | 8.97 |
| Inc MWOO 2 200t | 5.41 | 3.81 | 7.43 |
| *l.s.d. trt x year* | *1.85* | *1.85* | *1.85* |

*Included also are the l.s.d. values (in bold type) for each year following analysis of variance at p<0.05. MWOO = mixed waste organic output tables from sources 1 and 2; Inc = incorporated treatments; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

The observations from the SIR data propose that there is a different soil microbial response to the two different MWOO materials; increasing SIR for the MWOO treated soils and decreased SIR for MWOO 2. Similar to the discussion regarding SIN, Broos et.al. (2007), found that SIR on the flat paddock site was low compared to some of the soils discussed in his multi-soil evaluation of microbial responses to applied contaminants. Albiach et.al. (2000) found increased microbial activity in soils following the addition of various organic amendments, whereas Bhattacharyya et.al. (2001; 2003) found that microbial activity subsequently declined in soils amended with municipal solid waste compost, following an initial increase in microbial activity at the time of application. Conversely, Borken et.al. (2002) found that microbial activity was reduced in the top organic layer, but not in the lower mineral layers, of a degraded forest soil, two years after the application of compost from household organic wastes.

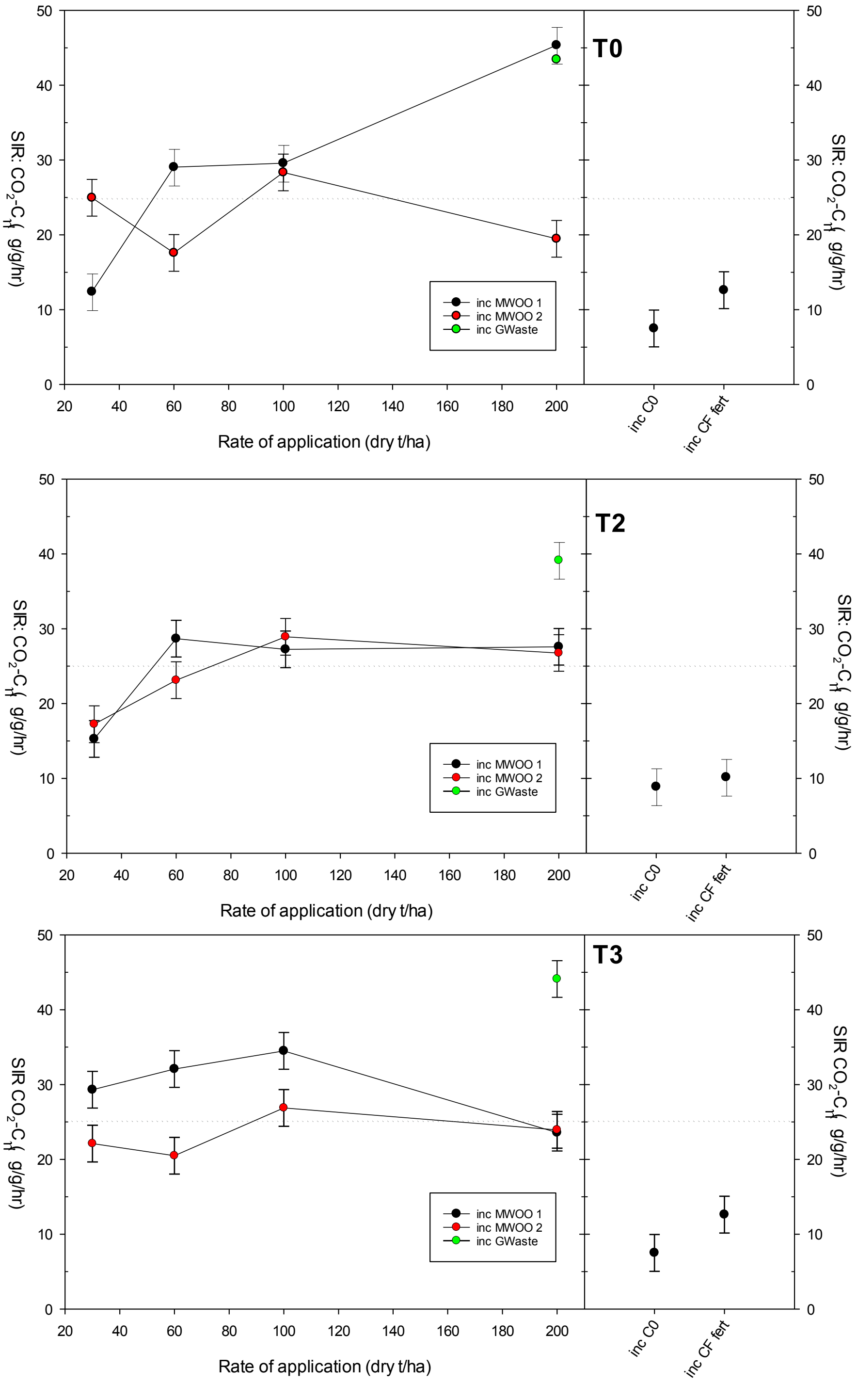


**Figure 53:** The effect of increasing rates of MWOO 1 and MWOO 2 on soil microbial substrate induced respiration for soils sampled at time T0, T1 and T2 (zero, 1 and 2 years post-application) compared to green waste (GWaste), control and control fertilizer treatments. Error bars indicate s.e.d. (standard error of the difference between means) at $p < 0.05$. Application rates (dry t/ha) indicated for each treatment represented in the Figure. Inc = incorporated treatments; surf = surface applied; CO = control, CF fert = control ferilizer

## Soil microbial function – MicroResp$^{TM}$.

in order to gain some further insight as to the influence of MWOO on soil microbial health by better understanding the changes in the SIR to applied MWOO discussed above, we attempted to separate the soil microbial respiration into a response to a series of different carbon substrates. In some other studies, this form of experiment has been used to develop what is known as a Community Level Physiological Profile (CLPP). The MicroResp$^{TM}$ procedure is such a test and has been successfully used to further elucidate various microbial responses to applied contaminants (e.g. Berard et.al. 2014) and the microbial of carbon and other elements in soils (e.g. Currey et.al. 2010).

We used a range of C substrates including, Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose and Alanine to further separate the respiration response (as evolved $CO_2$), to soils amended with MWOO and subsequently sampled at times T0, T1, T2 and T3. Water was used as the substrate for determining background or basal respiration levels (i.e. in the absence of added C substrate). Standard data analysis was supplemented by canonical variate analysis. The MicroResp data ($CO_2$ evolved [µg $CO_2$ C/g/h]) for each of the amended soils (MWOO 1 up to 200 t/ha and MWOO 2 200 t/ha), incubated with each of the nine C substrates, for each of the 4 sampling times, is represented in graphical form in Appendix 17a (T0), Appendix 17b (T1), Appendix 17c (T2) and Appendix 17d (T3). The canonical variate output table is summarized graphically in Appendix 18.

Figure 54 summarises the MicroResp response to each of the C substrates for the MWOO 1 treated soils, sampled at T0 and T3. Canonical variate analysis revealed that the response across the nine C substrates was significantly different for the MWOO 1 (200 t/ha) and MWOO 2 (200 t/ha treatments, which were in turn, significantly different from each other. This supports the general SIR response in the MWOO soils discussed above, where a difference in respiration response was seen for the two MWOO materials. The first two canonical variates (CV) explain 98% of the variation of the T0 data, while for T1 and T2, 85% of the variation was explained by the first two CV and for T3, 85% variation was explained.

Analysis of the MicroResp data presented in Figure 54 shows a different response to some of the added C substrates, between the T0 and T3 soils. In the T0 soils, the response to the added C substrate increased with increasing rates of MWOO application. Background respiration levels also increased (by 6.5 –fold), with increasing MWOO. These trends (increasing respiration with rates of application) are similar to the SIR response in the TO soils as discussed above.

However, there was a different response to some of the added C substrates in MWOO amended soils sampled at time T3. The respiration response to some of the C substrates, decreased with MWOO application. The concentrations of $CO_2$ produced dropped with increasing rates of MWOO following the addition of citric acid (30% decrease), glucose (37% drop), trehalose (23%), arabinose (62% drop) and galactose (34%), and the concentrations of $CO_2$ produced were equal to or lower than those in the unamended control soil (Figure 54). The SIR data described above (Figure 53) showed a decrease in soil respiration over time with the highest MWOO applications. Studies carried out using MicroResp have shown decreases in the soil microbial response to similar substrates as used in our experiments. Campbell et.al. (2008) observed an inhibition in the microbial response to added galactose and trehalose, following the burning of wet sclerophyll forests in Queensland Australia, while Tlili et.al. (2011) used differing utilization patterns of fructose, glucose, galactose and citric acid, to illustrate differing microbial community tolerances to soil Cu.

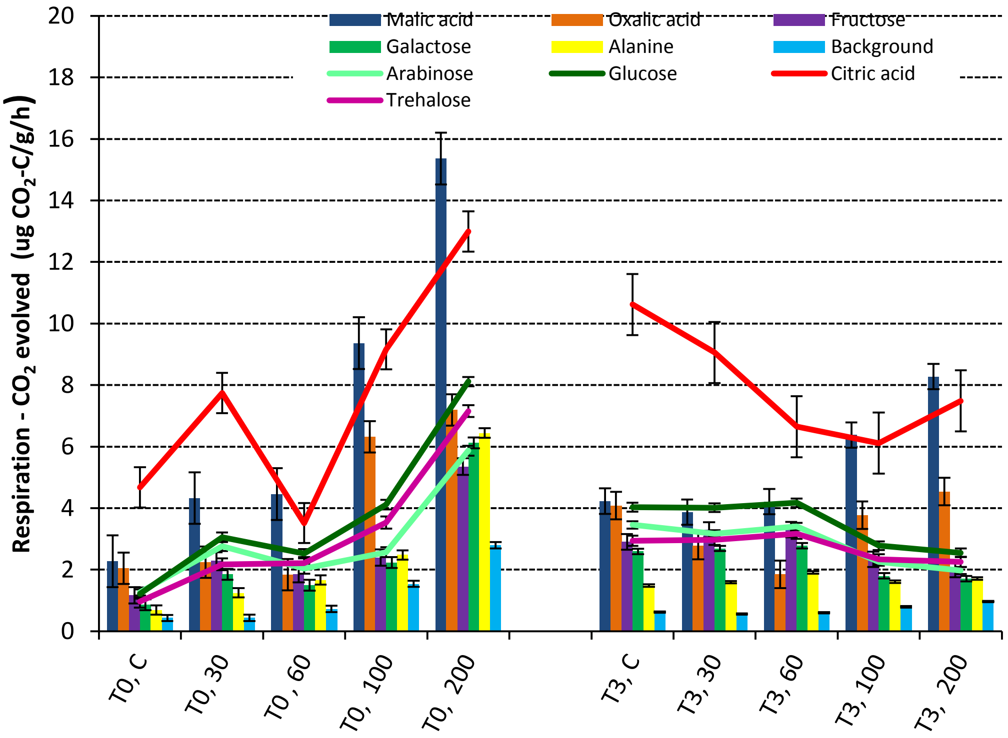


**Figure 54:** The effect of increasing rates of MWOO 1 on soil microbial respiration for soils incubated with different C sources, compared to the unamended control soil. Data is presented for soils sampled at time T0 and T3. For greater clarity, responses to different C sources are arbitrarily split between bars (malic acid, oxalic acid, fructose, galactose and background respiration), and lines (arabinose, glucose, citric acid, and Trehalose. The full data set is presented in Appendices 14 a – d for the T0 – T3 samplings. Error bars indicate s.e.d. (standard error of the difference between means) at $p < 0.05$.

# Conclusions

In summary, the data presented in this report does not provide support for the use of MWOO as a soil amendment in agriculture. Consistently high application rates were needed to produce positive gains in crop production (greater than 60 t/ha for incorporated MWOO), measured across three consecutive cropping cycles, but also led to a legacy of metal and organic residues in amended soils, and the concentrations of some of these approach (metals) or exceed (organic pollutants) relevant regulatory or environmental thresholds. Our data shows that there are potentially detrimental effects on biology at these rates of MWOO application and there appears to be some persistence of the organic contaminants applied with the MWOO. Even higher rates of application are needed to improve soil physical health (between 60 and 100 t/ha). Although similar application rates are needed with the use of other amendment materials (e.g. green waste), application of these do not contain the same levels of contaminants. Similar plant growth responses can be achieved with inorganic fertilizers without the inherent contamination risk.

Surface application of MWOO presents an even greater risk of exposure to these chemicals, including the possibility of losses to the environment via runoff, while at the same time surface application does not consistently result in higher levels of crop production.

Metal contaminant concentrations in MWOO were as high as, or higher than, the other organic amendment materials used in this trial, including composted biosolids. Following incorporation of MWOO into soils at rates of MWOO application seen to improve crop yields (60 t/ha), increases in soil concentrations of Cd (40% to 60%), Cu (50% to 78 %) and Zn (up 60%) were observed. To achieve measurable improvements in soil physical properties such as water holding capacity (applications greater than 100 t/ha), the soils concentrations of Cd, Cu and Zn were elevated above current MACC concentrations for these three metals in the amended soils.

Initially, the concentration of metal contaminants that were extractable in 0.01M $CaCl_2$ were higher in MWOO amended soils compared to the soils amended with the other organic materials, where this extract is also commonly used to estimate metal 'bioavailability' in soils. By the end of the trial however (T3), ageing of the MWOO and other amendments in the test soils has revealed that there is little difference in the overall metal extractability between the various materials. This is also the case when comparing metal extractability for the MWOO and other current treatments, with amendments previously studied at the test site (e.g. dewatered biosolids). It is therefore unlikely that the current framework for regulating soil metal inputs from biosolids, would underestimate the risk from these same metals for sources such as MWOO and the other amendment materials tested during this trial.

The increased metal extractability in the MWOO treated soils compared to the other amendments used in the trial was reflected by increased plant uptake of metal contaminants for millet and wheat grown on these soils. However, there was no evidence of reduced plant yield resulting from metal toxicity in any of the test crops and at no stage was product quality compromised by the accumulation of metal contaminants in plant tissue or grain.

The MWOO materials contained significant quantities of organic compounds associated with plastics manufacture and plastics breakdown, including phthalates (DEHP, DBP) and Bisphenol A. The concentrations of some of these chemical were higher in the MWOO used here than has been reported elsewhere. The other amendments used in this trial did not contain many of these similar contaminants, or else they were at very low concentrations. For incorporation of MWOO, soil concentrations of some of the organic compounds exceeded the ERL for that compound, where these exist, while for surface applications, these ERLs were exceeded at doses as low as 20 t/ha to 30 t/ha. Although the concentration of these compounds subsequently decreased post-application, of some concern, is that concentrations of these are still detectable in the amended soils after three years, where it would be expected that these compounds would have been degraded by soil microbial populations.

Using a soil water extract as a means of indicating the concentrations of potentially mobile contaminants and plant nutrient elements as a worst case scenario, showed that the concentration of some elements approached or exceeded irrigation water quality guideline concentrations (Cd, Cu, Mo, Ni and Zn) for some treatments, but more so for surface applications of MWOO. However, these concentrations have continued to decrease over time, and by year 3, were no longer at concentrations above those set for water quality guidelines. There was no evidence for downward movement of these elements through the soil profile.

The data in this report shows that by applying the amendments at ‘agronomically significant’ application rates, short term effects on soil biota are possible. It was unclear whether these effects would diminish once soil salinity levels were reduced i.e. that *in situ* worm populations could re-colonise the amended soils. It is also possible that the presence of organic contaminants (e.g. DEET), identified in the MWOO and amended soils, may also have had an adverse effect on soil biota. Indeed, an additive effect of high EC, heavy metals and organic contaminants was likely thus resulting in the observed earthworm avoidance following application. .

Initially, MWOO applications resulted in increased microbial activity in the amended soils, and while it is known that this site in particular has an inherently low microbial activity, levels increased above those of the control. At the same time, similar positive effects were also seen for other amendment materials, such as composted green waste. However, it is apparent that there has been a decline in microbial activity on the amended plots during the last year of the trial and in some cases these are now lower than the activity seen in control soils. Microbial activity in green waste treated plots continues to remain at high levels, exceeding those of the control.

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# Appendices:

## **Appendix 1:** Basic chemical, physical and morphological properties of Flat Paddock soils

| **Location ID** | **FA3** | | | | **FA4** | | |
|---|---|---|---|---|---|---|---|
| **Site Location** | **South - Western side near creek** | | | | **Western side near Creek** | | |
| **Classification Isbell (1996)**<br>**US taxonomy**<br>**Northcote (1979)** | Haplic Eutrophic Grey Chromosol<br>Aridisol$^*$<br>Dy3.12 | | | | Sodic Eutrophic Brown Dermosol<br>Aridisol$^*$<br>Dy3.12 | | |
| **Horizon** | A1 | B21 | B22 | B23 | A1 | B21 | B22 |
| **Depth (cm)** | 0-25 | 25-41 | 41-80 | 80-100 | 0-41 | 41-72 | 72-100 |
| **Boundary** | | clear | clear | gradual | | clear | |
| **Texture** | CL | L/M C | L/M C | LC | Sil CL | LC | |
| **FTG (span)** | 4 | 5 (>1.5) | 5 | 5 | 4 | 5 (>1.5) | |
| **Colour** | 10YR 4/3 bn | 7.5YR 5/2 bn | 5YR 5/6 yell-r | 10YR 5/6 yell bn | 10YR 4/3bn | 10YR 5/4 yell bn | |
| **VC rating** | 5 | 2 | 4 | 4 | 5 | 2 | |
| **Structure** | M | W/M | S | M/S | W | M | |
| **pH$_C$** | 4.61 | 6 | 6.66 | | 4.57 | 6.13 | 7.98 |
| **EC (dS/m)** | 0.04 | 0.05 | 0.05 | | 0.04 | 0.06 | 0.23 |
| **ECEC [cmol(+)/kg]** | 9.04 | 22 | 18.1 | | 10.1 | 19 | 19.5 |
| **Exch Al** | 0.34 | - | - | | 0.34 | - | - |
| **Exch Ca "** | 5.8 | 12 | 8.8 | | 7.2 | 11 | 11 |
| **Exch Mg "** | 2.5 | 9.1 | 8 | | 2.1 | 6.6 | 6.3 |
| **Exch Na "** | 0.16 | 0.6 | 1.1 | | 0.24 | 1.2 | 2 |
| **Exch K "** | 0.24 | 0.28 | 0.21 | | 0.18 | 0.24 | 0.21 |
| **ESP (%)** | 1.93 | 2.84 | 6.55 | | 2.58 | 6.82 | 11.6 |
| **Total P (%)** | 0.041 | 0.019 | | | 0.041 | 0.019 | |
| **Colwell P (mg/kg)** | 26 | 2.7 | | | 26 | 2.7 | |
| **Bray P (mg/kg)** | 9 | 0.14 | | | 9 | 0.14 | |
| **OC (%)** | 1.5 | 0.55 | | | 1.6 | 0.55 | |
| **Total N (%)** | 0.12 | 0.054 | | | 0.12 | 0.054 | |
| **Total As (mg/kg)** | 3.9 | 5.2 | | | 3.9 | 5.2 | |
| **Total Cd (mg/kg)** | 0.073 | - | | | 0.073 | - | |
| **Total Co (mg/kg)** | 12 | 12 | | | 12 | 12 | |
| **Total Cr (mg/kg)** | 10 | 12 | | | 10 | 12 | |
| **Total Cu (mg/kg)** | 15 | 18 | | | 15 | 18 | |
| **Total Fe (%)** | 1.6 | 2.1 | | | 1.6 | 2.1 | |
| **Total Mo (mg/kg)** | - | - | | | - | - | |
| **Total Ni (mg/kg)** | 9.8 | 8.9 | | | 9.8 | 8.9 | |
| **Total Pb (mg/kg)** | 17 | 18 | | | 17 | 18 | |
| **Total V (mg/kg)** | 20 | 25 | | | 20 | 25 | |
| **Total Zn (mg/kg)** | 31 | 27 | | | 31 | 27 | |

## **Appendix 2:** Schematic of randomized treatment allocations for field trial blocks

Key:
MWOO 1 = MWOO from source 1; MWOO 2 = MWOO from source 2; GW = green waste; Bio = composted biosolids; Man = poultry manure. Inc = incorporated; surf = surface applied; C = control; CF = control fertiliser; Application rates (dry t/ha) indicated treatment.

### Field trial replicate 1

■ = 5 m buffer ░ = 1 m buffer

**3 m** **5 m**

| | | | | | |
|---|---|---|---|---|---|
| | surf MWOO 2 50 | | inc MWOO 2 20 | surf MWOO 1 30 | inc Man 100 |
| inc Bio 60 | surf MWOO 1 50 | surf MWOO 2 30 | inc MWOO 2 60 | surf GW 30 | surf C |
| | inc MWOO 1 200 | inc GW 60 | inc CF | inc MWOO 1 20 | inc GW 10 |
| inc MWOO 1 10 | inc GW 200 | inc MWOO 1 60 | inc GW 100 | inc MWOO 2 100 | surf CF |
| inc MWOO 2 200 | surf GW 50 | | inc Man 20 | inc Man 10 | surf GW 10 |
| inc C | inc MWOO 1 100 | surf MWOO 2 10 | | inc GW 20 | inc MWOO 2 10 |
| inc Man 60 | surf MWOO 1 10 | surf MWOO 1 20 | surf MWOO 2 20 | surf GW 20 | inc Bio 10 |

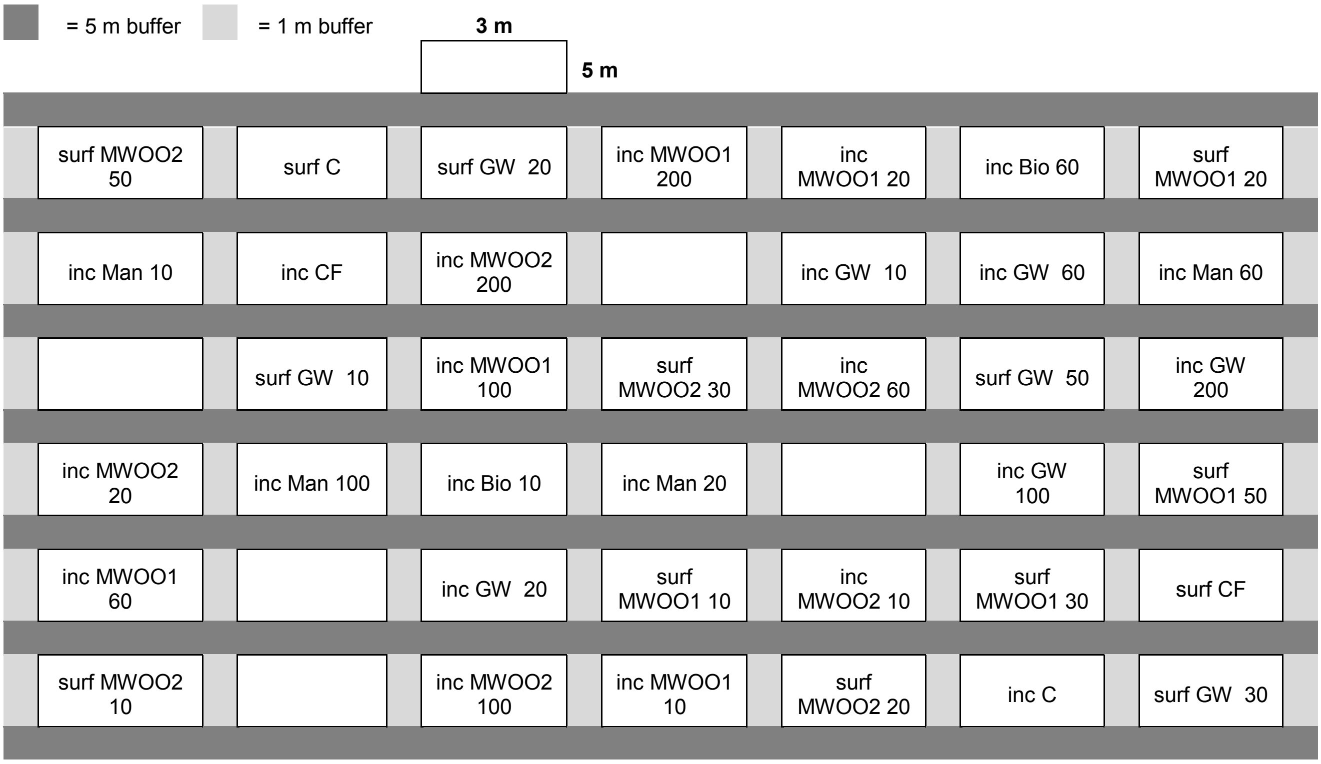
### Field trial replicate 2

■ = 5 m buffer ░ = 1 m buffer

**3 m** **5 m**

| | | | | | | |
|---|---|---|---|---|---|---|
| | inc MWOO 2 200 | inc Man 10 | inc MWOO 1 20 | inc GW 60 | surf MWOO 1 20 | |
| surf MWOO 1 10 | surf MWOO 1 30 | inc C | | inc CF | surf CF | inc MWOO 2 20 |
| inc Bio 10 | surf GW 30 | inc GW 10 | inc MWOO 1 100 | surf GW 10 | inc MWOO 1 10 | inc Man 100 |
| inc MWOO 1 60 | surf MWOO 1 50 | inc MWOO 2 100 | surf MWOO 2 10 | inc Man 20 | inc Bio 60 | surf C |
| inc Man 60 | | inc GW 100 | surf MWOO 2 30 | surf MWOO 2 50 | inc GW 20 | surf GW 20 |
| inc MWOO 2 10 | surf MWOO 2 20 | surf GW 50 | inc MWOO 2 60 | inc MWOO 1 200 | inc GW 200 | |

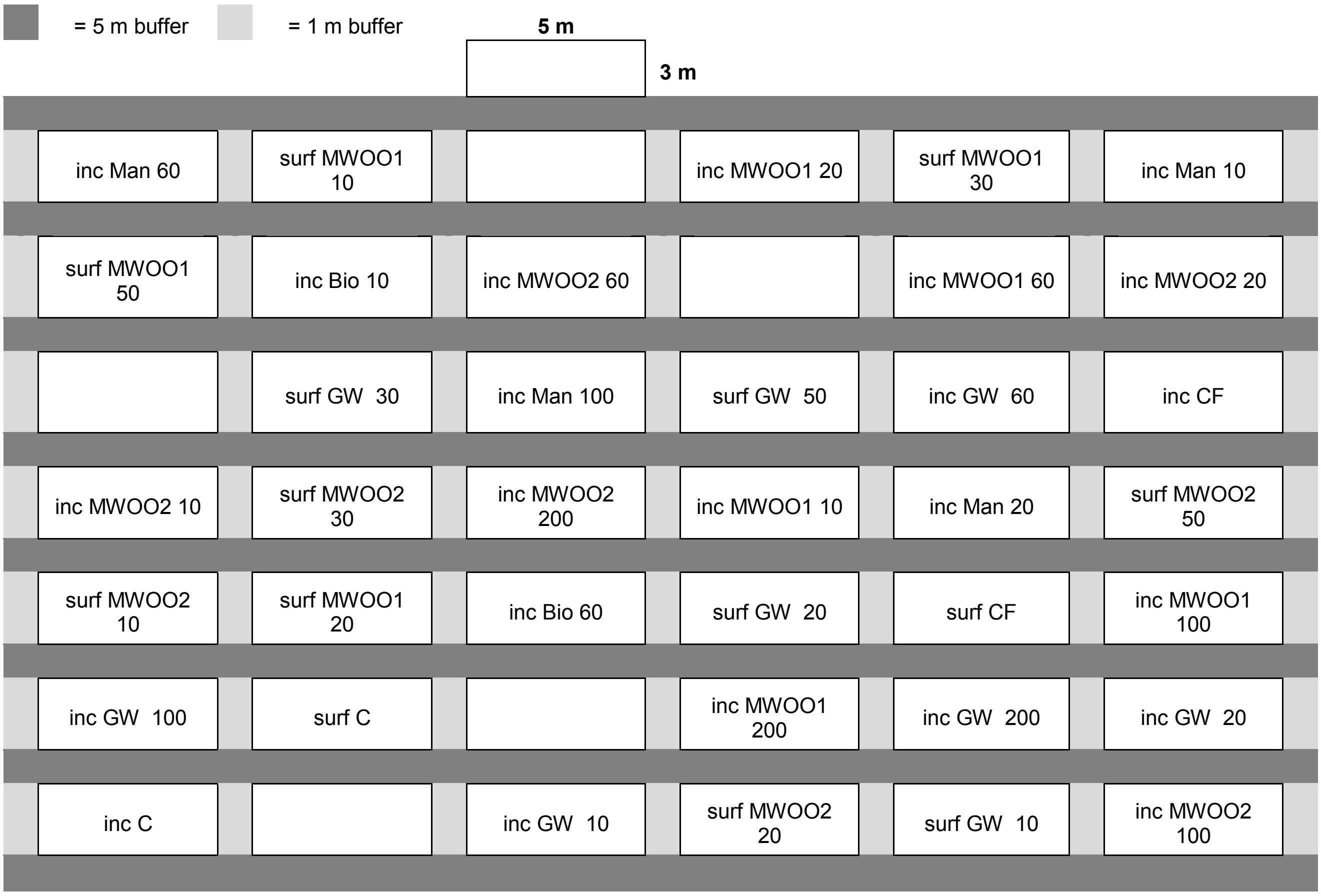
## Field trial replicate 3



■ = 5 m buffer ▒ = 1 m buffer

| | | | | | | |
|---|---|---|---|---|---|---|
| surf MWOO2 50 | surf C | surf GW 20 | inc MWOO1 200 | inc MWOO1 20 | inc Bio 60 | surf MWOO1 20 |
| inc Man 10 | inc CF | inc MWOO2 200 | | inc GW 10 | inc GW 60 | inc Man 60 |
| | surf GW 10 | inc MWOO1 100 | surf MWOO2 30 | inc MWOO2 60 | surf GW 50 | inc GW 200 |
| inc MWOO2 20 | inc Man 100 | inc Bio 10 | inc Man 20 | | inc GW 100 | surf MWOO1 50 |
| inc MWOO1 60 | | inc GW 20 | surf MWOO1 10 | inc MWOO2 10 | surf MWOO1 30 | surf CF |
| surf MWOO2 10 | | inc MWOO2 100 | inc MWOO1 10 | surf MWOO2 20 | inc C | surf GW 30 |

