Persistent Herbicides Risk Management Program

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Research report and recommendations

Department of
Environment and Conservation (NSW)

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Table of Contents

Executive Summary

The Department of Environment and Conservation (NSW) has funded a *Persistent Herbicides Risk Management Program* to identify and minimise risk to commercial horticultural industries and the recycled organics industry from three specific herbicides that have the potential to persist in compost products.

This risk management program was undertaken by the Recycled Organics Unit and comprised three stages:

- A risk assessment to identify problematic compounds;
- A risk management tools package to assist industry in managing potential risks; and
- An applied composting trial to determine the degradation of potentially problematic herbicides in commercial compost.

This report details the findings from the applied composting trial to confirm the persistence or otherwise of three specific herbicides: clopyralid, picloram and triclopyr.

An applied composting trial of domestic garden organics material was conducted over a 16 week composting period. Composting methods were consistent with commercial industry management practices, and the best practice guidelines specified in AS 4454 (Standards Australia, 2003b). The results of the trial identified that:

- The herbicides *clopyralid* and *picloram* were found to persist after composting and were present in the composted material at concentrations high enough to cause significant damage to sensitive plants.
- The herbicide *triclopyr* was sufficiently degraded under commercial composting conditions to a level that would not damage sensitive plants.

Compounds known to persist after undergoing composting, including the herbicides clopyralid and picloram, may impact on the recycled organics industry and a range of intensive horticulture industries that use recycled organics products. The presence of these herbicides has resulted in economic damage to crops overseas, and has the potential to undermine public confidence in composted products.

A discussion paper with recommended options for addressing this issue is provided in Section 4 of this report.

Section 1 About this report

1.1 Objectives of the report

The New South Wales State Government has supported the development of the recycled organics industry, and is reliant on the viability of this industry to achieve stated Government objectives regarding ecologically sustainable development through the diversion of compostable organic materials from landfill. The presence of residual garden maintenance chemicals in recycled organics products manufactured from garden organic material has the ability to undermine public confidence in such products, in addition, particular residual herbicides can cause damage to crops. As the diversion of materials from landfill is dependent upon markets for recycled products, the presence of such chemicals in recycled organic products could provide a barrier to the achievement of Government resource recovery targets. The Department of Environment and Conservation (Sustainability Programs Division) has funded a program to identify and minimise any risk to the recycled organics industry from persistent herbicides in compost. This program, undertaken by the Recycled Organics Unit, is the *Persistent Herbicides Risk Management Program* and has comprised of three stages:

1. The first stage of the *Persistent Herbicides Risk Management Program* was a risk assessment to identify the type and range of garden maintenance chemicals available in New South Wales on the domestic market. The report, titled “Risk Assessment of Garden Maintenance Chemicals in Recycled Organics Products” (Recycled Organics Unit, 2002), identified from the chemicals available on the domestic market, those deemed potentially persistent and considered to be a potential risk to the industry and therefore requiring further investigation.

2. The second stage of this program involved the development of a short-term range of resources and services to manage the potential risks posed by these potentially persistent herbicides. The report “Risk Management Tools for the Recycled Organics Industry” (Recycled Organics Unit, 2003c) was developed as a guide for the industry to manage potential risks to the extent possible, whilst longer term and sustainable resolution of the issue was also addressed.

The potentially problematic herbicides identified by the first two stages of the program included the two herbicides known to cause damage to composting industries internationally, clopyralid and picloram, and a third similar compound, triclopyr. Whilst no evidence of any herbicide contamination issues in commercial composts manufactured in New South Wales (or Australia) have been reported, this program has addressed the issues to ensure that the problems experienced overseas are not repeated in Australia.

3. The third stage of this program involves an applied composting trial to evaluate the degradation of the identified herbicides under Australian industry best practice composting conditions to determine whether they pose a threat to the industry. The results of this trial will guide a discussion paper for the registration of herbicides in Australia to include a requirement for degradation under commercial composting conditions, to minimise potential effects on the recycled organics industry, and a range of horticultural industries.

The objectives of this project are to:

- To undertake an applied composting trial that simulates commercial composting conditions to determine whether the herbicides clopyralid, picloram and triclopyr persist after undergoing composting.
- To determine whether these herbicides may persist in the commercial compost process.
- To review the regulatory framework for the registration of agricultural chemicals in relation to biodegradability criteria, particularly in relation to biodegradation in the commercial composting system.

1.2 Who is the report for?

This report has specifically been developed for the Department of Environment and Conservation (NSW) to support the development of initiatives and programs to maintain the viability of current markets and assist with development of new markets for recycled organic products.

This report will be of direct interest to:

- Government and chemical regulation agencies
- Manufacturers of recycled organics products
- Recycled organics industry associations
- Marketers of recycled organics products
- Researchers
- Agro-chemicals industry
- Industry consultants
- Waste educators
- Non-government environment organisations

1.3 How to use the report

The report is designed to provide an overview of the persistent herbicides risk management program.. The report provides an overview of the recycled organics industry and the potential impacts that may be caused by the persistent herbicides identified (Section 2). The program undertaken by the Recycled Organics Unit to identify and evaluate the persistence of these herbicides under Australian commercial composting conditions is summarised in Section 3. Section 3 details the project report including methodology, results and a discussion of the report findings.

Conclusions and recommendations are provided in Section 4, this section also details the background to the issue and the research and development has been performed to date to provide a stand-alone discussion paper in refining the herbicides registration process and reviewing the registration of herbicides of known persistence.

Recommendations are provided as well as a list of resources available to avoid and manage the risks from these compounds. This document should be used as a valuable information resource to provide an overview of the risk to industry from these persistent herbicides, and options to avoid impacts on the recycled organics industry and the commercial horticulture sector.

1.4 Terminology

Terms used throughout this report have been officially adopted by the NSW Waste Boards in July 2000 in the form of the Recycled Organics Dictionary and Thesaurus: Standard terminology for the New South Wales recycled organics sector, Second Edition (Recycled Organics Unit, 2003b). This document can be freely downloaded from www.recycledorganics.com.

Where possible, nationally accepted terms have been used in the preparation of this report. Definitions for key terms in the text are provided in the Glossary (Appendix 1).

1.5 How to cite the report

This publication should be cited in the following manner:

Recycled Organics Unit (2004). *Persistent Herbicides Risk Management Program: Research Report and Recommendations.* Report prepared for the Department of Environment and Conservation (NSW, Sustainability Programs Division) by the Recycled Organics Unit, The University of New South Wales, Sydney, Australia.

1.6 Acknowledgement

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- Mr Rob Niccol of Australian Native Landscapes for supplying a significant quantity of compostable organic materials for this trial and his advice in regard to commercial composting operations.

- Dr Marie Hendriks and the team at ViroLab Analytical Services for all their hard work developing the method for acid herbicide detection in compost and reporting results to the very low detection levels (1 ppb) required for this trial.

Section 2 Introduction to the recycled organics industry and potentially persistent herbicides

2.1 The Recycled Organics Industry

The Recycled Organics industry in New South Wales is a growing industry that produces a range of recycled organics products mostly from municipally collected garden organics material. The past ten years has seen significant growth and development in the industry due to Government policies requiring the diversion of garden organics material from landfill to improve resource management and ecologically sustainable development. The New South Wales Government has supported the development of markets for products containing recycled organics and consequently it is prudent to exhibit a proactive response to this issue in order to avoid impacts on current and potential new markets.

2.2 Potentially persistent herbicides

The herbicides clopyralid, picloram and triclopyr were identified as potentially persistent after undergoing composting and therefore considered to an issue for the recycled organics industry in Australia (Recycled Organics Unit, 2002). These herbicides are all pyridine-based compounds that act by mimicking plant growth hormones called auxins. An overview of each of these herbicides is given below.

2.2.1 Clopyralid

2.2.1.1 General properties and mode of action

Clopyralid is a pyridine carboxylic acid herbicide used to control annual and perennial broadleaf weeds in turf, pastures and some agricultural crops such as wheat, barley, oats, sugar beets, and mint. Clopyralid is a synthetic plant growth hormone that has some structural similarities to naturally occurring hormones called auxins. Clopyralid is more persistent in plant tissue than auxins. It disrupts plant growth by binding to molecules that are normally used as receptors for the natural growth hormones (auxins) causing abnormal growth leading to plant death within a few days or weeks depending on the species (Cox, 1998a).

Table 1: General chemical properties of clopyralid. (Source: Cox, 1998a; Bezdicek *et al.*, 2001; Tomlin, 1997; Vogue *et al.*, 1994).

Chemical name (IUPAC*)	Formula	Half-life (days)	Solubility in water	Volatility	K_{OC}**
3,6-dichloropyridine-2carboxylic acid	$C_6H_3Cl_3N_2O_2$	56 – 392	7.85 g/L (at 20^{o}C) ***	Considered volatile by US EPA	6 (indicates mobility)

* International Union of Pure and Applied Chemistry; **K_{OC} is the tendency of a pesticide to bind to soil particles, *** Very soluble as compared to Picloram (Table 2) and Triclopyr (Table 3).

2.2.1.2 Movement and degradation

Clopyralid is very soluble (see Table 1) and is considered by the US EPA to be very mobile in soil (Cox, 1998a). Therefore clopyralid has the potential to leach to ground water and/or contaminate surface water (Cox, 1998a). Cox (1998a) also reports that the US EPA lists clopyralid as a volatile substance indicating that it can evaporate from foliage and soil after application, move away from the application site and may adversely affect non-target broadleaf plants. Volatilisation of as low as one percent of applied clopyralid would be enough to damage non-target plants (Cox, 1998a). Clopyralid is stable to light (Tomlin, 1997).

Herbicides in the pyridine carboxylic acid group, which also includes picloram and triclopyr, breakdown very slowly (Bezdicek *et al.*, 2001). When ingested by animals, these compounds pass quickly through the animal into the urine and pass out of the animal without significant degradation (Bezdicek *et al.*, 2000).

Clopyralid is considered persistent in the soil (Table 1) with a reported half-life of up to 392 days (Cox, 1998a). Tu *et al.* (2001) summarise that clopyralid is degraded primarily by microbes in soils and aquatic sediments. Pik *et al.* (1977) investigated the fate of clopyralid in soil and found that degradation rates were fastest in moist soils and were inversely related to the organic carbon content of the soil. Furthermore, the rate of degradation was greatly reduced during dry and cold periods. No metabolites accumulate during the degradation process and therefore no additional contamination of the environment occurs (Pik *et al.*, 1977). Clopyralid is not susceptible to photo-degradation (Tu *et al.*, 2001).

2.2.1.3 Plant uptake and toxicity

Clopyralid is not metabolised in plants (Tomlin, 1997). Plants subjected to clopyralid may appear almost normal but there is generally a loss of apical dominance that is likely to prevent fruit set. Leaves may become compounded instead of single and side shoots may develop where they should not. Cupping of the leaves is also a typical symptom for legumes (Bezdicek *et al.*, 2001). Typical plant damage caused by clopyralid can be seen in Figure 1.

Figure 1. Photographs of typical growth-regulator type herbicide damage to plants. Damage includes cupping and twisting of leaves and stem distortion (Bezdicek *et al.*, 2000; Rynk, 2000).

Crops most susceptible to clopyralid can be sensitive at the part per billion (ppb) level, that is, very low concentrations of clopyralid (e.g. 1 ppb) can cause damage to plants. Plant families sensitive to clopyralid (Dow AgroSciences, no date-b) include:

- Legumes: peas, beans, lentils clover
- Solanaceous: potatoes, tomatoes
- Asteraceae: sunflower, thistle, dandelion

Clopyralid has contaminated the composting stream via a number of sources. Some of these include lawn clippings, garden organics, leaves, straw (wheat, barley, oats and grass seed), mint sludge, manure (beef cattle, chicken, dairy cattle, feedlot and horse), spent mushroom media, and timothy hay (Rynk, 2002a; Fietje, 2001; Bezdicek *et al.*, 2000).

2.2.2 Picloram

2.2.2.1 General properties and mode of action

Picloram is a pyridine herbicidal compound formulated as an acid (technical product), potassium or triisopropanolamine salt, or an isooctyl ester. Picloram is available as soluble concentrates, pellets or granular formulations (Extension Toxicology Network, 2002). Picloram is a systemic herbicide used for control of woody plants and a wide range of broadleaf weeds on pastures, rangeland, reforestation programs, uncultivated areas, and along rights-of-way (Cox, 1998b).

Picloram kills plants by acting like plant growth hormones or auxins. Picloram is more persistent than auxins. This compound inhibits the enzymes that normally break down auxins resulting in the disruption of normal plant growth and causing abnormal stimulation and maturation of tissues. Plant growth stops and the roots of the plants deteriorate, resulting in death (Cox, 1998b). Typical plant damage caused by picloram can be seen in Figure 1. Some general chemical properties of picloram are shown in Table 2.

Table 2: General chemical properties of picloram. (Source: Extension Toxicology Network, 2002; Bezdicek *et al.*, 2001; Tomlin, 1997; Vogue *et al.*, 1994).

Chemical name (IUPAC*)	Formula	Half-life (days)	Solubility in water	Volatility	K_{OC}**
4-amino-3,5,6-trichloropyridine-2-carboxylic acid	$C_6H_3Cl_2NO_2$	20 – 300	0.43 g/L (at 25°C)	Practically nil	16 (indicates mobility)

* International Union of Pure and Applied Chemistry; **K_{OC} is the tendency of a pesticide to bind to soil particles.

2.2.2.2 Movement and degradation

Increasing soil organic matter increases the adsorption of picloram. Picloram is poorly bound to soils, however, higher proportions of soil organic matter will result in an increase in soil residence time (Extension Toxicology Network, 2002). Picloram acid and salts are highly soluble in water indicating that this herbicide is extremely mobile under field conditions (Cox, 1998b). Picloram is considered persistent in soil (Table 2) with a reported half-life of up to 300 days (Extension Toxicology Network, 2002).

The combination of high water solubility, poor soil adsorption and the persistence of picloram indicate that this herbicide may pose a risk to groundwater contamination (Extension Toxicology Network, 2002). Volatilisation of picloram is practically nil (Extension Toxicology Network, 2002).

Herbicides in the pyridine carboxylic acid group, which also includes clopyralid and triclopyr, breakdown very slowly. When ingested by animals, these compounds pass quickly through the animal into the urine and pass out of the animal without significant degradation (Bezdicek *et al.*, 2000).

Picloram is readily degraded when exposed to sunlight in water or on the surface of plant foliage and soils. Photo-degradation occurs most rapidly in clear, moving water (Weed Science Society of America, 1994) and slowly when exposed on the soil surface (Tu *et al.*, 2001).

Microbial degradation of picloram is generally slow, however, this is believed to be the major pathway of picloram degradation in soils. The primary metabolites produced during microbial degradation are degraded through microbial metabolism more rapidly than the parent compound (Weed Science Society of America, 1994). The Weed Science Society of America (1994) also reports that conditions that favour microbial activity such as high soil moisture and temperature can increase the rate of microbial degradation of picloram. However, these conditions are present during composting and picloram is known to be highly persistent after composting of picloram-contaminated materials.

2.2.2.3 Plant uptake and toxicity

Picloram is readily absorbed by plant roots, less so by the foliage, and is readily translocated throughout the plant (Extension Toxicology Network, 2002). Metabolism of picloram in plants tends to vary between literature sources. The Extension Toxicology Network (2002) states that picloram remains stable and intact within the plant whilst Cox (1998b) reports that picloram is slowly metabolised by plants into water-soluble compounds. Another report indicates that picloram is metabolised or broken down by plants into carbon dioxide, oxalic acid, 4-amino-2,3,4-trichloropyridine and 4-amino-3,5-dichloro-6-hydroxypicolinic acid (Information Ventures, 2002). The Weed Science Society of America (1994) summarise that picloram is either rapidly metabolised in non-susceptible species such as grasses, or remains intact for extended periods in susceptible species such as broadleaf plants.

Plant species susceptible to picloram absorb more of the herbicide than resistant plants (Cox, 1998b). Picloram tends to accumulate in the meristematic (growing) tissues of the plant (Cox, 1998b; Tomlin, 1997). Tu *et al.* (2001) report that 70-90% of picloram remains in the leaves when applied to foliage and only a small percentage is distributed to stems and roots. Picloram absorbed by plants can be released into the soil by passive transport through the roots and taken up by the roots of nearby plants. Consequently, even selective application of picloram to specific target plants could potentially harm nearby desirable plants (Tu *et al.*, 2001).