## Field trial replicate 4



■ = 5 m buffer ▒ = 1 m buffer

| | | | | | |
|---|---|---|---|---|---|
| inc Man 60 | surf MWOO1 10 | | inc MWOO1 20 | surf MWOO1 30 | inc Man 10 |
| surf MWOO1 50 | inc Bio 10 | inc MWOO2 60 | | inc MWOO1 60 | inc MWOO2 20 |
| | surf GW 30 | inc Man 100 | surf GW 50 | inc GW 60 | inc CF |
| inc MWOO2 10 | surf MWOO2 30 | inc MWOO2 200 | inc MWOO1 10 | inc Man 20 | surf MWOO2 50 |
| surf MWOO2 10 | surf MWOO1 20 | inc Bio 60 | surf GW 20 | surf CF | inc MWOO1 100 |
| inc GW 100 | surf C | | inc MWOO1 200 | inc GW 200 | inc GW 20 |
| inc C | | inc GW 10 | surf MWOO2 20 | surf GW 10 | inc MWOO2 100 |

## **Appendix 3:** Preliminary chemical analysis of the two MWOO materials used in this trial.

| **MWOO1** |  | **MWOO2** |  |
|---|---|---|---|
| **Analyte** | unit/value | **Analyte** | unit/value |
| Moisture | % W/V | Moisture | % W/V |
|  | 22 |  | 34 |
| Particle size data | % W/V | Particle size data |  |
| Maximum particle size >16 mm | <0.01 | Maximum particle size >16 mm | <0.01 |
| Particle size <16 and >5 mm | 8.5 | Particle size <16 and >5 mm | 12 |
| Particle size <5mm | 92 | Particle size <5mm | 88 |
| Particle size grading - <2mm | 84 | Particle size grading - <2mm | 62 |
| Particle size grading - >2mm | 16 | Particle size grading - >2mm | 38 |
| Glass,metal rigid plastic >2mm | <0.01 | Glass,metal rigid plastic >2mm | 0.01 |
| Glass,metal rigid plastic >5mm | <0.01 | Glass,metal rigid plastic >5mm | <0.01 |
| Chemical data - organics | mg/kg | Chemical data - organics |  |
| 1,2,3,4-Tetrachlorobenzene | <0.38 | 1,2,3,4-Tetrachlorobenzene | <0.45 |
| 1,2,4,5-Tetrachlorobenzene | <0.26 | 1,2,4,5-Tetrachlorobenzene | <0.3 |
| 1,2,4-Trichlorobenzene | <0.38 | 1,2,4-Trichlorobenzene | <0.45 |
| 1,2-Dichlorobenzene | <0.38 | 1,2-Dichlorobenzene | <0.45 |
| 1,4-Dichlorobenzene | <0.38 | 1,4-Dichlorobenzene | <0.45 |
| 2,3,4,6-Tetrachlorophenol | <0.38 | 2,3,4,6-Tetrachlorophenol | <0.45 |
| 2,4,5-Trichlorophenol | <0.64 | 2,4,5-Trichlorophenol | <0.76 |
| 2,4,6-Trichlorophenol | <0.26 | 2,4,6-Trichlorophenol | <0.3 |
| 2,4-Dichlorophenol | <1.3 | 2,4-Dichlorophenol | <1.5 |
| 2,4-Dimethylphenol | <3.2 | 2,4-Dimethylphenol | <3.8 |
| 2,4-Dinitrophenol | <3.8 | 2,4-Dinitrophenol | <4.5 |
| 2,4-Dinitrotoluene | <0.26 | 2,4-Dinitrotoluene | <0.3 |
| 2,6-Dichlorophenol | <0.26 | 2,6-Dichlorophenol | <0.3 |
| 2-Chlorophenol | <0.38 | 2-Chlorophenol | <0.45 |
| 2-Methyl-4,6-dinitrophenol | <1.9 | 2-Methyl-4,6-dinitrophenol | <2.3 |
| 2-Methylphenol | <0.64 | 2-Methylphenol | <0.76 |
| 2-Nitrophenol | <0.38 | 2-Nitrophenol | <0.45 |
| 3+4-Methylphenol | 1.4 | 3+4-Methylphenol | 64 |
| 4-Chloro-3-methylphenol | <0.64 | 4-Chloro-3-methylphenol | <0.76 |
| 4-Nitrophenol | <2.6 | 4-Nitrophenol | <3.0 |
| Acenaphthene | <0.13 | Acenaphthene | <0.15 |
| Acenaphthylene | <0.13 | Acenaphthylene | <0.15 |
| Anthracene | <0.13 | Anthracene | <0.15 |
| Aroclor 1016 (screen) | <0.51 | Aroclor 1016 (screen) | <0.61 |
| Aroclor 1232 (screen) | <0.51 | Aroclor 1232 (screen) | <0.61 |
| Aroclor 1242 (screen) | <0.51 | Aroclor 1242 (screen) | <0.61 |
| Aroclor 1248 (screen) | <0.51 | Aroclor 1248 (screen) | <0.61 |
| Aroclor 1254 (screen) | <0.51 | Aroclor 1254 (screen) | <0.61 |
| Aroclor 1260 (screen) | <0.51 | Aroclor 1260 (screen) | <0.61 |
| Benzo (a) anthracene | <0.13 | Benzo (a) anthracene | <0.15 |
| Benzo (a) pyrene | <0.13 | Benzo (a) pyrene | <0.15 |
| Benzo (b) fluoranthene | <0.13 | Benzo (b) fluoranthene | <0.15 |
| Benzo (ghi) perylene | <0.13 | Benzo (ghi) perylene | <0.15 |
| Benzo (k) fluoranthene | <0.13 | Benzo (k) fluoranthene | <0.15 |
| Bis-2-ethyl hexyl adipate | 4.1 | Bis-2-ethyl hexyl adipate | <2.3 |
| Bis-2-ethyl hexyl phthalate | 150 | Bis-2-ethyl hexyl phthalate | 120 |

**Appendix 3** ….continued -

| **MWOO1** | | **MWOO2** | |
|---|---|---|---|
| **Analyte** | unit/value | **Analyte** | unit/value |
| Chrysene | <0.13 | Chrysene | <0.15 |
| Dibenzo (ah) anthracene | <0.13 | Dibenzo (ah) anthracene | <0.15 |
| Dibutyl phthalate | 8.6 | Dibutyl phthalate | 3.9 |
| Dinoseb | <0.64 | Dinoseb | <0.76 |
| Fluoranthene | <0.13 | Fluoranthene | <0.15 |
| Fluorene | <0.13 | Fluorene | <0.15 |
| Indeno (123cd) pyrene | <0.13 | Indeno (123cd) pyrene | <0.15 |
| Isodrin | <0.26 | Isodrin | <0.3 |
| Naphthalene | 0.42 | Naphthalene | 0.78 |
| Nitrobenzene | <0.13 | Nitrobenzene | <0.15 |
| Pentachlorobenzene | <0.13 | Pentachlorobenzene | <0.15 |
| Pentachloronitrobenzene | <0.26 | Pentachloronitrobenzene | <0.3 |
| Pentachlorophenol | <0.64 | Pentachlorophenol | <0.76 |
| Perylene | <0.13 | Perylene | <0.15 |
| Phenanthrene | 0.29 | Phenanthrene | 0.4 |
| Phenol | 19 | Phenol | 54 |
| Pyrene | <0.13 | Pyrene | <0.15 |
| Chemical data - inorganics | | | |
| Aluminium | 4700 | Aluminium | 7800 |
| Antimony | <3.8 | Antimony | <4.5 |
| Arsenic | 6.6 | Arsenic | 7.7 |
| Barium | 150 | Barium | 190 |
| Beryllium | <0.13 | Beryllium | 0.16 |
| Boron | 27 | Boron | 30 |
| Cadmium | 1.9 | Cadmium | 2 |
| Chromium | 48 | Chromium | 37 |
| Cobalt | 4.4 | Cobalt | 5.2 |
| Copper | 320 | Copper | 260 |
| Iron | 6500 | Iron | 1.3 |
| Lead | 220 | Lead | 210 |
| Lithium | <2.6 | Lithium | <3.0 |
| Manganese | 210 | Manganese | 340 |
| Molybdenum | 6.8 | Molybdenum | 9.2 |
| Nickel | 28 | Nickel | 38 |
| Phosphorus | 3000 | Phosphorus | 5400 |
| Selenium | <3.8 | Selenium | <4.5 |
| Silver | 2.2 | Silver | 1.6 |
| Strontium | 130 | Strontium | 94 |
| Sulfur | 2900 | Sulfur | 4700 |
| Thallium | <1.3 | Thallium | <1.5 |
| Tin | 18 | Tin | 33 |
| Titanium | 72 | Titanium | 62 |
| Vanadium | 7.9 | Vanadium | 12 |
| Zinc | 530 | Zinc | 770 |
| Mercury (µg/kg) | 320 | Mercury | 440 |
| Trace organics / VOC | µg/kg | Trace organics / VOC | µg/kg |
| Aldrin | <77 | Aldrin | <91 |
| alpha Chlordane | <64 | alpha Chlordane | <76 |
| alpha-BHC | <51 | alpha-BHC | <61 |

**Appendix 3** ....continued - Preliminary chemical analysis of MWOO material used in this trial

| **MWOO1** **Analyte** | unit/value µg/kg | **MWOO2** **Analyte** | unit/value µg/kg |
|---|---|---|---|
| beta-BHC | <38 | beta-BHC | <45 |
| delta-BHC | <38 | delta-BHC | <45 |
| Dieldrin | <64 | Dieldrin | <76 |
| Endosulfan I | <51 | Endosulfan I | <61 |
| Endosulfan II | <51 | Endosulfan II | <61 |
| Endosulfan sulfate | <77 | Endosulfan sulfate | <91 |
| Endrin | <51 | Endrin | <61 |
| gamma Chlordane | <77 | gamma Chlordane | <91 |
| gamma-BHC | <51 | gamma-BHC | <61 |
| HCB | <51 | HCB | <61 |
| Heptachlor | <64 | Heptachlor | <76 |
| Heptachlor epoxide | <51 | Heptachlor epoxide | <61 |
| Methoxychlor | <51 | Methoxychlor | <61 |
| pp'-DDD | <100 | pp'-DDD | <120 |
| pp'-DDE | <120 | pp'-DDE | <140 |
| pp'-DDT | <77 | pp'-DDT | <91 |
| Allethrin | <130 | Allethrin | <150 |
| Ametryn | <260 | Ametryn | <300 |
| Atraton | <640 | Atraton | <760 |
| Atrazine | <510 | Atrazine | <610 |
| Bifenthrin | <130 | Bifenthrin | <150 |
| Bioresmethrin | <130 | Bioresmethrin | <150 |
| Carbophenothion | <130 | Carbophenothion | <150 |
| Chlorpyrifos | <130 | Chlorpyrifos | <150 |
| cis-Permethrin | <130 | cis-Permethrin | <150 |
| Crotoxyphos | <130 | Crotoxyphos | <150 |
| Cyfluthrin | <310 | Cyfluthrin | <360 |
| Cypermethrin | <310 | Cypermethrin | <360 |
| Deltamethrin | <310 | Deltamethrin | <360 |
| Dichlorvos | <130 | Dichlorvos | <150 |
| Dimethoate | <130 | Dimethoate | <150 |
| Ethion | <130 | Ethion | <150 |
| Ethyl parathion | <310 | Ethyl parathion | <360 |
| Fenamiphos | <770 | Fenamiphos | <910 |
| Fenitrothion | <130 | Fenitrothion | <150 |
| Fenthion | <130 | Fenthion | <150 |
| Fenvalerate | <310 | Fenvalerate | <360 |
| Hexazinone | <260 | Hexazinone | <300 |
| l-Cyhalothrin | <130 | l-Cyhalothrin | <150 |
| Malathion | <130 | Malathion | <150 |
| Methidathion | <130 | Methidathion | <150 |
| Methoxychlor | <130 | Methoxychlor | <150 |
| Methyl azinphos | <130 | Methyl azinphos | <150 |
| Methyl chlorpyrifos | <130 | Methyl chlorpyrifos | <150 |
| Methyl parathion | <310 | Methyl parathion | <360 |
| Mevinphos | <130 | Mevinphos | <150 |
| Oxyfluorfen | <770 | Oxyfluorfen | <910 |
| Phorate | <130 | Phorate | <150 |
| Profenofos | <310 | Profenofos | <360 |
| Prometon | <260 | Prometon | <300 |
| Prometryn | <770 | Prometryn | <910 |

**Appendix 3** ....continued - Preliminary chemical analysis of MWOO material used in this trial

| **MWOO1** | unit/value | **MWOO2** | unit/value |
|---|---|---|---|
| **Analyte** | µg/kg | **Analyte** | µg/kg |
| Propargite | <640 | Propargite | <760 |
| Propazine | <260 | Propazine | <300 |
| Propetamphos | <130 | Propetamphos | <150 |
| Simazine | <380 | Simazine | <450 |
| Simetryn | <260 | Simetryn | <300 |
| Sulprofos | <130 | Sulprofos | <150 |
| Tebuconazole | <770 | Tebuconazole | <910 |
| Tebuthiuron | <260 | Tebuthiuron | <300 |
| Terbuthylazine | <260 | Terbuthylazine | <300 |
| Terbutryn | <260 | Terbutryn | <300 |
| Tetrachlorvinphos | <310 | Tetrachlorvinphos | <360 |
| trans-Permethrin | <130 | trans-Permethrin | <150 |

## **Appendix 4a:** Treatment averages for soil nutrients and fertility parameters for incorporated treatments T0

| | S | P | Col P | TN | $NH_4$ | $NO_3$ | TC% | TOC% | CEC | Ex Ca | Ex Mg | Ex K | Ex Na | ESP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/kg | | | | % | % | | | cmol(+)/kg | | | % |
| **inc C 0** | 8 | 338 | 17 | 1725 | 17 | 39 | 2.3 | 2.1 | 8.7 | 5.2 | 2.7 | 0.6 | 0.1 | 1.2 |
| **inc CF fert** | 13 | 398 | 35 | 1800 | 26 | 63 | 2.4 | 2.2 | 9.0 | 5.2 | 2.6 | 0.9 | 0.1 | 1.4 |
| **inc MWOO1 10** | 24 | 433 | 41 | 2025 | 21 | 35 | 2.8 | 2.7 | 12.0 | 7.7 | 3.1 | 0.8 | 0.5 | 4.2 |
| **inc MWOO1 20** | 24 | 513 | 52 | 2375 | 25 | 16 | 3.3 | 3.0 | 13.0 | 8.6 | 2.8 | 1.0 | 0.6 | 4.6 |
| **inc MWOO1 60** | 91 | 785 | 109 | 3450 | 19 | 6 | 5.0 | 4.9 | 21.8 | 14.0 | 3.6 | 1.7 | 2.2 | 9.9 |
| **inc MWOO1 100** | 170 | 1323 | 245 | 5900 | 33 | 10 | 8.4 | 8.1 | 31.0 | 19.5 | 3.8 | 3.2 | 4.3 | 13.8 |
| **inc MWOO1 200** | 250 | 1700 | 288 | 6900 | 36 | 116 | 9.7 | 9.0 | 36.0 | 21.5 | 4.1 | 4.1 | 6.4 | 17.5 |
| **inc MWOO2 10** | 23 | 483 | 47 | 2125 | 48 | 38 | 2.8 | 2.7 | 12.3 | 7.7 | 3.3 | 0.9 | 0.5 | 3.5 |
| **inc MWOO2 20** | 43 | 628 | 76 | 2675 | 63 | 40 | 3.4 | 3.2 | 15.0 | 9.7 | 3.1 | 1.4 | 0.8 | 5.1 |
| **inc MWOO2 60** | 59 | 1118 | 173 | 4200 | 57 | 25 | 5.2 | 5.0 | 21.3 | 14.5 | 3.5 | 2.2 | 1.3 | 6.0 |
| **inc MWOO2 100** | 101 | 1775 | 320 | 6800 | 39 | 27 | 8.1 | 7.8 | 31.5 | 20.8 | 4.3 | 3.8 | 2.7 | 8.4 |
| **inc MWOO2 200** | 123 | 2500 | 368 | 8400 | 63 | 80 | 9.6 | 8.8 | 33.8 | 21.3 | 4.3 | 4.6 | 3.3 | 9.3 |
| **inc GW 10** | 11 | 390 | 27 | 1850 | 17 | 42 | 2.5 | 2.4 | 9.1 | 5.4 | 2.8 | 0.7 | 0.2 | 2.1 |
| **inc GW 20** | 11 | 418 | 36 | 2175 | 21 | 37 | 3.0 | 2.9 | 11.8 | 6.5 | 4.0 | 0.9 | 0.3 | 2.4 |
| **inc GW 60** | 14 | 550 | 89 | 2750 | 13 | 56 | 4.2 | 4.0 | 14.8 | 8.5 | 3.9 | 2.0 | 0.4 | 2.6 |
| **inc GW 100** | 24 | 725 | 140 | 3850 | 18 | 43 | 5.7 | 5.6 | 19.0 | 10.9 | 5.1 | 2.5 | 0.6 | 3.0 |
| **inc GW 200** | 23 | 1003 | 215 | 5200 | 21 | 30 | 7.9 | 7.8 | 24.5 | 13.3 | 6.0 | 4.5 | 1.0 | 4.1 |
| **inc Bio 10** | 13 | 490 | 81 | 1975 | 20 | 42 | 2.5 | 2.5 | 9.4 | 5.5 | 3.3 | 0.6 | 0.2 | 2.0 |
| **inc Bio 60** | 30 | 1175 | 288 | 2575 | 20 | 65 | 3.9 | 3.8 | 12.0 | 7.3 | 3.4 | 1.1 | 0.3 | 2.8 |
| **inc Man 10** | 27 | 733 | 103 | 2650 | 195 | 78 | 3.0 | 2.8 | 11.8 | 6.4 | 4.1 | 1.4 | 0.3 | 2.5 |
| **inc Man 20** | 48 | 898 | 155 | 3000 | 352 | 54 | 3.1 | 3.2 | 13.0 | 6.4 | 4.5 | 1.7 | 0.5 | 3.6 |
| **inc Man 60** | 196 | 2900 | 558 | 5600 | 603 | 38 | 6.0 | 6.0 | 20.5 | 7.3 | 7.4 | 4.4 | 1.5 | 6.9 |
| **inc Man 100** | 248 | 4500 | 818 | 6950 | 459 | 69 | 7.1 | 6.9 | 24.8 | 7.9 | 9.3 | 5.9 | 2.1 | 8.2 |
| *Trans.* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.21*** | ***0.19*** | ***0.21*** | ***0.15*** | ***0.36*** | ***0.58*** | ***0.14*** | ***0.14*** | ***0.11*** | ***0.11*** | ***0.12*** | ***0.17*** | ***0.24*** | ***0.18*** |

*Values are averages of four replicates. Repeated measures (trt x time) l.s.d (transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$. MWOO = mixed waste organic output table from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. S = KCl extractable sulphur; P = total (Kjeldahl) phosphorus; Col P = Colwell (bicarbonate – extractible) P; Tot N = nitrogen (Dumas); $NH_4$ = ammonium (KCl); $N0_3$ = nitrate (KCl); TC (%) and TOC (%) = total and total organic carbon (Dumas); CEC = cation exchange capacity; Exch Na, K, Ca, Mg = exchangeable sodium, potassium, calcium and magnesium; ESP = exchangeable sodium percentage*

**Appendix 4a continued**: Treatment averages for soil nutrients and fertility parameters for surface treatments T0

| | **S** | **TKP** | **Col P** | **TN** | **$NH_4$** | **$NO_3$** | **TC%** | **T OC%** | **CEC** | **Ex Ca** | **Ex Mg** | **Ex K** | **Ex Na** | **ESP** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/kg | | | | % | % | | | cmol(+)/kg | | | % |
| **surf C 0** | 9 | 340 | 18 | 1800 | 18 | 65 | 2.4 | 2.2 | 8.3 | 4.9 | 2.6 | 0.7 | 0.2 | 2.0 |
| **surf CF fert** | 10 | 368 | 29 | 1550 | 40 | 44 | 2.0 | 2.0 | 7.4 | 4.1 | 2.2 | 0.8 | 0.1 | 1.4 |
| **surf MWOO1 10** | 102 | 1023 | 120 | 3675 | 18 | 2 | 6.0 | 5.6 | 18.3 | 11.7 | 2.8 | 1.7 | 2.2 | 10.3 |
| **surf MWOO1 20** | 122 | 863 | 131 | 3875 | 21 | 2 | 5.7 | 5.5 | 18.8 | 11.9 | 2.7 | 1.8 | 2.4 | 12.4 |
| **surf MWOO1 30** | 293 | 1240 | 188 | 5100 | 29 | 3 | 7.9 | 7.7 | 25.8 | 14.5 | 3.4 | 2.7 | 4.9 | 18.5 |
| **surf MWOO1 50** | 315 | 1503 | 253 | 7625 | 29 | 4 | 10.6 | 9.8 | 29.5 | 16.8 | 3.6 | 3.4 | 5.7 | 19.0 |
| **surf MWOO2 10** | 107 | 1305 | 231 | 5225 | 74 | 40 | 6.3 | 5.8 | 22.5 | 13.6 | 3.7 | 2.7 | 2.8 | 11.5 |
| **surf MWOO2 20** | 83 | 1018 | 171 | 4250 | 49 | 12 | 4.9 | 4.8 | 20.0 | 12.3 | 3.7 | 2.0 | 2.2 | 10.4 |
| **surf MWOO2 30** | 192 | 1900 | 260 | 6850 | 93 | 9 | 8.7 | 8.5 | 28.5 | 15.3 | 4.2 | 3.8 | 5.0 | 15.4 |
| **surf MWOO2 50** | 255 | 2700 | 408 | 8150 | 63 | 20 | 11.3 | 11.3 | 37.8 | 20.0 | 5.4 | 5.0 | 7.3 | 18.8 |
| **surf GW 10** | 13 | 420 | 53 | 2550 | 19 | 37 | 3.5 | 3.1 | 10.7 | 5.9 | 3.3 | 1.1 | 0.3 | 3.0 |
| **surf GW 20** | 18 | 615 | 115 | 3575 | 27 | 47 | 5.2 | 5.1 | 14.8 | 8.4 | 3.5 | 2.1 | 0.6 | 3.8 |
| **surf GW 30** | 20 | 710 | 146 | 3675 | 21 | 31 | 5.6 | 5.5 | 17.8 | 9.2 | 4.7 | 2.9 | 0.9 | 4.7 |
| **surf GW 50** | 19 | 795 | 205 | 4050 | 23 | 22 | 7.6 | 7.1 | 22.3 | 11.6 | 5.7 | 3.8 | 1.1 | 5.0 |
| *Trans.* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.21*** | ***0.19*** | ***0.21*** | ***0.15*** | ***0.36*** | ***0.58*** | ***0.14*** | ***0.14*** | ***0.11*** | ***0.11*** | ***0.12*** | ***0.17*** | ***0.24*** | ***0.18*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output table from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. S = KCl extractable sulphur; P = total (Kjeldahl) phosphorus; Col P = Colwell (bicarbonate – extractible) P; Tot N = nitrogen (Dumas); $NH_4$= ammonium (KCl); $N0_3$ = nitrate (KCl); TC (%) and TOC (%) = total and total organic carbon (Dumas); CEC = cation exchange capacity; Exch Na, K, Ca, Mg = exchangeable sodium, potassium, calcium and magnesium; ESP = exchangeable sodium percentage*