Symptoms of picloram plant injury include leaf cupping and distortion of stems. Picloram can be damaging to sensitive plants such as tomatoes, beans and peas at concentrations of as low as 0.3 ppb (Rynk, 2000). Picloram can undergo photodecomposition on plant surfaces, possibly resulting in cleavage of the pyridine ring (Tomlin, 1997).

Raw materials accepted at international composting facilities that have been contaminated with picloram include barley, manure (beef cattle, dairy cattle and horse) and timothy hay (Rynk, 2002a). There is the potential for picloram contamination of lawn clippings due to the use of this chemical on grassland and non-crop areas (Tomlin, 1997).

2.2.3 Triclopyr

2.2.3.1 General properties and mode of action

Triclopyr is a pyridine compound similar to clopyralid and picloram. Triclopyr is a selective systemic herbicide generally used for the control of woody and broadleaf plants typically along rights-of-way, in forests, industrial lands, grasslands and parks (Cox, 2000). Triclopyr acts by imitating a plant hormone called indoleacetic acid, which is one of a number of plant hormones classified as auxins. Some general chemical properties of triclopyr are shown in Table 3.

Table 3: General chemical properties of triclopyr. (Source: Vogue *et al.*, 1994; Tomlin, 1997; Information Ventures, 2002; Extension Toxicology Network, 2002)

Chemical name (IUPAC*)	Formula	Half-life (days)	Solubility in water	Volatility	K_{OC}**
3,5,6-trichloro-2-pyridyloxyacetic acid	$C_7H_4Cl_3NO_3$	30 – 90	0.108 g/L (at 20°C)	Very low	20 (indicates mobility)

* International Union of Pure and Applied Chemistry; **K_{OC} is the tendency of a pesticide to bind to soil particles.

2.2.3.2 Movement and degradation

Herbicides in the pyridine carboxylic acid group, which also includes clopyralid and picloram, breakdown very slowly. When ingested by animals, these compounds pass quickly through the animal into the urine and pass out of the animal without significant degradation (Bezdicek *et al.*, 2000).

The two formulations of triclopyr, triethylamine salt and butoxyethyl ester degrade to the parent compound triclopyr acid in soils. Degradation occurs primarily through microbial metabolism, however, degradation by photolysis and hydrolysis can also be important (Tu *et al.*, 2001). Triclopyr ester formulations can be highly volatile with the potential for volatilisation increasing with increasing temperature and soil moisture. The compounds bind readily to soil and therefore the tendency for volatilisation is reduced with high clay and organic matter content (Tu *et al.*, 2001). Ester and salt formulations of triclopyr are readily degraded in sunlight.

Microbial degradation accounts for a significant percentage of triclopyr degradation in soils. Generally, warm, moist soils with high organic matter content support the largest microbial populations and the highest rates of herbicide metabolism (Newton *et al.*, 1990). This may also be true for composting.

2.2.3.3 Plant uptake and toxicity

Triclopyr is absorbed by green bark, leaves and roots and moves throughout the plant accumulating in the meristem (growth region) (Information Ventures, 2002). Triclopyr causes the growing tips of a plant to elongate and become distorted resulting in withering of the plant and finally death. Triclopyr is selective, being mostly toxic to broadleaf plants, as grasses are quickly able to transform triclopyr into compounds that do not have hormonal activity (Cox, 2000).

The ester and salt formulations of triclopyr are hydrolysed to the acid form after entering plant tissue (Tu *et al.*, 2001). Triclopyr soil residues can also cause damage to non-target plants via root uptake (Newton *et al.*, 1990).

Section 3 Potentially persistent herbicides in commercial compost

3.1 Introduction

Recent reports from particular territories in the United States (USA) and in New Zealand (NZ) have revealed the impact that a small number of persistent herbicides are having on the quality of recycled organics products (Büyüksönmez *et al.*, 1999; Bezdicek *et al.*, 2001; Fietje, 2001). Many chemicals are known to break down during the hot composting process, however, three specific herbicidal chemicals have been shown to be potentially persistent beyond the commercial composting process, and to carry over into final products (Recycled Organics Unit, 2002; Vandervoort *et al.*, 1997). These three chemicals, picloram, clopyralid and triclopyr, are characterised as pyridine-based compounds, and the persistence of the picloram and clopyralid compounds has caused commercial impacts on the organics processing enterprises and the confidence of agricultural markets in these overseas territories.

Bench-scale trials have been published that do not accurately represent the conditions of a commercial-scale composting facility (e.g. Vandervoort *et al.*, 1997). Consequently, a full-scale commercial composting operation will be simulated to quantify the potential persistence or otherwise of clopyralid, picloram and triclopyr in commercially manufactured composts. This trial was conducted at a commercial scale under best practice industry management practices and Australian commercial composting conditions and was directly relevant to the recycled organics industry in Australia.

3.1.1 Overview

This study was undertaken in three stages:

Stage 1 consisted of an industry survey that documented standard industry management practices and identified a suitable composting recipe for the trial, including the proportion of lawn clippings in the raw materials used for composting. The survey completed by industry representatives is attached as Appendix 2.

Stage 2 involved a lawn grass pot trial that was conducted to determine the residual concentration of the herbicides in lawn clippings. The results were combined with the information obtained from Stage 1 and provided estimates of the potential range of these herbicides that may be present in fresh garden organics materials accepted at commercial composting facilities. The residual concentrations of these herbicides in lawn clippings were used to determine the quantity of herbicides to be used in raw materials for Stage 3.

Stage 3 was undertaken as an applied composting trial that involved shredded garden organics treated with the herbicides (determined in Stage 2) and formed into windrows for composting. The windrows were managed according to commercial industry practice as determined in Stage 1. Samples from the windrows were taken throughout the trial to determine the residual concentration of herbicides in the composted product. Persistence of the herbicides was assessed at a high and low application rate.

3.1.2 Acknowledgement

The research plan was peer reviewed by a wide range of stakeholders from the recycled organics industry in Australia. Feedback from these stakeholders was incorporated into the research methodology. The following contributors are thanked for their feedback:

- Dr Mark Jackson, Department of Environment and Conservation (NSW)
- Dr Kevin Wilkinson, Team Leader, Resource Recovery and Recycling, Department of Primary Industries, Institute for Horticultural Development
- Mr Ian Pitt, Chemical Assessment Section, Environment Australia
- Environmental Risk Assessment Unit, NSW EPA
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- Mr Bob Paulin, WA Agriculture
- COMPOST Australia
- COMMPOST NSW. The following specific members of the COMMPOST NSW committee; Australian Native Landscapes, Bedminster Bioconversions, Global Renewables Ltd, SAI Global.

In addition, the trial design was reviewed by Ms Sue Middleton, Associate Lecturer, School of Mathematics, The University of New South Wales.

3.2 Stage 1: National Industry Survey

A survey of Australian commercial composting facilities was performed to obtain information on standard Australian composting industry practice. This survey was conducted to inform *Stage 3: Applied Composting Trial* (Section 3.4) in order to undergo composting operations at standard operating procedures.

The survey was provided to licensed compost manufacturers who produce various composts in accordance with the relevant Australian Standard AS 4454 (Standards Australia, 2003b). This survey allowed a definition of standard industry management practice, processing duration and provided data on the type and proportions of raw material inputs in composting windrows.

3.2.1 Method

The industry survey was supplied to composting facilities across Australia who produce composts in accordance with the relevant Australian Standard AS 4454 (Standards Australia, 2003b). The survey involved written response to a number of questions requiring estimations of duration of composting process, operating procedures, moisture content and proportions of raw material inputs. Responses to the surveys were confidential. The survey is included as Appendix 2.

3.2.2 Results

The survey provided a guide to industry-standard processing time and moisture content that was used for *Stage 3: Applied Composting Trial*. The results from the survey applicable to the commercial trial are shown in Table 4.

The average processing time for commercial facilities was found to be 16 weeks for standard windrow composting operations. The frequency of turning averaged once every three weeks and moisture content was maintained between 45 and 55% according to the facilities surveyed. Lawn clippings were estimated to represent 40% (Summer average, by volume) of the compostable organics stream accepted at commercial facilities.

Table 4. Commercial industry management practices as determined by the *Industry Survey* (Stage 1).

Parameter	Industry standard
Lawn clippings as a percentage of total compostable organic material stream	40% (Summer average, by volume)
Moisture content	50% ± 5%
Turning frequency	3 weeks
Processing time period	16 weeks

3.3 Stage 2: Lawn Grass Pot Trial

A small-scale lawn grass pot trial was conducted in a greenhouse to determine approximate herbicide application rates to inform *Stage 3: Applied Composting Trial* (Section 3.4). This trial provided information on the residual concentrations of the potentially persistent herbicides, clopyralid, picloram and triclopyr, after use on lawns. Herbicide was applied to pots of established lawn according to recommended application rates and the grass was allowed to continue to grow for two weeks. Grass was harvested after two weeks growth and analysed for applied herbicides. This residual concentration of the herbicides present in the lawn clippings was used as an indicator of potential herbicides present in lawn clippings accepted at commercial composting facilities for processing.

3.3.1 Method

3.3.1.1 Lawn establishment and herbicide application

Kikuyu (*Pennisetum clandestinum*) lawn grass was established in 400 mm diameter (25 L) garden pots containing AS 3743 (Standards Australia, 2003a) certified potting mix as shown in Plate 1. The lawn grass was established in 12 pots in a greenhouse at The University of New South Wales, Kensington Campus. The greenhouse was evenly ventilated and shaded. The grass was allowed to establish for nine weeks (Plate 2) and subsequently trimmed to a blade length of 45 mm prior to herbicide application (Plate 3).

Plate 1. Turf was cut to size and placed in pots with AS 3743 certified potting mix. Pots were located in a greenhouse.

Plate 2. Lawn was established for nine weeks to allow sufficient development of the root system.

Plate 3. The lawn was trimmed to a blade length of 45 mm after nine weeks establishment prior to herbicide application.

The herbicides were applied at application rates according to Table 5. These application rates were derived from the suggested application rates provided by the labels of equivalent or similar products available in the United States. Application rates for lawns are not specifically available for the Australian products, as the herbicides are not currently registered (with the exception of clopyralid) for use as lawn herbicides. The herbicides were diluted in 50 mL of water and applied as a fine mist to the lawn surface (Plate 4). Herbicide application was performed in an isolated area away from the greenhouse to prevent cross-contamination.

All three herbicide treatments and the control treatment were replicated three times to compare lawn growth. The pots were placed randomly in the greenhouse and managed under constant conditions for two weeks (Plate 5). The location of the pots was not altered for the duration of the trial.

Table 5. Herbicide application rates.

Herbicide	Product	Application rate (L/ha)
Clopyralid	Lontrel Herbicide (Dow AgroSciences)	0.7
Picloram	Tordon 75-D Herbicide (Dow AgroSciences)	4.7
Triclopyr	Garlon 600 Herbicide (Dow Agrosciences)	4.7

3.3.1.2 Harvesting of lawn clippings and laboratory analysis

Lawn clippings were harvested using hand-held grass shears two weeks after herbicide application (Plate 6). Lawn clippings were harvested to a blade length of 45 mm. The harvested lawn clippings from the pots for each treatment were combined to form a composite sample. Samples were weighed and sent to the laboratory immediately under refrigerated conditions. Laboratory analysis was performed by ViroLab Analytical Services.

The laboratory blended (size-reduced) each sample and mixed the material to form a homogeneous sample ensuring the results were representative of the entire sample provided. A random sub-sample of approximately 50 g was taken from the homogenised sample for the analysis.

The herbicides were extracted from the sub-sample using an appropriate solvent and the extract was passed through a solid phase extraction cartridge to concentrate the extract. This process removed contaminants such as amino acids that are commonly found in plant materials and can interfere with accurate detection of the relevant herbicide compounds. The extract was injected into a liquid chromatography/mass spectrometry (LC/MS) instrument for analysis. Standard herbicide solutions of known concentrations (spikes) as well as blank samples were run through the instrument allowing the unknown concentration of herbicide in the sample to be determined (Dr Marie Hendriks, ViroLab Analytical Services, pers. comm.).

Plate 4. Herbicide was applied to the lawn using a fine mist. Application was performed in an isolated region away from the greenhouse to prevent cross-contamination.

Plate 5. After herbicide application, the lawn was allowed to grow for two weeks. This time simulated the growth period between average mowing periods.

Plate 6. Lawn was harvested two weeks after herbicide application. Harvesting was performed using hand shears and the lawn was trimmed to a blade length of 45 mm.

3.3.2 Results and discussion

ViroLab Analytical Services provided results for the herbicide analysis to a level of detection of 10 ppb. This level of detection was further improved to 1 ppb for subsequent testing. The concentration of the herbicides in the grass clippings harvested two weeks after herbicide application is shown in Table 6. The *Control* treatments did not contain any of the three acid herbicides, indicating no cross contamination occurred. Similarly, only the herbicides applied to each treatment were detected by the laboratory analysis.

Clopyralid was detected in the clopyralid treatment sample at a level of 6830 ppb (6.83 ppm). Picloram was detected at a level of 1420ppb (1.42 ppm) and triclopyr was detected at 430 ppb (0.43 ppm). The residual levels of these herbicides are at a significantly high concentration to result in damage to sensitive plants. For example, damage may occur if a home gardener applied these raw materials as mulch. The concentrations of herbicides determined in this pot trial are indicative of the level of residual herbicides possibly accepted in the lawn clippings stream by commercial composting facilities. These residual concentrations represent the proportion of the herbicide that is not metabolised by the plants after herbicide application and which remains in the plant material available to cause damage to any sensitive plants that may come into contact with this material. The residual herbicide concentrations determined in this small-scale pot trial were used to estimate the concentration of herbicides likely to be accepted at a commercial facility in the garden organics stream (Section 3.4).

Table 6. Residual herbicide concentrations from small scale pot trial. Concentration of herbicides in lawn clippings two weeks after herbicide application.

Treatment	**HERBICIDE CONCENTRATION (ppb)**		
	Clopyralid	**Picloram**	**Triclopyr**
Grass clippings – clopyralid	6830	<10	<10
Grass clippings – picloram	<10	1420	<10
Grass clippings – triclopyr	<10	<10	430
Grass clippings – control	<10	<10	<10

Note: The level of detection for the acid herbicides provide by ViroLab Analytical Services for this testing was 10 ppb. ViroLab Analytical Services further refined the level of detection to 1 ppb for subsequent analysis.

A similar trial conducted on a larger scale by the Washington State University found concentrations of clopyralid in lawn clippings at approximately 50 ppm two weeks after application. In this trial, clopyralid was applied at recommended label application rates over a 1.8 m^2 sample area. This trial determined that mowing practices did not impact the clopyralid content of grass clippings (Miltner *et al.*, 2002).

The clopyralid concentrations determined in the current small-scale pot trial were lower than those found by Miltner *et al.* (2002), indicating that the residual concentrations for the current trial are low compared with concentrations likely to be found at commercial composting facilities. However, the residual concentrations of the herbicides for the current trial are still unacceptably high and could result in significant damage to sensitive plants if applied as a raw material. The subsequent trial (Stage 3: *Applied Composting Trial*) determined whether a commercial composting phase would reduce this concentration to safe levels.

The growth of the lawn was compared between treatments to determine if any effect, negative or positive, occurred due to the herbicide application. Plate 7 shows a photographic comparison of the growth for each of the four treatments. The *Control* pots all showed healthy growth with approximate average blade length of 25-28 cm. The *Clopyralid* pots also appeared healthy and strong with an average blade length of 26-28 cm and a dense growth. The *Picloram* pots exhibited good growth although the average blade length was around 20-22cm, less than both the clopyralid and *Control* treatments. The grass still appeared healthy and dense. The *Triclopyr* treatments showed the least growth of the treatments and appeared to be stunted and sparse in comparison to the other treatments. Blades were significantly shorter, averaging a length of 8-10 cm and the individual blades were thin and spindly. The grass also appeared more yellow in colour than the other treatments and generally did not look as healthy.

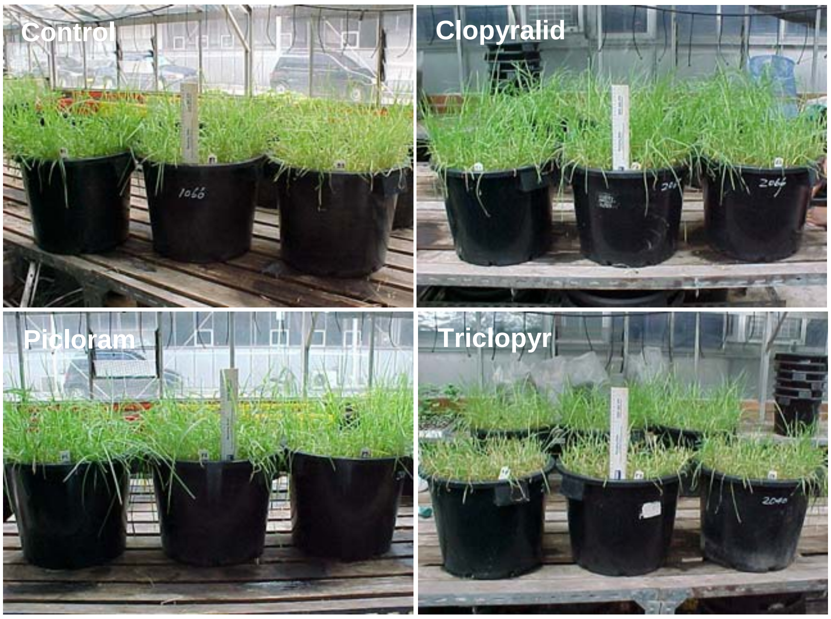

Plate 7. Comparison of lawn growth for each herbicide treatment against the control pots that were not treated with any herbicide.

The appearance of the *Triclopyr* treatment after the herbicide application and two weeks growth is consistent with the use of this herbicide as a woody weed herbicide rather than an herbicide for broadleaf weed control in turf or pastures. However, whilst triclopyr may not enter the compostable organics stream in lawn clippings it may be present in alternative streams such as woody materials including prunings or agricultural organics.

The strong growth of the *Picloram* treatment and particularly the *Clopyralid* treatment indicates the success of these herbicides for use on lawns. The growth and vigour did not seem to be affected in anyway by the application of these herbicides when compared against the *Control* treatment. Whilst the ability to kill broadleaf weeds was not investigated in this trial, the absence of detrimental effects to the lawns after application of these herbicides indicates that these products may be particularly successful on the Australian market. It is therefore prudent to ensure the effective degradation of these herbicides in the composting cycle to maximise any impacts on downstream recycling industries and horticulture industries.

Stage 3: Applied Composting Trial

A large scale composting trial was performed to monitor the degradation of the potentially persistent herbicides clopyralid, picloram and triclopyr under a best practice commercial composting management regime (as defined in *Stage 1: Industry survey*, see Section 3.2). Fresh size-reduced source-separated municipal garden organics were formed into nine, six tonne static piles.

The herbicides were applied to the piles in quantities calculated from data derived from *Stage 2: Lawn grass pot trial* (see Section 3.3) and composted for 16 weeks. Two application rates of each herbicide were used: a higher quantity of herbicide representative of higher application rates and/or market uptake; and a lower quantity of herbicide representative of lower application rates and/or market uptake. These application rates were derived from the residual concentration of herbicide determined in *Stage 2: Lawn grass pot trial* (see Section 3.3), the proportion of lawn grass likely to be present in the garden organics stream (determined by *Stage 1: Industry survey*, see Section 3.2), and a factor representing potential market uptake.

3.3.3 Method

3.3.3.1 Establishment of trial

The composting trial was located at Little Bay, The University of New South Wales, Sydney, Australia. The site was grassed and relatively flat and is generally unused. A small lake is situated on the site that collects rainwater and is used for irrigation of sports fields managed by the University.

Prior to establishment of the trial at the Little Bay site, grass and weed material was removed to create a flat surface for the compost piles with a slight gradient to allow drainage (Plate 8). An excavator was used to prepare the site and material that was removed from the surface was formed into a berm to prevent runoff from leaving the trial site (Plate 9). The composting trial was established on 21 May 2003.

Plate 8. Site preparation. Grass was removed from the surface of the site and formed into berms to prevent runoff.

Plate 9. Site established. A loader formed the nine static piles with a berm of compostable organics between each treatment to prevent cross-contamination.

Plate 10. Water and the herbicides were added to the flattened piles. The piles were then thoroughly turned and formed into a conical formation.

Garden organics material for nine statice piles was supplied by Australian Native Landscapes Ltd (ANL). The piles were approximately 5 m long, 4 m wide and 2 m high and were formed from shredded garden organics obtained from an ANL commercial composting facility. The piles were formed using a wheel loader with bucket scales ensuring each pile contained 6 tonne (6000 kg) of raw material. The raw material used to form the piles was selected randomly from a stockpile of shredded garden organics material ensuring a completely randomised trial design. Piles were located as shown in Figure 2.

The piles were located to ensure conditions in regard to solar access were consistent and therefore the replicates were subject to identical conditions. The piles were established on an area of 20 m^2 whilst occupying less than 10 m^2 at any time. The site layout, gradient and additional area provided to each pile as a dedicated turning pad combined to ensure contamination between replicates and treatments did not occur. A berm of raw garden organics material was placed in between each treatment to ensure contamination by overland flow did not occur.

The *Control* piles were formed and water was added via a water truck to achieve a moisture content of 55-65% consistent with the best practice guidelines specified in Australian Standard AS 4454 (Standards Australia, 2003b). The *Low Concentration* and *High Concentration* replicates were treated with the herbicides clopyralid, picloram and triclopyr and then thoroughly combined and formed into piles.

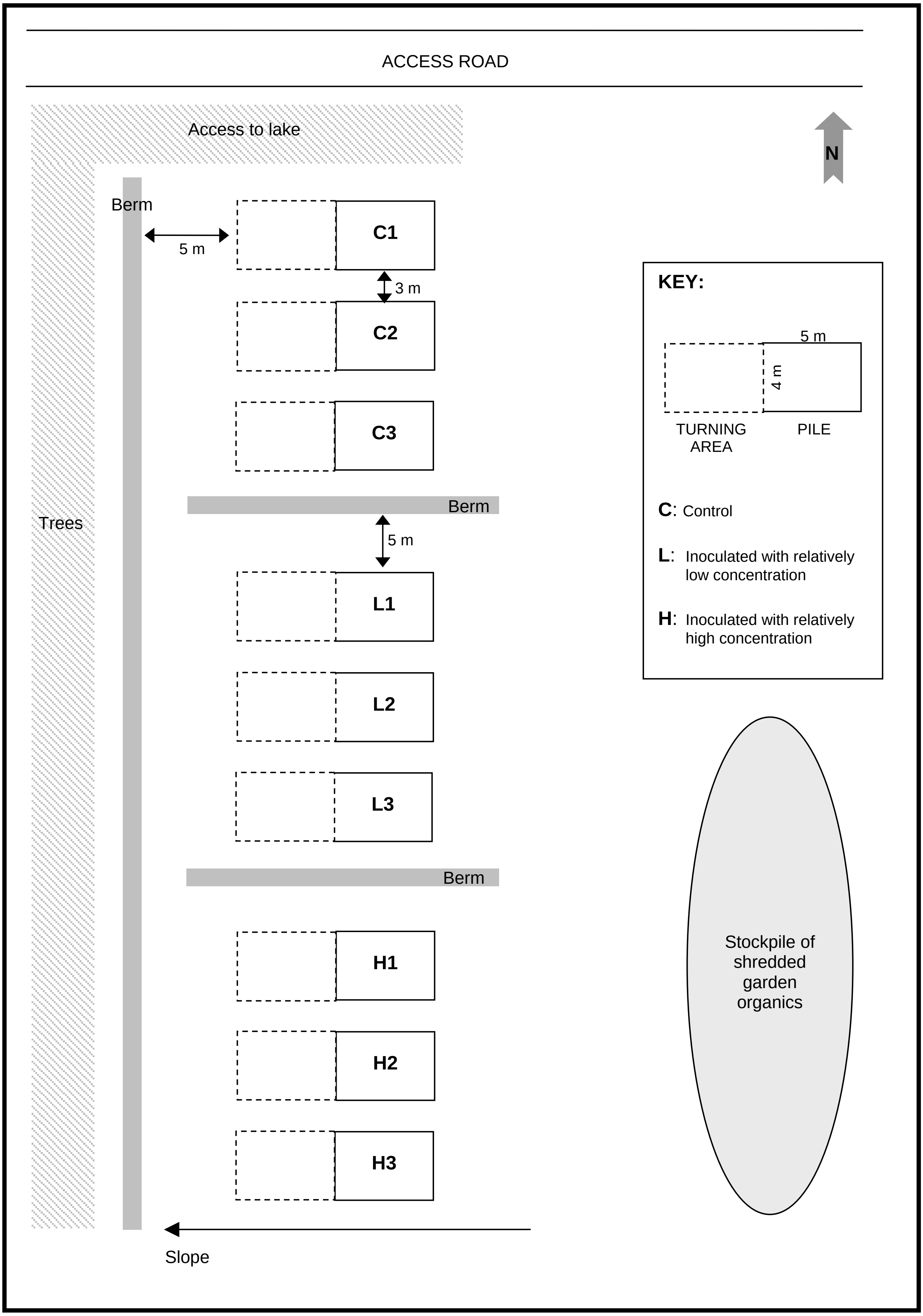

Figure 2. Site layout for Stage 3: *Applied Composting Trial*.

3.3.3.2 Herbicide application

The material for each pile was spread to a thickness of approximately 40 cm (Plate 10). Herbicide was applied by diluting the chemicals in 300 L of water and sprayed over the material of each pile. After herbicide application, the material from each replicate was mixed thoroughly with a loader and formed into a pile. An overview of the entire trial site is shown in Plate 11. Herbicide application rates are shown in Table 7.

Table 7. Quantity of herbicide incorporated into each pile.

Treatment	HERBICIDE QUANTITY (mL)		
	Clopyralid	**Picloram**	**Triclopyr**
Control	0	0	0
Low concentration	3.48	4.55	2.73
High concentration	10.43	13.65	8.20

Plate 11. Site overview. *Control* piles (labelled C1, C2 and C3) are located on the left of the site, the *Low Concentration* piles (labelled L1, L2 and L3) are located in the centre and the *High Concentration* piles (labelled H1, H2 and H3) at the right of the site. A berm of compostable organics separates each of the treatments. The stockpile of material is located in the background.

The herbicide application rates were estimated from the residual concentration of the herbicides in lawn clippings (determined in Stage 2) and a proposed market uptake rate of 10% for the *Low Concentration* and 30% for the *High Concentration* as shown in **Equation 1**. This represented an assumed rate 10% and 30% of the market using these herbicides for lawn applications only. Lawn clippings were estimated to comprise 40% of the garden organics stream as determined by the *Stage 1: Industry Survey*.

$$A = P \times C \times M \quad \text{… } \textbf{Equation 1}$$

Where:

A is the herbicide application rate used in this applied composting trial (mL/kg garden organics in each pile)

P is the percentage of lawn grass and/or other ‘at risk’ raw materials in compost windrows (by weight). This was determined in *Stage 1: Industry Survey* (Section 3.2).

C is the proportion of active herbicide remaining in the lawn clippings that is not metabolised within a reasonable time frame. This was determined in *Stage 2: Lawn Grass Pot Trial* (Section 3.3).

M is the percentage multiplier for the potential market uptake or use of the chemical. This value is modelled at 10% and 30% market uptake for the purpose of this trial, resulting in low and high range application rates respectively.

Samples from each of the piles were collected on the day of formation of the piles for analysis of moisture content and herbicide concentration. Temperatures of all the piles were monitored weekly and oxygen concentration was monitored on the *Control* piles weekly. Moisture content was determined every three weeks to ensure moisture content was maintained above 45% according to industry best practice (Standards Australia, 2003b). The piles were turned every three weeks according to industry practice determined by the survey of commercial composting facilities. Samples from each of the piles were collected at week 0, 3, 6, 9, 12 and 16 weeks and analysed for herbicide concentration. At the conclusion of the trial, the material was spread over the site.

3.3.3.3 Analysis of samples

Samples of approximately 2 kg were removed from each of the piles at weeks 0, 3, 6, 9, 12, 16 and were screened through a 16 mm sieve for herbicide analysis by ViroLab Analytical Services. The laboratory blended and size-reduced each sample to form a homogeneous sample ensuring the results were representative of the entire sample provided. A random sub-sample of approximately 50 g was taken from the homogenised sample for the analysis.

The herbicides were extracted from the sub-sample using an appropriate solvent and the extract was passed through a solid phase extraction cartridge to concentrate the extract. This process removed contaminants such as amino acids that are commonly found in plant materials and can interfere with accurate detection of the relevant herbicide compounds. The extract was injected into a liquid chromatography/mass spectrometer (LC/MS) instrument for analysis. Standard herbicide solutions of known concentrations (spikes) as well as blank samples were run through the instrument allowing the unknown concentration of herbicide in the sample to be determined (Dr Marie Hendriks, ViroLab Analytical Services, pers. comm.).

ViroLab Analytical Services provided results to a level of detection of 1 ppb (μg/kg) for all three herbicides, clopyralid, picloram and triclopyr. Results were reported on a wet weight basis by the laboratory.

Results and discussion

3.3.3.4 Industry best practice management

The compost piles were monitored weekly to ensure standard industry composting conditions were maintained and to closely represent commercial composting conditions. Moisture content was determined every three weeks to ensure there was sufficient moisture for aerobic composting. Moisture content was maintained between 45% and 65% for the entire trial. Figure 3 shows the mean moisture content profile for each treatment for the entire duration of the trial and a comparison to ambient air temperature. This figure shows that moisture content was consistently maintained within the optimal conditions for the entire trial. A decreasing profile can be seen indicative of moisture loss over time, though sufficient moisture was retained for effective composting.

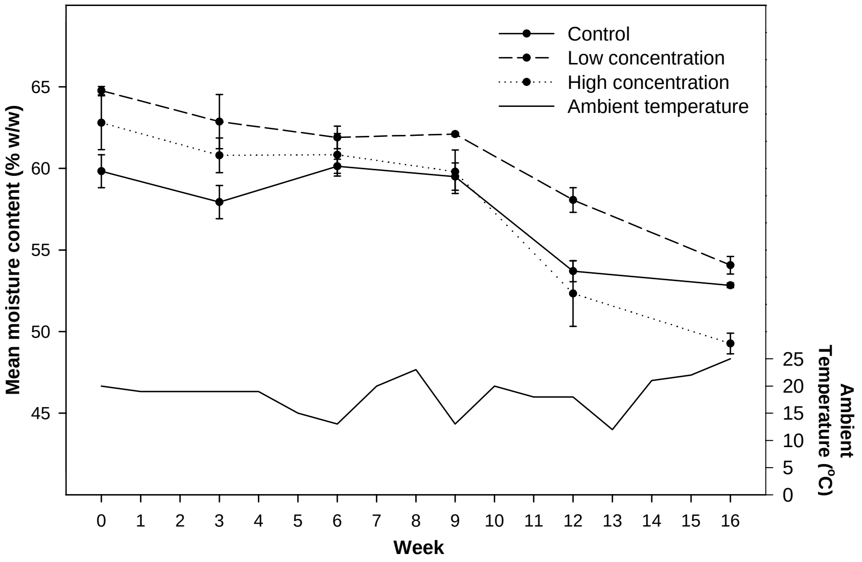

Figure 3. Mean moisture content profile for each herbicide treatment. A comparison to the ambient air temperature for the entire trial duration is also shown. Bars represent standard error of the mean of samples from three replicates (*n*=3).

Temperature of the piles was monitored weekly to ensure thermophilic conditions were reached as specified by Standards Australia (2003b). The Australian Standard AS 4454 (Standards Australia, 2003a) requires that the pile is subjected to at least three turns with internal temperature reaching a minimum of 55°C for three consecutive days prior to each turn. Temperature was monitored at a height of 1.2 m for each of the piles and a temperature profile for the piles was achieved by monitoring temperature to the cross-sectional depth of the pile of 0.3 m, 0.6 m and 0.9 m. Temperature was monitored by using a hand-held digital temperature meter with a 0.9 m long probe.

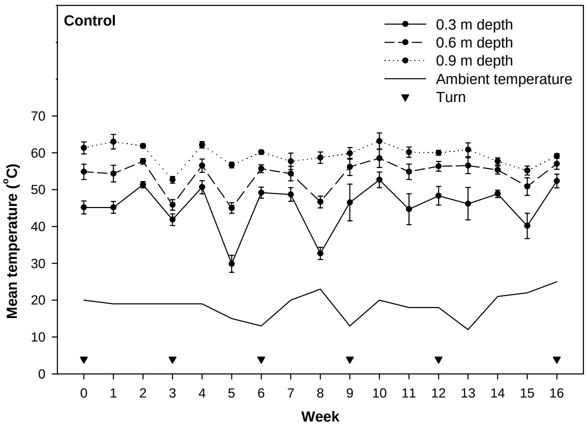

Figure 4. Mean temperature profile for *Control* piles at 1.2 m height. Bars represent standard error of the mean of samples from three replicates (*n*=3).