## **Appendix 4b:** Treatment averages for soil nutrients and fertility parameters for incorporated treatments T1

| | S | TKP | Col P | TN | $NH_4$ | $NO_3$ | TC | TOC | CEC | ex Ca | ex Mg | ex K | ex Na | ESP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/kg | | | | % | % | | | cmol(+)/kg | | | % |
| **inc C 0** | 13 | 338 | 18 | 1800 | 18 | 36 | 2.1 | 2.1 | 9.3 | 5.7 | 2.7 | 0.4 | 0.3 | 3.6 |
| **inc CF fert** | 12 | 380 | 26 | 1825 | 29 | 36 | 2.3 | 2.2 | 8.6 | 5.0 | 2.5 | 0.6 | 0.2 | 2.9 |
| **inc MWOO1 10** | 14 | 410 | 32 | 2050 | 17 | 35 | 2.5 | 2.5 | 11.4 | 7.4 | 2.9 | 0.6 | 0.4 | 3.2 |
| **inc MWOO1 20** | 19 | 538 | 54 | 2675 | 16 | 47 | 3.2 | 3.1 | 13.8 | 9.8 | 2.7 | 0.9 | 0.3 | 2.3 |
| **inc MWOO1 60** | 33 | 905 | 118 | 3800 | 44 | 54 | 4.3 | 4.1 | 20.3 | 14.8 | 3.4 | 1.2 | 0.7 | 3.2 |
| **inc MWOO1 100** | 56 | 1475 | 258 | 6150 | 80 | 102 | 6.9 | 6.8 | 27.0 | 20.0 | 3.6 | 2.0 | 1.2 | 4.4 |
| **inc MWOO1 200** | 64 | 1700 | 240 | 6075 | 55 | 106 | 6.7 | 6.5 | 26.0 | 19.8 | 2.9 | 2.3 | 1.2 | 4.7 |
| **inc MWOO2 10** | 15 | 463 | 37 | 2175 | 19 | 30 | 2.5 | 2.5 | 12.8 | 8.2 | 3.3 | 0.7 | 0.4 | 3.1 |
| **inc MWOO2 20** | 23 | 573 | 62 | 2575 | 37 | 42 | 2.7 | 2.7 | 15.0 | 10.8 | 2.9 | 1.0 | 0.4 | 2.4 |
| **inc MWOO2 60** | 33 | 1133 | 165 | 4575 | 35 | 53 | 4.6 | 4.5 | 23.0 | 17.5 | 3.4 | 1.4 | 0.5 | 2.1 |
| **inc MWOO2 100** | 57 | 1395 | 210 | 5175 | 71 | 72 | 5.1 | 5.5 | 25.3 | 18.8 | 3.6 | 2.2 | 0.8 | 3.3 |
| **inc MWOO2 200** | 107 | 2700 | 410 | 9400 | 83 | 153 | 9.1 | 8.9 | 37.0 | 27.8 | 4.5 | 3.5 | 1.6 | 4.2 |
| **inc GW 10** | 14 | 373 | 32 | 2150 | 15 | 20 | 2.6 | 2.6 | 11.8 | 7.5 | 3.1 | 0.7 | 0.4 | 3.2 |
| **inc GW 20** | 14 | 385 | 33 | 2225 | 17 | 24 | 2.7 | 2.6 | 12.3 | 7.3 | 4.0 | 0.7 | 0.3 | 2.7 |
| **inc GW 60** | 19 | 500 | 64 | 2825 | 26 | 37 | 3.6 | 3.6 | 16.0 | 10.3 | 4.0 | 1.4 | 0.3 | 2.2 |
| **inc GW 100** | 24 | 578 | 91 | 3375 | 37 | 39 | 4.3 | 4.1 | 18.8 | 12.3 | 4.6 | 1.4 | 0.5 | 2.5 |
| **inc GW 200** | 26 | 853 | 183 | 5375 | 33 | 44 | 7.1 | 6.7 | 27.8 | 18.0 | 6.5 | 2.9 | 0.5 | 1.8 |
| **inc Bio 10** | 13 | 420 | 47 | 1975 | 25 | 22 | 2.4 | 2.2 | 10.8 | 6.8 | 3.2 | 0.5 | 0.3 | 2.7 |
| **inc Bio 60** | 27 | 938 | 185 | 2450 | 27 | 19 | 3.1 | 3.0 | 13.0 | 8.7 | 3.3 | 0.7 | 0.4 | 3.1 |
| **inc Man 10** | 17 | 598 | 106 | 2350 | 19 | 34 | 2.6 | 2.6 | 13.5 | 8.6 | 3.8 | 0.9 | 0.3 | 2.3 |
| **inc Man 20** | 20 | 958 | 175 | 2625 | 16 | 61 | 2.8 | 2.7 | 14.8 | 9.1 | 4.3 | 1.1 | 0.3 | 2.3 |
| **inc Man 60** | 39 | 1875 | 333 | 3775 | 51 | 67 | 3.7 | 3.7 | 17.8 | 10.1 | 5.3 | 1.9 | 0.3 | 1.7 |
| **inc Man 100** | 72 | 4600 | 855 | 6325 | 95 | 93 | 5.8 | 5.5 | 26.0 | 12.3 | 9.8 | 3.1 | 0.6 | 2.4 |
| *Trans.* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.21*** | ***0.19*** | ***0.21*** | ***0.15*** | ***0.36*** | ***0.58*** | ***0.14*** | ***0.14*** | ***0.11*** | ***0.11*** | ***0.12*** | ***0.17*** | ***0.24*** | ***0.18*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output table from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. S = KCl extractable sulphur; TKP = total (Kjeldahl) phosphorus; Col P = Colwell (bicarbonate – extractible) P; Tot N = nitrogen (Dumas); $NH_4$ = ammonium (KCl); $N0_3$ = nitrate (KCl); TC (%) and TOC (%) = total and total organic carbon (Dumas); CEC = cation exchange capacity; Exch Na, K, Ca, Mg = exchangeable sodium, potassium, calcium and magnesium; ESP = exchangeable sodium percentage*

**Appendix 4b continued:** Treatment averages for soil nutrients and fertility parameters for surface treatments T1

| | **S** | **TKP** | **Col P** | **TN** | **NH$_4$** | **NO$_3$** | **TC** | **TOC** | **CEC** | **ex Ca** | **ex Mg** | **ex K** | **ex Na** | **ESP** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/kg | | | | % | % | | | cmol(+)/kg | | | % |
| **surf C 0** | 12 | 320 | 19 | 1900 | 17 | 23 | 2.3 | 2.2 | 9.2 | 5.8 | 2.4 | 0.6 | 0.3 | 2.7 |
| **surf CF fert** | 13 | 353 | 29 | 1675 | 25 | 42 | 1.9 | 1.9 | 8.0 | 4.5 | 2.3 | 0.6 | 0.3 | 3.6 |
| **surf MWOO1 10** | 15 | 440 | 37 | 2175 | 19 | 33 | 2.5 | 2.3 | 12.0 | 8.5 | 2.8 | 0.6 | 0.3 | 2.6 |
| **surf MWOO1 20** | 22 | 943 | 84 | 3025 | 40 | 45 | 3.5 | 3.6 | 17.8 | 13.0 | 3.1 | 1.0 | 0.5 | 2.8 |
| **surf MWOO1 30** | 25 | 645 | 92 | 3400 | 52 | 59 | 3.8 | 3.9 | 19.3 | 13.5 | 3.7 | 1.3 | 0.6 | 3.3 |
| **surf MWOO1 50** | 34 | 1030 | 191 | 4625 | 62 | 69 | 5.4 | 5.4 | 25.0 | 18.0 | 3.7 | 1.9 | 1.0 | 4.0 |
| **surf MWOO2 10** | 18 | 500 | 52 | 2450 | 28 | 39 | 2.8 | 2.6 | 14.5 | 9.5 | 3.7 | 0.8 | 0.5 | 3.3 |
| **surf MWOO2 20** | 20 | 783 | 74 | 3075 | 21 | 48 | 3.4 | 3.2 | 17.5 | 12.1 | 4.0 | 1.0 | 0.4 | 2.5 |
| **surf MWOO2 30** | 31 | 953 | 138 | 3950 | 51 | 42 | 4.2 | 4.3 | 21.3 | 15.0 | 4.0 | 1.6 | 0.7 | 3.1 |
| **surf MWOO2 50** | 60 | 1845 | 265 | 6475 | 74 | 81 | 6.8 | 6.4 | 30.3 | 22.5 | 4.8 | 2.4 | 1.0 | 3.3 |
| **surf GW 10** | 13 | 378 | 33 | 2025 | 13 | 23 | 2.5 | 2.6 | 13.0 | 7.7 | 4.1 | 0.8 | 0.4 | 2.8 |
| **surf GW 20** | 14 | 413 | 43 | 2575 | 20 | 40 | 3.2 | 3.2 | 14.5 | 9.6 | 3.6 | 1.0 | 0.4 | 2.5 |
| **surf GW 30** | 16 | 478 | 74 | 2975 | 36 | 28 | 3.8 | 4.0 | 17.3 | 11.2 | 4.3 | 1.5 | 0.4 | 2.2 |
| **surf GW 50** | 18 | 655 | 105 | 3600 | 34 | 30 | 4.8 | 4.8 | 23.8 | 15.8 | 6.0 | 1.4 | 0.5 | 1.9 |
| *Trans.* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.21*** | ***0.19*** | ***0.21*** | ***0.15*** | ***0.36*** | ***0.58*** | ***0.14*** | ***0.14*** | ***0.11*** | ***0.11*** | ***0.12*** | ***0.17*** | ***0.24*** | ***0.18*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output table from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. S = KCl extractable sulphur; TKP = total (Kjeldahl) phosphorus; Col P = Colwell (bicarbonate – extractible) P; Tot N = nitrogen (Dumas); NH$_4$ = ammonium (KCl); N0$_3$ = nitrate (KCl); TC (%) and TOC (%) = total and total organic carbon (Dumas); CEC = cation exchange capacity; Exch Na, K, Ca, Mg = exchangeable sodium, potassium, calcium and magnesium; ESP = exchangeable sodium percentage*

**Appendix 4c:** Treatment averages for soil nutrients and fertility parameters for incorporated and surface treatments T2

| | S | TKP | Col P | TN | $NH_4$ | $NO_3$ | TC | TOC | CEC | ExCa | ExMg | ExK | ExNa | ESP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg | | | | | | % | % | cmol(+)/kg | | | | | % |
| **inc C0** | 13 | 400 | 38 | 2200 | 0.17 | 65 | 2.5 | 2.5 | 10.3 | 6.8 | 2.6 | 0.5 | 0.2 | 2.6 |
| **inc CF** | 11 | 443 | 67 | 2150 | 21.93 | 165 | 2.5 | 2.6 | 9.6 | 5.6 | 2.9 | 0.8 | 0.2 | 2.3 |
| **inc MWOO 1 10** | 13 | 385 | 36 | 2100 | 0.21 | 70 | 2.5 | 2.5 | 10.4 | 6.6 | 2.8 | 0.6 | 0.3 | 3.0 |
| **inc MWOO 1 20** | 12 | 500 | 50 | 2450 | 0.22 | 55 | 2.9 | 2.9 | 12.3 | 8.3 | 2.7 | 0.9 | 0.2 | 1.6 |
| **inc MWOO 1 60** | 14 | 673 | 94 | 3275 | - | 40 | 3.7 | 3.6 | 17.3 | 12.5 | 3.3 | 1.0 | 0.3 | 1.8 |
| **inc MWOO 1 100** | 23 | 1305 | 248 | 5750 | 0.46 | 110 | 6.1 | 6.0 | 22.8 | 17.5 | 3.3 | 1.5 | 0.5 | 2.3 |
| **inc MWOO 1 200** | 25 | 1413 | 230 | 5350 | 0.43 | 110 | 5.8 | 5.7 | 22.5 | 17.0 | 3.3 | 1.8 | 0.5 | 2.0 |
| **inc MWOO 2 200** | 34 | 1775 | 343 | 6775 | 0.50 | 120 | 6.6 | 4.7 | 25.3 | 19.5 | 3.5 | 1.8 | 0.4 | 1.8 |
| **surf C0** | 14 | 340 | 29 | 2175 | - | - | 2.4 | 2.4 | 8.6 | 5.3 | 2.4 | 0.6 | 0.2 | 2.4 |
| **surf CF** | 12 | 378 | 49 | 2225 | - | - | 2.2 | 2.2 | 8.2 | 4.6 | 2.4 | 0.7 | 0.3 | 3.1 |
| **surf MWOO 1 10** | 12 | 1293 | 43 | 2375 | - | - | 2.6 | 2.5 | 10.7 | 7.0 | 2.9 | 0.7 | 0.2 | 2.1 |
| **surf MWOO 1 20** | 16 | 645 | 64 | 2975 | - | - | 3.0 | 3.0 | 13.3 | 9.5 | 2.8 | 0.8 | 0.3 | 2.5 |
| **surf MWOO 1 30** | 18 | 728 | 104 | 3525 | - | - | 4.0 | 3.8 | 17.0 | 12.8 | 3.1 | 1.1 | 0.3 | 1.9 |
| **surf MWOO 1 50** | 18 | 918 | 164 | 4275 | 0.43 | 100 | 5.1 | 5.1 | 20.5 | 15.8 | 3.0 | 1.3 | 0.3 | 1.7 |
| **surf MWOO 2 50** | 27 | 1603 | 286 | 5800 | 0.55 | 95 | 6.1 | 5.9 | 23.5 | 18.2 | 3.7 | 1.3 | 0.4 | 1.7 |
| *Trans.* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.21*** | ***0.19*** | ***0.21*** | ***0.15*** | ***0.36*** | ***0.58*** | ***0.14*** | ***0.14*** | ***0.11*** | ***0.11*** | ***0.12*** | ***0.17*** | ***0.24*** | ***0.18*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output table from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. S = KCl extractable sulphur; TKP = total (Kjeldahl) phosphorus; Col P = Colwell (bicarbonate – extractible) P; Tot N = nitrogen (Dumas); $NH_4$ = ammonium (KCl); $N0_3$ = nitrate (KCl); TC (%) and TOC (%) = total and total organic carbon (Dumas); CEC = cation exchange capacity; Exch Na, K, Ca, Mg = exchangeable sodium, potassium, calcium and magnesium; ESP = exchangeable sodium percentage; - = not detected*

**Appendix 5a:** Average (T0) soil heavy metal concentrations (mg/kg) following application of amendments to the treatment plots.

| **Application, Treatment and rate** | **Cd mg/kg** | **Cr mg/kg** | **Cu mg/kg** | **Ni mg/kg** | **Pb mg/kg** | **Zn mg/kg** |
|---|---|---|---|---|---|---|
| inc C | 0.08 | 15.3 | 14.2 | 7.5 | 16.0 | 21.7 |
| inc CF | 0.09 | 17.8 | 16.0 | 7.6 | 18.2 | 21.3 |
| inc MWOO 1 10 | 0.19 | 16.5 | 24.9 | 8.6 | 24.2 | 40.2 |
| inc MWOO 1 20 | 0.26 | 17.9 | 29.6 | 8.5 | 29.4 | 52.1 |
| inc MWOO 1 60 | 0.62 | 23.8 | 78.3 | 12.2 | 63.0 | 117.2 |
| inc MWOO 1 100 | 1.41 | 31.3 | 134.9 | 16.8 | 113.7 | 241.2 |
| inc MWOO 1 200 | 1.43 | 31.1 | 158.3 | 21.0 | 128.6 | 275.3 |
| inc MWOO 2 10 | 0.15 | 17.6 | 24.2 | 9.1 | 23.9 | 45.7 |
| inc MWOO 2 20 | 0.24 | 19.6 | 32.4 | 10.7 | 31.2 | 68.2 |
| inc MWOO 2 60 | 0.40 | 22.9 | 50.8 | 12.4 | 45.8 | 124.1 |
| inc MWOO 2 100 | 0.87 | 25.9 | 100.8 | 19.0 | 83.7 | 264.1 |
| inc MWOO 2 200 | 1.05 | 27.3 | 117.9 | 20.5 | 102.7 | 325.8 |
| inc GW 10 | 0.10 | 20.8 | 15.4 | 9.9 | 17.2 | 23.1 |
| inc GW 20 | 0.09 | 23.3 | 17.4 | 12.7 | 17.4 | 26.5 |
| inc GW 60 | 0.13 | 18.5 | 18.2 | 9.2 | 18.9 | 36.4 |
| inc GW 100 | 0.15 | 21.0 | 22.8 | 11.3 | 23.7 | 49.8 |
| inc GW 200 | 0.47 | 24.8 | 32.2 | 11.5 | 30.5 | 84.6 |
| inc Bio 10 | 0.10 | 21.3 | 19.4 | 11.5 | 16.4 | 28.3 |
| inc Bio 60 | 0.13 | 20.2 | 29.1 | 11.9 | 19.4 | 43.3 |
| inc Man 10 | 0.08 | 18.5 | 19.1 | 10.8 | 14.4 | 37.9 |
| inc Man 20 | 0.08 | 21.5 | 21.5 | 12.1 | 16.5 | 46.8 |
| inc Man 60 | 0.09 | 18.4 | 36.3 | 10.9 | 13.5 | 124.3 |
| inc Man 100 | 0.09 | 22.8 | 44.6 | 13.6 | 15.0 | 157.0 |
| surf C | 0.07 | 17.7 | 14.8 | 8.0 | 18.3 | 21.1 |
| surf CF | 0.08 | 18.1 | 14.5 | 7.7 | 18.0 | 21.2 |
| surf MWOO 1 10 | 0.76 | 24.3 | 74.9 | 12.2 | 64.7 | 134.4 |
| surf MWOO 1 20 | 0.61 | 21.6 | 71.0 | 11.9 | 65.2 | 133.4 |
| surf MWOO 1 30 | 1.08 | 28.8 | 128.2 | 15.5 | 99.9 | 210.7 |
| surf MWOO 1 50 | 1.40 | 29.0 | 147.2 | 17.9 | 126.2 | 265.4 |
| surf MWOO 2 10 | 0.63 | 38.9 | 78.6 | 21.3 | 70.4 | 203.0 |
| surf MWOO 2 20 | 0.39 | 31.6 | 50.7 | 18.4 | 43.1 | 123.6 |
| surf MWOO 2 30 | 0.77 | 23.1 | 98.4 | 16.7 | 79.4 | 257.4 |
| surf MWOO 2 50 | 1.24 | 35.8 | 144.9 | 27.9 | 109.8 | 374.4 |
| surf GW 10 | 0.11 | 17.9 | 17.1 | 9.1 | 18.1 | 31.4 |
| surf GW 20 | 0.15 | 17.7 | 21.6 | 9.7 | 20.4 | 44.5 |
| surf GW 30 | 0.18 | 20.1 | 22.5 | 9.8 | 23.3 | 51.5 |
| surf GW 50 | 0.22 | 22.1 | 33.4 | 11.3 | 29.4 | 69.8 |
| *trans* | *log* | *none* | *log* | *sqrt* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.22*** | ***15.5*** | ***0.18*** | ***0.61*** | ***0.15*** | ***0.19*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

**Appendix 5b:** Average (T1) soil heavy metal concentrations (mg/kg) following application of amendments to the treatment plots.

| Application, treatment and rate | Cd mg/kg | Cr mg/kg | Cu mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|---|
| inc C | 0.06 | 18.0 | 13.3 | 7.9 | 18.5 | 21.0 |
| inc CF | 0.06 | 18.0 | 13.5 | 7.5 | 20.8 | 19.5 |
| inc MWOO 1 10 | 0.14 | 18.5 | 21.0 | 8.7 | 25.0 | 34.8 |
| inc MWOO 1 20 | 0.27 | 19.8 | 32.0 | 9.8 | 37.8 | 57.3 |
| inc MWOO 1 60 | 0.44 | 25.8 | 64.8 | 13.3 | 65.3 | 126.3 |
| inc MWOO 1 100 | 1.16 | 89.5 | 125.3 | 48.0 | 134.8 | 290.0 |
| inc MWOO 1 200 | 1.13 | 28.3 | 145.0 | 19.5 | 121.8 | 245.0 |
| inc MWOO 2 10 | 0.12 | 19.3 | 22.3 | 10.3 | 26.0 | 51.3 |
| inc MWOO 2 20 | 0.16 | 17.3 | 25.8 | 9.2 | 29.5 | 58.0 |
| inc MWOO 2 60 | 0.36 | 20.0 | 51.0 | 11.8 | 54.8 | 130.0 |
| inc MWOO 2 100 | 0.46 | 22.8 | 60.5 | 13.3 | 65.5 | 170.0 |
| inc MWOO 2 200 | 0.90 | 26.8 | 125.5 | 21.5 | 108.3 | 355.0 |
| inc GW 10 | 0.06 | 16.0 | 13.5 | 7.5 | 18.0 | 22.8 |
| inc GW 20 | 0.08 | 16.8 | 15.0 | 8.3 | 19.3 | 24.0 |
| inc GW 60 | 0.10 | 16.3 | 16.8 | 7.7 | 20.5 | 34.3 |
| inc GW 100 | 0.17 | 18.5 | 18.8 | 8.2 | 23.0 | 42.5 |
| inc GW 200 | 0.22 | 18.8 | 24.3 | 9.0 | 31.0 | 72.3 |
| inc Bio 10 | 0.10 | 14.8 | 15.5 | 7.8 | 18.3 | 23.8 |
| inc Bio 60 | 0.14 | 16.8 | 23.3 | 8.1 | 20.3 | 36.8 |
| inc Man 10 | 0.07 | 17.8 | 15.8 | 7.9 | 17.5 | 30.8 |
| inc Man 20 | 0.11 | 19.3 | 17.8 | 7.9 | 21.8 | 41.8 |
| inc Man 60 | 0.08 | 13.9 | 22.5 | 7.5 | 15.0 | 76.3 |
| inc Man 100 | 0.10 | 19.3 | 36.0 | 8.6 | 17.0 | 149.5 |
| surf C | 0.08 | 18.0 | 12.3 | 7.0 | 18.0 | 18.8 |
| surf CF | 0.08 | 21.3 | 12.7 | 7.2 | 21.0 | 18.3 |
| surf MWOO 1 10 | 0.23 | 18.3 | 25.5 | 8.5 | 28.8 | 44.3 |
| surf MWOO 1 20 | 0.47 | 22.8 | 48.0 | 10.6 | 48.8 | 89.8 |
| surf MWOO 1 30 | 0.35 | 23.3 | 71.5 | 11.3 | 52.0 | 96.3 |
| surf MWOO 1 50 | 2.85 | 26.0 | 91.5 | 13.8 | 90.0 | 174.3 |
| surf MWOO 2 10 | 0.22 | 17.0 | 21.8 | 8.4 | 25.8 | 46.5 |
| surf MWOO 2 20 | 0.25 | 17.8 | 31.3 | 9.5 | 31.3 | 74.0 |
| surf MWOO 2 30 | 0.32 | 19.8 | 50.8 | 11.7 | 48.0 | 129.8 |
| surf MWOO 2 50 | 0.55 | 22.0 | 81.3 | 16.0 | 74.3 | 232.5 |
| surf GW 10 | 0.09 | 17.0 | 15.0 | 7.3 | 19.3 | 25.3 |
| surf GW 20 | 0.10 | 15.8 | 14.8 | 7.9 | 27.8 | 33.0 |
| surf GW 30 | 0.12 | 16.8 | 16.3 | 7.4 | 21.5 | 36.3 |
| surf GW 50 | 0.17 | 17.8 | 21.5 | 8.2 | 26.0 | 52.3 |
| trans | log | none | log | sqrt | log | log |
| l.s.d. trt x time | 0.22 | 15.5 | 0.18 | 0.61 | 0.15 | 0.19 |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

**Appendix 5c:** Average (T2) soil heavy metal concentrations (mg/kg) following application of amendments to the treatment plots.

| Application, treatment and rate | Cd mg/kg | Cr mg/kg | Cu mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|---|
| inc C | 0.12 | 10.8 | 13.9 | 6.0 | 19.0 | 26.0 |
| inc CF | 0.09 | 10.4 | 10.6 | 5.4 | 15.3 | 14.8 |
| inc MWOO 1 10 | 0.14 | 13.3 | 16.5 | 6.7 | 22.5 | 26.8 |
| inc MWOO 1 20 | 0.21 | 15.3 | 25.8 | 7.9 | 27.3 | 41.0 |
| inc MWOO 1 60 | 0.51 | 16.0 | 339.5 | 9.2 | 48.8 | 94.8 |
| inc MWOO 1 100 | 1.35 | 21.3 | 124.5 | 14.7 | 106.8 | 222.5 |
| inc MWOO 1 200 | 1.02 | 20.5 | 117.0 | 14.0 | 99.8 | 224.5 |
| inc MWOO 2 200 | 0.70 | 19.0 | 80.5 | 14.0 | 71.8 | 225.0 |
| surf C | 0.08 | 11.3 | 10.6 | 6.1 | 16.3 | 15.0 |
| surf CF | 0.08 | 16.0 | 10.8 | 5.6 | 18.5 | 15.5 |
| surf MWOO 1 10 | 0.18 | 13.0 | 18.8 | 6.8 | 22.5 | 32.5 |
| surf MWOO 1 20 | 0.39 | 14.0 | 36.5 | 7.7 | 36.3 | 62.3 |
| surf MWOO 1 30 | 0.65 | 15.3 | 58.5 | 9.2 | 56.5 | 107.0 |
| surf MWOO 1 50 | 0.87 | 17.8 | 88.8 | 11.2 | 88.8 | 160.5 |
| surf MWOO 2 50 | 0.73 | 17.8 | 74.5 | 13.4 | 72.5 | 201.8 |
| *trans* | *log* | *none* | *log* | *sqrt* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.22*** | ***15.5*** | ***0.18*** | ***0.61*** | ***0.15*** | ***0.19*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

**Appendix 5d:** Average (T3) soil heavy metal concentrations (mg/kg) following application of amendments to the treatment plots.

| Application, treatment and rate | Cd mg/kg | Cr mg/kg | Cu mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|---|
| inc C | 0.07 | 21.3 | 14.0 | 9.5 | 17.5 | 24.8 |
| inc CF | 0.08 | 20.5 | 14.3 | 9.2 | 17.8 | 23.8 |
| inc MWOO 1 10 | 0.14 | 22.0 | 20.5 | 10.3 | 24.3 | 36.3 |
| inc MWOO 1 20 | 0.21 | 22.3 | 26.3 | 11.3 | 28.5 | 48.8 |
| inc MWOO 1 60 | 0.42 | 24.3 | 48.0 | 13.8 | 43.5 | 86.0 |
| inc MWOO 1 100 | 0.56 | 27.5 | 89.8 | 16.3 | 78.8 | 180.0 |
| inc MWOO 1 200 | 0.91 | 30.0 | 128.3 | 18.0 | 114.5 | 232.5 |
| inc MWOO 2 10 | 0.12 | 19.0 | 17.3 | 9.8 | 21.8 | 34.5 |
| inc MWOO 2 20 | 0.19 | 20.0 | 23.0 | 10.2 | 29.0 | 51.5 |
| inc MWOO 2 60 | 0.31 | 19.8 | 34.5 | 11.3 | 37.8 | 86.0 |
| inc MWOO 2 100 | 0.49 | 22.5 | 57.0 | 15.0 | 55.0 | 147.3 |
| inc MWOO 2 200 | 0.57 | 25.8 | 79.8 | 18.0 | 72.0 | 222.5 |
| inc GW 10 | 0.09 | 16.8 | 14.0 | 9.3 | 19.0 | 24.3 |
| inc GW 20 | 0.10 | 22.8 | 17.0 | 16.0 | 21.8 | 28.5 |
| inc GW 60 | 0.12 | 19.8 | 16.0 | 9.8 | 21.3 | 31.8 |
| inc GW 100 | 0.14 | 21.8 | 18.5 | 10.3 | 24.5 | 41.0 |
| inc GW 200 | 0.23 | 21.5 | 24.0 | 10.3 | 30.8 | 64.5 |
| inc Bio 10 | 0.12 | 17.5 | 16.8 | 10.3 | 19.3 | 28.0 |
| inc Bio 60 | 0.12 | 19.0 | 19.3 | 9.9 | 21.0 | 32.0 |
| inc Man 10 | 0.09 | 18.0 | 16.3 | 9.8 | 18.5 | 30.8 |
| inc Man 20 | 0.08 | 19.0 | 17.3 | 9.1 | 18.5 | 38.3 |
| inc Man 60 | 0.10 | 17.5 | 22.3 | 9.0 | 18.0 | 69.0 |
| inc Man 100 | 0.09 | 18.3 | 28.0 | 8.9 | 20.0 | 93.5 |
| surf C | 0.08 | 16.3 | 13.0 | 7.7 | 16.3 | 21.3 |
| surf CF | 0.09 | 19.8 | 14.0 | 7.6 | 18.8 | 23.0 |
| surf MWOO 1 10 | 0.14 | 20.5 | 25.3 | 8.9 | 22.8 | 36.3 |
| surf MWOO 1 20 | 0.22 | 18.0 | 28.8 | 9.5 | 27.0 | 49.5 |
| surf MWOO 1 30 | 0.30 | 23.8 | 37.8 | 10.8 | 35.8 | 70.3 |
| surf MWOO 1 50 | 0.28 | 22.3 | 36.5 | 10.4 | 36.3 | 72.5 |
| surf MWOO 2 50 | 0.30 | 21.8 | 40.0 | 12.0 | 38.8 | 98.0 |
| *trans* | *log* | *none* | *log* | *sqrt* | *log* | *log* |
| ***l.s.d. trt x time*** | ***0.22*** | ***15.5*** | ***0.18*** | ***0.61*** | ***0.15*** | ***0.19*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

## Appendix 6a: Output table for multiple linear regression analysis of data describing relationship between the proportion of extractable soil Cd, total soil Cd, soil pH and how this relationship changed over time.

**Response variate: Prop Ca-ext Cd (log )**

**Fitted terms: Constant + log total Cd + pH + log total Cd.pH + time + log total Cd.time + pH.time + log total Cd.pH.time**

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 11.00 | 90.93 | 8.27 | 187.60 | <.001 |
| Residual | 274.00 | 12.07 | 0.04 | | |
| Total | 285.00 | 103.01 | 0.36 | | |
| Change | -6.00 | -5.66 | 0.94 | 21.39 | <.001 |

Percentage variance accounted for 87.8

Standard error of observations is estimated to be 0.210.