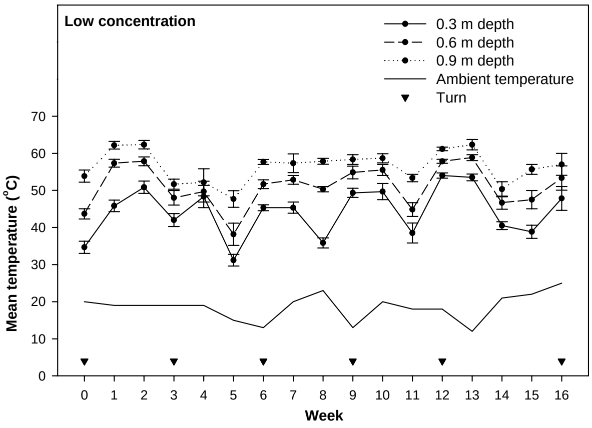

Figure 5. Mean temperature profile for *Low Concentration* piles at 1.2 m height. Bars represent standard error of the mean of samples from three replicates (*n*=3).

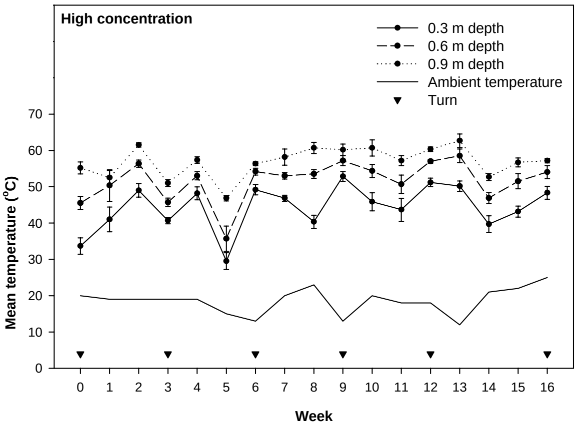

Figure 6. Mean temperature profile for *High Concentration* piles at 1.2 m height. Bars represent standard error of the mean of samples from three replicates (*n*=3).

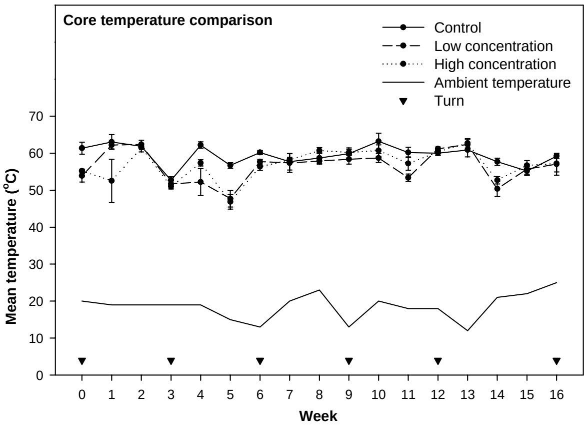

Figure 7. Comparison of mean core temperature (0.9 m depth, 1.2 m height) between treatments. Bars represent standard error of the mean of samples from three replicates (*n*=3).

The temperature profiles were relatively consistent across the three treatments as shown in Figures 4, 5 and 6 with temperatures on the inside of the piles (0.9 m depth) higher than the outside as expected. Adequate thermophilic conditions were achieved for all treatments with core temperatures (0.9 m depth) consistently above 55°C for most of the processing period. Week five exhibited lower than usual temperatures across the treatments and for all depths, which may have been due to the weather conditions. A small rain event occurred during the week resulting in increased moisture within the piles. This can also be seen in Figure 3 showing a slight increase in moisture content going against the general trend of decreasing moisture content for the duration of the trial. These damper conditions may have affect porosity and the decomposition process and therefore slightly reduced the temperature of the piles.

Consistently high temperatures were observed from weeks 6 to 13 across all treatments. Temperatures from week 14 were observed to decrease from the previous weeks indicating a decrease in the degradation activity occurring within the piles as the compost reached maturity. The core temperatures for all of the piles were relatively consistently across the trial indicating consistent composting conditions between treatments (Figure 7).

Oxygen concentration was monitored for the *Control* piles to indicate the availability of oxygen for the aerobic composting process. Oxygen was monitored at a height of 1.2 m and at depths of 0.3 m, 0.6 m and 0.9 m to obtain an oxygen profile. Figure 8 shows the mean oxygen profile for the *Control* treatment. The oxygen concentration was highly variable across the trial with concentrations as low as 4% monitored for the *Control* piles. However, subsequent weeks showed significant increases in oxygen concentration, particularly for weeks directly following the turning of the piles. This increase in oxygen concentration after turning would be expected due to the aeration of material in the turning process.

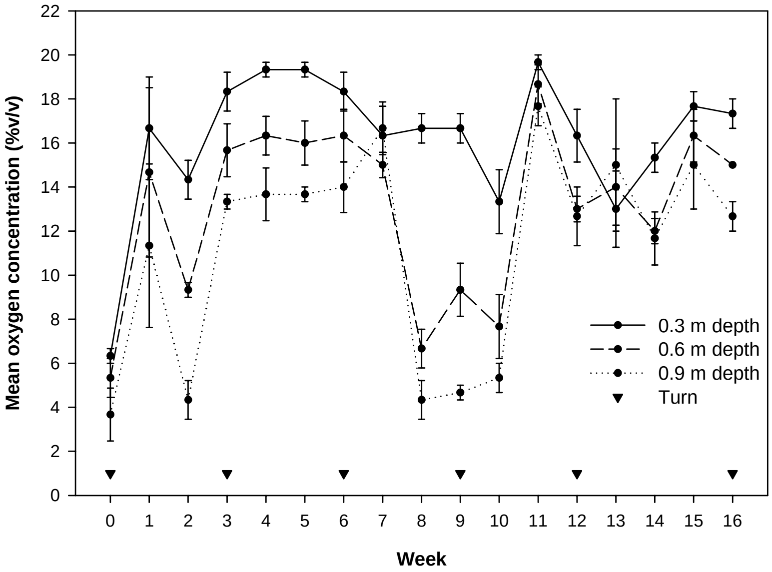

Figure 8. Mean oxygen concentration profile for the *Control* treatment. Bars represent standard error of the mean of samples from three replicates (*n*=3).

3.3.3.5 Herbicide application

The herbicides were combined in each of the piles rather than separating each herbicide into an individual pile for each treatment. This was considered a valid approach for two reasons. Firstly, chemical manufacturers produce and market a variety of combined formulations of these specific herbicides, as shown by the example formulations in Appendix 3. Secondly, persistent chemicals that are marketed commercially for agricultural and/or landscaping applications will invariably be combined together in the mixed compostable organics stream accepted at commercial composting facilities and ultimately composted. Therefore, the method used was seen as not a simulation but a reflection of the conditions that would occur in reality at a commercial facility.

The herbicides were applied to the fresh garden organics material. The application of the herbicide directly rather than incorporation into the growing tissue of the plant material prior to addition, was suitable due to the minimal metabolism upon uptake by living plant tissues. Clopyralid is not metabolised in plants (Tomlin, 1997); and reports of metabolism for picloram vary from no metabolism (remains stable and intact within plant) (Extension Toxicology Network, 2002) to slow metabolism (Cox, 1998b). The Weed Science Society of America (1994) summarise that picloram is either rapidly metabolised in non-susceptible species such as grasses, or remains intact for extended periods in susceptible species such as broadleaf plants. Triclopyr is hydrolysed to the acid form after entering the plant tissue (Tu *et al.*, 2001). The application of the herbicide to fresh garden organics was performed to ensure minimum variation to actual conditions that would occur in real life situations. Due to minimal change in the form of the herbicides after uptake by the plants, the detection of herbicides in the compost material for Week 0 should be indicative of the herbicides as may be detected in raw material accepted at a commercial composting facility.

3.3.3.6 Residual herbicide concentrations

The herbicide concentrations determined for the trial are shown graphically in Figures 9, 10 and 11 for the three herbicides clopyralid, picloram and triclopyr respectively. Tabular data for these herbicide concentrations are contained in the Appendix. Week 0 is the establishment of the trial and week 16 is the conclusion of the trial.

ViroLab Analytical Services provided results to a level of detection of 1 ppb for all three herbicides, clopyralid, picloram and triclopyr. Results were reported on a wet weight basis by the laboratory. ViroLab Analytical Services reported on a wet weight basis as it was considered more representative of the original condition of the compost sample. Results reported in the literature are often provided on a dry weight basis. This process of drying the sample may result in a significant change to the material and loss of chemical, or change in the structure of the chemical. Therefore, reporting on a wet weight basis was considered by the laboratory to be more representative of the original condition of the material and provide a more accurate representation of the concentration of the herbicides in the compost (Dr Marie Hendriks, ViroLab Analytical Services, pers. comm.).

The initial clopyralid concentration in the raw garden organics material prior to composting was relatively consistent with reported concentrations detected at composting facilities in the US. The initial clopyralid concentration for this trial of 50 ppb (mean) is not unrealistic and may be considered a conservative value in comparison to Rynk (2002a). Rynk (2002b) has reported clopyralid levels in raw materials accepted at a composting facility at 100-250 ppb for garden organics; 1550 ppb for lawn clippings; and 600 ppb for leaves and grass. No testing of picloram or triclopyr in raw materials has been reported in the literature to the author's knowledge to allow a comparison for these herbicides.

3.3.3.6.1 Clopyralid degradation

The results of this trial for the herbicide clopyralid confirm the many international reports that clopyralid persists in compostable organics that have undergone composting. The conditions of the Australian commercial composting industry, simulated in this trial, do not seem to differ from those reported in the literature in regard to this compound persisting under composting conditions. Results for clopyralid degradation for the duration of this applied composting trial are shown in Figure 9.

The *Control* treatment, which was not treated with any herbicides (other than herbicides that may have been present in the raw materials), had a concentration of clopyralid of less than 1 ppb (the limit of detection). Less than 1 ppb of clopyralid was recorded for every sample for the *Control* piles. Therefore, it may be assumed that clopyralid was not present in the raw materials or finished compost at any level that would result in damage to sensitive plants and that this herbicide was not introduced to the trial from outside sources or cross-contaminated from the other treatments.

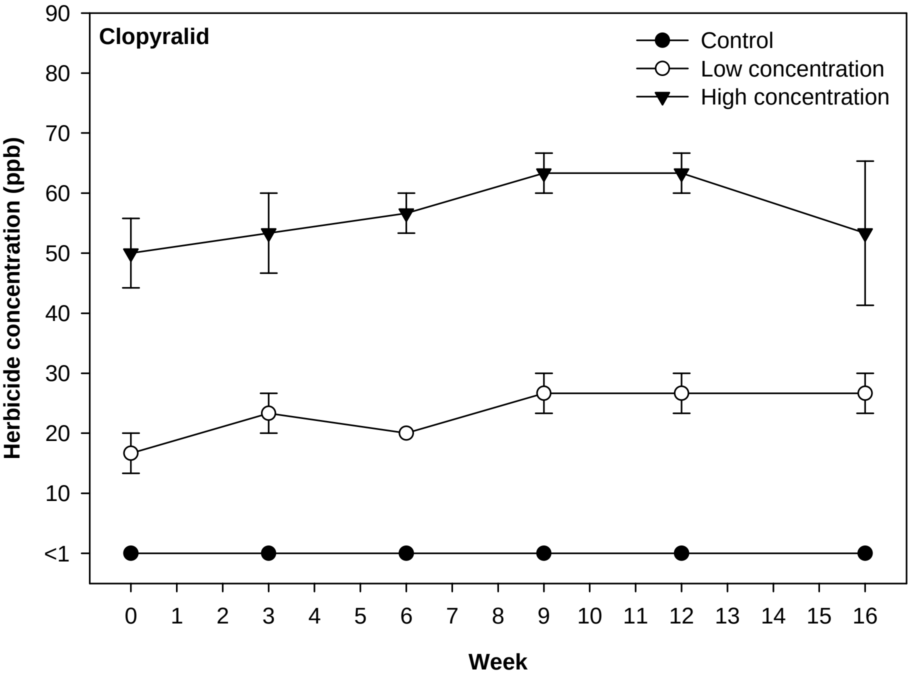

Figure 9. Mean clopyralid concentration for each treatment for the duration of the trial. Bars represent standard error of the mean of samples from three replicates (n=3).

The *Low Concentration* treatment and the *High Concentrations* treatments exhibited clopyralid concentrations consistent with the concentration of herbicide applied at the commencement of the trial. The mean minimum and maximum recorded concentration of clopyralid for the *Low Concentration* treatment ranged from 16.7 to 26.7 ppb over the course of the trial and these in fact represented the mean initial concentration and mean final concentration respectively. Interestingly, the trend did not decrease over time as might be assumed with the degradation of an herbicide, but actually increased marginally from Week 0 through to Week 16 except for a small decrease recorded at Week 6. Due to the extremely low concentrations of herbicide throughout this trial, some sampling discrepancies may have occurred that could explain this slight decrease. Similarly for the *High Concentration* treatment, the clopyralid concentration increased from the start of the trial however a decrease was observed for Week 16. Mean clopyralid concentrations ranged from 50 ppb at Week 0 to a maximum of 63.3 ppb at Weeks 9 to 12 to 53.3 ppb at Week 16. However, results for Week 16 exhibited high variation between piles (standard error of 12) with one pile recording up to 70 ppb for this herbicide.

The trend of increased concentration over time could be explained by the loss of volume (water + dry matter as CO_2) of the piles in this trial. Composting results in a significant reduction in volume of the material due to the process of microbial degradation. Recycled Organics Unit (2003a) reports that composted mulch can decrease in bulk density from 3 m^3 per tonne as shredded raw materials, to 2 m^3 per after screening and curing. Whilst the material in this trial did not undergo screening, it is clear that a significant change in volume, a reduction of up to one third, would have occurred between the start and finish of this trial. This would explain the slight increase in concentration of clopyralid over the duration of the trial.

This change aside, it is obvious from the trial that clopyralid has not been degraded by the composting process and that with the relatively low initial concentration when compared to reported concentrations in raw materials given by Rynk (2002a) of between 100 and 1550 ppb, enough herbicide is still present after 16 weeks of composting to cause significant damage to sensitive plants. When factors are considered such as the high solubility of clopyralid and the susceptibility of this herbicide to undergo photo-degradation and hydrolysis (Dow AgroSciences, 1997) (all of which would occur during commercial composting conditions), the fact that this chemical remains in significant concentrations to damage plants is a serious threat to users of contaminated compost.

Whilst limited studies on the degradation of this herbicide in compost have occurred, a study by Vandervoort *et al.* (1997) indicated that clopyralid degrades very slowly in compost produced from lawn clippings when composted for up to a year as static piles. Whilst this does not represent commercial composting conditions, the present trial confirms the lack of degradation even under controlled, commercial conditions where thermophilic temperatures were maintained for the duration of the trial.

3.3.3.6.2 Picloram degradation

Similar to the results for clopyralid, picloram was seen to persist through the commercial composting process as determined by this trial and confirming reports of picloram contamination internationally. Results for picloram degradation for the duration of this applied composting trial are shown in Figure 10.

The *Control* treatment did not contain any detectable picloram indicating no cross-contamination between treatments occurred and that no picloram was introduced to the trial through the raw materials. The *Control* treatments remained at less than 1 ppb of picloram throughout the duration of the trial.

Both the *Low Concentration* and *High Concentration* treatments for picloram exhibited a similar profile to clopyralid whereby the concentration of the herbicide did not decrease according to a trend. The *Low Concentration* treatment exhibited a small decrease initially from Week 0 to 3 (mean of 13.3 to 8.3 ppb) and then remained steady at 10 ppb for the remainder of the trial with the exception of Week 9, which exhibited a small spike in concentration to 16.7 ppb. This may have occurred due to sampling variation. The *High Concentration* treatment exhibited a slight increase in concentration from Week 0 to 6 (mean of 23.3 to 26.7 ppb) and a marginal drop for Week 9 and 16 (23.3 ppb) and a slight peak at week 12 (30 ppb). However, the range between maximum and minimum recorded picloram concentration for the entire trial was 6.7 ppb for the *High Concentration* treatment and 8.4 ppb for the *Low Concentration* treatment which is extraordinary considering the minute quantities of herbicide present in the tonnes of compost material.