Estimates of parameters

| Parameter | estimate | s.e. | t(274) | t pr. |
|---|---|---|---|---|
| Constant | -0.39 | 0.56 | -0.70 | 0.49 |
| log total Cd | -3.00 | 0.50 | -5.99 | <.001 |
| pH | 0.01 | 0.08 | 0.15 | 0.88 |
| log total Cd.pH | 0.41 | 0.07 | 5.91 | <.001 |
| time T1 | 3.58 | 0.79 | 4.53 | <.001 |
| time T3 | 4.75 | 0.77 | 6.21 | <.001 |
| log total Cd.time T1 | 1.49 | 0.69 | 2.15 | 0.03 |
| log total Cd.time T3 | 2.38 | 0.72 | 3.29 | 0.00 |
| pH.time T1 | -0.56 | 0.11 | -4.89 | <.001 |
| pH.time T3 | -0.74 | 0.11 | -6.65 | <.001 |
| log total Cd.pH.time T1 | -0.17 | 0.10 | -1.63 | 0.11 |
| log total Cd.pH.time T3 | -0.28 | 0.11 | -2.57 | 0.01 |

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + log total Cd | 1.00 | 54.72 | 54.72 | 1241.86 | <.001 |
| + pH | 1.00 | 24.34 | 24.34 | 552.27 | <.001 |
| + log total Cd.pH | 1.00 | 5.23 | 5.23 | 118.63 | <.001 |
| + time | 2.00 | 0.99 | 0.49 | 11.22 | <.001 |
| + log total Cd.time | 2.00 | 1.69 | 0.84 | 19.15 | <.001 |
| + pH.time | 2.00 | 3.66 | 1.83 | 41.56 | <.001 |
| + log total Cd.pH.time | 2.00 | 0.31 | 0.15 | 3.47 | 0.032 |
| Residual | 274.00 | 12.07 | 0.04 | | |
| Total | 285.00 | 103.01 | 0.36 | | |

**Appendix 6b:** Output table for multiple linear regression analysis of data describing relationship between the proportion of extractable soil Cu, total soil Cu, soil pH and how this relationship changed over time.

**Response variate: Prop Ca-ext Cu (log)**
**Fitted terms: Constant + log total Cu + pH + log total Cu.pH + time + log total Cu.time + pH.time + log total Cu.pH.time**

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 11.00 | 29.33 | 2.67 | 78.42 | <.001 |
| Residual | 314.00 | 10.68 | 0.03 | | |
| Total | 325.00 | 40.01 | 0.12 | | |
| Change | -6.00 | -3.24 | 0.54 | 15.86 | <.001 |

Percentage variance accounted for 72.4

Standard error of observations is estimated to be 0.184.

Estimates of parameters

| Parameter | estimate | s.e. | t(314) | t pr. |
|---|---|---|---|---|
| Constant | -4.99 | 1.00 | -4.99 | <.001 |
| log total Cu | 1.70 | 0.76 | 2.25 | 0.03 |
| pH | 0.61 | 0.14 | 4.37 | <.001 |
| log total Cu.pH | -0.20 | 0.10 | -1.92 | 0.06 |
| time T1 | 3.73 | 1.23 | 3.03 | 0.00 |
| time T3 | 4.50 | 1.27 | 3.53 | <.001 |
| log total Cu.time T1 | -2.03 | 0.96 | -2.12 | 0.04 |
| log total Cu.time T3 | -2.33 | 0.99 | -2.36 | 0.02 |
| pH.time T1 | -0.53 | 0.18 | -2.93 | 0.00 |
| pH.time T3 | -0.66 | 0.19 | -3.52 | <.001 |
| log total Cu.pH.time T1 | 0.27 | 0.13 | 1.99 | 0.05 |
| log total Cu.pH.time T3 | 0.30 | 0.14 | 2.16 | 0.03 |

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + log total Cu | 1.00 | 18.09 | 18.09 | 531.82 | <.001 |
| + pH | 1.00 | 4.73 | 4.73 | 139.06 | <.001 |
| + log total Cu.pH | 1.00 | 1.74 | 1.74 | 51.13 | <.001 |
| + time | 2.00 | 1.55 | 0.77 | 22.72 | <.001 |
| + log total Cu.time | 2.00 | 2.22 | 1.11 | 32.59 | <.001 |
| + pH.time | 2.00 | 0.83 | 0.42 | 12.21 | <.001 |
| + log total Cu.pH.time | 2.00 | 0.19 | 0.09 | 2.78 | 0.06 |
| Residual | 314.00 | 10.68 | 0.03 | | |
| Total | 325.00 | 40.01 | 0.12 | | |

**Appendix 6c:** Output table for multiple linear regression analysis of data describing relationship between the proportion of extractable soil Zn, total soil Zn, soil pH and how this relationship changed over time.

**Response variate: Prop Ca-ext Zn (log)**

**Fitted terms: Constant + log total Zn + pH + log total Zn.pH + Time + log total Zn. time +pH.time + log total Zn.pH.time**

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 11.00 | 63.97 | 5.82 | 140.01 | <.001 |
| Residual | 335.00 | 13.91 | 0.04 | | |
| Total | 346.00 | 77.88 | 0.23 | | |
| Change | -6.00 | -9.28 | 1.55 | 37.24 | <.001 |

Percentage variance accounted for 81.5

Standard error of observations is estimated to be 0.204.

Estimates of parameters

| Parameter | estimate | s.e. | t(335) | t pr. |
|---|---|---|---|---|
| Constant | 7.51 | 0.67 | 11.27 | <.001 |
| log total Zn | -3.11 | 0.47 | -6.57 | <.001 |
| pH | -1.43 | 0.11 | -13.59 | <.001 |
| log total Zn.pH | 0.57 | 0.06 | 9.15 | <.001 |
| time T1 | -2.74 | 0.97 | -2.83 | 0.005 |
| time T3 | -5.62 | 1.06 | -5.31 | <.001 |
| log total Zn.time T1 | 1.93 | 0.66 | 2.93 | 0.004 |
| log total Zn.time T3 | 3.91 | 0.73 | 5.38 | <.001 |
| pH.time T1 | 0.58 | 0.17 | 3.48 | <.001 |
| pH.time T3 | 1.07 | 0.18 | 6.04 | <.001 |
| log total Zn.pH.time T1 | -0.39 | 0.09 | -4.19 | <.001 |
| log total Zn.pH.time T3 | -0.72 | 0.10 | -6.94 | <.001 |

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + log total Zn | 1.00 | 40.44 | 40.44 | 973.73 | <.001 |
| + pH | 1.00 | 6.14 | 6.14 | 147.91 | <.001 |
| + log total Zn. pH | 1.00 | 7.62 | 7.62 | 183.47 | <.001 |
| + time | 2.00 | 0.48 | 0.24 | 5.77 | 0.003 |
| + log total Zn.time | 2.00 | 7.18 | 3.59 | 86.47 | <.001 |
| + pH.time | 2.00 | 0.00 | 0.00 | 0.04 | 0.962 |
| + log total Zn.pH.time | 2.00 | 2.10 | 1.05 | 25.23 | <.001 |
| Residual | 335.00 | 13.91 | 0.04 | | |
| Total | 346.00 | 77.88 | 0.23 | | |

**Appendix 6d:** Output table for multiple nonlinear groups regression analysis of data describing relationship between the proportion of extractable soil Cd and soil pH and how this relationship changed over time for soils amended with a range of organic materials, including MWOO 1, MWOO 2, green waste, composted biosolids and poultry manure.

<u>non-linear groups regression analysis of proportion Ca-extractable Cd (log)</u>

| | |
|---|---|
| Response variate: | Proportion Ca-extractable Cd (log) |
| Explanatory: | pH |
| 1. Grouping factor | ***Single curve*** |
| Fitted Curve: | A + B*(R**X) + C*X |
| Constraints: | R > 1 |

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 3.00 | 129.09 | 43.03 | 723.46 | <.001 |
| Residual | 382.00 | 22.72 | 0.06 | | |
| Total | 385.00 | 151.81 | 0.39 | | |

Percentage variance accounted for 84.9

Standard error of observations is estimated to be 0.244.

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + pH | 3.00 | 129.09 | 43.03 | 723.46 | <.001 |
| Residual | 382.00 | 22.72 | 0.06 | | |
| Total | 385.00 | 151.81 | 0.39 | | |

**Appendix 6e:** Output table for multiple nonlinear groups regression analysis of data describing relationship between the proportion of extractable soil Cu and soil pH and how this relationship changed over time for soils amended with a range of organic materials, including MWOO 1, MWOO 2, green waste, composted biosolids and poultry manure.

non-linear groups regression analysis of proportion Ca-extractable Cu (log)

| | |
|---|---|
| Response variate: | Proportion Ca-extractable Cu (log) |
| Explanatory: | pH |

1. Grouping factor: ***Time, all linear parameters separate***

Fitted Curve: A + B*(R**X) + C*X

| Summary of analysis | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Source | 12 | 37.6 | 3.1 | 99.56 | <.001 |
| Regression | 441 | 13.9 | 0.0 | | |
| Residual | 453 | 51.4 | 0.1 | | |
| Total | -6 | -4.0 | 0.7 | 21.32 | <.001 |

Percentage variance accounted for 72.3
Standard error of observations is estimated to be 0.177.

| Accumulated analysis of variance | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Change | 3 | 32.2 | 10.7 | 341.95 | <.001 |
| + pH | 3 | 1.3 | 0.4 | 13.66 | <.001 |
| + Time | 6 | 4.0 | 0.7 | 21.32 | <.001 |
| + pH.Time | 441 | 13.9 | 0.0 | | |
| Residual | 453 | 51.4 | 0.1 | | |

2. Grouping factor: ***Time, all parameters separate***

Fitted Curve: A + B*(R**X) + C*X
Constraints: R < 1

| Summary of analysis | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Source | 15 | 37.64 | 2.51 | 79.8 | <.001 |
| Regression | 438 | 13.77 | 0.031 | | |
| Residual | 453 | 51.42 | 0.11 | | |
| Total | -3 | -0.09 | 0.03 | 0.93 | 0.426 |

Percentage variance accounted for 72.3
Standard error of observations is estimated to be 0.177.

| Accumulated analysis of variance | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Change | 3 | 32.25 | 10.75 | 341.79 | <.001 |
| + pH | 3 | 1.29 | 0.43 | 13.66 | <.001 |
| + Time | 6 | 4.02 | 0.67 | 21.31 | <.001 |
| + pH.Time | 3 | 0.09 | 0.03 | 0.93 | 0.426 |
| + Separate nonlinear | 438 | 13.77 | 0.03 | | |
| Residual | 453 | 51.42 | 0.11 | | |

## Appendix 6f: Output table for multiple nonlinear groups regression analysis of data describing relationship between the proportion of extractable soil Zn and soil pH and how this relationship changed over time for soils amended with a range of organic materials, including MWOO 1, MWOO 2, green waste, composted biosolids and poultry manure.

non-linear groups regression analysis of proportion Ca-extractable Zn (log)

Response variate: Prop Ca-extractable Zn (log)
Explanatory: pH
1. Grouping factor **_Single curve_**
Fitted Curve: A + B*(R**X) + C*X

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 3 | 87.69 | 29.23 | 564.85 | <.001 |
| Residual | 472 | 24.42 | 0.05 | | |
| Total | 475 | 112.11 | 0.24 | | |

Percentage variance accounted for 78.1
Standard error of observations is estimated to be 0.227.

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + pH | 3 | 87.69 | 29.23 | 564.85 | <.001 |
| Residual | 472 | 24.42 | 0.05 | | |
| Total | 475 | 112.11 | 0.24 | | |

2. Grouping factor: **_Time, all linear parameters separate_**
Fitted Curve: A + B*(R**X) + C*X
Constraints: R < 1

Summary of analysis

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 12 | 93.98 | 7.83 | 200.05 | <.001 |
| Residual | 463 | 18.13 | 0.04 | | |
| Total | 475 | 112.11 | 0.24 | | |
| Change | -6 | -6.00 | 1.00 | 25.56 | <.001 |

Percentage variance accounted for 83.4
Standard error of observations is estimated to be 0.198.

Accumulated analysis of variance

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + pH | 3 | 87.69 | 29.23 | 746.56 | <.001 |
| + Time | 3 | 0.29 | 0.10 | 2.49 | 0.059 |
| + pH.Time | 6 | 6.00 | 1.00 | 25.56 | <.001 |
| Residual | 463 | 18.13 | 0.04 | | |
| Total | 475 | 112.11 | 0.24 | | |

**Appendix 7:** Average concentrations of additional organic contaminants measured in MWOO amended soils sampled at times T0 – T3

| TRT ID | T | Benzophenone | Bis (2-ethylhexyl) phthalate [DEHP] | Bisphenol A [BPA] | Di-n-butyl phthalate [DBP] | N,N-Diethyl-m-toluamide [DEET] |
|---|---|---|---|---|---|---|
| | | | | mg/kg | | |
| inc C0 | 0 | - | - | - | - | - |
| inc MWOO1 10 | 0 | 0.0268 | 5.65 | 1.15 | 0.12 | - |
| inc MWOO1 20 | 0 | 0.0246 | 1.46 | 18.00 | - | - |
| inc MWOO1 60 | 0 | 0.1387 | 9.06 | 40.06 | 0.60 | 0.1421 |
| inc MWOO1 100 | 0 | 0.5265 | 49.92 | 96.61 | 2.63 | 0.7379 |
| inc MWOO1 200 | 0 | 0.3674 | 55.95 | 36.02 | 3.26 | 1.2867 |
| inc MWOO2 200 | 0 | 0.3615 | 30.76 | 294.57 | 0.99 | 0.5702 |
| surf MWOO1 10 | 0 | 0.2156 | 55.31 | 17.57 | 1.28 | 0.4632 |
| surf MWOO1 20 | 0 | 0.1838 | 38.26 | 7.92 | 1.48 | 0.2221 |
| surf MWOO1 30 | 0 | 0.3371 | 83.95 | 106.00 | 6.17 | 0.4364 |
| surf MWOO1 50 | 0 | 0.3276 | 40.81 | 45.91 | 2.55 | 0.5298 |
| surf MWOO2 50 | 0 | 0.5107 | 73.72 | 548.74 | 1.71 | 0.9135 |
| inc C0 | 1 | - | - | - | - | - |
| inc MWOO1 10 | 1 | 0.0131 | 1.17 | 1.69 | - | - |
| inc MWOO1 20 | 1 | 0.0109 | 1.45 | 2.00 | - | - |
| inc MWOO1 60 | 1 | 0.0507 | 6.54 | 10.49 | 0.87 | 0.0762 |
| inc MWOO1 100 | 1 | 0.1146 | 45.97 | 19.51 | 1.21 | 0.1250 |
| inc MWOO1 200 | 1 | 0.0936 | 5.75 | 27.15 | 0.88 | 0.1907 |
| inc MWOO2 200 | 1 | 0.0760 | 3.98 | 64.65 | 0.31 | 0.1492 |
| surf MWOO1 10 | 1 | 0.0342 | 3.17 | 3.45 | - | 0.0348 |
| surf MWOO1 20 | 1 | 0.0349 | 10.80 | 4.52 | 0.19 | - |
| surf MWOO1 30 | 1 | 0.0699 | 12.13 | 18.99 | 1.68 | 0.0704 |
| surf MWOO1 50 | 1 | 0.2543 | 8.12 | 28.76 | 0.58 | 0.2001 |
| surf MWOO2 50 | 1 | 0.0634 | 2.40 | 45.82 | 0.55 | 0.0607 |
| inc C0 | 2 | - | - | - | - | - |
| inc MWOO1 10 | 2 | - | 1.68 | 7.74 | - | - |
| inc MWOO1 20 | 2 | 0.0279 | 0.12 | 0.56 | - | - |
| inc MWOO1 60 | 2 | 0.0321 | 1.99 | 1.33 | 0.02 | 0.0323 |
| inc MWOO1 100 | 2 | 0.1429 | 12.83 | 28.69 | 1.35 | 0.2114 |

| TRT ID | T | Benzophenone | Bis (2-ethylhexyl) phthalate [DEHP] | Bisphenol A [BPA] | Di-n-butyl phthalate [DBP] | N,N-Diethyl-m-toluamide [DEET] |
|---|---|---|---|---|---|---|
| | | | | mg/kg | | |
| inc MWOO1 200 | 2 | 0.1022 | 5.39 | 35.75 | 0.99 | 0.2243 |
| inc MWOO2 200 | 2 | 0.0434 | 1.07 | 69.30 | 0.34 | 0.1026 |
| surf MWOO1 10 | 2 | - | 0.25 | 27.82 | - | 0.0565 |
| surf MWOO1 20 | 2 | 0.0202 | 4.24 | 1.17 | - | 0.0536 |
| surf MWOO1 30 | 2 | 0.0128 | 1.05 | 11.97 | 0.17 | - |
| surf MWOO1 50 | 2 | 0.0955 | 23.87 | 24.42 | 0.91 | 0.2505 |
| surf MWOO2 50 | 2 | 0.0611 | 0.59 | 24.97 | 0.93 | 0.0992 |
| inc C0 | 3 | - | 0.09 | - | - | - |
| inc MWOO1 10 | 3 | - | 0.14 | 1.68 | - | - |
| inc MWOO1 20 | 3 | - | 28.99 | 0.20 | 0.02 | - |
| inc MWOO1 60 | 3 | 0.0119 | 0.21 | 1.00 | 0.02 | - |
| inc MWOO1 100 | 3 | 0.0379 | 3.39 | 4.47 | 1.56 | 0.0618 |
| inc MWOO1 200 | 3 | 0.0881 | 3.11 | 43.27 | 0.71 | 0.1702 |
| inc MWOO2 200 | 3 | 0.0516 | 2.21 | 75.23 | 0.12 | 0.1857 |
| surf MWOO1 10 | 3 | - | 1.09 | 2.07 | - | - |
| surf MWOO1 20 | 3 | 0.1006 | 2.60 | 0.73 | 0.47 | 0.1344 |
| surf MWOO1 30 | 3 | 0.0111 | 0.72 | 9.87 | 0.12 | - |
| surf MWOO1 50 | 3 | 0.0094 | 1.27 | 0.71 | 0.23 | - |
| surf MWOO2 50 | 3 | - | 0.85 | 4.55 | - | - |
| *trans* | | *log* | *log* | *log* | *log* | *log* |
| ***l.s.d. trt x time*** | | ***0..34*** | ***0.81*** | ***0.61*** | ***0.57*** | ***0.52*** |

*Values are averages of four replicates. Acronym for each compound given [ ]. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2 Inc = incorporated treatments; surf = surface applied; C0 = control; Application rates (dry t/ha) indicated for each treatment; - = not detected*

## **Appendix 8:** Summary of monthly climatic conditions during the field trial compared to long-term district averages published by the Australian Bureau of Meteorology

| Rain (mm) | January | February | March | April | May | June | July | August | September | October | November | December | Yearly |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *average* | *80.6* | *96.8* | *90.6* | *68.4* | *53.5* | *67* | *37* | *42.1* | *39.2* | *61* | *76.2* | *57.1* | *792* |
| 2013 | 174 | 137 | 35 | 65 | 55 | 160 | 8 | 5 | 31 | 8 | 106 | 27 | 811 |
| 2014 | 22 | 40 | 122 | 48 | 6 | 30 | 5 | 135 | 24 | 51 | 10 | 138 | 631 |
| 2015 | 99 | 40 | 31 | 195 | 26 | 48 | 32 | 75 | 15 | 10 | 68 | 53 | 692 |
| Max temp (ºC) | | | | | | | | | | | | | |
| *average* | *29.6* | *28.6* | *26.8* | *23.8* | *20.6* | *17.7* | *17.3* | *19.1* | *22* | *24.3* | *26.3* | *28.5* | |
| 2013 | 31.6 | 27.5 | 27.3 | 24.2 | 20.7 | 17.2 | 18.4 | 20.7 | 25.3 | 27.6 | 26.7 | 29.6 | |
| 2014 | 30.9 | 28.4 | 27.4 | 24.2 | 22.4 | 18.6 | 18.7 | 18.6 | 22.2 | 26.9 | 29.2 | 28.7 | |
| 2015 | 29.3 | 28.2 | 27 | 22.6 | 19.8 | 17.8 | 16.5 | 19.1 | 21.3 | 27 | 27.6 | 29.4 | |
| Min temp (ºC) | | | | | | | | | | | | | |
| *average* | *16.9* | *16.8* | *14.9* | *11* | *7* | *4.6* | *3* | *3.9* | *6.8* | *9.9* | *13* | *15.2* | |
| 2013 | 17.8 | 16.5 | 14.8 | 10.1 | 6.5 | 6.4 | 2.8 | 3.6 | 7.9 | 8.6 | 12.2 | 15 | |
| 2014 | 15.9 | 16.8 | 15.5 | 12.2 | 6.9 | 5.6 | 2.2 | 5.1 | 7.8 | 10.3 | 14.2 | 16.5 | |
| 2015 | 17.9 | 16.7 | 14.1 | 11.9 | 7.8 | 4.2 | 2 | 3.8 | 7 | 11.7 | 14.1 | 14.9 | |

## **Appendix 9A:** Treatment averages for chemical analysis of millet leaves harvested at 12 weeks – incorporated treatments

| | Al<br>mg/kg | Ca<br>% | Cr<br>mg/kg | Cu<br>mg/kg | Fe<br>mg/kg | K<br>% | Mg<br>% | Mn<br>mg/kg | Na<br>% | Ni<br>mg/kg | Zn<br>mg/kg | P<br>% | S<br>% | N<br>% | Cl<br>% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| inc_C_0 | 28.3 | 0.40 | 0.64 | 5.53 | 55.8 | 2.50 | 0.42 | 150 | 0.16 | 1.88 | 33.8 | 0.09 | 0.28 | 1.73 | 1.60 |
| inc_CF_0 | 33.5 | 0.45 | 0.84 | 7.15 | 65.0 | 2.53 | 0.47 | 255 | 0.21 | 2.45 | 34.0 | 0.13 | 0.33 | 2.15 | 1.70 |
| inc_MWOO1_10 | 29.0 | 0.42 | 0.76 | 6.40 | 58.5 | 2.43 | 0.47 | 111 | 0.22 | 1.98 | 49.1 | 0.11 | 0.28 | 1.65 | 1.90 |
| inc_MWOO1_20 | 23.8 | 0.45 | 0.66 | 6.83 | 50.0 | 2.85 | 0.48 | 99 | 0.24 | 1.93 | 46.8 | 0.12 | 0.29 | 1.73 | 1.98 |
| inc_MWOO1_60 | 40.3 | 0.46 | 0.89 | 8.15 | 65.8 | 3.20 | 0.54 | 76 | 0.24 | 1.95 | 48.7 | 0.14 | 0.35 | 2.08 | 2.50 |
| inc_MWOO1_100 | 25.5 | 0.44 | 0.78 | 9.93 | 68.5 | 3.70 | 0.53 | 108 | 0.29 | 1.85 | 61.1 | 0.16 | 0.40 | 2.20 | 2.95 |
| inc_MWOO1_200 | 27.0 | 0.44 | 0.93 | 11.23 | 64.5 | 4.40 | 0.57 | 423 | 0.42 | 1.80 | 80.5 | 0.17 | 0.54 | 2.53 | 3.50 |
| inc_MWOO2_10 | 29.5 | 0.42 | 0.70 | 6.50 | 56.0 | 2.43 | 0.50 | 98 | 0.31 | 1.95 | 46.0 | 0.12 | 0.30 | 1.68 | 2.05 |
| inc_MWOO2_20 | 24.3 | 0.45 | 0.73 | 7.50 | 57.8 | 2.93 | 0.51 | 95 | 0.21 | 2.05 | 46.2 | 0.13 | 0.31 | 1.95 | 2.15 |
| inc_MWOO2_60 | 27.0 | 0.48 | 0.87 | 8.95 | 65.3 | 3.35 | 0.56 | 121 | 0.22 | 2.20 | 50.2 | 0.15 | 0.35 | 2.15 | 2.45 |
| inc_MWOO2_100 | 39.8 | 0.43 | 1.11 | 9.33 | 74.8 | 3.93 | 0.59 | 177 | 0.25 | 1.93 | 59.0 | 0.17 | 0.43 | 2.53 | 3.00 |
| inc_MWOO2_200 | 20.0 | 0.44 | 0.79 | 10.50 | 67.5 | 4.45 | 0.58 | 335 | 0.40 | 1.70 | 68.1 | 0.18 | 0.50 | 2.73 | 3.20 |
| inc_GW_10 | 25.8 | 0.34 | 0.74 | 5.55 | 49.8 | 2.23 | 0.47 | 165 | 0.17 | 1.98 | 35.8 | 0.09 | 0.28 | 1.52 | 1.68 |
| inc_GW_20 | 27.8 | 0.35 | 0.63 | 4.90 | 45.3 | 2.28 | 0.47 | 130 | 0.14 | 1.80 | 34.1 | 0.11 | 0.28 | 1.16 | 1.88 |
| inc_GW_60 | 26.0 | 0.36 | 0.71 | 5.53 | 44.3 | 2.70 | 0.50 | 148 | 0.23 | 1.50 | 37.4 | 0.17 | 0.29 | 1.34 | 1.95 |
| inc_GW_100 | 30.8 | 0.41 | 0.85 | 5.63 | 50.3 | 2.83 | 0.51 | 103 | 0.23 | 1.55 | 36.9 | 0.20 | 0.33 | 1.37 | 2.33 |
| inc_GW_200 | 29.0 | 0.41 | 0.82 | 6.88 | 53.0 | 3.23 | 0.56 | 137 | 0.30 | 2.00 | 36.3 | 0.19 | 0.33 | 1.60 | 2.78 |
| inc_Bio_10 | 26.8 | 0.36 | 0.75 | 5.23 | 47.5 | 2.20 | 0.51 | 139 | 0.18 | 2.05 | 35.3 | 0.14 | 0.29 | 1.27 | 1.80 |
| inc_Bio_60 | 28.0 | 0.41 | 1.18 | 5.53 | 48.3 | 2.25 | 0.53 | 138 | 0.33 | 2.10 | 35.0 | 0.17 | 0.36 | 1.25 | 2.00 |
| inc_Man_10 | 24.0 | 0.47 | 0.77 | 6.58 | 53.3 | 2.63 | 0.61 | 113 | 0.30 | 1.78 | 33.7 | 0.19 | 0.29 | 1.88 | 2.00 |
| inc_Man_20 | 44.3 | 0.44 | 1.00 | 8.78 | 69.5 | 3.08 | 0.70 | 121 | 0.46 | 2.05 | 40.8 | 0.29 | 0.36 | 2.45 | 2.48 |
| inc_Man_60 | 27.0 | 0.41 | 0.74 | 9.65 | 67.0 | 4.15 | 0.70 | 300 | 0.35 | 2.03 | 44.9 | 0.40 | 0.43 | 3.03 | 2.53 |
| inc_Man_100 | 28.5 | 0.34 | 0.91 | 10.80 | 70.3 | 4.43 | 0.66 | 488 | 0.28 | 1.63 | 45.8 | 0.44 | 0.57 | 2.88 | 3.00 |
| *trans* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* |
| ***l.s.d.*** | ***18.81*** | ***0.06*** | ***0.59*** | ***1.37*** | ***13.79*** | ***0.57*** | ***0.08*** | ***125*** | ***0.11*** | ***0.47*** | ***9.73*** | ***0.04*** | ***0.07*** | ***0.38*** | ***0.49*** |

*Values are averages of four replicates. L.s.d (transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