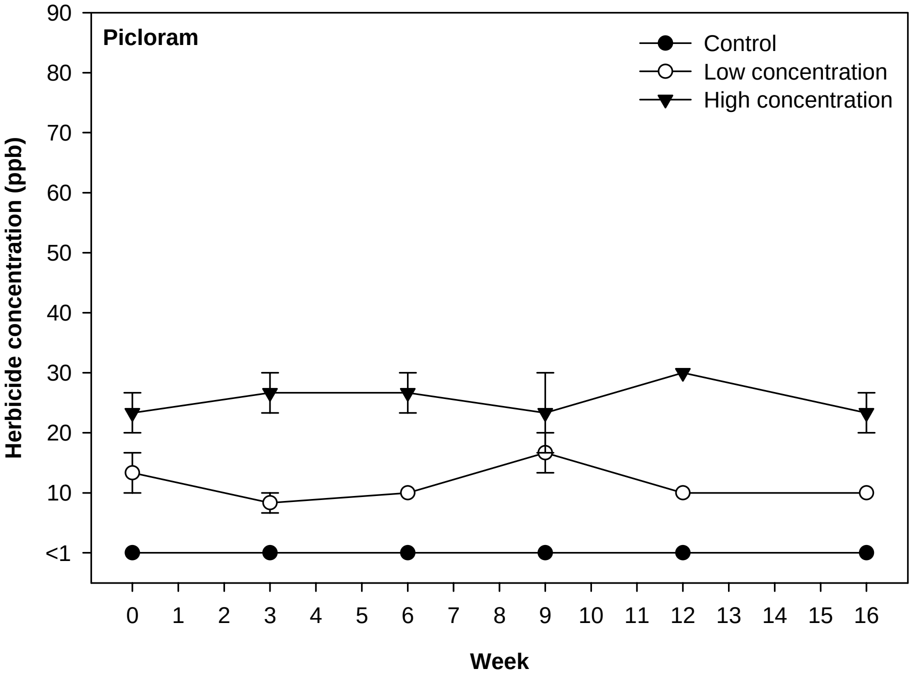

Figure 10. Mean picloram concentration for each treatment for the duration of the trial. Bars represent standard error of the mean of samples from three replicates (*n*=3).

As with the results for clopyralid, it is evident that picloram has not been degraded under commercial composting conditions. The remaining concentrations represent quantities that could cause significant damage to sensitive crops and applications. Whilst no studies on the degradation of picloram in compost were identified in the literature, the properties of this compound including high solubility and photo-degradation (Weed Science Society of America, 1994; Extension Toxicology Network, 2002) would seem to indicate that wet, exposed, outdoor composting conditions would degrade this compound. This trial indicates that this is not the case and that the concentration of this compound remained relatively unchanged after 16 weeks of thermophilic composting under best practice management as specified in AS 4454 (Standards Australia, 2003b).

3.3.3.6.3 Triclopyr degradation

In contrast to the results obtained for clopyralid and picloram, the herbicide triclopyr was found to undergo significant degradation when composted under commercial conditions. It should be reaffirmed at this time that no reports of triclopyr contamination of compost have been reported and this herbicide was included in this study due to this chemical being identified as a domestically available herbicide in Australia with a similar chemical form to the known persistent herbicides clopyralid and picloram (Recycled Organics Unit, 2002). Results for triclopyr degradation for the duration of this applied composting trial are shown in Figure 11.

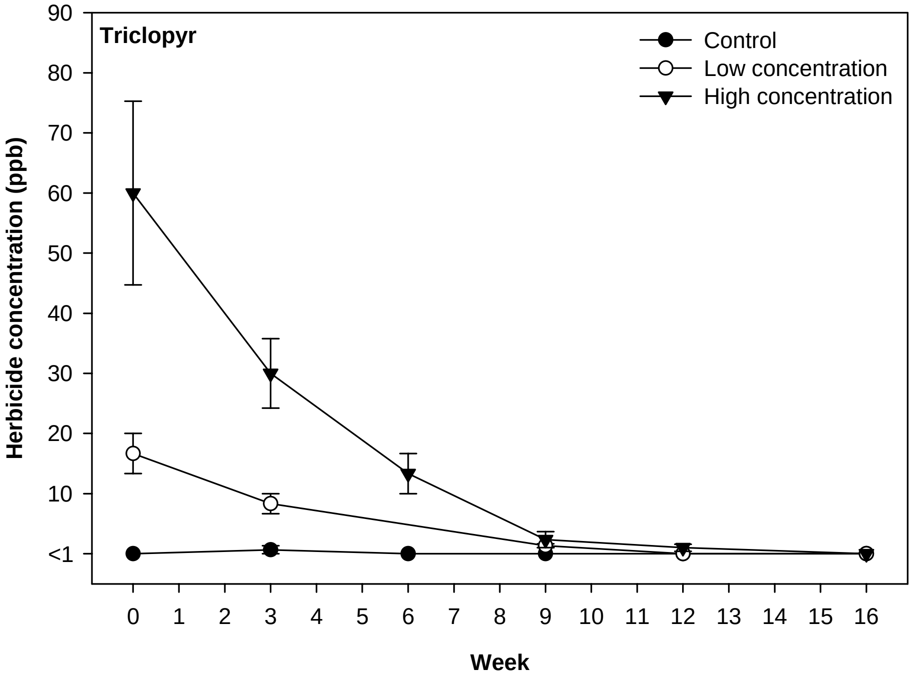

Figure 11. Mean triclopyr concentration for each treatment for the duration of the trial. Bars represent standard error of the mean of samples from three replicates (*n*=3).

The *Control* treatments were consistent across the duration of the trial with no reported triclopyr present with the exception of replication 1 of *Control* treatment recording 2 ppb of triclopyr for Week 3. No triclopyr was detected for this pile in Week 0 indicating that this may be a sampling error or contamination artefact. This result does not affect the results of the trial in anyway and indicates the extreme sensitivity and difficulties inherent in dealing with the low level of detection required for these herbicides.

The *Low Concentration* treatment decreased over the duration of the trial in contrast to both clopyralid and picloram as discussed previously. The mean initial concentration of triclopyr was detected as 16.7 ppb and the concentration decreased steadily for the duration of the trial to a mean of 1 ppb at Week 9 and less than 1 ppb for the remainder of the trial. Note that a data point for the *Low Concentration* treatment for Week 6 was not consistent with results for the trial and therefore was not included in the graph (raw data is shown in Appendix 5 Table A5.1). It is likely that the error may have been due to laboratory methods, contamination, sampling, or due to the very low levels of herbicide present in the materials.

The *High Concentration* treatment exhibited an even clearer degradation profile over the duration of the trial decreasing from a mean initial concentration of 60 ppb to 1 ppb at Week 12 and less than 1 ppb for Week 16. Figure 11 shows a very clear degradation profile for this herbicide for both the *Low* and *High Concentration* treatments for the duration of the trial. Clearly, this herbicide is shown to degrade significantly in a commercial composting scenario under industry best practice conditions where thermophilic conditions are maintained for the duration of the trial.

This result is relatively consistent with the study by Vandervoort *et al.* (1997) who determined that triclopyr degraded to a level below detection (detection limit in this study was 10 ppb) after 365 days of composting, however after 128 days of the Vandervoort *et al.* trial, levels of triclopyr were still detected. This trial by Vandervoort *et al.* (1997) was not performed on a commercial scale or under industry best practice conditions and therefore did not conclusively determine that triclopyr would not be a risk to compost users in Australia (Recycled Organics Unit, 2002). The current trial, however, provides a clear profile of the degradation of this herbicide under commercial conditions and indicates that this chemical should no longer be included in the Risk Management Program as a potential threat to the recycled organics industry in Australia.

One data point that was not consistent with results for the trial was removed from the figures and considered to be aberrations. This error occurred for the triclopyr treatment during Week 6. Data errors may have been due to laboratory methods, contamination, sampling, or due to the very low levels of herbicide present in the materials.

3.3.3.7 Difficulties with laboratory analysis and quantifying herbicide concentrations

Laboratory analysis of clopyralid in compost can result in significant difficulties and widely varying results between analytical methods. In particular, the difficulties encountered by laboratories centre on the very low detection limit required as clopyralid can affect sensitive plants at concentrations as low as 1 ppb. In general, laboratory analysis of compost is difficult due to inorganic and organic chemicals such as humic acids, salts and nutrients that make extraction of the chemical from the compost matrix very difficult. Compounds that are targeted for analysis are extracted from the solid media using solvents. The resulting extract, containing the solvent and the extracted compound, is measured to determine the concentration of the particular compound. However, chemical compounds in organic media can bind with other reactive surfaces in the compost matrix and avoid extraction by the solvent. The extraction step is a key part of the procedure that can significantly influence results of the analysis, especially when very low detection limits are required as is the case for clopyralid (Bezdicek *et al.*, 2003).

ViroLab Analytical Services encountered difficulties extracting the herbicide from the compost samples and achieving the low detection limits required for this trial. To overcome some difficulties, Virolab Analytical Services used a larger sample size (50 g) than usually required to perform this analysis to more accurately reflect the nature of the entire sample material. Variations in cartridges between batches contributed to significant difficulties for the laboratory, however the final method developed by Virolab Analytical Services and used on all samples, provided results to the level of detection required and provided sufficient results for interpretation.

Section 4 Conclusions and recommendations

4.1 Overview

This section provides an overview to the Persistent Herbicides Risk Management Program undertaken to identify and minimise the risk of potentially persistent herbicides to the Recycled Organics Industry and a range of horticultural industries in Australia. This section includes:

- *Background to persistent herbicides and compost* – brief review of international incidents of compost contamination and how this issue has come to light.
- *Evidence of herbicide persistence* – conclusions of *Stage 3: Applied Composting Trial* (Section 3.4) undertaken by the Recycled Organics Unit to determine whether the herbicides clopyralid, picloram and triclopyr persist under Australian industry-standard commercial composting conditions.
- *What has been done: risk management program* – what has been investigated so far in regard to persistent herbicides in Australia and the tools available to industry to minimise the risk of herbicide contamination of recycled organics products.
- *Recommended plan of action* – for industry and Government to address this issue effectively.

4.2 Background to persistent herbicides and compost

International incidents of herbicide contamination of compost have highlighted the importance of the recycled organics industry and the need for a pre-emptive approach to protect the significant investments made in this industry. Problems of compost quality in the past have involved such issues as high soluble salts; extremes in pH, organic matter, ammonia and/or organic acids; or high carbon to nitrogen rations (Bezdicek *et al.*, 2000). More recently however, the issue of herbicide contamination of compost has compromised the quality of these products and confidence in the industry by consumers. No reports of significant herbicide contamination of compost have been reported in Australia, however it is prudent and responsible to address this risk to ensure issues observed internationally are not encountered in Australia. A brief review of the international incidents of reported herbicide compost contamination is given below.

The international incidents of compost contamination have focussed primarily on a commonly used herbicide known as clopyralid (Dow AgroSciences). Clopyralid is a chlorinated pyridinecarboxylate that is used to control annual and perennial broadleaf weeds in crops and turf. Clopyralid is a non-selective herbicide and is therefore toxic to a wide range of plants. Tolerance levels for this herbicide are as low as 1 ppb for clover and tomatoes and less than 1 ppb for beans, peas, sunflowers and lettuce (Bezdicek *et al.*, 2002).

The US Department of Agriculture found plants grown in compost from a facility in Washington showed symptoms of herbicide damage, later confirmed as damage by clopyralid (Washington State Department of Agriculture, 2002b). In 2000, compost products from two separate facilities in Washington State were contaminated with clopyralid, and a similar herbicide picloram, and reported to cause damage to crops and gardens after the product was purchased (Bezdicek *et al.*, 2000; Rynk, 2000). In Spokane, Washington, compost produced at a regional facility caused damage to tomato seedlings at a commercial greenhouse. Trace levels of clopyralid were found in samples, however, the levels detected were low (0.03 ppm or 30 ppb).

In Pullman, Washington, a composting site operated by Washington State University (WSU) applied compost from the site at a community garden resulting in damage to plants. Tests confirmed picloram and clopyralid were present in the compost (Bezdicek *et al.*, 2001). Following these reports of contamination at WSU and Spokane, further contamination was detected at facilities in Cheney and Whitman County both in Washington State, as well as Pennsylvania and also New Zealand. Samples of compost from the Spokane facility were found to contain clopyralid residues of between 31 and 75 ppm nine months after the problem was discovered. Fietje (2001) reported that in Christchurch, New Zealand, clopyralid was detected in compost produced by an open-air windrow composting facility. Levels of clopyralid increased since it was first detected in 1999, with grass clippings found to be the main cause of the problem. Overall, clopyralid has been identified at potentially damaging concentrations in a dozen widely dispersed states of the US (Rynk, 2003). Labelling by the manufacturer of clopyralid, Dow AgroSciences, acknowledges that this herbicide can persist after composting. Labels on clopyralid products advise “Do not use compost containing grass clippings from turf treated with Confront [herbicide] in the growing season of application” (Dow AgroSciences, 2001).

In October 2001, the US Composting Council (USCC) replied to the clopyralid problem by issuing a position paper (US Composting Council, 2001). The USCC identified that the existing system of governing clopyralid and clopyralid-treated residues is insufficient at protecting downstream recycling industries and markets. This is evident by the inability of compost producers and users to control the conditions that lead to clopyralid contamination of feedstocks from diffuse and unverifiable sources such as example lawn clippings. Factors resulting in difficulties with clopyralid and composting were identified by the USCC as inappropriate labelling of products and the inability of a label to effectively prevent composting of contaminated materials.

Dow AgroSciences replied to the clopyralid controversy by issuing a position statement that reviewed the incidents in which clopyralid was detected (Dow AgroSciences, no date-a). This paper suggested that clopyralid incidents involved circumstances that were unique or unusual or resulted from off-label uses. It was also implied that clopyralid is largely confined to grass clippings and that the herbicide serves important functions for managing weeds that are hard to control in minor crops. However, the composting industry replied that compostable organics such as grass clippings, straw and manure are no longer discarded waste products but valuable feedstocks that yield marketable products and therefore the quality of these materials is crucial to the industry and further market development (Rynk, 2001).

The Washington State Department of Agriculture (WSDA) placed a ban on the use of clopyralid on lawns from 1 March 2002 in Washington State (Washington State Department of Agriculture, 2002a). Dow AgroSciences responded further by discontinuing the use of all clopyralid products for residential turf uses and petitioning the US EPA to eliminate residual turf as an allowable application for the herbicide (Dow AgroSciences, 2002; BioCycle, 2002b). California placed restrictions on the sale of clopyralid pesticides not only for residential uses but also commercial lawn/turf uses (BioCycle, 2002a). Oregon also restricted clopyralid for residential and commercial uses excluding golf courses (BioCycle, 2003b; BioCycle, 2003a). In 2002, a year after the WSDA ban on clopyralid, sampling and testing indicated that the level of clopyralid in commercial compost had decreased by an average of 80% since 2001 (Washington State Department of Agriculture, 2003a; Washington State Department of Agriculture, 2003b).

Clopyralid can damage varying plant species to different degrees, for example, plants in the grass family are not harmed by moderate to low levels of clopyralid compared to broadleaf plants such as beans, peas, potatoes and tomatoes, which can be severely damaged (Rynk, 2002a). Clopyralid is active at very low levels and can therefore result in damage to sensitive plants at a concentration as low as 1 ppb (Rynk, 2000; Bezdicek *et al.*, 2001; Bezdicek *et al.*, 2002). Laboratory analysis for clopyralid has required testing to be performed at the part per billion level, as opposed to the more common part per million range. Concentration levels for detection of clopyralid can seemingly vary depending on the extraction method and therefore bioassays may more accurately reflect the real situation.

A number of researchers have focussed on developing plant bioassays to determine the response of plants to various concentrations of clopyralid in compost (Bary *et al.*, 2002; Cogger *et al.*, 2002; Fauci, 2002; Fauci, no date; Fauci *et al.*, 2002; Washington State University, 2003; Woods End Research Laboratory, 2002). Bioassays involve growing sensitive plants in compost containing a known quantity of the herbicide and assessing the plant growth to identify plant response. These bioassays have been developed to determine whether contaminated compost will pose a threat to sensitive plants if applied at certain application rates. Laboratory analysis of contaminated compost has not always proved effective due to the low levels at which clopyralid can elicit a response in sensitive plants (1 ppb).