## Appendix 9B: Treatment averages for chemical analysis of millet leaves harvested at 12 weeks – surface treatments

| | Al | Ca | Cr | Cu | Fe | K | Mg | Mn | Na | Ni | Zn | P | S | N | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg | % | mg/kg | mg/kg | mg/kg | % | % | mg/kg | % | mg/kg | mg/kg | % | % | % | % |
| surf_C_0 | 24.3 | 0.40 | 0.55 | 6.13 | 54.5 | 2.50 | 0.48 | 150 | 0.17 | 2.08 | 36.4 | 0.11 | 0.32 | 2.03 | 1.65 |
| surf_CF_0 | 26.3 | 0.41 | 0.58 | 7.03 | 59.0 | 2.53 | 0.49 | 260 | 0.18 | 2.58 | 35.8 | 0.11 | 0.30 | 2.38 | 1.63 |
| surf_MWOO1_10 | 37.8 | 0.40 | 0.97 | 6.13 | 57.8 | 2.43 | 0.44 | 145 | 0.20 | 2.43 | 37.8 | 0.11 | 0.28 | 1.68 | 1.55 |
| surf_MWOO1_20 | 21.8 | 0.44 | 0.69 | 6.38 | 47.8 | 2.38 | 0.53 | 120 | 0.20 | 2.13 | 41.8 | 0.11 | 0.31 | 1.70 | 1.88 |
| surf_MWOO1_30 | 25.0 | 0.43 | 0.79 | 6.70 | 55.5 | 2.83 | 0.49 | 98 | 0.19 | 1.95 | 43.0 | 0.12 | 0.34 | 1.68 | 2.18 |
| surf_MWOO1_50 | 28.0 | 0.45 | 0.94 | 9.43 | 58.8 | 3.48 | 0.59 | 111 | 0.32 | 2.13 | 53.8 | 0.15 | 0.41 | 2.00 | 2.70 |
| surf_MWOO2_10 | 25.5 | 0.41 | 0.56 | 6.53 | 51.5 | 2.68 | 0.48 | 112 | 0.21 | 1.98 | 41.9 | 0.12 | 0.32 | 1.68 | 2.10 |
| surf_MWOO2_20 | 35.8 | 0.45 | 0.85 | 6.70 | 62.3 | 2.70 | 0.51 | 109 | 0.15 | 2.13 | 41.4 | 0.12 | 0.30 | 1.83 | 2.05 |
| surf_MWOO2_30 | 27.0 | 0.44 | 0.66 | 8.05 | 60.8 | 3.15 | 0.52 | 134 | 0.24 | 2.13 | 45.3 | 0.12 | 0.34 | 2.08 | 2.33 |
| surf_MWOO2_50 | 34.8 | 0.44 | 0.99 | 9.55 | 70.8 | 3.70 | 0.57 | 139 | 0.32 | 2.13 | 54.7 | 0.16 | 0.41 | 2.35 | 2.75 |
| surf_GW_10 | 25.5 | 0.37 | 0.93 | 5.85 | 55.0 | 2.38 | 0.43 | 155 | 0.13 | 2.50 | 35.5 | 0.10 | 0.29 | 1.88 | 1.63 |
| surf_GW_20 | 38.8 | 0.41 | 1.06 | 5.68 | 56.3 | 2.35 | 0.45 | 148 | 0.13 | 2.28 | 36.7 | 0.13 | 0.28 | 1.56 | 1.55 |
| surf_GW_30 | 25.5 | 0.36 | 1.63 | 5.63 | 48.3 | 2.48 | 0.52 | 153 | 0.17 | 2.60 | 32.6 | 0.13 | 0.30 | 1.40 | 1.95 |
| surf_GW_50 | 33.5 | 0.35 | 0.92 | 5.08 | 54.8 | 2.35 | 0.48 | 170 | 0.15 | 1.60 | 33.4 | 0.17 | 0.29 | 1.16 | 1.75 |
| *trans* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* |
| ***l.s.d.*** | ***18.81*** | ***0.06*** | ***0.59*** | ***1.37*** | ***13.79*** | ***0.57*** | ***0.08*** | ***125*** | ***0.11*** | ***0.47*** | ***9.73*** | ***0.04*** | ***0.07*** | ***0.38*** | ***0.49*** |

*Values are averages of four replicates. L.s.d (transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

## **Appendix 10A:** Treatment averages for chemical analysis of millet grain as harvested

| | Al<br>mg/kg | Ca<br>% | Cr<br>mg/kg | Fe<br>mg/kg | K<br>% | Mg<br>% | Mn<br>mg/kg | Na<br>% | Ni<br>mg/kg | Zn<br>mg/kg | N<br>% | P<br>% | S<br>% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| inc C 0 | 22.6 | 0.031 | 0.53 | 56.0 | 0.31 | 0.11 | 48.3 | 0.007 | 4.50 | 56.0 | 2.3 | 0.24 | 0.17 |
| inc CF 0 | 13.3 | 0.034 | 0.45 | 52.5 | 0.31 | 0.12 | 58.5 | 0.006 | 5.18 | 55.3 | 2.4 | 0.26 | 0.18 |
| inc MWOO1 10 | 11.0 | 0.035 | 0.45 | 51.0 | 0.31 | 0.12 | 37.5 | 0.006 | 3.68 | 65.5 | 2.4 | 0.27 | 0.18 |
| inc MWOO1 20 | 24.0 | 0.035 | 0.43 | 65.7 | 0.34 | 0.13 | 29.8 | 0.006 | 3.60 | 73.0 | 2.6 | 0.29 | 0.19 |
| inc MWOO1 60 | 17.8 | 0.036 | 0.45 | 65.0 | 0.37 | 0.15 | 28.5 | 0.006 | 3.73 | 75.8 | 2.69 | 0.34 | 0.20 |
| inc MWOO1 100 | 15.7 | 0.034 | 0.42 | 69.8 | 0.44 | 0.16 | 31.0 | 0.007 | 3.35 | 82.5 | 2.71 | 0.39 | 0.21 |
| inc MWOO1 200 | 12.8 | 0.033 | 0.40 | 68.5 | 0.43 | 0.17 | 42.8 | 0.007 | 3.23 | 85.0 | 2.87 | 0.40 | 0.21 |
| inc MWOO2 10 | 45.3 | 0.043 | 0.39 | 61.0 | 0.40 | 0.15 | 42.0 | 0.008 | 7.40 | 71.8 | 2.50 | 0.34 | 0.19 |
| inc MWOO2 20 | 12.1 | 0.034 | 0.33 | 57.3 | 0.39 | 0.14 | 29.3 | 0.006 | 4.08 | 65.8 | 2.62 | 0.31 | 0.19 |
| inc MWOO2 60 | 20.5 | 0.034 | 0.37 | 70.5 | 0.46 | 0.14 | 32.5 | 0.008 | 3.70 | 69.3 | 2.67 | 0.36 | 0.18 |
| inc MWOO2 100 | 27.7 | 0.032 | 0.33 | 75.0 | 0.43 | 0.15 | 27.8 | 0.007 | 4.33 | 78.0 | 2.82 | 0.36 | 0.20 |
| inc MWOO2 200 | 29.8 | 0.034 | 0.35 | 64.3 | 0.44 | 0.15 | 60.3 | 0.007 | 3.53 | 86.5 | 2.91 | 0.39 | 0.20 |
| inc GW 10 | 21.5 | 0.033 | 0.37 | 53.3 | 0.33 | 0.13 | 55.0 | 0.007 | 4.33 | 55.5 | 2.53 | 0.26 | 0.17 |
| inc GW 20 | 10.9 | 0.036 | 0.38 | 48.5 | 0.33 | 0.14 | 52.0 | 0.006 | 4.30 | 58.8 | 2.07 | 0.29 | 0.16 |
| inc GW 60 | 9.6 | 0.037 | 0.39 | 48.3 | 0.38 | 0.18 | 44.3 | 0.006 | 3.73 | 61.5 | 2.20 | 0.41 | 0.17 |
| inc GW 100 | 49.0 | 0.036 | 0.48 | 51.5 | 0.41 | 0.18 | 36.8 | 0.006 | 3.58 | 58.5 | 2.20 | 0.43 | 0.17 |
| inc GW 200 | 10.7 | 0.036 | 0.43 | 52.5 | 0.45 | 0.19 | 38.3 | 0.006 | 3.65 | 56.8 | 2.42 | 0.46 | 0.17 |
| inc Bio 10 | 16.5 | 0.038 | 0.43 | 51.5 | 0.40 | 0.15 | 60.8 | 0.007 | 4.85 | 53.5 | 2.02 | 0.34 | 0.17 |
| inc Bio 60 | 20.2 | 0.041 | 0.40 | 52.3 | 0.45 | 0.19 | 47.3 | 0.007 | 4.45 | 63.0 | 2.29 | 0.45 | 0.16 |
| inc Man 10 | 22.5 | 0.042 | 0.47 | 65.0 | 0.39 | 0.18 | 38.8 | 0.006 | 4.20 | 66.3 | 2.60 | 0.41 | 0.18 |
| inc Man 20 | 16.5 | 0.044 | 0.47 | 66.5 | 0.43 | 0.22 | 33.5 | 0.007 | 3.53 | 72.8 | 2.65 | 0.50 | 0.19 |
| inc Man 60 | 20.6 | 0.045 | 0.53 | 70.7 | 0.44 | 0.22 | 54.3 | 0.009 | 3.73 | 71.0 | 2.80 | 0.50 | 0.20 |
| inc Man 100 | 11.5 | 0.039 | 0.42 | 67.5 | 0.44 | 0.22 | 80.8 | 0.007 | 3.25 | 74.5 | 3.00 | 0.51 | 0.20 |
| surf C 0 | 20.4 | 0.038 | 0.45 | 58.8 | 0.30 | 0.12 | 59.5 | 0.006 | 4.98 | 57.5 | 2.44 | 0.25 | 0.17 |
| surf CF 0 | 15.3 | 0.037 | 0.39 | 55.3 | 0.30 | 0.12 | 63.8 | 0.006 | 5.98 | 57.8 | 2.50 | 0.24 | 0.18 |
| surf MWOO1 10 | 12.0 | 0.039 | 0.43 | 50.8 | 0.28 | 0.13 | 46.3 | 0.006 | 3.95 | 62.0 | 2.26 | 0.26 | 0.17 |
| surf MWOO1 20 | 15.5 | 0.038 | 0.46 | 63.8 | 0.31 | 0.13 | 38.8 | 0.006 | 4.80 | 66.8 | 2.52 | 0.29 | 0.18 |
| surf MWOO1 30 | 9.8 | 0.036 | 0.46 | 54.3 | 0.31 | 0.14 | 34.5 | 0.005 | 4.18 | 68.0 | 2.34 | 0.30 | 0.18 |
| surf MWOO1 50 | 11.2 | 0.036 | 0.44 | 62.0 | 0.33 | 0.15 | 34.0 | 0.006 | 3.65 | 75.0 | 2.62 | 0.35 | 0.19 |
| surf MWOO2 10 | 18.5 | 0.036 | 0.46 | 64.5 | 0.29 | 0.14 | 40.5 | 0.005 | 4.35 | 63.0 | 2.65 | 0.30 | 0.17 |
| surf MWOO2 20 | 17.5 | 0.038 | 0.42 | 65.0 | 0.30 | 0.14 | 34.3 | 0.006 | 4.13 | 65.0 | 2.53 | 0.29 | 0.18 |
| surf MWOO2 30 | 36.8 | 0.037 | 0.51 | 60.0 | 0.33 | 0.15 | 34.3 | 0.006 | 4.20 | 70.0 | 2.67 | 0.32 | 0.19 |
| surf MWOO2 50 | 30.6 | 0.043 | 0.46 | 68.3 | 0.38 | 0.17 | 39.3 | 0.007 | 4.25 | 83.5 | 2.90 | 0.39 | 0.21 |
| surf GW 10 | 17.1 | 0.037 | 0.46 | 53.5 | 0.29 | 0.13 | 54.3 | 0.006 | 5.43 | 54.8 | 2.13 | 0.26 | 0.16 |
| surf GW 20 | 17.5 | 0.037 | 0.46 | 54.8 | 0.30 | 0.14 | 45.8 | 0.006 | 4.43 | 56.3 | 2.24 | 0.30 | 0.16 |
| surf GW 30 | 15.3 | 0.034 | 0.40 | 52.0 | 0.30 | 0.15 | 44.5 | 0.006 | 5.00 | 56.5 | 2.27 | 0.31 | 0.17 |
| surf GW 50 | 28.8 | 0.038 | 0.53 | 59.3 | 0.32 | 0.18 | 47.0 | 0.006 | 3.43 | 53.8 | 1.83 | 0.39 | 0.14 |
| *trans* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* |
| *l.s.d.* | ***23.9*** | ***0.006*** | ***0.09*** | ***28.76*** | ***0.04*** | ***0.02*** | ***15.91*** | ***0.001*** | ***5.47*** | ***7.1*** | ***0.41*** | ***0.06*** | ***0.02*** |

*Values are averages of four replicates. L.s.d (transformed where appropriate) for each parameter indicates statistical significance at $p<0.05$, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

## **Appendix 10B:** Feed quality parameters of millet grain as harvested – averages for each treatment

| | DM % | NDF % | ADF % | CP % | ASH % | OM % | DMD % | DOMD % | ME MJ/kg dm | FAT % |
|---|---|---|---|---|---|---|---|---|---|---|
| inc C 0 | 96.6 | 22.2 | 12.8 | 14.35 | 2.9 | 97.1 | 77.7 | 76.7 | 12.6 | 4.1 |
| inc CF 0 | 96.0 | 20.9 | 12.9 | 15.14 | 2.8 | 97.2 | 78.3 | 77.3 | 12.6 | 4.0 |
| inc MWOO1 10 | 97.0 | 22.2 | 12.7 | 14.81 | 3.1 | 96.9 | 77.6 | 76.7 | 12.6 | 4.3 |
| inc MWOO1 20 | 96.6 | 19.6 | 12.4 | 16.46 | 3.2 | 96.8 | 78.5 | 77.5 | 12.8 | 4.6 |
| inc MWOO1 60 | 96.7 | 20.4 | 12.1 | 16.79 | 3.2 | 96.8 | 78.6 | 77.6 | 12.9 | 4.8 |
| inc MWOO1 100 | 95.6 | 20.2 | 11.7 | 16.93 | 3.1 | 96.9 | 79.0 | 78.0 | 13.0 | 4.9 |
| inc MWOO1 200 | 96.3 | 19.1 | 11.4 | 17.94 | 3.5 | 96.5 | 80.1 | 79.1 | 13.0 | 4.6 |
| inc MWOO2 10 | 97.0 | 22.8 | 12.8 | 15.60 | 3.5 | 96.5 | 77.5 | 76.6 | 12.9 | 5.4 |
| inc MWOO2 20 | 95.1 | 21.3 | 12.7 | 16.38 | 2.7 | 97.3 | 78.2 | 77.3 | 12.8 | 4.8 |
| inc MWOO2 60 | 96.2 | 19.9 | 11.8 | 16.66 | 3.2 | 96.8 | 78.9 | 77.9 | 12.8 | 4.5 |
| inc MWOO2 100 | 96.9 | 21.8 | 11.5 | 17.63 | 3.1 | 96.9 | 79.4 | 78.4 | 13.0 | 4.8 |
| inc MWOO2 200 | 95.7 | 21.3 | 11.8 | 18.20 | 3.0 | 97.0 | 78.9 | 77.9 | 12.9 | 4.7 |
| inc GW 10 | 96.9 | 21.7 | 12.6 | 15.80 | 2.6 | 97.4 | 77.5 | 76.6 | 12.7 | 4.6 |
| inc GW 20 | 96.1 | 20.3 | 12.6 | 12.97 | 2.5 | 97.5 | 77.6 | 76.7 | 12.6 | 4.3 |
| inc GW 60 | 96.2 | 19.9 | 12.4 | 13.73 | 2.9 | 97.1 | 78.4 | 77.4 | 12.8 | 4.7 |
| inc GW 100 | 97.5 | 19.0 | 11.6 | 13.77 | 3.1 | 96.9 | 79.1 | 78.1 | 12.9 | 4.8 |
| inc GW 200 | 96.7 | 18.2 | 11.6 | 15.14 | 3.1 | 96.9 | 79.1 | 78.1 | 12.9 | 4.8 |
| inc Bio 10 | 97.1 | 19.5 | 12.6 | 12.63 | 2.7 | 97.3 | 77.7 | 76.7 | 12.7 | 4.6 |
| inc Bio 60 | 97.3 | 19.1 | 12.1 | 14.33 | 2.8 | 97.2 | 78.2 | 77.2 | 12.9 | 5.1 |
| inc Man 10 | 95.4 | 16.5 | 11.5 | 16.26 | 3.7 | 96.3 | 79.9 | 78.8 | 12.9 | 4.1 |
| inc Man 20 | 96.3 | 16.4 | 11.5 | 16.55 | 4.0 | 96.0 | 80.4 | 79.4 | 12.9 | 4.1 |
| inc Man 60 | 97.1 | 17.9 | 11.8 | 17.52 | 4.0 | 96.0 | 79.7 | 78.7 | 12.9 | 4.2 |
| inc Man 100 | 97.1 | 16.8 | 11.0 | 18.73 | 4.0 | 96.0 | 80.5 | 79.5 | 13.0 | 4.2 |
| surf C 0 | 96.9 | 21.0 | 13.9 | 15.25 | 3.1 | 96.9 | 77.4 | 76.4 | 12.5 | 3.9 |
| surf CF 0 | 97.4 | 20.8 | 12.4 | 15.60 | 3.2 | 96.8 | 78.2 | 77.3 | 12.6 | 4.1 |
| surf MWOO1 10 | 97.3 | 20.2 | 12.9 | 14.11 | 3.1 | 96.9 | 78.0 | 77.0 | 12.6 | 4.1 |
| surf MWOO1 20 | 96.1 | 20.3 | 12.2 | 15.72 | 3.2 | 96.8 | 79.0 | 78.0 | 12.8 | 4.2 |
| surf MWOO1 30 | 96.9 | 19.0 | 12.3 | 14.60 | 3.4 | 96.6 | 79.0 | 78.1 | 12.8 | 4.2 |
| surf MWOO1 50 | 96.4 | 19.2 | 11.9 | 16.36 | 3.5 | 96.5 | 79.3 | 78.3 | 12.9 | 4.4 |
| surf MWOO2 10 | 97.5 | 20.1 | 12.6 | 16.56 | 3.4 | 96.6 | 78.8 | 77.8 | 12.7 | 4.2 |
| surf MWOO2 20 | 96.2 | 18.9 | 12.2 | 15.79 | 3.7 | 96.3 | 79.5 | 78.5 | 12.8 | 4.2 |
| surf MWOO2 30 | 96.6 | 19.7 | 11.5 | 16.70 | 3.6 | 96.4 | 80.2 | 79.2 | 12.9 | 4.2 |
| surf MWOO2 50 | 96.0 | 19.1 | 11.3 | 18.10 | 4.1 | 95.9 | 80.2 | 79.2 | 13.0 | 4.3 |
| surf GW 10 | 97.0 | 21.5 | 12.8 | 13.33 | 3.0 | 97.0 | 77.8 | 76.9 | 12.6 | 4.3 |
| surf GW 20 | 97.5 | 20.8 | 11.9 | 13.98 | 3.0 | 97.0 | 78.8 | 77.8 | 12.8 | 4.4 |
| surf GW 30 | 97.0 | 21.0 | 11.8 | 14.18 | 2.6 | 97.4 | 78.6 | 77.7 | 12.9 | 4.7 |
| surf GW 50 | 97.2 | 22.0 | 13.0 | 11.45 | 2.3 | 97.7 | 77.0 | 76.1 | 12.7 | 4.9 |
| *trans* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *none* |
| *l.s.d.* | **1.4** | **0.04** | **0.04** | **2.4** | **0.5** | **0.5** | **1.3** | **1.4** | **0.2** | **0.4** |

*Values are averages of four replicates. L.s.d ( transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed solid waste from sources 1 and 2; GW = composted green waste; Bio = composted biosolids; Man = poultry manure (Man); Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. DM (%) = dry matter: NDF (%) = neutral detergent fibre; ADF (%) = acid detergent fibre; CP (%) = crude protein; ASH (%) = inorganic ash; OM (%) = organic matter; DMD (%)= dry matter digestibility; DOMD(%) = dry organic matter digestibility; ME (MJ/kg DM) = metabolisable energy; Fat (%)= crude fat*

## **Appendix 11a:** Treatment averages for chemical analysis of wheat grain harvested in December 2014

| | Ca | Cd | Cu | Fe | K | Mg | Mn | Mo | Na | P | S | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | mg/kg | mg/kg | mg/kg | % | % | mg/kg | mg/kg | % | % | % | mg/kg |
| **inc C** | 0.036 | 0.003 | 5.35 | 31.0 | 0.365 | 0.115 | 45.5 | 0.480 | 0.002 | 0.325 | 0.155 | 34.0 |
| **inc CF** | 0.036 | 0.015 | 5.23 | 31.3 | 0.340 | 0.113 | 57.0 | 0.350 | 0.002 | 0.285 | 0.165 | 36.0 |
| **inc MWOO 1 10t/ha** | 0.033 | 0.014 | 5.80 | 31.0 | 0.370 | 0.125 | 49.5 | 0.570 | 0.002 | 0.365 | 0.155 | 43.5 |
| **inc MWOO 1 20t/ha** | 0.036 | 0.020 | 5.40 | 29.0 | 0.353 | 0.118 | 39.3 | 0.410 | 0.002 | 0.353 | 0.155 | 40.0 |
| **inc MWOO 1 60t/ha** | 0.033 | 0.019 | 5.33 | 29.5 | 0.340 | 0.123 | 35.5 | 0.570 | 0.002 | 0.353 | 0.150 | 38.8 |
| **inc MWOO 1 100t/ha** | 0.0 36 | 0.020 | 5.48 | 33.8 | 0.350 | 0.128 | 37.3 | 0.753 | 0.002 | 0.360 | 0.163 | 44.3 |
| **inc MWOO 1 200t/ha** | 0.043 | 0.021 | 5.60 | 34.8 | 0.345 | 0.123 | 42.8 | 0.708 | 0.002 | 0.325 | 0.165 | 47.8 |
| **inc MWOO 2 200t/ha** | 0.044 | 0.015 | 5.33 | 35.5 | 0.355 | 0.128 | 45.3 | 0.580 | 0.003 | 0.378 | 0.178 | 49.0 |
| **surf C** | 0.033 | 0.009 | 6.10 | 31.3 | 0.347 | 0.120 | 49.0 | 0.590 | 0.003 | 0.333 | 0.163 | 36.3 |
| **surf CF** | 0.037 | 0.012 | 5.70 | 31.5 | 0.320 | 0.115 | 55.0 | 0.390 | 0.002 | 0.305 | 0.175 | 39.0 |
| **surf MWOO 1 10t/ha** | 0.032 | 0.018 | 5.20 | 30.0 | 0.330 | 0.130 | 52.3 | 0.370 | 0.002 | 0.383 | 0.153 | 38.0 |
| **surf MWOO 1 20t/ha** | 0.034 | 0.015 | 5.30 | 27.5 | 0.375 | 0.130 | 41.0 | 0.310 | 0.002 | 0.440 | 0.145 | 37.5 |
| **surf MWOO 1 30t/ha** | 0.032 | 0.013 | 5.33 | 31.0 | 0.360 | 0.123 | 39.7 | 0.463 | 0.002 | 0.353 | 0.153 | 39.3 |
| **surf MWOO 1 50t/ha** | 0.034 | 0.017 | 5.13 | 29.8 | 0.325 | 0.118 | 41.0 | 0.565 | 0.002 | 0.338 | 0.155 | 38.3 |
| **surf MWOO 2 50t/ha** | 0.034 | 0.016 | 5.35 | 31.8 | 0.343 | 0.128 | 45.8 | 0.435 | 0.003 | 0.380 | 0.163 | 41.3 |
| ***l.s.d.*** | *0.006* | *0.008* | *0.59* | *2.9* | *0.023* | *0.012* | *13.0* | *0.232* | *0.0004* | *0.052* | *0.014* | *6.0* |

*Values are averages of 4 replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output tables from sources 1 and 2; inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

**Appendix 11b:** Quality parameters for wheat grain as harvested December 2014 – averages for each treatment

| | NDF<br>% | ADF<br>% | C P<br>% | ASH<br>% | O M<br>% | DMD<br>% | DOMD<br>% | ME<br>MJ/kg dm | Fat<br>% |
|---|---|---|---|---|---|---|---|---|---|
| **inc C** | 7.5 | 1.8 | 14.6 | 1.4 | 98.6 | 93.2 | 91.7 | 14.1 | 1.7 |
| **inc CF** | 7.8 | 1.8 | 15.5 | 1.6 | 98.4 | 94.2 | 92.6 | 14.1 | 1.5 |
| **inc MWOO 1 10t/ha** | 7.4 | 2.0 | 14.8 | 1.6 | 98.4 | 93.5 | 92.0 | 14.0 | 1.5 |
| **inc MWOO 1 20t/ha** | 7.5 | 1.9 | 14.9 | 1.7 | 98.3 | 93.4 | 91.9 | 14.0 | 1.6 |
| **inc MWOO 1 60t/ha** | 7.4 | 2.0 | 14.3 | 1.6 | 98.4 | 93.2 | 91.7 | 13.9 | 1.5 |
| **inc MWOO 1 100t/ha** | 6.8 | 2.0 | 15.2 | 1.9 | 98.1 | 93.6 | 92.0 | 13.9 | 1.3 |
| **inc MWOO 1 200t/ha** | 7.4 | 1.7 | 15.4 | 1.6 | 98.5 | 94.1 | 92.6 | 14.1 | 1.6 |
| **inc MWOO 2 200t/ha** | 8.7 | 1.6 | 15.9 | 1.3 | 98.7 | 94.4 | 92.9 | 14.1 | 1.7 |
| **surf C** | 7.6 | 2.0 | 15.0 | 1.7 | 98.3 | 93.7 | 92.1 | 14.0 | 1.5 |
| **surf CF** | 7.9 | 1.8 | 15.6 | 1.6 | 98.4 | 94.1 | 92.5 | 14.0 | 1.3 |
| **surf MWOO 1 10t/ha** | 7.1 | 1.4 | 14.2 | 1.7 | 98.3 | 93.9 | 92.3 | 14.0 | 1.6 |
| **surf MWOO 1 20t/ha** | 7.1 | 1.9 | 13.7 | 1.7 | 98.4 | 93.3 | 91.7 | 14.0 | 1.9 |
| **surf MWOO 1 30t/ha** | 7.0 | 1.9 | 14.6 | 1.6 | 98.4 | 93.7 | 92.2 | 14.0 | 1.5 |
| **surf MWOO 1 50t/ha** | 7.7 | 1.3 | 14.5 | 1.4 | 98.6 | 94.2 | 92.6 | 14.1 | 1.7 |
| **surf MWOO 2 50t/ha** | 7.4 | 1.7 | 15.2 | 1.6 | 98.4 | 94.1 | 92.5 | 14.1 | 1.5 |
| ***l.s.d.*** | ***1.2*** | ***0.7*** | ***0.9*** | ***0.4*** | ***0.35*** | ***0.69*** | ***0.66*** | ***0.15*** | ***0.4*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output tables from sources 1 and 2; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. DM (%) = dry matter: NDF (%) = neutral detergent fibre; ADF (%) = acid detergent fibre; CP (%) = crude protein; ASH (%) = inorganic ash; OM (%) = organic matter; DMD (%)= dry matter digestibility; DOMD(%) = dry organic matter digestibility; ME (MJ/kg DM) = metabolisable energy; Fat (%)= crude fat*

## Appendix 12a: Treatment averages for chemical analysis of wheat grain harvested in December 2015

| | **Ca**<br>% | **Cd**<br>mg/kg | **Cu**<br>mg/kg | **Fe**<br>mg/kg | **K**<br>% | **Mg**<br>% | **Mn**<br>mg/kg | **Na**<br>% | **P**<br>% | **S**<br>% | **Zn**<br>mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **inc C0** | 0.034 | 0.0070 | 4.85 | 36 | 0.35 | 0.12 | 50 | 0.0036 | 0.30 | 0.13 | 25 |
| **inc CF** | 0.040 | 0.0184 | 5.63 | 44 | 0.35 | 0.13 | 69 | 0.0028 | 0.30 | 0.17 | 34 |
| **inc MWOO1 10** | 0.035 | 0.0108 | 4.95 | 34 | 0.38 | 0.13 | 51 | 0.0037 | 0.35 | 0.13 | 30 |
| **inc MWOO1 20** | 0.039 | 0.0217 | 5.23 | 34 | 0.39 | 0.13 | 49 | 0.0035 | 0.37 | 0.14 | 37 |
| **inc MWOO1 60** | 0.043 | 0.0146 | 4.88 | 37 | 0.40 | 0.14 | 40 | 0.0036 | 0.39 | 0.15 | 37 |
| **inc MWOO1 100** | 0.050 | 0.0191 | 5.20 | 41 | 0.40 | 0.14 | 39 | 0.0034 | 0.39 | 0.17 | 45 |
| **inc MWOO1 200** | 0.056 | 0.0196 | 5.13 | 45 | 0.43 | 0.15 | 43 | 0.0036 | 0.39 | 0.17 | 50 |
| **inc MWOO2 200** | 0.055 | 0.0108 | 5.10 | 48 | 0.41 | 0.14 | 43 | 0.0032 | 0.39 | 0.18 | 48 |
| **surf C0** | 0.035 | 0.0063 | 5.00 | 36 | 0.40 | 0.11 | 52 | 0.0040 | 0.29 | 0.13 | 29 |
| **surf CF** | 0.039 | 0.0155 | 5.30 | 43 | 0.34 | 0.12 | 65 | 0.0032 | 0.27 | 0.17 | 37 |
| **surf MWOO1 10** | 0.035 | 0.0088 | 4.58 | 33 | 0.39 | 0.13 | 53 | 0.0043 | 0.33 | 0.13 | 31 |
| **surf MWOO1 20** | 0.039 | 0.0188 | 5.18 | 36 | 0.42 | 0.13 | 51 | 0.0041 | 0.39 | 0.14 | 38 |
| **surf MWOO1 30** | 0.038 | 0.0219 | 4.95 | 32 | 0.40 | 0.13 | 47 | 0.0040 | 0.37 | 0.13 | 35 |
| **surf MWOO1 50** | 0.042 | 0.0231 | 4.83 | 32 | 0.41 | 0.13 | 48 | 0.0037 | 0.38 | 0.13 | 36 |
| **surf MWOO2 50** | 0.040 | 0.0160 | 5.53 | 38 | 0.40 | 0.14 | 49 | 0.0035 | 0.38 | 0.14 | 37 |
| **l.s.d.** | ***0.006*** | ***0.0087*** | ***0.64*** | ***5*** | ***0.04*** | ***0.01*** | ***10*** | ***0.0004*** | ***0.04*** | ***0.01*** | ***6*** |