The state of California in the US implemented a bold step in 2002 by cancelling the registration of 15 clopyralid-based herbicide products for use on lawns (Rynk, 2002b). Additionally, the California Department of Pesticide Regulation (DPR) implemented and passed a bill effective from January 1 2003 that allows the DPR to cancel the registration of any herbicide used for lawn and turf applications that the department determines is likely to result in persistent residues in compost (Assembly Bill Number 2356, 2003).

Restrictions on the use of clopyralid in turf and lawn herbicides have been widely adopted across the US, for example in California, Washington State, and Oregon. However, sampling and testing programs in the US have also detected high clopyralid concentrations in manure-based composts (Rynk, 2002a). This can occur as a result of livestock feed treated with the compound and passing through the animals into the manure. This would indicate that agricultural crops, primarily grains and hay, could be a source of clopyralid in livestock manure

(Rynk, 2002b). Agricultural uses of this herbicide may therefore indirectly reach composting facilities in livestock manure. Agricultural uses whilst excluded from most restrictions in the US, can be a further source of contamination.

Clopyralid and similar compounds such as picloram are known to pass through the digestion systems of animals unchanged whilst posing no health threat to the animal. Manure and urine can contain the herbicide and therefore contamination of manure and bedding material such as straw can occur and has been reported in the US. To prevent this source of contamination, WSU who house livestock, and compost the bedding material and manure, requires vendors of grass hay and straw to be certified by the university and guarantee that their product is free from herbicide contamination (Bezdicek *et al.*, 2001). This certification is successful as WSU purchases the straw and hay for use and then processes the manure and bedding, however most processors would only have access to the materials at the end of the cycle and therefore no access to the supplier or able to guarantee the source of the material.

Oregon Department of Environmental Quality conducted a study of clopyralid contamination in “for sale” compost from 12 commercial facilities (Department of Environmental Quality, 2003). All facilities reported compost contaminated with clopyralid at levels ranging from 6 to 94 ppb for samples taken in October 2002.

Washington State rescinded a zero tolerance ban on compost containing clopyralid in October 2003. The zero tolerance limit was thought to be affecting all composts as trace levels could be detected by advanced laboratory methods, yet these concentrations may not have direct relevance to plants. Reports by researchers from Washington State University and Woods End Research Laboratory indicate that only levels well over 25 ppb had any possible effects, and at that, only at very high application rates (Woods End Research Laboratory, 2003).

Recent studies conducted by Woods End Research Laboratory have indicated that clopyralid damage may not be as severe as first reported. This research has involved bioassays where sensitive plants are grown in compost containing a known quantity of the herbicide and plant growth is assessed. Results indicated that damage to crops from compost containing clopyralid would occur only at high application rates (up to 500 t/ha) (Brinton and Evans, 2002). Some bioassay procedures have been criticised for failing to eliminate the presence of factors that may influence plant growth such as salt content and compost maturity (Keating, 2002). Additionally, testing by different laboratories using varying methods has resulted in results that differ greatly for identical samples. For example, some laboratories identified clopyralid levels up to 43 ppb whilst another was unable to detect the herbicide at all. This may be due to the method of chemical extraction, which is highly complicated and variable due to the significant amount of organic components present in compost (Bezdicek *et al.*, 2003).

Laboratory analysis of clopyralid in compost can result in significant difficulties and widely varying results between analytical methods. In particular, the difficulties encountered by laboratories centre on the very low detection limit required as clopyralid can impact sensitive plants at concentrations as low as 1 ppb. In general, laboratory analysis of compost is difficult due to inorganic and organic chemicals including humic acids, salts and nutrients that make extraction of the chemical from the compost matrix very difficult.

4.3 Evidence of herbicide persistence

A 16-week composting trial performed under industry best practice conditions determined that the herbicides *clopyralid* and *picloram* did not degrade sufficiently to ensure sensitive crops and applications would be unaffected by residual concentrations of these herbicides. Consequently, impacts could occur on the recycled organics industry from these chemicals if present in organic materials processed. The herbicide *triclopyr* was found to be effectively degraded under these same conditions and not pose a threat to the integrity of the recycled organics industry or sensitive crops and applications receiving recycled organics products. Evidence of the persistence and degradation of these herbicides is provided in the attached report.

4.4 What has been done: risk management program

A risk management program has been implemented in NSW to prevent the issue of potentially persistent herbicides from threatening the recycled organics industry. This risk management program has identified a range of preventative measures to avoid any contamination issues from arising and has implemented a research program to ensure this potential issue is managed appropriately and impacts on industry are avoided. A summary of the work performed under this risk management program to date is given below.

- **Risk Assessment of Garden Maintenance Chemicals in Recycled Organics Products** (Recycled Organics Unit, 2002). This risk assessment involved a qualitative evaluation of the risk of garden maintenance chemicals in recycled organics products and was completed in September 2002. This project was undertaken to provide an overview of the garden maintenance chemicals (herbicides, insecticides, fungicides etc.) available on the domestic market and to identify the active chemical ingredients in these products. These products were assessed for the potential to persist after undergoing composting and the subsequent risk of impact to a plant and/or crop. A review of the international incidents of herbicide contamination of compost, in particular the recent clopyralid issues, is also included in this report. The recommendations from this study included the development of a test methodology to enable appropriate screening of material, confirmatory testing and risk reduction strategies, and the development of a paper on registration practices for garden maintenance chemicals.

- **Risk Management Tools for the Recycled Organics Industry** (Recycled Organics Unit, 2003c). This document was produced as an aid to the recycled organics industry to avoid the risk of potentially persistent herbicides in compostable organic materials. This report highlights that there is currently no evidence of problematic herbicides in raw materials used for compost production or any contamination issues in commercially produced composts in NSW. However, it is prudent to ensure a risk management strategy is in place to prevent these issues from arising. Consequently, this document provides a range of resources to support the industry including: an aid to identification of potentially contaminated raw material sources; a protocol for representative sampling and sample preparation for laboratory analysis of products and raw materials; a bioassay method for detection of herbicide in plants; contact details for commercial laboratories capable of testing for the problematic compounds, an overview of the laboratory test method and a list of sensitive crops and tolerance levels for the problematic compounds. The recommendations from this document included the validation of the herbicide bioassay that can be readily conducted by facilities.

In addition to these projects commissioned by the Department of Environment and Conservation, the Australian Mushroom Growers Association has developed a *Declaration Form* supplied to their growers as part of a quality assurance package to reduce the risk of herbicide in straw material. An example of this form is included as Appendix 4. A similar form may be beneficial for individual facilities in order to track sources of raw materials from agricultural sources as these can be readily traced.

In addition to these currently available tools, the bioassay proposed by the Recycled Organics Unit (2003c) will be validated to assist the industry to identify whether a product contains the herbicides to a level that would be damaging if applied to sensitive plant species (Recycled Organics Unit, 2004). This bioassay documents a method that provides results within 14 days at the lowest levels of contamination and is relatively cheap to conduct. A range of colour photographs will be produced for facilities to compare the results of the bioassay with known plant response to specific concentrations of the problematic herbicides.

4.5 Recommendations

The risk management program and associated applied composting trial suggest a need for evaluation of the regulatory framework for the registration of agricultural chemicals in relation to biodegradability criteria, particularly in relation to biodegradation in the commercial composting system. Options for further work for industry and Government is presented below for consideration.

4.5.1 Options for industry

To ensure persistent herbicides do not contaminate commercial recycled organics products, recycled organics industry should do everything possible to act responsibly from a risk management perspective:

- Industry should be encouraged to make use of the available information and tools and to take a responsible risk management approach to this issue. Tools available to the recycled organics industry regarding this issue include:
    - *Risk Management Tools for the Recycled Organics Industry* (Recycled Organics Unit, 2003c), which will be updated post validation of the bioassay methodology (Recycled Organics Unit, 2004).
- Industry should be encouraged to introduce a supplier management Quality Assurance process for suppliers of agricultural residuals similar to that instituted by the Australian Mushroom Growers Association (see Appendix 4). This will complement and support changes to labelling instituted by Dow AgroSciences. These changes state that compost produced from material treated with clopyralid should not be used in the growing season of the application. Since the issue of clopyralid in compost has come to light, Dow AgroSciences have updated Australian product labels for the clopyralid herbicide Lontrel^{TM} to state that this herbicide should not

be applied “to crops or pastures which are to be used for the production of compost or mulches” and that “The use of straw, hay or other plant material treated with Lontrel^{TM} Herbicide for composting or mulching susceptible crop may damage these crops”[1]. Label warnings such as this do little to prevent these materials entering the compost stream unless facilities actively seek information from the farmer. Therefore, point source materials such as agricultural residuals can be effectively tracked using a supplier management system, and a history of paddock and herbicide use can be easily traced using this method.

4.5.2 Options for Government

It is not possible for the recycled organics industry to address the potential contamination issues that arise from turf and lawn grass as these raw materials enter the compostable organics stream as diffuse sources. As such, whilst the approach taken by the mushroom industry may be adequate where the entire quantity of compostable materials are from a single known source, it is not adequate where small quantities or raw materials are received from many diffuse sources. To address this, a regulatory response to this issue is required.

In Australia, the responsible national authority for the registration of agricultural chemicals is the Australian Pesticides and Veterinary Medicines Authority (APVMA, previously the National Registration Authority), which is located in the Commonwealth Department of *Agriculture, Fisheries and Forestry, Australia* (AFFA). Registration by the APVMA requires consideration of the impact of a chemical on the environment before an agricultural chemical can be legally supplied or sold in Australia. The registration process and requirements are defined in the APVMA *Ag Manual* (1997). The associated environmental assessment criteria are documented in Part 7 *Agricultural Requirement Series: Environment* of the APVMA *Ag Manual*, which was developed for the APVMA by the *Chemicals Assessment Section* of the *Environment Protection Branch* of *Environment Australia*.

The registration process commonly involves the *Chemicals Assessment Section* undertaking an environmental hazard assessment on the basis of data supplied by the chemical manufacturer and providing advice to the APVMA as to whether a chemical meets the environmental risk requirements for registration.

The Chemicals Assessment Section (Environment Australia) recommends that review of the environmental risk assessment criteria and registration of existing chemicals should be addressed via the APVMA *National Registration Liaison Committee.* It is understood that the *Department of Environment and Conservation (NSW) (Policy and Science Division)* is represented on the *APVMA National Registration Liaison Committee*, and can work directly with the various state agriculture department representatives on the committee to implement these regulations.

Therefore, the recommended options for Government is detailed below:

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[1] Direct quotes from Lontrel^{TM} Herbicide label (Dow AgroSciences, 1998).

- Work directly with relevant units of the NSW and interstate agricultural agencies; and via direct engagement with Environment Australia Chemicals Risk Assessment Unit to address the following issues via the APVMA *National Registration Liaison Committee*:

  - To ensure that "*biodegradability of herbicides in the commercial composting process*" is included as an assessment requirement for the environmental risk assessment component for the registration of chemicals, particularly herbicides, via the APVMA to prevent new problem chemicals from being registered for use and entering the Australian market. This will require cooperation from Environment Australia and the APVMA.

  - To review existing methodologies and specify a reliable and valid method for demonstrating assurance of "*biodegradability of herbicides in the commercial composting process*".

- The greatest risk of the persistent herbicides entering the composting stream is from collections of raw materials from diffuse waste generators such as home lawns, and municipal and commercial and industrial sources (specifically turf and lawn) such as golf course and other recreational facilities. To address this risk, the registered uses of these specified chemicals should be reviewed by the APVMA. Consideration should be given to consulting the APVMA *National Registration Liaison Committee* (with the support of interstate departments of Agriculture) to place restrictions on the registration of these chemicals such that they are not permitted to be sold, marketed, or registered for commercial and industrial (C&I) or home lawn and turf applications.

  It is important that this issue be addressed as new products can become available on the market, in particular for the domestic market. For example, since the completion of the Risk Assessment (Recycled Organics Unit, 2002), it is understood that a new product called *Nuturf Millennium Herbicide* has come onto the domestic market that contains clopyralid and is registered for use on turf for the control of clover and bindii (Nuturf, 2003). Clopyralid products for turf applications are the products that have caused the most damage internationally and initially brought this problem to light. Warnings on product labels, such as the warning on *Nuturf Millennium Herbicide* stating, "Do not use clippings from turf, which has been treated with this product, for mulch or in the production of compost" (Nuturf, 2003) does not adequately address the associated risks to horticultural and recycled organics industries.

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Section 6 Appendices

Appendix 1 Glossary

All terms defined in this glossary are given in the Recycled Organics Industry Dictionary and Thesaurus, 2nd Edition (Recycled Organics Unit, 2003b) unless otherwise noted.

Term	**Definition**
Aerobic	In the presence of, or requiring, oxygen.
Adsorption	The way in which nutrient cations are attracted and attached to the surface of clay and organic particles in the soil (NSW Agriculture, 1999).
Agricultural areas	Fallow land cultivated for cropping, and pastures including natural pastures (Australian Pesticides and Veterinary Medicines Authority, 2001).
Agricultural organics	Any residual organic materials produced as by-products of agricultural and forestry operations, including: weeds (woody and non-woody), animals (processing residuals, stock mortalities, pests), crop residuals (woody and non-woody), and manures.
Anaerobic	In the absence of oxygen, or not requiring oxygen. Composting systems subject to anaerobic conditions often produce odorous compounds and other metabolites that are partly responsible for the temporary phytotoxic properties of compost. Anaerobic conditions are important for anaerobic digestion systems.
AS 4454 (Australian Standard AS 4454 – 2003)	AS 4454 – 2003 is a document outlining the Australian Standard for Composts, Soil Conditioners, and Mulches. The objective of the Standard is to provide manufacturers, local government bodies, consumers and growers with the minimum requirements for the physical, chemical and biological properties of composts, soil conditioners, and mulches. It also aims to standardise labelling and marking, in order to facilitate the beneficial recycling and use of organic materials with minimal adverse impact on environmental and public health. This Standard also sets out composting best practice procedures. By following these guidelines, products of consistent quality can be produced.
Best practice	For any area of waste management, this represents the current 'state-of-the-art' in achieving particular goals. Best Practice is dynamic and subject to continual review and improvement.
Broadleaf plants	Dicotyledonous plants, including both herbaceous and woody species, which have wide, rounded or flattened leaves and netted veins, as distinct from grasses and grass-like plants (Australian Pesticides and Veterinary Medicines Authority, 2001).
Bulk density	Weight or mass per unit of volume of a material comprised of many individual particles. For example, the weight of a pile of wood chips divided by the volume of the pile is the bulk density. This is different from the particle density (which, in this case, equals the weight of a single wood chip divided by its volume).
Carbon dioxide	An inorganic gaseous compound comprised of carbon and oxygen. Carbon dioxide is produced by the oxidation of organic compounds during composting. Carbon Dioxide is a greenhouse gas with a global warming potential (GWP) of 1.
Commercial and Industrial (C&I) waste	Inert, solid, industrial or hazardous wastes generated by businesses and industries (including shopping centres, restaurants and offices) and institutions (such as schools, hospitals and government offices), excluding construction and demolition waste and municipal waste.
Chemical persistence	The time a chemical remains essentially unaltered in the environment.

Continued next page

Term	Definition
Compost	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation and a specified level of maturity. Compost is suitable for the use as soil conditioner or mulch and can improve soil structure, water retention, aeration, erosion control, and other soil properties.
Compostable organics	Compostable organics is a generic term for all organic materials that are appropriate for collection and use as feedstocks for composting or in related biological treatment systems (e.g. anaerobic digestion). Compostable organics is defined by its material components: residual food organics; garden organics; wood and timber; biosolids, and agricultural organics.
Composting	The process whereby organic materials are pasteurised and microbially transformed under aerobic and thermophilic conditions for a period not less than 6 weeks. By definition, it is a process that must be carried out under controlled conditions yielding mature products that do not contain any weed seeds or pathogens.
Contact herbicide	An herbicide that kills only the tissues with which it comes into contact (NSW Agriculture, 1999).
Contamination (generic)	Any introduction into the environment or a product (water, air, soil, or recyclable materials) of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the environment or the product unfit for its intended use.
Contamination (composting)	Contaminants within this context include physical inorganic materials (metals, glass etc.), non-biodegradable organic materials (plastics), chemical compounds and/or biological agents that can have a detrimental impact on the quality of any recycled organic products manufactured from source separated compostable organic materials.
Curing	Final stage of composting in which stabilisation of the compost continues but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures.
Decomposition	The breakdown of organic waste materials by micro-organisms.
Degradability	Term describing the ease and extent that a substance is decomposed by the composting process. Materials which break down quickly and/or completely during the time frame of composting are highly degradable. Materials which resist biological decomposition are poorly or even non-degradable.
Electrical conductivity (EC)	A measure of the ability of a solution to carry an electrical current; varies both with the number and type of ions contained in the solution. Usually measured in deci-Siemens per metre (dS m^{-1}).
Feedstock	Organic materials used for composting or related biological treatment systems. Different feedstocks have different nutrient concentrations, moisture, structure and contamination levels (physical, chemical and biological).
Garden organics	The garden organics material definition is defined by its component materials including: Putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs; stumps and rootballs. Such materials may be derived from domestic, commercial and industrial and commercial and demolition sources. Garden organics is one of the primary components of the compostable organics stream. Garden organics is the standard material description from the Australian Waste Database.
Herbicides	A material that will kill plants. Herbicide may kill virtually all plants (non-selective) or be quite selective in the way they work. They may be knockdown (short-lived) or residual in the soil.

Continued next page

Term	**Definition**
Hydrolysis	Any reaction in which a bond is broken by the agency of water and the hydrogen and hydroxyl of the water become independently attached to the two atoms previously linked; the decomposition or splitting of a compound in this way. Also applied to the analogous decomposition of an organic compound by the action of an acid or alkali, and to any reaction between a water molecule and an ion that produces a hydrogen or hydroxyl ion (Oxford University Press, 2002).
Manure	Refers to all faecal and urinary excretion of livestock and poultry that are appropriate for collection and use as feedstock materials for composting or in related biological treatment systems. This material may also contain bedding, spilled feed, water or soil. See also agricultural organics. Such material may be derived from agricultural sources. These materials form one of the material description subcategories within the Agricultural Organics material description.
Maturation	Final stage of composting where temperatures remain steady below 45ºC, and the compost becomes safe to use with plants due to the absence of toxins.
Maturity (of compost)	Is related to the level of composting feedstock material receives. A mature product is stable and does not cause toxicity to plants.
Moisture content	The fraction or percentage of a substrate comprised of water. Moisture content equals the weight of the water portion divided by the total weight (water plus dry matter portion).
Non-crop areas	Areas of land not being used or not intended to be used for cropping. These areas include industrial sites, timber yards, areas around farm buildings, along fences and roadsides, rights-of-way, storage areas, wastelands, vacant lots, cemeteries etc (Australian Pesticides and Veterinary Medicines Authority, 2001).
Non-woody garden organics	Refers to leafy and/or succulent compostable organic plant materials that generally have a diameter of less than 5 mm that are appropriate for collection and use as feedstock materials for composting without necessarily requiring size reduction. Some materials including vines and tussocky grasses may be relatively unchanged through size reduction processes, and loads can often contain inorganic soil, rubble and physical contaminants. Such material may be derived from domestic, agricultural, forestry, C&D or C&I sources. Non-woody garden organics form one of the material description subcategories within the Garden Organics material description.
Organic matter	Chemical substances of animal or vegetable origin, consisting of hydrocarbons and their derivates.
Pasteurisation	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation, but is relatively immature and lacking in stability compared to compost.
Pasteurised product	A process whereby organic materials are treated to kill plant and animal pathogens and plant propagules. Pasteurisation can be achieved by the controlled biological transformation of organic materials under aerobic and thermophilic conditions such that the whole mass of constantly moist material is subjected to at least 3 consecutive days to a minimum temperature of 55°C (or by equivalent process).
Pastures	Herbage grown specifically for the purpose of being grazed by, or fed to, livestock. Pastures include lucerne, medics, clovers and grasses, whether for grazing or seed crops. The word 'herbage' excludes crops such as cereals, oilseeds, vegetables and cole crops.
pH	A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Material that has a pH of 8 has ten times fewer hydrogen ions than a material with a pH of 7. The lower the pH, the more hydrogen ions are present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.

Continued next page

Term	**Definition**
Photo-degradation	Degradation of a substance caused by light (Oxford University Press, 2002).
Photolysis	Decomposition or dissociation of molecules by the action of light (Oxford University Press, 2002).
Recycled organics	The term Recycled Organics has been adopted by NSW Waste Boards and EcoRecycle Victoria as a generic term for a range of products manufactured from compostable organic materials (garden organics, food organics, residual wood and timber, biosolids and agricultural organics). Specific recycled organic (RO) products are defined in the following Australian Standards and NSW EPA guidelines: AS 4454 (2003) Composts, mulches and soil conditioners; AS 3743 (2003) Potting mixes; AS 4419 (2003) Soils for landscaping and garden use; AS/NZS 4422 (1998) Playground surfacing: specifications, requirements and test methods; NSW EPA (1997) Environmental guidelines: use and disposal of biosolids products. Whilst quality standards exist, there are also many raw RO products that are not defined in any standard and are completely unregulated, certain risks are associated with their use.
Recycled organics industry	A range of related business enterprises involved in the processing of compostable organics into a range of recycled organics products, and the development, assessment, marketing, promotion, distribution and application of those products.
Rights-of-way	Roads, stock routes, pathways, railways, power lines, telephone lines, fuel and water pipelines (Australian Pesticides and Veterinary Medicines Authority, 2001).
Selective herbicide	An herbicide that kills only certain groups of plants (NSW Agriculture, 1999).
Shredding	An operation that reduces the particle size of materials. Shredding implies that the particles are broken apart by tearing and slicing.
Systemic	Entering the system of a plant and freely transported within its tissues (Oxford University Press, 2002).
Thermophilic	Temperatures above 45ºC. Used to describe a stage of composting in which high temperatures are sustained resulting in high rates of decomposition and pasteurisation of the organic material. Heat tolerant microorganisms survive well in these conditions.
Turning	A composting operation that mixes and agitates material in a windrow pile or vessel. Its main aeration effect is to increase the porosity of the windrow to enhance passive aeration. It can be accomplished with front-end loaders or specially designed turning machines.
Volatilisation	The conversion of a chemical from liquid or solid to a gas or vapour (NSW Agriculture, 1999).
Windrow with or without aeration	System of composting involving the aeration of horizontally extended piles formed by a front-end loader or windrow turner. Extended piles are generally 1.5 to 3 m in height, and length is limited by the size of the composting pad. Aeration can be achieved by mechanical turning and/or the delivery of air from the base of the windrow.
Woody garden organics	Refers to all compostable organic plant materials that have a diameter of between 5 and 150 mm that are appropriate for collection and use as feedstock materials for composting or in related biological treatment systems. Such material may be derived from domestic, agricultural, forestry, construction and demolition or commercial and industrial sources. These materials contain a significant wood or cellulose component, requiring different size reduction technology from non-woody garden organics. Examples include: branches; twigs and bark. Woody Garden Organics forms one of the material description subcategories within the Garden Organics material description.

Appendix 2 Industry survey

The survey used in *Stage 1: Industry Survey* to determine standard industry practice is included on the following pages. This survey was sent to compost manufacturers across Australia producing to the relevant Australian Standard AS 4454 (Standards Australia, 2003b).

Persistent Chemicals Risk Management Program:
Documenting standard industry practice

To make our case to the NRA in relation to persistent herbicides, we must provide evidence that our biodegradability/persistence composting trial methodology is representative of standard industry practice, hence this industry survey. **This information will not be distributed, responses will be treated as confidential information. Only aggregated data will be published.**

Please complete this 3 page survey and return ASAP to enable the persistent herbicides risk management program to proceed. Fax and mail address for completed surveys are provided on page 3 of this survey.

Please refer to the specific operational practices of your own enterprise/s. In some instances the answer will be "it depends", in this instance, please provide a range, and state the variables that are responsible for the higher and lower ends of this range.

Name: ______________________________ Position: _______________________________

Organisation: ______________________________________ Phone: ___________________

Signature: ____ Date:_______ / 11 / 2002

On the basis of your experience:

1) What is the typical duration (range) for your completed composting process?
From ____________ to_________ weeks,
depending upon:____

2) What is the standard frequency of turning during composting for your operation?
Every ____________ to_________ weeks,
depending upon:____

3) What moisture level do you try to maintain in composting windrows:
between __ % to ___ %,
depending upon:____

4) How regularly do you tend to water compost windrows during the warmer months (summer to mid autumn: January, February, March, April)?
Every ____________ to_________ days,
depending upon:____

5) For the purpose of defining appropriate inoculation levels for the persistent herbicides to be evaluated in the composting trial, it is important for us to know the feedstock recipes used for commercial composting processes. **This information will not be distributed**. Please provide details below, you will notice there is an opportunity to identify whether the information relates to your operations, to trials or research you may have conducted, or to your knowledge of someone else's commercial operation. If you do not have knowledge of some categories, please leave blank.

Please note, garden organics are also commonly referred to as green organics or garden waste in various states. "Other raw materials" may include forestry residuals such as sawdusts or barks, or a range of other materials such as food waste, paper, cardboard, sludges, etc. Please be specific.

When forming compost windrows (etc) IN SUMMER from source separate municipal **garden organics**, do you commonly add other raw organic materials? ☐ **YES** ☐ **NO**, if “yes”, please define below:

Raw materials (compostable organic materials)	**Complementary materials**	**Proportions in recipe**	**Source of information**
Key raw material	Garden organics	By volume %______	☐ Direct operational experience ☐ Operational trials ☐ Research ☐ Knowledge of other processing operations
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	

When forming compost windrows (etc) IN SUMMER from **food waste**, do you commonly add other raw organic materials to form a suitable compost recipe? ☐ **YES** ☐ **NO**, if “yes”, please define below:

Raw materials (compostable organic materials)	**Complementary materials**	**Proportions in recipe**	**Source of information**
Key raw material	Food waste	By volume %______	☐ Direct operational experience ☐ Operational trials ☐ Research ☐ Knowledge of other processing operations
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	

When forming compost windrows (etc) IN SUMMER from **biosolids**, do you commonly add other raw organic materials to form a suitable compost recipe? ☐ **YES** ☐ **NO**, if “yes”, please define below:

Raw materials (compostable organic materials)	**Complementary materials**	**Proportions in recipe**	**Source of information**
Key raw material	Biosolids	By volume %______	☐ Direct operational experience ☐ Operational trials ☐ Research ☐ Knowledge of other processing operations
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	
Other raw materials		By volume %______	
		By weight % ______	

6) Please estimate the proportion of lawn clippings present in a typical SUMMER source separated municipal garden organics (green organics / garden waste) stream?
% of total by volume =___________________
% of total by weight = ___________________

7) Please provide estimates of the bulk density of the raw materials processed by your company:

Raw materials (compostable organic materials)	**Do you process this material**	**Bulk density (use your preferred units)** [1]		
		Kg/litre	**Kg/cum**	**Cum/tonne**
Shredded garden organics (green organics, garden waste)	☐ YES ☐ NO			
Wood & timber (from commercial or industrial sources)	☐ YES ☐ NO			
Sawdusts (from forestry residuals)	☐ YES ☐ NO			
Barks (from forestry residuals)	☐ YES ☐ NO			
Food organics (food waste)	☐ YES ☐ NO			
Biosolids	☐ YES ☐ NO			
Straw (agricultural residuals)	☐ YES ☐ NO			
Manure (agricultural residuals)	☐ YES ☐ NO			
Animal bedding (agricultural residuals)	☐ YES ☐ NO			
Other:	☐ YES ☐ NO			
Other:	☐ YES ☐ NO			
Other:	☐ YES ☐ NO			

[1] Please provide response in the format you use in your operation. Note cum = cubic metres.

END

Responses can be sent via mail to the address in the header, or
by fax to 02 9385 6866

Submissions must be received by Friday 29th November 2002

Thank you for your assistance with this essential project. As stated, there is no intention to publish primary data, this will remain confidential. This information is essential to establish a robust case against these potentially industry threatening herbicides. If you require further clarification or detail, please contact me directly via email a.campbell@unsw.edu.au or via mobile 0414 385 226 and I will respond directly.

Sincerely,

Angus Campbell
Recycled Organics Unit
The University of New South Wales

Appendix 3 Example of commercial formulations containing multiple active ingredients

Introduction to commercial herbicide products

Herbicides can contain one or more active chemicals that result in toxicity to plants. These active chemicals can be included in a variety of concentrations and in combination with other chemicals and this results in the availability of a large variety of commercial products. Table A3.1 shows examples of the range of multiple active ingredient herbicides registered in Australia and internationally. These tables include commercial products containing the herbicides clopyralid, picloram and triclopyr and do not include a comprehensive list of all products registered.

This inclusion of multiple active ingredients in commercial herbicide products provides a rationale for *Stage 3: Applied Composting Trial*. The compost windrows will be inoculated with all three herbicides clopyralid, picloram and triclopyr. This also imitates the situation at a commercial composting facility whereby municipally collected garden organics could be contaminated with a variety of herbicidal products.

Table A3.1. Commercial preparations containing multiple active ingredients currently registered for use in Australia and internationally.

Commercial product	Manufacturer and place of registration	Active ingredients	Application rate	Use
Battleship™ Herbicide	Helena Chemical Company United States	(MCPA 37.9%) Triclopyr 3.8% Clopyralid 1.3%	5 L/ha	For the control of broadleaf weeds in turf, non-crop areas and roadsides.
Confront™ Herbicide	Dow AgroSciences United States	Triclopyr 33% Clopyralid 12.1%	2 L/ha	For the control of annual and perennial broadleaf weeds in established turf.
Grass-Up Herbicide	Grow Choice Pty Ltd Australia	Triclopyr 300 g/L Picloram 100 g/L	10 L/ha	For the control of brush, briars and woody weeds.
Grazon™ DS Herbicide	Dow AgroSciences Australia	Triclopyr 300 g/L Picloram 100 g/L	10 L/ha	For control of a range of environmental and noxious woody and herbaceous weeds.
Radiate™ Herbicide	Dow AgroSciences New Zealand	Clopyralid 225g/L Picloram 150 g/L	2 L/ha	For the release of Radiata Pine from gorse and broom and for the control of certain broadleaf weeds in fodder brassicas.
Redeem™ R&P	Dow AgroSciences United States	Triclopyr 33% Clopyralid 12.1%	2-5 L/ha	For the control of annual and perennial broadleaf weeds in rangeland and permanent grass pastures, non-crop areas such as fence rows, non-irrigation ditchbanks, and around farm buildings, and CRP acres.
Tordon™ Double Strength Herbicide	Dow AgroSciences Australia	Triclopyr 200 g/L Picloram 100 g/L	Apply directly to cut stump	For the control of unwanted timber by stem injection or cut stump/brushcutter application and control of blackberry, gorse and harrisia by foliage spray.

Appendix 4 Australian Mushroom Growers Association Declaration Form

STRAW SUPPLIERS DECLARATION FORM

Supplier's Details

Name: ______________________________

Address: ______________________________

Phone: ______________ Fax: ______________

Straw Details

Grower's Name: ______________________________

Grower's Address: ______________________________

Identification of paddock(s) that straw came from: ______________

Number of bales supplied: ______________ Identification mark on bales: ______________

The straw is from a paddock that has any of the following herbicides applied in the last two years:

Clopyralid: Lontrel Herbicide; Nufarm Archer Herbicide; Lontrel 750 SG Herbicide: Farmoz Victory Herbicide;

Transit Herbicide; Victory Herbicide.

Picloram: Tordon 75-D; Tordon 242; Farmoz Enforcer 242 cereal herbicide; Jab Cereal Herbicide; Nufarm Trooper Herbicide.

Sulfonylureas: Ally (and its mimics); Glean (and its mimics); Lo-Gran (and its mimics).

☐ Yes ☐ No

Paddock History

2 years ago

Crop(s) grown: ______________________________

Pesticides used: ______________________________

1 year ago

Crop(s) grown: ______________________________

Pesticides used: ______________________________

Declarations

I/we declare that the above information is true and accurate

Supplier	Date	Grower/producer	Date

Source: Australian Mushroom Growers Association

Appendix 5 Raw data for Stage 3: Applied Composting Trial

Table A5.1. Concentration of clopyralid, picloram and triclopyr detected in each pile in parts per billion, ppb (µg/kg) on a wet weight basis.