*Values are averages of 4 replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output tables from sources 1 and 2; inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.*

**Appendix 12b:** Quality parameters for wheat grain as harvested December 2015 – averages for each treatment

| | NDF<br>% | ADF<br>% | CP<br>% | ASH<br>% | OM<br>% | DMD<br>% | DOMD<br>% | ME<br>Mj/kg dm | FAT<br>% |
|---|---|---|---|---|---|---|---|---|---|
| **inc C0** | - | - | 12.5 | 3.5 | 97 | 87 | 86 | 13.1 | 1.5 |
| **inc CF** | - | - | 17.5 | 3.0 | 97 | 89 | 87 | 13.3 | 1.4 |
| **inc MWOO1 10** | - | - | 12.7 | 3.5 | 97 | 87 | 86 | 13.0 | 1.5 |
| **inc MWOO1 20** | - | - | 13.2 | 3.3 | 97 | 87 | 86 | 13.1 | 1.6 |
| **inc MWOO1 60** | - | - | 14.0 | 3.8 | 96 | 87 | 86 | 13.0 | 1.4 |
| **inc MWOO1 100** | - | - | 16.4 | 4.8 | 95 | 89 | 87 | 13.0 | - |
| **inc MWOO1 200** | - | - | 17.9 | 4.8 | 95 | 90 | 88 | 13.1 | 1.2 |
| **inc MWOO2 200** | - | - | 18.4 | 3.3 | 97 | 89 | 88 | 13.3 | 1.5 |
| **surf C0** | - | - | 13.3 | 3.5 | 97 | 87 | 86 | 13.2 | 2.1 |
| **surf CF** | - | - | 17.8 | 3.0 | 97 | 89 | 88 | 13.3 | 1.6 |
| **surf MWOO1 10** | - | - | 12.2 | 3.3 | 97 | 87 | 85 | 13.1 | 1.6 |
| **surf MWOO1 20** | - | - | 13.7 | 3.7 | 96 | 88 | 87 | 13.3 | 1.7 |
| **surf MWOO1 30** | - | - | 12.6 | 3.3 | 97 | 87 | 85 | 13.1 | 1.9 |
| **surf MWOO1 50** | - | - | 12.8 | 3.0 | 97 | 86 | 85 | 13.1 | 2.0 |
| **surf MWOO2 50** | - | - | 13.9 | 3.3 | 97 | 87 | 86 | 13.1 | 1.6 |
| **l.s.d.** | | | ***1*** | ***1*** | ***1*** | ***2*** | ***1.5*** | ***0.2*** | ***0.4*** |

*Values are averages of four replicates. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. MWOO = mixed waste organic output tables from sources 1 and 2; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. DM (%) = dry matter: NDF (%) = neutral detergent fibre; ADF (%) = acid detergent fibre; CP (%) = crude protein; ASH (%) = inorganic ash; OM (%) = organic matter; DMD (%)= dry matter digestibility; DOMD(%) = dry organic matter digestibility; ME (MJ/kg DM) = metabolisable energy; Fat (%)= crude fat, - = not measured*

## Appendix 13a: Treatment averages for inorganic chemical analysis of runoff collected at time t=T0 following a simulated rainfall event.

| | Al mg/L | As µg/L | Ca mg/L | Cd µg/L | Co µg/L | Cr µg/L | Cu mg/L | Fe mg/L | K mg/L | Mg mg/L | Mn mg/L | Mo µg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **inc C 0** | 4.4 | 1.64 | - | 0.06 | 4.62 | 4.1 | 0.01 | 5.3 | 3.4 | 3.0 | 0.52 | 0.25 |
| **inc CF 0** | 3.8 | 1.60 | - | 0.04 | 4.32 | 5.2 | 0.01 | 4.3 | 5.3 | 1.9 | 0.47 | 0.20 |
| **inc MWOO1 10** | 5.6 | 2.84 | 1.5 | 0.27 | 9.22 | 6.8 | 0.03 | 7.2 | 5.2 | 3.2 | 0.87 | 1.22 |
| **inc MWOO1 20** | 6.4 | 2.70 | - | 0.16 | 7.62 | 5.8 | 0.01 | 7.0 | 4.8 | 1.9 | 0.85 | 0.43 |
| **inc MWOO1 60** | 3.2 | 1.47 | - | 0.21 | 3.72 | 4.6 | 0.02 | 3.4 | 6.0 | 2.7 | 0.36 | 0.94 |
| **inc MWOO1 100** | 2.7 | 3.74 | 28.5 | 0.60 | 8.26 | 11.7 | 0.11 | 2.9 | 26.4 | 8.6 | 0.42 | 4.99 |
| **inc MWOO1 200** | 4.4 | 3.37 | 19.7 | 1.47 | 10.46 | 16.0 | 0.26 | 4.8 | 20.7 | 4.7 | 0.73 | 6.13 |
| **inc MWOO2 200** | 3.6 | 5.24 | 21.5 | 0.96 | 6.09 | 11.5 | 0.13 | 4.3 | 41.8 | 4.2 | 0.50 | 8.70 |
| **surf CF 0** | 3.0 | 1.60 | - | 0.06 | 4.79 | 5.8 | 0.01 | 3.8 | 5.8 | 2.0 | 0.50 | 0.10 |
| **surf MWOO1 10** | 3.5 | 2.30 | 1.0 | 0.32 | 5.39 | 6.8 | 0.04 | 4.1 | 6.9 | 2.2 | 0.48 | 1.66 |
| **surf MWOO1 20** | 3.2 | 2.40 | 6.7 | 0.73 | 6.99 | 9.3 | 0.12 | 3.8 | 14.1 | 3.4 | 0.55 | 3.80 |
| **surf MWOO1 30** | 2.5 | 3.34 | 21.0 | 1.74 | 7.52 | 20.3 | 0.33 | 2.7 | 30.1 | 5.3 | 0.45 | 10.63 |
| **surf MWOO1 50** | 4.3 | 6.50 | 42.3 | 3.51 | 19.12 | 42.0 | 0.73 | 4.6 | 70.1 | 10.0 | 0.70 | 23.50 |
| **surf MWOO2 50** | 4.7 | 9.47 | 23.7 | 1.47 | 9.56 | 17.3 | 0.24 | 6.1 | 58.1 | 6.7 | 0.49 | 11.86 |
| *trans* | *none* | *none* | *none* | *log* | *log* | *log* | *log* | *log* | *none* | *none* | *log* | *log* |
| ***l.s.d.*** | ***4.1*** | ***3.19*** | ***-*** | ***0.53*** | ***0.41*** | ***0.37*** | ***0.67*** | ***0.39*** | ***31.1*** | ***6.3*** | ***0.38*** | ***0.55*** |

| | Na mg/L | Ni µg/L | Pb µg/L | Zn mg/L | TN mg/L | $NH_4$ mg/L | $NO_3$ mg/L | Cl mg/L | TP mg/L | React P mg/L | $SO_4$ mg/L | TOC mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **inc C 0** | 2.3 | 6.84 | 7.03 | 0.02 | 3.7 | 0.1 | 3.5 | 11.0 | 0.3 | 0.01 | 1.7 | 0.1 |
| **inc CF 0** | 1.5 | 4.90 | 5.46 | 0.02 | 3.2 | 0.8 | 3.1 | 1.0 | 0.4 | 0.04 | 1.1 | 0.1 |
| **inc MWOO1 10** | 8.3 | 11.47 | 19.46 | 0.12 | 4.5 | 0.2 | 1.2 | 6.0 | 0.7 | 0.04 | 6.0 | 8.7 |
| **inc MWOO1 20** | 4.3 | 9.47 | 14.90 | 0.03 | 2.7 | 0.3 | 0.1 | 3.0 | 0.5 | 0.02 | 2.3 | 2.6 |
| **inc MWOO1 60** | 7.7 | 8.00 | 15.13 | 0.03 | 2.5 | 0.4 | 0.1 | 5.3 | 0.3 | 0.05 | 5.4 | 6.0 |
| **inc MWOO1 100** | 67.3 | 32.17 | 26.70 | 0.22 | 11.1 | 0.7 | - | 102.0 | 0.7 | 0.15 | 49.4 | 62.7 |
| **inc MWOO1 200** | 32.0 | 37.77 | 112.23 | 0.44 | 15.9 | 0.7 | - | 33.7 | 1.7 | 0.28 | 27.7 | 66.3 |
| **inc MWOO2 200** | 45.0 | 27.67 | 64.23 | 0.30 | 14.6 | 1.7 | - | 63.5 | 1.5 | 0.21 | 24.1 | 57.3 |
| **surf CF 0** | 1.0 | 4.57 | 5.80 | 0.05 | 3.8 | 1.5 | 2.2 | 2.5 | 0.5 | 0.18 | 2.2 | 0.1 |
| **surf MWOO1 10** | 10.0 | 12.54 | 23.26 | 0.12 | 4.4 | 0.6 | 1.0 | 4.3 | 0.5 | 0.07 | 7.6 | 11.3 |
| **surf MWOO1 20** | 24.0 | 27.10 | 41.23 | 0.16 | 9.9 | 1.2 | 0.3 | 21.3 | 0.9 | 0.22 | 18.8 | 44.3 |
| **surf MWOO1 30** | 50.3 | 68.44 | 99.90 | 0.89 | 23.9 | 2.7 | 0.3 | 44.3 | 1.4 | 0.41 | 42.5 | 144.0 |
| **surf MWOO1 50** | 124.0 | 142.10 | 180.23 | 1.54 | 53.9 | 8.7 | 0.3 | 115.0 | 2.8 | 0.90 | 101.1 | 297.7 |
| **surf MWOO2 50** | 65.0 | 48.44 | 105.90 | 0.75 | 33.5 | 3.9 | - | 55.3 | 3.4 | 0.42 | 39.1 | 129.7 |
| *trans* | *none* | *none* | *log* | *log* | *log* | *log* | *log* | *none* | *none* | *log* | *log* | *log* |
| ***l.s.d.*** | ***71.2*** | ***61.14*** | ***0.50*** | ***0.50*** | ***0.52*** | ***0.31*** | ***0.33*** | ***75.5*** | ***0.44*** | ***0.63*** | ***0.89*** | ***0.81*** |

*Data presented is for the averages of 3 replicates sampled in the field from soils amended with increasing rates of either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d. (transformed where appropriate) for each element is included and indicates significance at $p < 0.05$. Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment.TN = total nitrogen; $NH_4$ = ammonium; $NO_3$ = nitrate, Cl = chloride; TP = total phosphorus; react P = Reactive (ortho)-phosphate; $SO_4$ = sulphate, TOC = total organic carbon, - = not detected*

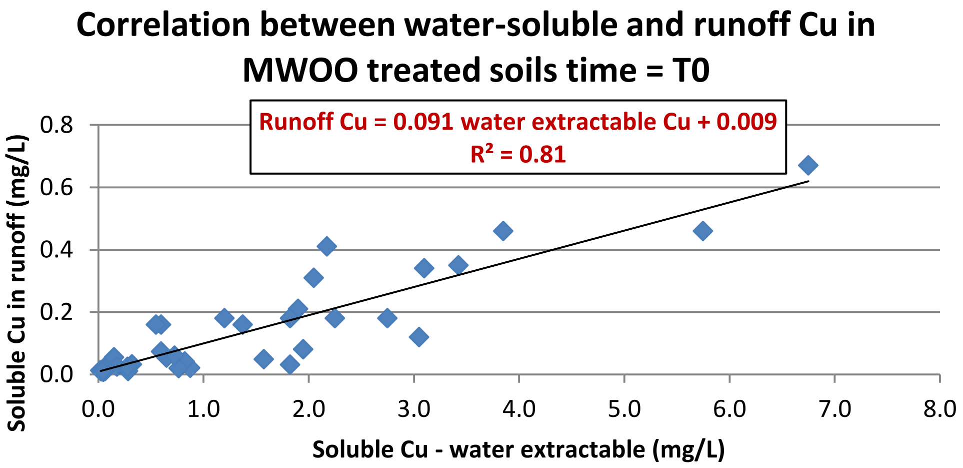
## Appendix 13b: Treatment averages for inorganic chemical analysis of runoff collected at time t=T1 following a simulated rainfall event

| | **Al** | **As** | **Ca** | **Cd** | **Co** | **Cr** | **Cu** | **Fe** | **K** | **Mg** | **Mn** | **Mo** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/L | mg/L | µg/L | µg/L | µg/L | µg/L | mg/L | mg/L | mg/L | mg/L | µg/L |
| **inc C 0** | 2.9 | 1.73 | 9.3 | 0.19 | 2.40 | 6.30 | 30.0 | 3.3 | 7.3 | 4.0 | 0.3 | 1.12 |
| **inc MWOO1 200** | 2.1 | 2.53 | 13.0 | 0.41 | 5.90 | 10.80 | 54.0 | 2.3 | 7.6 | 2.6 | 0.2 | 1.31 |
| **inc MWOO2 200** | 2.9 | 2.87 | 14.3 | 0.51 | 4.83 | 10.70 | 67.3 | 3.5 | 8.2 | 2.9 | 0.3 | 1.16 |
| **surf MWOO1 50** | 4.7 | 2.50 | 15.3 | 0.31 | 3.37 | 8.43 | 34.3 | 4.9 | 5.6 | 3.0 | 0.6 | 2.27 |
| **surf MWOO1 50** | 3.5 | 2.37 | 15.3 | 0.28 | 4.07 | 7.90 | 34.7 | 6.1 | 7.8 | 3.2 | 0.4 | 1.20 |
| *trans* | *none* | *none* | *none* | *sqrt* | *sqrt* | *none* | *sqrt* | *log* | *none* | *none* | *sqrt* | *none* |
| ***l.s.d.*** | ***2.0*** | ***1.26*** | ***4.1*** | ***0.69*** | ***0.67*** | ***3.32*** | ***0.12*** | ***0.37*** | ***2.6*** | ***1.1*** | ***0.15*** | ***1.12*** |

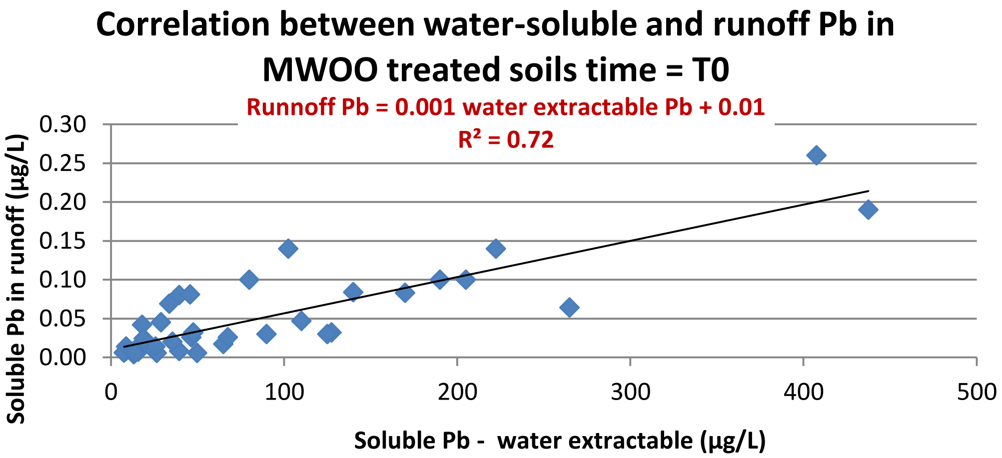
| | **Na** | **Ni** | **Pb** | **Zn** | **TN** | **$NH_4$** | **$NO_3$** | **Cl** | **T. P** | **React P** | **$SO_4$** | **TOC** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/L | µg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| **inc C 0** | 11.3 | 5.33 | 14.10 | 0.03 | 3.5 | 0.2 | 0.7 | 30.0 | 0.7 | 0.23 | 5.6 | 12.3 |
| **inc MWOO1 200** | 10.7 | 9.13 | 32.30 | 0.09 | 4.0 | 0.2 | 0.7 | 33.3 | 0.8 | 0.18 | 6.3 | 12.6 |
| **inc MWOO2 200** | 10.3 | 9.53 | 50.00 | 0.10 | 4.7 | 0.1 | 0.7 | 31.0 | 1.0 | 0.16 | 4.6 | 6.6 |
| **surf MWOO1 50** | 10.3 | 5.97 | 19.60 | 0.13 | 2.6 | 0.1 | 0.6 | 30.7 | 0.4 | 0.09 | 4.7 | 6.3 |
| **surf MWOO1 50** | 10.7 | 5.57 | 22.67 | 0.11 | 2.6 | 0.1 | 0.5 | 29.0 | 0.6 | 0.12 | 4.3 | 6.3 |
| *trans* | *none* | *log* | *log* | *none* | *none* | *none* | *none* | *none* | *none* | *none* | *log* | *none* |
| ***l.s.d.*** | ***1.6*** | ***0.13*** | ***0.72*** | ***0.07*** | ***3.0*** | ***0.1*** | ***0.4*** | ***3.9*** | ***0.8*** | ***0.18*** | ***0.05*** | ***6.3*** |

*Data presented is for the averages of 3 replicates sampled in the field from soils amended with the highest rates of either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d. (transformed where appropriate) for each element is included and indicates significance at $p< 0.05$. Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment. TN = total nitrogen; $NH_4$ = ammonium; $NO_3^-$ = nitrate, Cl = chloride; TP = total phosphorus; react P = Reactive (ortho)-phosphate; $SO_4$ = sulphate, TOC = total organic carbon; sqrt = square root transformation.*

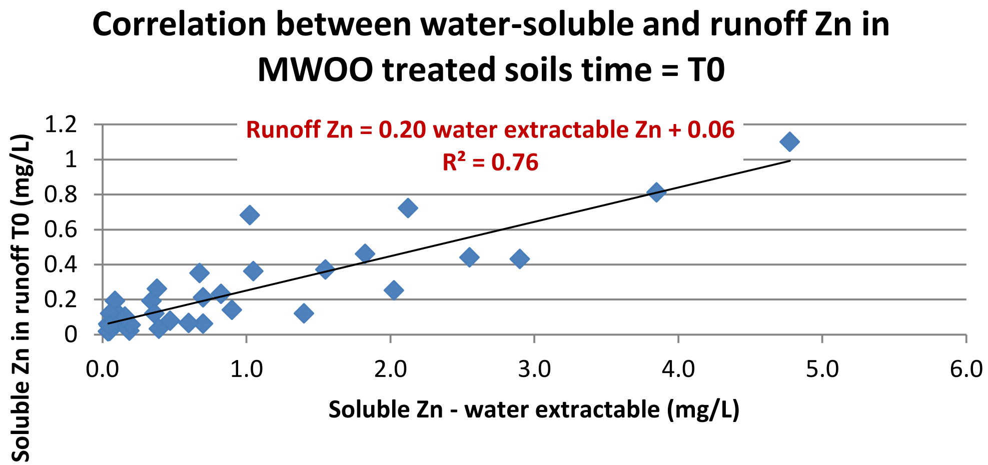
**Appendix 14:** a – c. Example correlations between water-extractable metal contaminants with those measured in runoff solutions.



**14a:** The relationship between water extractable Cu (1:5 soil water extract) and water measured in runoff solutions; both collected immediately after treatment application (T0).



**14b:** The relationship between water extractable Pb (1:5 soil water extract) and water measured in runoff solutions; both collected immediately after treatment application (T0).



**14c:** The relationship between water extractable Zn (1:5 soil water extract) and water measured in runoff solutions; both collected immediately after treatment application (T0).

**Appendix 15a:** Treatment averages for inorganic element concentrations of water soluble (1:5 soil water extract) elements extracted from soils sampled from MWOO treated plots at time t=T0

| Trt ID | Al<br>mg/L | As<br>µg/l | Ca<br>mg/L | Cd<br>µg/l | Co<br>µg/l | Cr<br>µg/l | Cu<br>µg/l | Fe<br>mg/L | K<br>mg/L | Mg<br>mg/L | Mn<br>mg/L | Na<br>mg/L | Ni<br>µg/l | P<br>mg/L | Pb<br>µg/l | Zn<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **inc C** | 3.1 | 0.85 | 6.4 | 0.05 | 2.59 | 0.93 | 8.1 | 1.2 | 7.8 | 3.0 | 0.38 | 3.1 | 6.58 | 0.3 | 1.94 | 0.016 |
| **inc CF** | 4.1 | 1.11 | 9.1 | 0.10 | 4.32 | 1.28 | 9.8 | 1.7 | 14.3 | 4.3 | 0.99 | 4.2 | 8.23 | 0.5 | 2.25 | 0.013 |
| **inc MWOO 1 10** | 2.9 | 2.19 | 9.7 | 0.18 | 8.67 | 2.46 | 35.3 | 1.3 | 8.7 | 3.8 | 0.75 | 16.5 | 17.23 | 0.5 | 3.56 | 0.027 |
| **inc MWOO 1 20** | 2.2 | 2.44 | 8.8 | 0.22 | 7.39 | 2.59 | 45.3 | 0.9 | 10.1 | 2.6 | 0.54 | 18.5 | 19.61 | 0.6 | 3.68 | 0.032 |
| **inc MWOO 1 60** | 4.9 | 4.82 | 25.6 | 1.21 | 24.02 | 9.16 | 199.3 | 1.9 | 27.1 | 6.1 | 0.60 | 72.0 | 51.47 | 1.2 | 9.45 | 0.102 |
| **inc MWOO 1 100** | 5.7 | 13.61 | 46.9 | 3.14 | 43.49 | 21.37 | 549.9 | 3.1 | 67.9 | 7.9 | 0.63 | 145.4 | 118.86 | 3.4 | 30.25 | 0.310 |
| **inc MWOO 1 200** | 5.7 | 9.44 | 60.0 | 3.67 | 39.62 | 23.37 | 567.4 | 2.5 | 107.5 | 10.0 | 0.40 | 220.0 | 132.36 | 3.7 | 35.00 | 0.386 |
| **inc MWOO 2 10** | 6.6 | 4.02 | 8.9 | - | 11.03 | 2.11 | 32.5 | 2.6 | 10.6 | 3.8 | 0.86 | 14.4 | 16.75 | 0.6 | 3.33 | 0.030 |
| **inc MWOO 2 20** | 4.7 | 4.58 | 13.4 | - | 11.18 | 2.59 | 48.0 | 2.3 | 20.0 | 4.2 | 0.39 | 26.0 | 22.26 | 0.7 | 4.42 | 0.039 |
| **inc MWOO 2 60** | 4.5 | 5.94 | 21.1 | 0.45 | 15.91 | 5.39 | 91.4 | 2.0 | 37.2 | 5.2 | 0.41 | 46.4 | 31.87 | 1.5 | 6.13 | 0.074 |
| **inc MWOO 2 100** | 2.8 | 16.07 | 30.5 | 1.31 | 24.18 | 10.11 | 182.5 | 1.7 | 74.2 | 6.1 | 0.28 | 88.5 | 56.37 | 2.4 | 10.28 | 0.174 |
| **inc MWOO 2 200** | 4.7 | 17.49 | 34.7 | 1.44 | 13.71 | 8.77 | 180.1 | 2.1 | 112.1 | 6.7 | 0.20 | 108.6 | 51.24 | 2.1 | 13.55 | 0.249 |
| **inc GWaste 10** | 8.1 | 1.23 | 7.1 | - | 4.13 | 2.58 | 11.6 | 2.9 | 9.6 | 3.9 | 0.84 | 6.4 | 11.13 | 0.5 | 2.23 | 0.016 |
| **inc GWaste 20** | 7.7 | 2.34 | 6.6 | - | 4.83 | 2.31 | 13.3 | 2.8 | 11.2 | 4.1 | 0.73 | 8.3 | 10.84 | 0.5 | 2.51 | 0.017 |
| **inc GWaste 60** | 6.8 | 2.80 | 9.3 | - | 3.62 | 1.97 | 14.1 | 2.6 | 35.0 | 4.8 | 0.34 | 12.9 | 9.28 | 1.2 | 2.51 | 0.021 |
| **inc GWaste 100** | 9.3 | 5.57 | 8.9 | - | 4.44 | 1.77 | 22.8 | 3.2 | 43.0 | 4.7 | 0.30 | 18.3 | 12.39 | 1.7 | 2.62 | 0.027 |
| **inc GWaste 200** | 4.9 | 11.75 | 6.6 | 0.13 | 3.55 | 1.76 | 23.9 | 1.8 | 89.5 | 3.0 | 0.23 | 27.7 | 12.15 | 3.4 | 2.99 | 0.030 |
| **inc Biosolids 10** | 6.5 | 1.24 | 6.6 | - | 3.68 | 1.01 | 12.4 | 2.4 | 6.3 | 3.8 | 0.76 | 6.3 | 9.61 | 0.5 | 2.14 | 0.015 |
| **inc Biosolids 60** | 5.2 | 1.82 | 9.1 | 0.05 | 1.90 | 0.88 | 13.6 | 1.7 | 17.9 | 4.5 | 0.25 | 10.9 | 7.73 | 1.2 | 1.27 | 0.015 |
| **inc Manure 10** | 10.0 | 2.53 | 11.4 | - | 9.37 | 2.75 | 26.6 | 3.8 | 25.9 | 6.7 | 0.76 | 10.5 | 17.39 | 1.6 | 2.57 | 0.027 |
| **inc Manure 20** | 10.3 | 4.09 | 7.5 | - | 16.44 | 3.88 | 47.4 | 3.8 | 28.4 | 5.1 | 0.55 | 15.6 | 25.50 | 2.6 | 3.10 | 0.035 |
| **inc Manure 60** | 4.7 | 13.16 | 14.8 | 0.36 | 81.96 | 8.44 | 131.4 | 3.4 | 134.0 | 11.2 | 1.39 | 51.0 | 42.16 | 20.4 | 4.68 | 0.292 |
| **inc Manure 100** | 2.6 | 20.58 | 20.3 | 0.63 | 68.35 | 5.11 | 148.4 | 2.9 | 216.6 | 17.5 | 1.68 | 72.1 | 46.77 | 33.2 | 3.44 | 0.511 |
| **surf CF** | 4.4 | 1.12 | 5.8 | 0.08 | 6.41 | 0.96 | 10.0 | 1.6 | 11.9 | 3.0 | 0.99 | 3.3 | 9.35 | 0.5 | 2.28 | 0.011 |
| **surf C** | 2.1 | 0.78 | 8.2 | 0.06 | 3.42 | 0.55 | 5.2 | 0.7 | 9.7 | 4.2 | 0.57 | 5.7 | 6.62 | 0.3 | 1.48 | 0.007 |
| **surf MWOO 1 10** | 4.6 | 7.91 | 27.7 | 1.22 | 24.72 | 11.62 | 242.1 | 2.7 | 33.4 | 5.9 | 1.09 | 78.9 | 65.52 | 1.9 | 12.58 | 0.143 |
| **surf MWOO 1 20** | 9.1 | 5.42 | 28.4 | 1.23 | 23.97 | 12.29 | 228.6 | 3.4 | 35.8 | 6.2 | 0.56 | 88.2 | 62.84 | 1.9 | 13.93 | 0.146 |
| **surf MWOO 1 30** | 16.4 | 7.72 | 58.1 | 2.70 | 45.74 | 27.12 | 641.1 | 5.8 | 71.0 | 11.9 | 1.27 | 188.7 | 158.09 | 2.9 | 39.74 | 0.445 |
| **surf MWOO 1 50** | 7.2 | 12.31 | 67.0 | 4.19 | 61.63 | 36.26 | 788.9 | 4.0 | 105.6 | 12.0 | 0.97 | 222.5 | 181.28 | 4.9 | 49.38 | 0.528 |
| **surf MWOO 2 10** | 6.9 | 11.92 | 30.0 | 0.74 | 16.85 | 9.39 | 162.6 | 3.0 | 67.8 | 7.3 | 0.37 | 104.9 | 60.00 | 1.5 | 7.78 | 0.149 |
| **surf MWOO 2 20** | 7.2 | 11.26 | 23.8 | 0.34 | 22.11 | 7.13 | 145.6 | 2.9 | 40.6 | 6.9 | 0.53 | 82.4 | 56.90 | 1.3 | 6.64 | 0.106 |
| **surf MWOO 2 30** | 6.3 | 17.64 | 43.6 | 1.40 | 37.05 | 14.33 | 400.2 | 3.2 | 131.3 | 9.8 | 0.53 | 201.9 | 136.30 | 2.7 | 18.86 | 0.468 |

## Appendix 15a continued …

| **TrtID** | **Al** | **As** | **Ca** | **Cd** | **Co** | **Cr** | **Cu** | **Fe** | **K** | **Mg** | **Mn** | **Na** | **Ni** | **P** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/l | mg/L | µg/l | µg/l | µg/l | µg/l | mg/L | mg/L | mg/L | mg/L | mg/L | µg/l | mg/L | µg/l | mg/L |
| **surf MWOO 2 50** | 3.8 | 26.75 | 62.9 | 2.18 | 30.63 | 19.25 | 425.1 | 3.0 | 208.5 | 12.8 | 0.46 | 305.0 | 147.90 | 3.4 | 24.17 | 0.569 |
| **surf GWaste 10** | 8.4 | 2.31 | 6.3 | - | 6.31 | 2.11 | 14.1 | 2.9 | 16.6 | 3.9 | 0.78 | 11.2 | 10.32 | 0.6 | 2.28 | 0.018 |
| **surf GWaste 20** | 10.5 | 4.80 | 8.1 | - | 5.09 | 1.65 | 19.1 | 3.7 | 40.8 | 4.0 | 0.66 | 18.4 | 13.39 | 1.4 | 3.10 | 0.022 |
| **surf GWaste 30** | 8.4 | 7.00 | 8.1 | - | 5.11 | 2.92 | 22.9 | 2.9 | 63.1 | 4.7 | 0.41 | 29.3 | 14.69 | 1.8 | 2.69 | 0.026 |
| **surf GWaste 50** | 3.3 | 11.90 | 7.9 | 0.13 | 3.24 | 1.60 | 22.5 | 1.4 | 85.1 | 3.9 | 0.23 | 34.8 | 12.80 | 2.7 | 3.03 | 0.028 |
| *LTV* | | *20* | | *2* | *10* | *20*[*] | *40* | *40* | | | | | *40* | | *400* | |
| *trans* | *sqrt* | *log* | *log* | *log* | *log* | *log* | *log* | *sqrt* | *log* | *sqrt* | *sqrt* | *log* | *log* | *log* | *log* | *log* |
| **l.s.d. trt x time** | ***0.67*** | ***0.3*** | ***0.19*** | ***0.32*** | ***0.23*** | ***0.26*** | ***0.23*** | ***0.39*** | ***0.24*** | ***0.44*** | ***0.2*** | ***0.22*** | ***0.19*** | ***0.23*** | ***0.19*** | ***0.25*** |

[*] *LTV for Cr equates to the more toxic Cr (VI) species, our data is for total Cr.*

*Data presented is for the averages of 4 replicates sampled in the field from soils amended with either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. LTV = long term trigger value for irrigation water, adjusted to reflect dilution used in 1:5 soil water extract, to be used for comparison only; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment; - = not detected.*

**Appendix 15b:** Treatment averages for inorganic element concentrations of water soluble (1:5 soil water extract) elements extracted from sols sampled from MWOO treated plots at time t=T1

| trtID | Al | As | Ca | Cd | Co | Cr | Cu | Fe | K | Mg | Mn | Na | Ni | P | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/l | mg/L | µg/l | µg/l | µg/l | µg/l | mg/L | mg/L | mg/L | mg/L | mg/L | µg/l | mg/L | µg/l | mg/L |
| **inc C 0** | 14.8 | 1.03 | 7.2 | 0.06 | 4.11 | 1.36 | 9.8 | 4.8 | 3.2 | 4.2 | 1.15 | 12.4 | 10.83 | 0.5 | 1.24 | 0.020 |
| **inc CF** | 12.2 | 0.91 | 8.9 | 0.07 | 5.08 | 0.88 | 8.5 | 3.5 | 6.3 | 4.3 | 1.64 | 9.1 | 8.40 | 0.5 | 1.14 | 0.019 |
| **inc MWOO 1 10** | 12.5 | 1.33 | 9.5 | 0.11 | 3.76 | 1.52 | 21.8 | 3.8 | 7.5 | 4.2 | 0.65 | 12.0 | 15.44 | 0.7 | 2.19 | 0.034 |
| **inc MWOO 1 20** | 11.6 | 1.68 | 14.3 | 0.19 | 3.91 | 1.67 | 33.8 | 3.7 | 13.3 | 4.6 | 0.63 | 11.3 | 17.45 | 0.9 | 3.32 | 0.048 |
| **inc MWOO 1 60** | 9.3 | 2.95 | 23.9 | 0.42 | 4.68 | 3.06 | 85.4 | 3.2 | 17.3 | 5.8 | 0.36 | 23.1 | 27.91 | 1.3 | 7.15 | 0.081 |
| **inc MWOO 1 100** | 5.5 | 5.99 | 36.9 | 0.85 | 6.98 | 6.53 | 218.4 | 2.2 | 30.9 | 6.6 | 0.21 | 40.0 | 46.83 | 2.6 | 10.06 | 0.150 |
| **inc MWOO 1 200** | 4.8 | 5.51 | 35.8 | 0.96 | 8.54 | 7.45 | 237.3 | 2.1 | 39.5 | 5.7 | 0.21 | 44.4 | 54.78 | 2.5 | 11.73 | 0.169 |
| **inc MWOO 2 10** | 5.7 | 0.67 | 8.1 | - | 4.10 | 1.75 | 15.9 | 1.9 | 8.2 | 3.5 | 0.52 | 12.2 | 11.88 | 0.4 | 2.61 | 0.023 |
| **inc MWOO 2 20** | 2.1 | 1.44 | 11.9 | - | 4.56 | 2.38 | 22.4 | 0.9 | 14.2 | 3.7 | 0.42 | 11.2 | 13.13 | 0.5 | 3.41 | 0.031 |
| **inc MWOO 2 60** | 2.1 | 2.86 | 20.8 | - | 5.45 | 2.07 | 53.6 | 1.0 | 18.5 | 4.7 | 0.25 | 15.1 | 20.75 | 1.0 | 3.70 | 0.058 |
| **inc MWOO 2 100** | 2.9 | 4.61 | 22.1 | - | 8.94 | 3.89 | 81.9 | 1.3 | 36.7 | 5.1 | 0.20 | 26.4 | 29.13 | 1.2 | 5.02 | 0.087 |
| **inc MWOO 2 200** | 3.9 | 9.06 | 43.1 | 0.68 | 9.01 | 5.71 | 154.6 | 1.9 | 70.9 | 7.4 | 0.16 | 56.1 | 45.60 | 2.0 | 7.72 | 0.193 |
| **inc GWaste 10** | 1.9 | 1.23 | 6.4 | 0.52 | 9.08 | 2.72 | 11.8 | 0.8 | 7.1 | 3.3 | 0.70 | 10.4 | 10.35 | 0.5 | 2.52 | 0.013 |
| **inc GWaste 20** | 2.0 | 0.39 | 7.1 | - | 4.36 | 2.38 | 9.1 | 0.8 | 7.0 | 4.0 | 0.65 | 10.0 | 7.73 | 0.4 | 2.30 | 0.012 |
| **inc GWaste 60** | 2.3 | 1.19 | 9.0 | - | 4.54 | 2.69 | 11.5 | 1.0 | 19.3 | 4.1 | 0.61 | 9.3 | 8.74 | 0.9 | 2.51 | 0.017 |
| **inc GWaste 100** | 4.3 | 2.68 | 9.8 | - | 3.96 | 1.97 | 13.4 | 1.8 | 20.0 | 4.7 | 0.38 | 13.4 | 8.94 | 1.1 | 2.25 | 0.021 |
| **inc GWaste 200** | 2.7 | 6.07 | 10.9 | 0.10 | 3.82 | 1.29 | 20.4 | 1.2 | 46.4 | 5.1 | 0.34 | 14.8 | 11.04 | 3.1 | 3.73 | 0.034 |
| **inc Biosolids 10** | 3.0 | 0.76 | 6.0 | - | 4.61 | 1.66 | 9.1 | 1.1 | 5.5 | 3.2 | 0.80 | 8.6 | 9.03 | 0.4 | 1.46 | 0.012 |
| **inc Biosolids 60** | 1.8 | 1.76 | 8.9 | 0.05 | 3.37 | 0.72 | 19.6 | 0.8 | 9.4 | 4.2 | 0.53 | 13.5 | 12.35 | 1.5 | 2.09 | 0.022 |
| **inc Manure 10** | 2.8 | 2.79 | 9.9 | - | 4.58 | 1.85 | 13.1 | 1.1 | 11.4 | 4.9 | 0.70 | 9.5 | 11.26 | 1.7 | 1.40 | 0.019 |
| **inc Manure 20** | 5.0 | 3.44 | 13.2 | - | 5.92 | 1.76 | 20.7 | 1.8 | 16.0 | 6.9 | 0.63 | 10.7 | 13.45 | 3.5 | 1.47 | 0.031 |
| **inc Manure 60** | 5.2 | 3.64 | 13.0 | - | 9.37 | 2.78 | 30.3 | 2.4 | 34.6 | 8.2 | 0.63 | 9.9 | 14.15 | 7.3 | 1.92 | 0.048 |
| **inc Manure 100** | 2.7 | 5.43 | 15.4 | 0.11 | 12.90 | 1.58 | 56.3 | 1.4 | 69.1 | 15.8 | 0.55 | 21.4 | 16.87 | 19.8 | 1.43 | 0.112 |
| **surf C 0** | 1.3 | 0.99 | 5.8 | 0.04 | 4.11 | 0.26 | 10.1 | 0.5 | 7.4 | 2.7 | 0.85 | 8.2 | 9.64 | 0.4 | 1.97 | 0.010 |
| **surf CF** | 1.6 | 0.97 | 8.1 | 0.10 | 7.89 | 0.22 | 10.1 | 0.7 | 9.0 | 4.1 | 1.93 | 10.7 | 10.18 | 0.5 | 2.23 | 0.013 |
| **surf MWOO 1 10** | 2.8 | 1.37 | 9.8 | 0.12 | 3.58 | 0.78 | 25.9 | 1.1 | 6.2 | 3.5 | 0.58 | 10.3 | 14.54 | 0.6 | 2.92 | 0.029 |
| **surf MWOO 1 20** | 3.0 | 2.05 | 17.6 | 0.27 | 4.25 | 1.74 | 60.2 | 1.3 | 11.1 | 4.7 | 0.45 | 16.3 | 20.82 | 0.9 | 5.23 | 0.051 |
| **surf MWOO 1 30** | 3.4 | 1.97 | 19.1 | 0.26 | 4.26 | 1.79 | 58.8 | 1.2 | 14.9 | 5.1 | 0.39 | 19.8 | 19.99 | 0.8 | 5.31 | 0.056 |

## Appendix 15b continued…

| trtID | Al<br>mg/L | As<br>µg/l | Ca<br>mg/L | Cd<br>µg/l | Co<br>µg/l | Cr<br>µg/l | Cu<br>µg/l | Fe<br>mg/L | K<br>mg/L | Mg<br>mg/L | Mn<br>mg/L | Na<br>mg/L | Ni<br>µg/l | P<br>mg/L | Pb<br>µg/l | Zn<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **surf MWOO 1 50** | 2.9 | 3.53 | 25.1 | 0.44 | 4.52 | 3.60 | 136.5 | 1.0 | 22.8 | 5.4 | 0.28 | 29.6 | 29.77 | 1.6 | 8.05 | 0.096 |
| **surf MWOO 2 10** | 2.1 | 1.34 | 9.9 | - | 4.10 | 2.70 | 15.4 | 0.8 | 7.6 | 3.6 | 0.39 | 13.0 | 7.53 | 0.3 | 2.54 | 0.021 |
| **surf MWOO 2 20** | 2.0 | 2.06 | 13.6 | - | 3.62 | 2.66 | 20.8 | 0.8 | 10.8 | 4.5 | 0.31 | 12.3 | 11.08 | 0.4 | 2.56 | 0.026 |
| **surf MWOO 2 30** | 2.7 | 3.77 | 15.4 | - | 6.28 | 3.35 | 49.3 | 1.1 | 20.6 | 4.2 | 0.33 | 18.4 | 20.25 | 0.8 | 4.32 | 0.050 |
| **surf MWOO 2 50** | 2.4 | 5.26 | 30.9 | 0.34 | 7.70 | 3.10 | 97.4 | 1.1 | 37.6 | 6.8 | 0.28 | 31.4 | 31.39 | 1.3 | 5.57 | 0.101 |
| **surf GWaste 10** | 1.8 | 2.10 | 5.7 | - | 3.98 | 2.70 | 10.1 | 0.8 | 7.5 | 3.2 | 0.53 | 9.5 | 5.68 | 0.4 | 2.21 | 0.012 |
| **surf GWaste 20** | 1.7 | 3.27 | 8.1 | - | 3.74 | 0.87 | 9.5 | 0.8 | 12.0 | 3.6 | 0.56 | 10.0 | 9.08 | 0.5 | 2.21 | 0.013 |
| **surf GWaste 30** | 2.5 | 4.49 | 6.7 | - | 4.66 | 1.44 | 14.5 | 1.1 | 18.5 | 3.4 | 0.44 | 9.8 | 10.28 | 1.0 | 2.44 | 0.017 |
| **surf GWaste 50** | 6.2 | 2.89 | 10.0 | 0.05 | 3.07 | 0.88 | 14.5 | 2.2 | 17.4 | 5.2 | 0.34 | 12.2 | 10.10 | 1.2 | 2.09 | 0.023 |
| *LTV* |  | *20* |  | *2* | *10* | *20*[*] | *40* | *40* |  |  |  |  | *40* |  | *400* |  |
| *trans* | *sqrt* | *log* | *log* | *log* | *log* | *log* | *log* | *sqrt* | *log* | *sqrt* | *sqrt* | *log* | *log* | *log* | *log* | *log* |
| **l.s.d. trt x time** | ***0.67*** | ***0.3*** | ***0.19*** | ***0.32*** | ***0.23*** | ***0.26*** | ***0.23*** | ***0.39*** | ***0.24*** | ***0.44*** | ***0.2*** | ***0.22*** | ***0.19*** | ***0.23*** | ***0.19*** | ***0.25*** |

*[*] LTV for Cr equates to the more toxic Cr (VI) species, our data is for total Cr.*

*Data presented is for the averages of 4 replicates sampled in the field from soils amended with either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. LTV = long term trigger value for irrigation water, adjusted to reflect dilution used in 1:5 soil water extract, to be used for comparison only; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment; - = not detected.*

**Appendix 15c:** Treatment averages for inorganic element concentrations of water soluble (1:5 soil water extract) elements extracted from sols sampled from MWOO treated plots at time t=T2

| **trtID** | **Al** | **As** | **Ca** | **Cd** | **Co** | **Cr** | **Cu** | **Fe** | **K** | **Mg** | **Mn** | **Na** | **Ni** | **P** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/L | mg/L | µg/L | µg/L | µg/L | µg/L | mg/L | mg/L | mg/L | mg/L | mg/L | µg/L | mg/L | µg/L | mg/L |
| **inc C0** | 1.22 | 1.32 | 7.4 | - | 3.67 | 0.91 | 18.12 | 0.54 | 5.00 | 3.14 | 0.55 | 6.91 | 10.6 | 0.39 | 1.63 | 0.01 |
| **inc CF** | 1.17 | 1.20 | 13.1 | - | 6.86 | 0.86 | 11.46 | 0.53 | 12.73 | 6.18 | 2.05 | 6.85 | 9.5 | 0.67 | 1.35 | 0.01 |
| **inc MWOO1 10** | 1.29 | 1.22 | 7.6 | - | 4.11 | 1.07 | 23.58 | 0.57 | 5.90 | 3.44 | 0.53 | 8.66 | 13.9 | 0.45 | 2.28 | 0.02 |
| **inc MWOO1 20** | 1.05 | 1.53 | 8.7 | - | 3.60 | 1.26 | 37.52 | 0.46 | 9.88 | 2.71 | 0.41 | 5.34 | 16.6 | 0.62 | 2.67 | 0.03 |
| **inc MWOO1 60** | 1.36 | 2.30 | 15.0 | 0.32 | 3.41 | 2.46 | 73.38 | 0.61 | 11.34 | 3.75 | 0.22 | 8.13 | 20.5 | 0.76 | 4.33 | 0.05 |
| **inc MWOO1 100** | 1.28 | 4.55 | 23.0 | 0.70 | 4.25 | 4.84 | 172.00 | 0.73 | 15.82 | 4.34 | 0.14 | 13.61 | 32.9 | 1.42 | 7.50 | 0.11 |
| **inc MWOO1 200** | 1.21 | 4.38 | 24.1 | 0.87 | 4.89 | 6.21 | 186.09 | 0.79 | 23.63 | 4.87 | 0.16 | 13.54 | 38.2 | 1.51 | 8.20 | 0.14 |
| **inc MWOO2 200** | 1.25 | 5.48 | 25.3 | 0.55 | 5.80 | 4.14 | 105.03 | 0.86 | 26.32 | 4.69 | 0.14 | 12.03 | 31.2 | 1.16 | 4.47 | 0.11 |
| **surf C0** | 1.50 | 1.09 | 5.8 | - | 4.48 | 0.75 | 12.95 | 0.66 | 7.75 | 2.84 | 0.82 | 6.46 | 10.3 | 0.43 | 1.56 | 0.01 |
| **surf CF** | 1.36 | 0.99 | 16.4 | - | 13.83 | 0.69 | 9.59 | 0.54 | 15.65 | 8.39 | 3.74 | 9.73 | 11.2 | 0.42 | 1.21 | 0.02 |
| **surf MWOO1 10** | 1.34 | 1.41 | 6.7 | - | 3.89 | 1.04 | 25.14 | 0.59 | 7.46 | 2.91 | 0.52 | 6.72 | 12.3 | 0.57 | 2.18 | 0.02 |
| **surf MWOO1 20** | 1.28 | 1.74 | 11.8 | - | 3.77 | 1.46 | 54.25 | 0.59 | 8.46 | 3.55 | 0.39 | 9.47 | 16.3 | 0.68 | 3.79 | 0.05 |
| **surf MWOO1 30** | 1.36 | 2.06 | 16.2 | 0.58 | 3.56 | 2.12 | 82.67 | 0.59 | 12.58 | 3.95 | 0.29 | 9.50 | 21.5 | 0.81 | 4.83 | 0.06 |
| **surf MWOO1 50** | 1.56 | 2.88 | 20.4 | 0.63 | 3.76 | 2.95 | 110.30 | 0.72 | 14.02 | 4.24 | 0.24 | 9.59 | 24.7 | 1.18 | 6.07 | 0.07 |
| **surf MWOO2 50** | 2.07 | 3.74 | 21.1 | - | 4.26 | 2.24 | 75.06 | 0.93 | 14.56 | 4.58 | 0.19 | 10.69 | 23.1 | 1.08 | 3.74 | 0.07 |
| *LTV* | | *20* | | *2* | *10* | *20*[*] | *40* | *40* | | | | | *40* | | *400* | |
| *trans* | *sqrt* | *log* | *log* | *log* | *log* | *log* | *log* | *sqrt* | *log* | *sqrt* | *sqrt* | *log* | *log* | *log* | *log* | *log* |
| **l.s.d. trt x time** | ***0.67*** | ***0.30*** | ***0.19*** | ***0.32*** | ***0.23*** | ***0.26*** | ***0.23*** | ***0.39*** | ***0.24*** | ***0.44*** | ***0.20*** | ***0.22*** | ***0.19*** | ***0.23*** | ***0.19*** | ***0.25*** |

[*] *LTV for Cr equates to the more toxic Cr (VI) species, our data is for total Cr.*

*Data presented is for the averages of 4 replicates sampled in the field from soils amended with either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. LTV = long term trigger value for irrigation water, adjusted to reflect dilution used in 1:5 soil water extract, to be used for comparison only; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment; - = not detected.*

**Appendix 15d:** Treatment averages for inorganic element concentrations of water soluble (1:5 soil water extract) elements extracted from sols sampled from MWOO treated plots at time t=T3

| trtID | Al | As | Ca | Cd | Co | Cr | Cu | Fe | K | Mg | Mn | Na | Ni | P | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/l | mg/L | µg/l | µg/l | µg/l | µg/l | mg/L | mg/L | mg/L | mg/L | mg/L | µg/l | mg/L | µg/l | mg/L |
| **inc C 0** | 7.0 | 1.12 | 4.1 | 0.05 | 3.08 | 0.82 | 11.1 | 2.6 | 3.8 | 1.8 | 0.40 | 4.7 | 8.50 | 0.4 | 2.46 | 0.011 |
| **inc CF** | 3.8 | 1.00 | 6.2 | 0.10 | 6.28 | 0.73 | 9.0 | 1.5 | 6.9 | 2.7 | 1.43 | 3.6 | 7.99 | 0.4 | 2.50 | 0.013 |
| **inc MWOO 1 10** | 2.9 | 1.24 | 5.0 | 0.09 | 2.98 | 0.91 | 18.7 | 1.2 | 4.2 | 2.0 | 0.32 | 4.8 | 10.05 | 0.4 | 3.06 | 0.022 |
| **inc MWOO 1 20** | 2.5 | 1.32 | 6.5 | 0.13 | 3.03 | 1.19 | 28.8 | 0.9 | 5.7 | 1.9 | 0.32 | 4.0 | 12.58 | 0.5 | 3.76 | 0.031 |
| **inc MWOO 1 60** | 2.2 | 1.42 | 9.8 | 0.22 | 2.77 | 1.71 | 45.7 | 0.8 | 6.4 | 2.5 | 0.23 | 5.6 | 13.42 | 0.5 | 5.98 | 0.048 |
| **inc MWOO 1 100** | 3.2 | 2.67 | 17.0 | 0.44 | 2.44 | 2.56 | 90.7 | 1.3 | 13.2 | 3.1 | 0.11 | 6.8 | 17.24 | 0.9 | 7.40 | 0.069 |
| **inc MWOO 1 200** | 4.2 | 4.10 | 20.5 | 0.54 | 2.45 | 3.93 | 139.4 | 1.7 | 21.1 | 3.5 | 0.09 | 7.5 | 25.41 | 1.5 | 8.51 | 0.095 |
| **inc MWOO 2 10** | 8.0 | - | 5.6 | 0.17 | - | 5.60 | 19.0 | 3.0 | 5.7 | 2.4 | 0.39 | 5.1 | 12.25 | 0.7 | - | 0.061 |
| **inc MWOO 2 20** | 7.7 | - | 8.6 | 0.13 | - | - | 20.8 | 2.7 | 12.3 | 2.9 | 0.36 | 4.6 | 10.95 | 0.7 | - | 0.048 |
| **inc MWOO 2 60** | 6.9 | - | 11.1 | 0.17 | - | 6.20 | 33.3 | 2.7 | 11.8 | 2.9 | 0.27 | 4.2 | 13.74 | 0.8 | - | 0.054 |
| **inc MWOO 2 100** | 15.2 | - | 19.0 | 0.25 | - | 8.47 | 60.8 | 4.7 | 20.5 | 4.5 | 0.16 | 5.8 | 19.00 | 1.0 | - | 0.083 |
| **inc MWOO 2 200** | 2.8 | 3.42 | 24.0 | 0.27 | 2.84 | 2.21 | 58.2 | 1.2 | 26.3 | 4.1 | 0.10 | 4.8 | 16.37 | 1.0 | 4.34 | 0.069 |
| **inc GWaste 10** | 6.7 | - | 4.5 | 0.06 | - | - | 13.0 | 2.5 | 5.3 | 2.1 | 0.52 | 4.7 | 10.88 | 0.5 | - | 0.046 |
| **inc GWaste 20** | 6.6 | - | 5.4 | 0.05 | - | 5.30 | 14.5 | 2.5 | 6.1 | 2.7 | 0.41 | 5.2 | 12.33 | 0.6 | - | 0.061 |
| **inc GWaste 60** | 5.3 | - | 6.7 | 0.04 | - | - | 14.1 | 1.8 | 10.8 | 2.9 | 0.42 | 4.2 | 10.78 | 0.7 | - | 0.032 |
| **inc GWaste 100** | 6.4 | - | 8.1 | 0.07 | - | 5.60 | 17.5 | 2.6 | 12.9 | 3.5 | 0.36 | 5.1 | 11.13 | 0.9 | - | 0.042 |
| **inc GWaste 200** | 7.3 | - | 10.3 | 0.08 | - | - | 18.3 | 2.5 | 18.0 | 4.3 | 0.32 | 3.8 | 11.40 | 1.9 | - | 0.049 |
| **inc Biosolids 10** | 7.3 | - | 5.8 | 0.12 | - | - | 12.5 | 2.8 | 5.2 | 2.7 | 0.59 | 4.8 | 11.43 | 0.6 | - | 0.034 |
| **inc Biosolids 60** | 4.7 | - | 6.7 | 0.11 | - | - | 20.3 | 2.2 | 6.9 | 2.8 | 0.48 | 5.3 | 11.55 | 1.5 | - | 0.029 |
| **inc Manure 10** | 4.2 | - | 6.9 | 0.08 | - | - | 17.1 | 1.6 | 6.9 | 2.7 | 0.43 | 4.2 | 13.25 | 1.4 | - | 0.036 |
| **inc Manure 20** | 11.8 | - | 8.4 | 0.10 | - | 9.35 | 21.8 | 4.3 | 13.2 | 3.9 | 0.47 | 4.7 | 17.25 | 2.4 | - | 0.170 |
| **inc Manure 60** | 5.5 | - | 13.0 | 0.05 | - | - | 25.8 | 2.3 | 20.8 | 5.7 | 0.29 | 4.1 | 11.43 | 4.2 | - | 0.051 |
| **inc Manure 100** | 3.3 | - | 13.0 | 0.08 | - | - | 27.5 | 1.6 | 24.0 | 6.7 | 0.26 | 4.2 | 11.33 | 4.9 | - | 0.052 |
| **Surf C 0** | 3.0 | 1.25 | 3.6 | 0.05 | 4.17 | 0.72 | 10.8 | 1.1 | 3.9 | 1.6 | 0.51 | 4.3 | 8.85 | 0.4 | 2.74 | 0.009 |
| **Surf CF** | 4.3 | 1.08 | 6.1 | 0.12 | 6.35 | 0.72 | 10.6 | 1.5 | 5.9 | 2.8 | 1.23 | 3.7 | 8.82 | 0.4 | 2.84 | 0.016 |
| **Surf MWOO 1 10** | 3.7 | 1.34 | 4.9 | 0.10 | 3.10 | 0.95 | 23.7 | 1.5 | 4.1 | 2.0 | 0.38 | 4.7 | 11.62 | 0.5 | 3.14 | 0.030 |
| **Surf MWOO 1 20** | 3.7 | 1.45 | 7.3 | 0.14 | 2.80 | 1.09 | 32.6 | 1.4 | 5.1 | 2.3 | 0.33 | 5.1 | 12.28 | 0.5 | 3.81 | 0.031 |
| **Surf MWOO 1 30** | 2.7 | 1.58 | 8.3 | 0.18 | 2.78 | 1.30 | 38.4 | 1.0 | 6.0 | 2.4 | 0.27 | 4.7 | 12.99 | 0.5 | 4.61 | 0.041 |