Pile ID	CLOPYRALID CONCENTRATION (ppb)					
	Week 0	**Week 3**	**Week 6**	**Week 9**	**Week 12**	**Week 16**
	21/05/03	**12/06/03**	**2/07/03**	**23/07/03**	**13/08/03**	**10/09/03**
Control 1	<1	<1	<1	<1	<1	<1
Control 2	<1	<1	<1	<1	<1	<1
Control 3	<1	<1	<1	<1	<1	<1
Low concentration 1	10	20	20	30	30	30
Low concentration 2	20	30	20	30	30	30
Low concentration 3	20	20	20	20	20	20
High concentration 1	50	40	60	70	60	70
High concentration 2	60	60	50	60	60	60
High concentration 3	40	60	60	60	70	30

Pile ID	PICLORAM CONCENTRATION (ppb)					
	Week 0	**Week 3**	**Week 6**	**Week 9**	**Week 12**	**Week 16**
	21/05/03	**12/06/03**	**2/07/03**	**23/07/03**	**13/08/03**	**10/09/03**
Control 1	<1	<1	<1	<1	<1	<1
Control 2	<1	<1	<1	<1	<1	<1
Control 3	<1	<1	<1	<1	<1	<1
Low concentration 1	10	10	10	20	10	10
Low concentration 2	10	10	10	20	10	10
Low concentration 3	20	5	10	10	10	10
High concentration 1	30	20	20	10	30	30
High concentration 2	20	30	30	30	30	20
High concentration 3	20	30	30	30	30	20

Pile ID	TRICLOPYR CONCENTRATION (ppb)					
	Week 0	**Week 3**	**Week 6**	**Week 9**	**Week 12**	**Week 16**
	21/05/03	**12/06/03**	**2/07/03**	**23/07/03**	**13/08/03**	**10/09/03**
Control 1	<1	<1	<1	<1	<1	<1
Control 2	<1	<1	<1	<1	<1	<1
Control 3	<1	<1	<1	<1	<1	<1
Low concentration 1	10	10	40	1	<1	<1
Low concentration 2	20	10	40	1	<1	<1
Low concentration 3	20	5	30	2	<1	<1
High concentration 1	90	20	20	5	2	<1
High concentration 2	50	40	10	1	<1	<1
High concentration 3	40	30	10	1	1	<1

Table A5.2. Temperature (^{o}C) for *Control* piles for the duration of the Applied Composting Trial (Stage 3).

Week	Date	CONTROL PILE 1						CONTROL PILE 2						CONTROL PILE 3						MEAN AND STANDARD ERROR					
		0.3a	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3avg**	**0.3SEM**	**0.6avg**	**0.6SEM**	**0.9avg**	**0.9SEM**
0	21/05/2003	39	47	47	53	54	61	44	52	56	63	63	66	44	45	55	55	62	62	45.17	1.74	54.83	2.10	61.33	1.63
1	28/05/2003	46	49	62	60	69	69	49	46	52	54	58	62	39	42	48	50	59	61	45.17	1.62	54.33	2.28	63.00	1.98
2	4/06/2003	53	49	60	56	64	61	51	54	58	58	63	60	49	52	55	59	61	62	51.33	0.84	57.67	0.76	61.83	0.60
3	11/06/2003	36	41	41	44	55	51	47	40	50	45	55	51	42	45	45	50	50	54	41.83	1.58	45.83	1.45	52.67	0.92
4	18/06/2003	46	54	52	60	60	64	52	47	57	55	63	61	48	57	52	63	60	65	50.67	1.78	56.50	1.80	62.17	0.87
5	25/06/2003	22	29	46	47	57	59	30	38	46	49	58	57	34	26	43	39	55	54	29.83	2.32	45.00	1.44	56.67	0.76
6	2/07/2003	49	52	54	58	59	61	54	50	58	58	61	62	45	45	52	54	59	59	49.17	1.49	55.67	1.09	60.17	0.54
7	9/07/2003	42	45	52	47	57	48	52	54	59	59	62	63	51	48	57	52	60	56	48.67	1.86	54.33	1.96	57.67	2.23
8	16/07/2003	26	30	43	42	53	55	33	37	50	52	62	62	36	34	46	47	60	60	32.67	1.67	46.67	1.58	58.67	1.54
9	23/07/2003	24	41	46	53	53	58	54	55	59	61	62	64	51	54	59	59	61	61	46.50	4.97	56.17	2.32	59.83	1.58
10	30/07/2003	52	55	56	61	58	63	53	60	61	66	68	70	52	44	59	48	64	56	52.67	2.12	58.50	2.49	63.17	2.23
11	6/08/2003	27	42	46	54	54	59	54	51	60	57	63	63	53	41	59	53	61	61	44.67	4.20	54.83	2.09	60.17	1.38
12	13/08/2003	39	50	51	57	57	60	43	54	54	59	60	61	49	55	58	59	61	61	48.33	2.55	56.33	1.31	60.00	0.63
13	20/08/2003	26	48	50	58	60	64	54	43	61	50	62	52	54	52	62	58	64	63	46.17	4.38	56.50	2.16	60.83	1.87
14	27/08/2003	53	50	59	57	61	57	46	48	54	55	58	59	49	47	56	51	57	54	48.83	1.01	55.33	1.12	57.67	0.95
15	3/09/2003	27	35	41	48	52	56	47	38	54	50	60	55	49	45	57	55	56	52	40.17	3.43	50.83	2.39	55.17	1.22
16	10/09/2003	52	52	56	58	58	60	45	58	50	60	57	60	51	56	59	59	59	61	52.33	1.84	57.00	1.51	59.17	0.60

Note: temperature was taken at a pile height of 1.2 m and a depth of 0.3 m, 0.6 m and 0.9 m. Two readings were taken at each depth (a and b).

Table A5.2 continued. Temperature (^{o}C) for *Low Concentration* piles for the duration of the Applied Composting Trial (Stage 3).

Week	Date	LOW CONCENTRATION PILE 1						LOW CONCENTRATION PILE 1						LOW CONCENTRATION PILE 1						MEAN AND STANDARD ERROR					
		0.3a	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3avg**	**0.3SEM**	**0.6avg**	**0.6SEM**	**0.9avg**	**0.9SEM**
0	21/05/2003	38	31	43	40	50	50	41	34	48	44	59	51	33	31	47	40	58	55	34.67	1.65	43.67	1.38	53.83	1.66
1	28/05/2003	46	44	61	57	64	64	46	53	56	60	60	63	42	44	55	55	64	58	45.83	1.56	57.33	1.05	62.17	1.05
2	4/06/2003	56	47	62	55	64	57	46	55	56	61	63	65	50	51	56	57	62	63	50.83	1.66	57.83	1.19	62.33	1.15
3	11/06/2003	49	41	57	46	58	49	40	36	46	43	51	49	44	42	49	47	52	51	42.00	1.77	48.00	1.97	51.67	1.36
4	18/06/2003	51	58	57	50	58	54	50	50	55	52	63	54	45	36	46	38	46	38	48.33	3.00	49.67	2.81	52.17	3.64
5	25/06/2003	29	36	30	48	39	54	30	36	33	46	46	53	29	27	38	34	48	46	31.17	1.58	38.17	2.99	47.67	2.23
6	2/07/2003	45	43	46	54	59	59	47	47	53	52	57	59	43	47	53	52	55	57	45.33	0.80	51.67	1.17	57.67	0.67
7	9/07/2003	38	46	47	54	45	58	47	47	55	53	61	60	48	46	54	54	59	61	45.33	1.50	52.83	1.19	57.33	2.51
8	16/07/2003	31	39	48	51	55	56	35	36	51	49	60	58	34	40	50	53	59	59	35.83	1.35	50.33	0.71	57.83	0.79
9	23/07/2003	46	45	51	49	56	54	51	52	58	56	62	58	51	51	55	60	58	62	49.33	1.23	54.83	1.70	58.33	1.31
10	30/07/2003	55	41	58	50	61	55	51	49	57	57	62	60	55	47	59	52	59	55	49.67	2.17	55.50	1.48	58.67	1.23
11	6/08/2003	45	27	49	38	55	49	44	38	49	43	56	53	41	36	48	42	54	53	38.50	2.69	44.83	1.85	53.33	0.99
12	13/08/2003	53	54	59	56	62	60	53	52	59	57	63	61	57	55	59	57	61	60	54.00	0.73	57.83	0.54	61.17	0.48
13	20/08/2003	53	51	57	56	58	62	56	54	60	61	64	68	56	51	60	59	60	62	53.50	0.92	58.83	0.79	62.33	1.41
14	27/08/2003	43	43	53	46	56	47	42	40	49	43	55	49	38	37	48	41	52	43	40.50	1.06	46.67	1.76	50.33	2.03
15	3/09/2003	39	31	49	36	57	49	38	41	47	49	57	56	44	40	53	51	58	57	38.83	1.78	47.50	2.45	55.67	1.36
16	10/09/2003	44	53	51	57	56	58	48	58	56	63	62	65	35	49	39	54	44	57	47.83	3.22	53.33	3.29	57.00	2.94

Note: temperature was taken at a pile height of 1.2 m and a depth of 0.3 m, 0.6 m and 0.9 m. Two readings were taken at each depth (a and b).

Table A5.2 continued. Temperature (^oC) for *High Concentration* piles for the duration of the Applied Composting Trial (Stage 3).

Week	Date	HIGH CONCENTRATION PILE 1						HIGH CONCENTRATION PILE 2						HIGH CONCENTRATION PILE 3						MEAN AND STANDARD ERROR					
		0.3a	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3a**	**0.3b**	**0.6a**	**0.6b**	**0.9a**	**0.9b**	**0.3avg**	**0.3SEM**	**0.6avg**	**0.6SEM**	**0.9avg**	**0.9SEM**
0	21/05/2003	26	29	39	42	54	54	32	39	44	50	54	57	37	39	49	49	56	56	33.67	2.25	45.50	1.84	55.17	0.54
1	28/05/2003	37	49	54	59	63	63	46	33	54	30	47	26	31	50	48	57	60	56	41.00	3.42	50.33	4.34	52.50	5.84
2	4/06/2003	47	55	55	59	61	65	42	48	53	57	57	62	53	49	59	55	64	60	49.00	1.88	56.33	0.99	61.50	1.18
3	11/06/2003	43	41	50	46	53	51	38	38	43	42	52	48	42	42	47	46	51	51	40.67	0.88	45.67	1.17	51.00	0.68
4	18/06/2003	51	42	54	51	59	57	44	53	49	57	58	60	48	51	53	54	55	55	48.17	1.78	53.00	1.13	57.33	0.84
5	25/06/2003	26	24	24	28	38	46	40	27	47	36	52	47	30	30	37	42	49	49	29.50	2.31	35.67	3.49	46.83	1.96
6	2/07/2003	46	52	51	55	56	56	44	49	54	54	55	56	52	52	58	53	61	54	49.17	1.42	54.17	0.95	56.33	0.99
7	9/07/2003	49	47	56	50	58	56	45	49	51	54	58	61	44	47	53	54	57	59	46.83	0.83	53.00	0.89	58.17	0.70
8	16/07/2003	39	39	51	49	60	58	41	45	55	57	62	63	45	33	54	55	59	62	40.33	1.84	53.50	1.20	60.67	0.80
9	23/07/2003	50	52	55	58	59	61	49	58	52	62	58	64	55	53	58	58	60	59	52.83	1.35	57.17	1.38	60.17	0.87
10	30/07/2003	47	41	54	50	58	60	57	42	61	49	62	55	41	47	56	56	64	65	45.83	2.51	54.33	1.80	60.67	1.54
11	6/08/2003	41	35	47	45	55	55	42	38	47	48	52	56	51	55	57	60	62	63	43.67	3.16	50.67	2.54	57.17	1.78
12	13/08/2003	49	52	57	57	60	60	48	55	55	59	60	62	54	49	57	57	60	60	51.17	1.19	57.00	0.52	60.33	0.33
13	20/08/2003	47	45	55	51	60	58	53	54	61	63	64	66	51	51	61	60	63	65	50.17	1.42	58.50	1.86	62.67	1.26
14	27/08/2003	44	29	51	40	54	49	44	42	49	48	51	55	38	41	47	46	55	52	39.67	2.32	46.83	1.54	52.67	0.99
15	3/09/2003	42	39	49	49	52	56	47	39	58	44	59	54	47	45	55	54	60	59	43.17	1.51	51.50	2.08	56.67	1.31
16	10/09/2003	52	45	53	48	54	48	51	53	58	60	62	63	42	47	51	54	59	57	48.33	1.78	54.00	1.81	57.17	2.27

Note: temperature was taken at a pile height of 1.2 m and a depth of 0.3 m, 0.6 m and 0.9 m. Two readings were taken at each depth (a and b).

Table A5.3. Oxygen concentration (%v/v) for *Control* piles for the duration of the Applied Composting Trial (Stage 3).

Week	Date	C1 0.3	C1 0.6	C1 0.9	C2 0.3	C2 0.6	C2 0.9	C3 0.3	C3 0.6	C3 0.9	0.3 avg	0.3 SEM	0.6 avg	0.6 SEM	0.9 avg	0.9 SEM
0	21/05/2003	6	4	2	6	7	6	7	5	3	6.33	0.33	5.33	0.88	3.67	1.20
1	28/05/2003	12	7	4	19	18	16	19	19	14	16.67	2.33	14.67	3.84	11.33	3.71
2	4/06/2003	16	9	3	14	9	4	13	10	6	14.33	0.88	9.33	0.33	4.33	0.88
3	11/06/2003	20	18	13	17	14	13	18	15	14	18.33	0.88	15.67	1.20	13.33	0.33
4	18/06/2003	20	18	16	19	15	13	19	16	12	19.33	0.33	16.33	0.88	13.67	1.20
5	25/06/2003	19	18	14	20	15	14	19	15	13	19.33	0.33	16.00	1.00	13.67	0.33
6	2/07/2003	20	18	14	17	14	12	18	17	16	18.33	0.88	16.33	1.20	14.00	1.15
7	9/07/2003	19	15	15	15	14	16	15	16	19	16.33	1.33	15.00	0.58	16.67	1.20
8	16/07/2003	16	8	6	16	7	3	18	5	4	16.67	0.67	6.67	0.88	4.33	0.88
9	23/07/2003	18	11	5	16	10	5	16	7	4	16.67	0.67	9.33	1.20	4.67	0.33
10	30/07/2003	16	10	6	11	5	4	13	8	6	13.33	1.45	7.67	1.45	5.33	0.66
11	6/08/2003	20	19	18	19	17	16	20	20	19	19.67	0.33	18.67	0.88	17.67	0.88
12	13/08/2003	17	14	14	18	12	10	14	13	14	16.33	1.20	13.00	0.58	12.67	1.33
13	20/08/2003	16	11	9	13	17	18	10	14	18	13.00	1.73	14.00	1.73	15.00	3.00
14	27/08/2003	16	13	11	14	11	14	16	12	10	15.33	0.67	12.00	0.58	11.67	1.20
15	3/09/2003	17	17	17	17	14	11	19	18	17	17.67	0.67	16.33	1.20	15.00	2.00
16	10/09/2003	18	15	12	16	15	14	18	15	12	17.33	0.67	15.00	0.00	12.67	0.67

Note: C1 is Control pile 1, C2 Control pile 2, C3 Control pile 3. Oxygen concentration was taken at a pile height of 1.2 m and a depth of 0.3 m, 0.6 m and 0.9 m.

Table A5.4. Moisture content data for each treatment for the duration of the Applied Composting Trial (Stage 3).

Week	Date	CONTROLS (%w/w)					LOW CONCENTRATION (%w/w)					HIGH CONCENTRATION (%w/w)				
		C1	C2	C3	C avg	C SEM	L1	L2	L3	L avg	L SEM	H1	H2	H3	H avg	H SEM
0	21/05/2003	58.1	61.6	59.8	59.83	1.01	64.3	64.8	65.2	64.77	0.26	66	61.9	60.5	62.80	1.65
1	28/05/2003															
2	4/06/2003															
3	11/06/2003	59.1	58.8	55.9	57.93	1.02	59.8	63.3	65.5	62.87	1.66	62.8	60.4	59.2	60.80	1.06
4	18/06/2003															
5	25/06/2003															
6	2/07/2003	60.1	59.4	60.9	60.13	0.43	60.7	61.9	63.1	61.90	0.69	58.6	60.8	63.1	60.83	1.30
7	9/07/2003															
8	16/07/2003															
9	23/07/2003	59.9	60.7	57.9	59.50	0.83	62.1	61.9	62.3	62.10	0.12	62	60	57.4	59.80	1.33
10	30/07/2003															
11	6/08/2003															
12	13/08/2003	52.7	53.5	54.9	53.70	0.64	56.7	59.3	58.2	58.07	0.75	56.3	50.9	49.8	52.33	2.01
13	20/08/2003															
14	27/08/2003															
15	3/09/2003															
16	10/09/2003	53.1	52.8	52.6	52.83	0.15	53	54.7	54.5	54.07	0.54	49.9	49.9	48	49.27	0.63