## Appendix 15d continued …

| trtID | Al<br>mg/L | As<br>µg/l | Ca<br>mg/L | Cd<br>µg/l | Co<br>µg/l | Cr<br>µg/l | Cu<br>µg/l | Fe<br>mg/L | K<br>mg/L | Mg<br>mg/L | Mn<br>mg/L | Na<br>mg/L | Ni<br>µg/l | P<br>mg/L | Pb<br>µg/l | Zn<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Surf MWOO 1 50** | 3.2 | 1.92 | 8.7 | 0.19 | 2.95 | 1.41 | 41.5 | 1.2 | 7.3 | 2.4 | 0.28 | 4.6 | 13.53 | 0.6 | 4.73 | 0.040 |
| **Surf MWOO 2 50** | 2.5 | 2.20 | 12.2 | 0.16 | 2.91 | 1.38 | 34.1 | 1.0 | 8.6 | 3.1 | 0.19 | 5.2 | 13.32 | 0.5 | 3.42 | 0.041 |
| *LTV* |  | *20* |  | *2* | *10* | *20*[*] | *40* | *40* |  |  |  |  | *40* |  | *400* |  |
| *trans* | *sqrt* | *log* | *log* | *log* | *log* | *log* | *log* | *sqrt* | *log* | *sqrt* | *sqrt* | *log* | *log* | *log* | *log* | *log* |
| **l.s.d. trt x time** | ***0.67*** | ***0.3*** | ***0.19*** | ***0.32*** | ***0.23*** | ***0.26*** | ***0.23*** | ***0.39*** | ***0.24*** | ***0.44*** | ***0.2*** | ***0.22*** | ***0.19*** | ***0.23*** | ***0.19*** | ***0.25*** |

*[*] LTV for Cr equates to the more toxic Cr (VI) species, our data is for total Cr.*

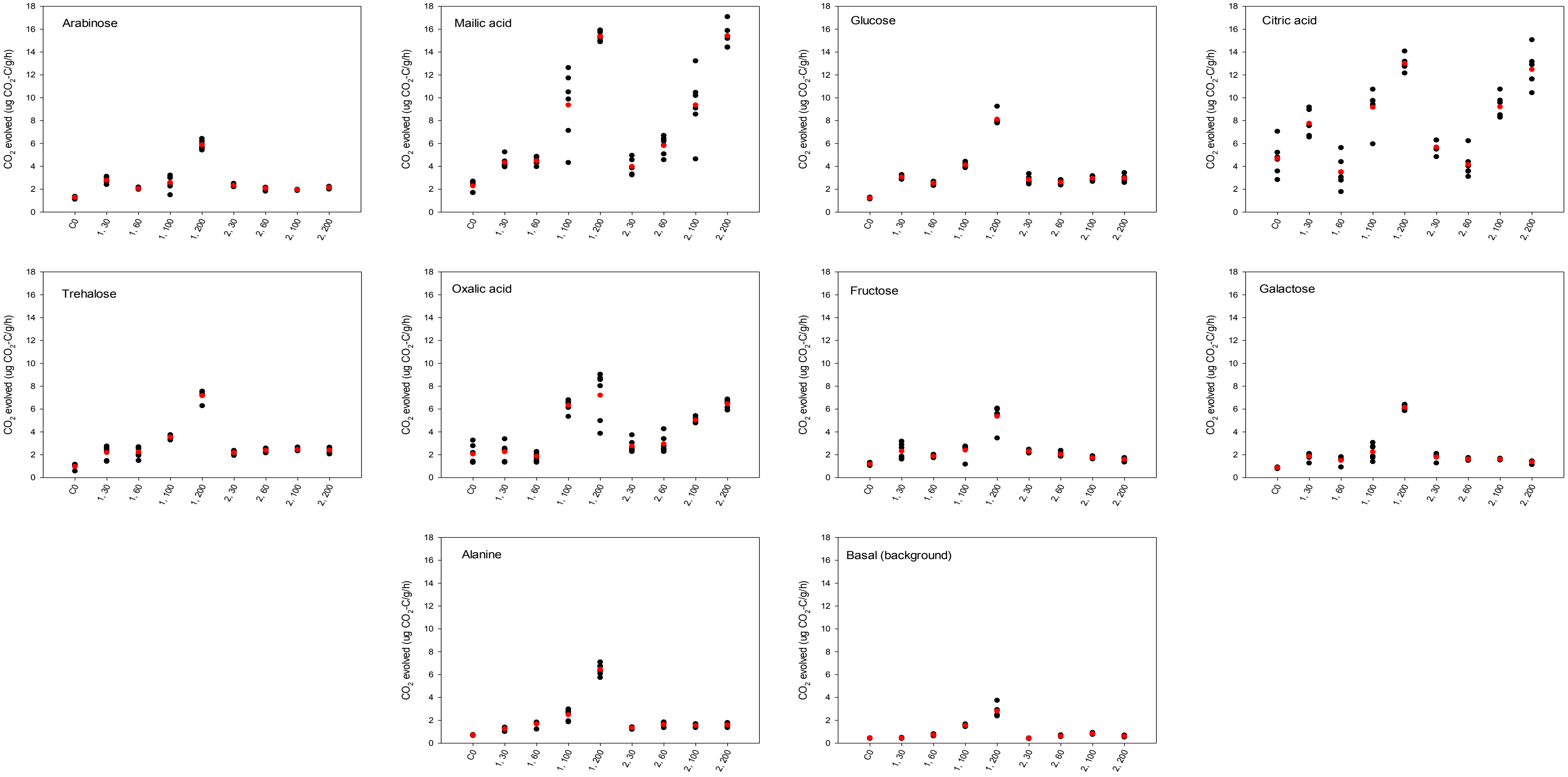
*Data presented is for the averages of 4 replicates sampled in the field from soils amended with either incorporated or surface applied mixed solid waste 1 and 2 (MWOO1 and MWOO 2) compared to control treatments. L.s.d (trt x time, transformed where appropriate) for each parameter indicates statistical significance at p<0.05, following repeated measures analysis of variance on orthogonally partitioned data. LTV = long term trigger value for irrigation water, adjusted to reflect dilution used in 1:5 soil water extract, to be used for comparison only; Inc = incorporated treatments; surf = surface applied; C = control; CF = control fertiliser. Application rates (dry t/ha) indicated for each treatment; - = not detected.*

**Appendix 16:** Average total soil metal and nutrient concentrations at increasing depths down the soil profile sampled from the Flat paddock sites treated with MWOO at rates of 60 and 100 dry t/ha, three years after initial application (T3).

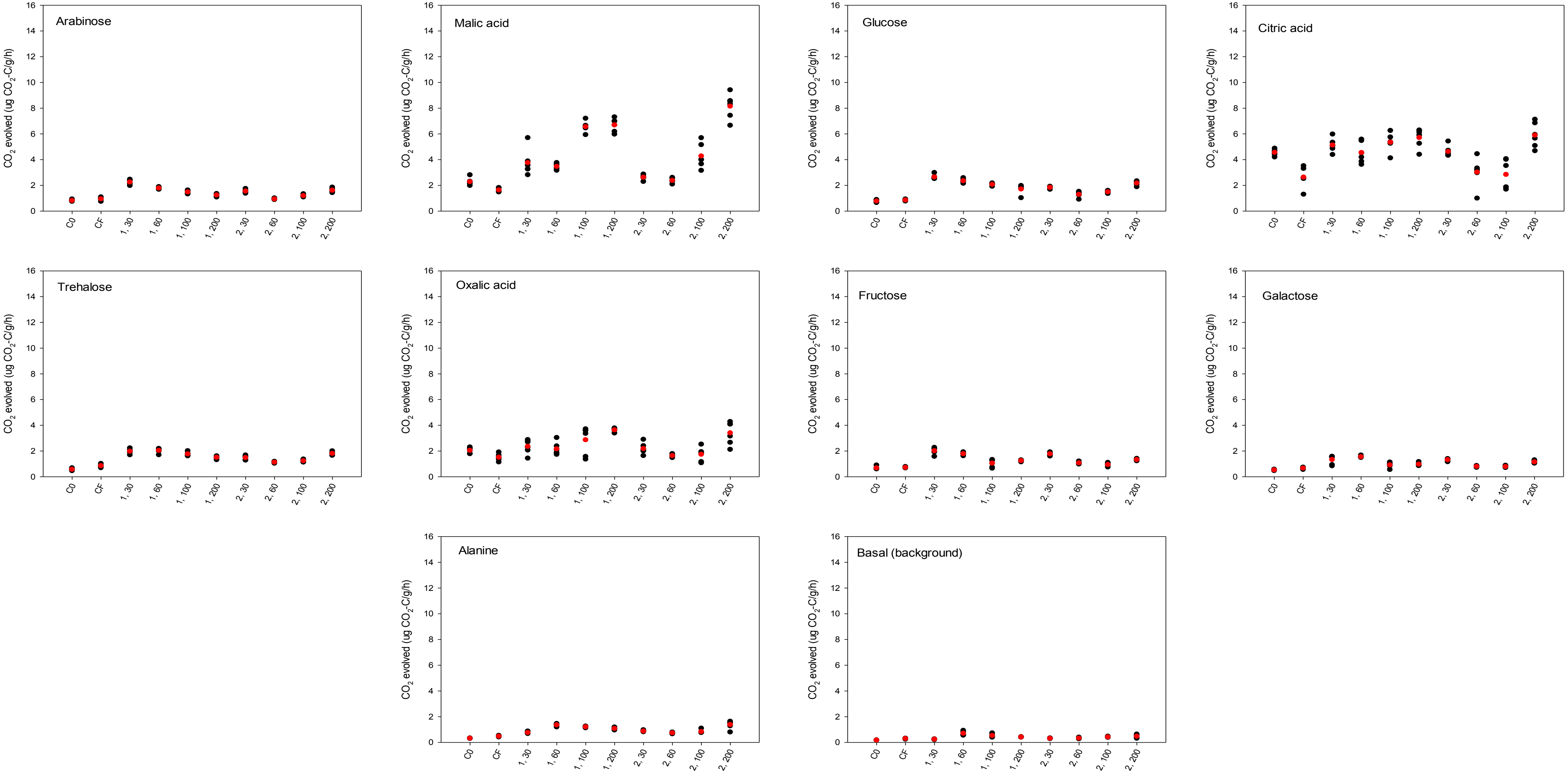
| **Trt** | **Depth** | **Al** | **As** | **Ca** | **Cd** | **Co** | **Cr** | **Cu** | **Fe** | **K** | **Mg** | **Mn** | **N** | **Na** | **Ni** | **P** | **Pb** | **S** | **Zn** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | % | mg/kg | % | mg/kg | mg/kg | mg/kg | mg/kg | % | % | % | mg/kg | % | % | mg/kg | % | mg/kg | % | mg/kg |
| **C** | 0-7.5 | 0.95 | 7.10 | 0.11 | 0.0740 | 15.5 | 20.0 | 15.0 | 2.70 | 0.10 | 0.07 | 1325 | 0.16 | 0.01 | 8.4 | 0.029 | 22.3 | 0.020 | 25.0 |
| **C** | 7.5-15 | 1.08 | 7.57 | 0.11 | 0.0611 | 15.3 | 20.5 | 15.0 | 2.93 | 0.10 | 0.08 | 1245 | 0.11 | 0.01 | 8.9 | 0.021 | 20.8 | 0.015 | 23.0 |
| **C** | 15-30 | 1.90 | 8.10 | 0.14 | - | 13.7 | 23.8 | 19.8 | 3.25 | 0.13 | 0.15 | 603 | 0.06 | 0.02 | 11.1 | 0.008 | 18.5 | 0.009 | 23.0 |
| **C** | 30-45 | 2.15 | 7.25 | 0.15 | - | 14.9 | 22.8 | 22.0 | 3.28 | 0.13 | 0.20 | 368 | 0.05 | 0.03 | 13.0 | 0.005 | 16.8 | 0.009 | 25.8 |
| **C** | 45-60 | 2.00 | 9.08 | 0.13 | - | 17.3 | 24.5 | 22.3 | 3.65 | 0.13 | 0.22 | 783 | 0.04 | 0.04 | 14.8 | 0.004 | 19.0 | 0.008 | 29.0 |
| **C** | 60-75 | 1.63 | 9.15 | 0.12 | - | 20.3 | 18.8 | 22.5 | 3.23 | 0.10 | 0.23 | 1248 | 0.03 | 0.05 | 15.8 | 0.003 | 19.0 | 0.007 | 31.3 |
| **C** | 75-90 | 1.60 | 8.17 | 0.12 | - | 14.0 | 16.7 | 24.3 | 3.10 | 0.11 | 0.26 | 587 | 0.02 | 0.09 | 15.0 | 0.005 | 16.3 | 0.006 | 37.3 |
| **MWOO 1 60** | 0-7.5 | 1.11 | 7.48 | 0.30 | 0.3850 | 15.8 | 22.0 | 43.5 | 2.80 | 0.12 | 0.09 | 1210 | 0.26 | 0.01 | 11.2 | 0.062 | 45.0 | 0.028 | 80.8 |
| **MWOO 1 60** | 7.5-15 | 1.16 | 8.48 | 0.15 | 0.1041 | 14.3 | 21.0 | 20.5 | 2.93 | 0.09 | 0.09 | 1135 | 0.11 | 0.01 | 9.2 | 0.026 | 24.3 | 0.018 | 30.5 |
| **MWOO 1 60** | 15-30 | 1.85 | 7.90 | 0.14 | - | 13.0 | 22.5 | 21.8 | 2.90 | 0.11 | 0.18 | 675 | 0.06 | 0.03 | 10.4 | 0.008 | 17.3 | 0.010 | 22.3 |
| **MWOO 1 60** | 30-45 | 2.53 | 8.88 | 0.15 | - | 14.0 | 24.3 | 25.3 | 3.25 | 0.15 | 0.26 | 503 | 0.06 | 0.05 | 14.0 | 0.005 | 17.3 | 0.012 | 26.0 |
| **MWOO 1 60** | 45-60 | 2.38 | 10.08 | 0.24 | - | 12.0 | 23.0 | 27.0 | 3.63 | 0.26 | 0.35 | 525 | 0.05 | 0.07 | 15.3 | 0.005 | 17.0 | 0.013 | 30.3 |
| **MWOO 1 60** | 60-75 | 2.35 | 7.85 | 0.58 | - | 9.5 | 20.3 | 25.0 | 3.13 | 0.36 | 0.46 | 368 | 0.04 | 0.09 | 13.7 | 0.003 | 15.3 | 0.012 | 32.5 |
| **MWOO 1 60** | 75-90 | 2.20 | 6.83 | 0.91 | - | 8.2 | 17.8 | 25.3 | 2.95 | 0.66 | 0.56 | 308 | 0.03 | 0.11 | 13.0 | 0.003 | 13.5 | 0.011 | 35.8 |
| **MWOO 1 100** | 0-7.5 | 1.10 | 7.70 | 0.39 | 0.5525 | 14.0 | 24.5 | 62.3 | 2.75 | 0.24 | 0.09 | 1100 | 0.31 | 0.01 | 12.5 | 0.067 | 59.8 | 0.034 | 112.8 |
| **MWOO 1 100** | 7.5-15 | 1.32 | 7.38 | 0.17 | 0.1395 | 13.7 | 18.5 | 26.0 | 2.58 | 0.11 | 0.10 | 1048 | 0.12 | 0.02 | 10.0 | 0.025 | 26.5 | 0.019 | 40.0 |
| **MWOO 1 100** | 15-30 | 1.88 | 8.08 | 0.14 | - | 11.6 | 22.3 | 23.0 | 3.15 | 0.11 | 0.18 | 485 | 0.05 | 0.03 | 10.2 | 0.006 | 17.0 | 0.012 | 22.8 |
| **MWOO 1 100** | 30-45 | 1.93 | 7.43 | 0.13 | - | 12.7 | 19.8 | 24.3 | 3.08 | 0.11 | 0.22 | 438 | 0.05 | 0.04 | 13.3 | 0.005 | 16.0 | 0.011 | 24.3 |
| **MWOO 1 100** | 45-60 | 2.15 | 7.63 | 0.12 | - | 14.0 | 20.0 | 23.3 | 2.98 | 0.13 | 0.26 | 558 | 0.04 | 0.05 | 13.8 | 0.004 | 16.0 | 0.011 | 27.0 |
| **MWOO 1 100** | 60-75 | 2.03 | 7.78 | 0.37 | - | 10.8 | 19.3 | 22.8 | 3.05 | 0.31 | 0.35 | 463 | 0.04 | 0.06 | 12.2 | 0.003 | 16.5 | 0.009 | 29.0 |
| **MWOO 1 100** | 75-90 | 1.63 | 7.17 | 0.69 | - | 8.1 | 15.7 | 23.0 | 2.80 | 0.53 | 0.40 | 345 | 0.04 | 0.07 | 10.2 | 0.004 | 13.7 | 0.007 | 30.3 |
| ***l.s.d.:*** | | | | | | | | | | | | | | | | | | | |
| ***rate*** | | ***0.28*** | ***0.75*** | ***0.17*** | ***0.1002*** | ***2.0*** | ***1.8*** | ***5.4*** | ***0.25*** | ***0.11*** | ***0.08*** | ***237*** | ***0.04*** | ***0.02*** | ***1.5*** | ***0.011*** | ***6.2*** | ***0.004*** | ***11.8*** |
| ***depth*** | | ***0.24*** | ***1.12*** | ***0.24*** | ***0.1459*** | ***3.2*** | ***2.4*** | ***7.3*** | ***0.35*** | ***0.15*** | ***0.09*** | ***286*** | ***0.03*** | ***0.02*** | ***1.6*** | ***0.008*** | ***6.1*** | ***0.003*** | ***13.3*** |
| ***rate x depth*** | | ***0.13*** | ***0.72*** | ***0.15*** | ***0.0293*** | ***1.8*** | ***1.6*** | ***2.1*** | ***0.24*** | ***0.09*** | ***0.06*** | ***178*** | ***0.01*** | ***0.01*** | ***1.0*** | ***0.004*** | ***2.3*** | ***0.001*** | ***3.7*** |

*Values are averages of four replicates. Included also are the l.s.d. values (in bold type) for the rate, depth and rate x depth interactions for element following analysis of variance at p<0.05. - = not detected; MWOO = mixed solid waste from sources 1; C = control. Depth increments and application rates (dry t/ha) indicated for each treatment; - = not detected.*

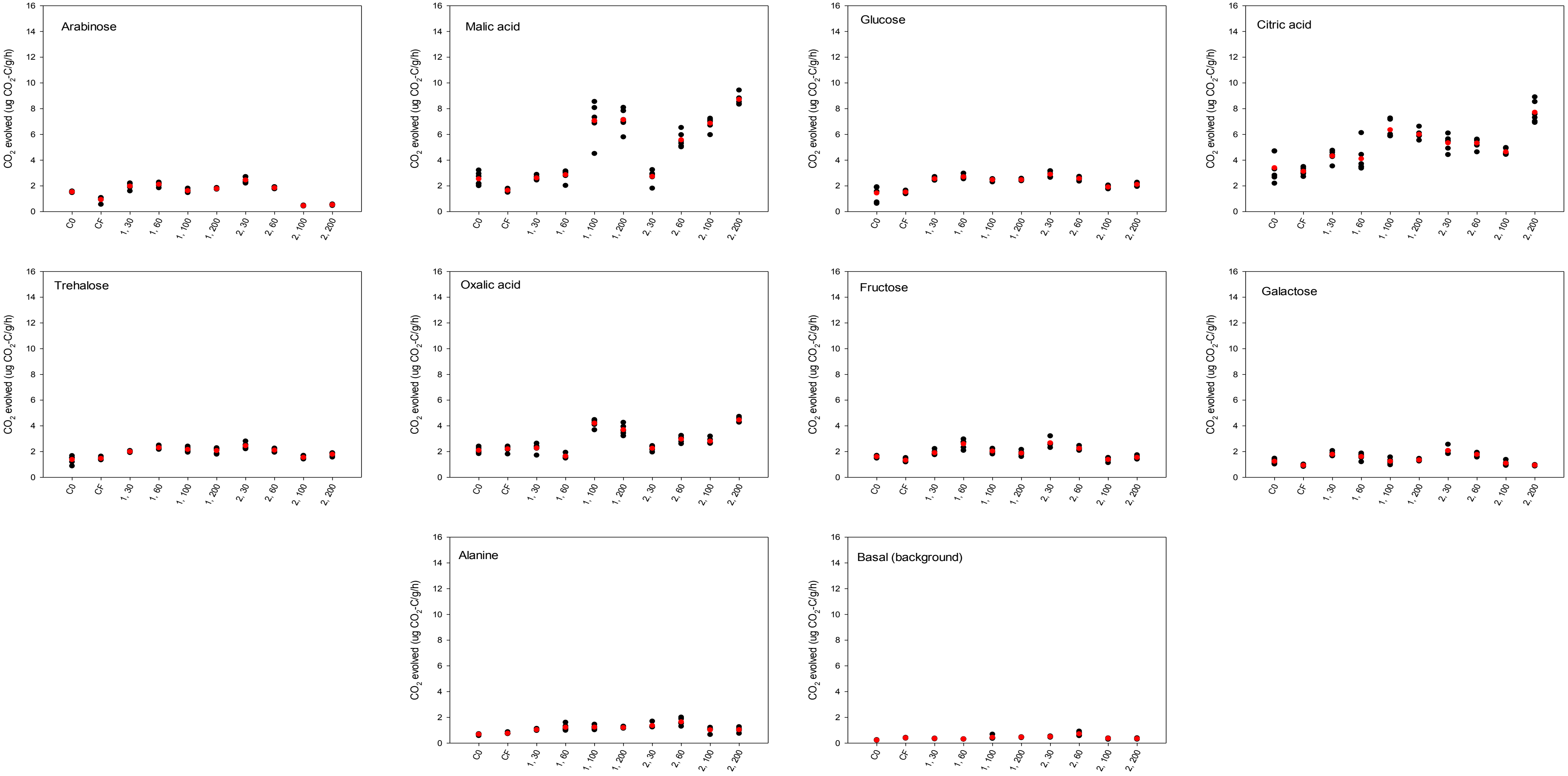
**Appendix 17a:** MicroResp output table T0. The effect of increasing rates of MWOO application (1 and 2) on soil microbial respiration (CO2 evolved [µg CO2 C/g/h]) for soils incubated with different carbon sources during the MicroResp procedure experiments. Average of 5 replicates indicated by ●. Soils were sampled from the field trial site at time T0. The C source respiration is compared to basal or background respiration levels (no sugar added). Carbon sources were; Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose, Alanine; while the background or basal level was measured after incubating soil with water. Treatment (x-axis) CO =control; 1, = MWOO 1; 2, MWOO 2; 30, 60, 100 and 200 = MWOO application rates (t/ha).



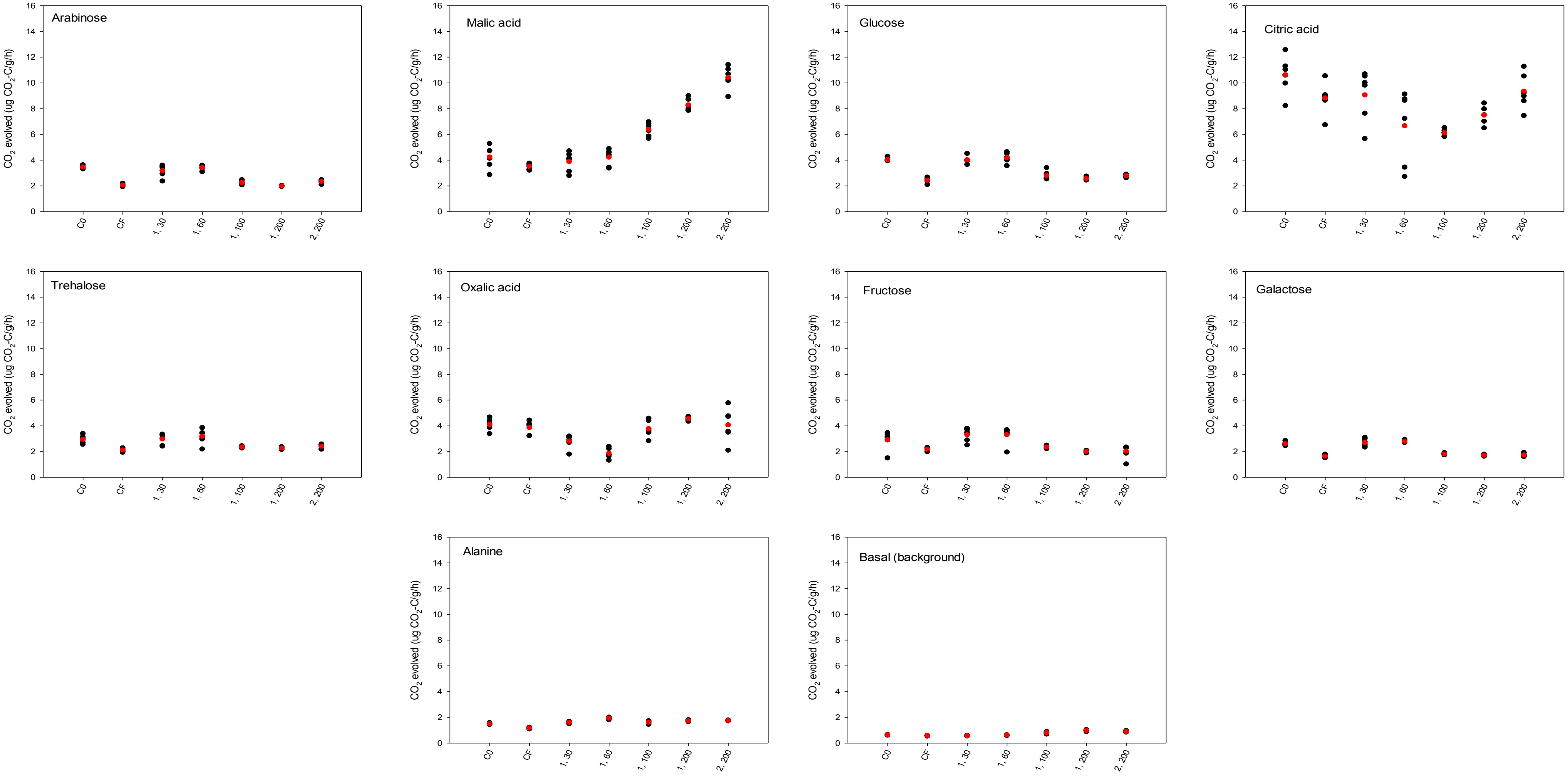
**Appendix 17b**: MicroResp output table T1. The effect of increasing rates of MWOO application (1 and 2) on soil microbial respiration (CO$_2$ evolved [µg CO$_2$ C/g/h]) for soils incubated with different carbon sources during the MicroResp procedure experiments. Average of 5 replicates indicated by ● . Soils were sampled from the field trial site at time T1. The C source respiration is compared to basal or background respiration levels (no sugar added). Carbon sources were; Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose, Alanine; while the background or basal level was measured after incubating soil with water. Treatment (x-axis) CO =control; CF = control fertilizer; 1, = MWOO 1; 2, MWOO 2; 30, 60, 100 and 200 = MWOO application rates (t/ha).



**Appendix 17c:** MicroResp output table T2. The effect of increasing rates of MWOO application (1 and 2) on soil microbial respiration ($CO_2$ evolved [µg $CO_2$ C/g/h]) for soils incubated with different carbon sources during the MicroResp procedure experiments. Average of 5 replicates indicated by●. Soils were sampled from the field trial site at time T2. The C source respiration is compared to basal or background respiration levels (no sugar added). Carbon sources were; Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose, Alanine; while the background or basal level was measured after incubating soil with water. Treatment (x-axis) CO =control; CF = control fertilizer; 1, = MWOO 1; 2, MWOO 2; 30, 60, 100 and 200 = MWOO application rates (t/ha).



**Appendix 17d:** MicroResp output table T3. The effect of increasing rates of MWOO application (1 and 2) on soil microbial respiration ($CO_2$ evolved [µg $CO_2$ C/g/h]) for soils incubated with different carbon sources during the MicroResp procedure experiments. Average of 5 replicates indicated by●. Soils were sampled from the field trial site at time T3. The C source respiration is compared to basal or background respiration levels (no sugar added). Carbon sources were; Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose, Alanine; while the background or basal level was measured after incubating soil with water. Treatment (x-axis) CO =control; CF = control fertilizer; 1, = MWOO 1; 2, MWOO 2; 30, 60, 100 and 200 = MWOO application rates (t/ha).



**Appendix 18**: MicroResp canonical variate analysis output table T0 – T3 for MWOO and control treatments. Arrows illustrate treatments that are statistically different from the control for each sampling, in terms of the combined utilisation of the range of applied C sources; Arabinose, Malic acid, Glucose, Citric acid, Trehalose, Oxalic acids, Fructose, Galactose and Alanine. Treatments indicated by CO =control; CF = control fertilizer; 1, = MWOO 1; 2, MWOO 2; 30, 60, 100 and 200 = MWOO application rates (t/ha).