POULTRY CRC LTD

FINAL REPORT

Sub-Project No: 2.2.4

PROJECT LEADER: Eugene McGahan

Odour Measurement and Impact from Spent Hen Composting: Final Report

DATE OF COMPLETION: 13 February 2014

ISBN 1 921010 83 5

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Published in February 2014

Abstract

Composting has long been used as a suitable management tool for handling the solid wastes produced in layer hen facilities and is now becoming a more common practice for managing both spent hens and mortalities. Spent hens have traditionally been removed from farm and converted to human and animal food at processing facilities. The Australian egg industry is investigating other viable options to handle this by-product from the industry due to the potential lack of availability and capacity of these processing facilities to accept and process spent hens, the increasing costs of transporting spent hens and the loss in farm productivity while a shed is being destocked. This project collected and analysed odour samples from layer hen carcass compost windrows to develop an odour emission profile of the process. This emission data profile was used to assess the likely increased odour impact of a layer farm if they changed from exporting spent hens off-farm to a composting process on-farm.

Executive Summary

FSA Consulting was engaged by the Poultry Cooperative Research Centre (CRC) to undertake Sub Project 2.2.4 – Odour Measurement and Impact from Spent Hen Composting. Composting has long been used as a suitable management tool for handling the solid wastes produced in layer hen facilities and is now becoming a more common practice for managing both spent hens and mortalities. Spent hens have traditionally been removed from farm and converted to human and animal food at processing facilities. The Australian egg industry is investigating other viable options to handle this by-product from the industry due to the potential lack of availability and capacity of these processing facilities to accept and process spent hens. Additionally, transport costs and the loss in farm productivity while a shed is being destocked has made this traditional method less financially viable.

Composting spent hens on-farm is an option that has the potential to increase the flexibility of an egg producer's production system however, the potential odour emissions from an on-farm composting facility maybe a barrier to the adoption of this method of spent hen disposal.

This project had two primary objectives:

1. Quantify odour generation and emissions produced by composting spent hens on-farm and the likely impact these have on community amenity.
2. To determine if different cover materials, moisture levels or compost ages influence odour generation at the Pittsworth and Tamworth trial sites.

To address these objectives, a comprehensive review of the literature on odour emissions from composting (specifically animal composting) was conducted, along with the measurement of odour emission rates from two compost trial sites (Pittsworth and Tamworth). This information was used to conduct an odour impact assessment of the likely increased odour impacts of conducting spent hen composting on-farm.

The two trial sites were chosen to provide varying demographics and meteorological conditions under which the composting was undertaken. The two farms also used different methods of composting, however both were typical of practices used by industry. Two different composting substrate materials (layer manure and sawdust) were used to represent typical materials that are available and used by Australian egg producers that currently utilise composting as a method to manage hen mortalities and spent hens. Both summer and winter compost trials were conducted at each site.

A total of 99 odour emission samples were collected (65 at the Pittsworth site and 34 at the Tamworth site) using a flux chamber and then analysed at the Department of Agriculture, Fisheries and Forestry olfactometer in Toowoomba, using the AS/NZS 4323.3 standard. The odour samples collected included the two different materials (sawdust and manure); both wet and dry windrow surfaces; and disturbed and undisturbed windrows. Additionally, testing was conducted to investigate the decay in odour emission up to three hours post disturbance of a windrow. Some of the samples were also assessed for character to determine if aged compost produced a different type of odour to freshly placed windrows.

The detailed literature review indicated that odour emission rates are driven by a number of key factors: the location of the site (i.e. climatic conditions); type of base material (manure vs sawdust); age of the windrow; and management of the windrow (wet vs dry, turning vs unturned). The odour emission rate data was analysed based on these factors and it was found that the general range of emissions by site is similar, with the median emission rate being 0.3 ou/m^2/s (Pittsworth) and 0.35 ou/m^2/s (Tamworth). The range of emissions associated with sawdust is less than that of manure, with the median emission rate for

sawdust being 2.7 times less than that of manure and the minimum emission rate for sawdust being 11 times lower than that of manure.

In relation to windrow age, odour emissions for both wet and dry compost windrows were typically higher in the few weeks after the windrows were placed and then dropped away with time. The difference between wet and dry manure does not appear to be significant in the period close to placement. However, wet manure, when aged, appears to have higher emissions than dry manure. The sawdust based emissions rose from day 7 to about day 28 and then decreased. The data indicated that wet windrows tended to have elevated emissions compared to dry windrows, at least in the first few weeks. In contrast, the manure emissions were highest at day 7, dropped at day 10, then rose slightly at day 28 before dropping away to a background value. The odour decay experiment, where emission rates were estimated immediately after turning, 1 hour after turning, and 3 hours after turning showed that the emissions rose after turning but dropped off again rapidly.

Experience with composting has shown that the finished product is often far less odorous than the initial product. This might be expected as the initial material (dead birds in this case) is high in protein and fats, which decompose creating a wide range of odorous gases. Decomposition converts the original complex chemistry into simpler, less odorous breakdown products. Different odour compounds are expected to be produced at different stages of composting. Odour descriptors were compiled for 56 of the odour samples collected and whilst not conclusive, it was observed that the general character of the odour changed from "decaying, putrid, pungent, dead chickens, chicken manure" for a new windrow to "silo smell, earthy, damp soil, vege patch" for a composted windrow.

Using the collected odour emission data, a typical emissions profile (by windrow age) was developed for sawdust and manure based windrows. The emission rate as a function of age for manure based windows can best be described as:

$$y = 3.0527 \times x^{-0.34}$$

Where:

y is the odour emission rate (ou/m^2/s) and
x is the age of the windrow in days.

The emission rate for sawdust based windrows up to day 59 can be described as:

$$y = -0.0004x^2 + 0.0279x + 0.174.$$

For windrows older than 60 days, a constant odour emission rate of 0.3 ou/m^2/s can be applied.

To quantify odour generation and emissions produced by composting spent hens on-farm and the likely impact these have on community amenity, three odour modelling scenarios were run for two meteorological sites: composting emissions only; sheds emissions only; and shed and composting emissions combined. The meteorological sites were locations near Pittsworth in Queensland and Tamworth in New South Wales.

The odour modelling impact assessment showed that the addition of composting operations to a typical farm (based on flux chamber measured emission rate data) would have a negligible impact on overall emissions. However, this is based on the assumption that the windrows would be placed and then disturbed infrequently, and managed appropriately.

One item not factored into the assessment is the character of the odour from the windrows. The data collected during the study indicates that the character of the odour changes over time from more offensive to less offensive. The modelling impact assessment modelling assumed that the odour is additive to that from other sources. In reality, compost odour is less offensive than shed odour (if covered and managed appropriately) and therefore the assumption that it is additive is only likely to be relevant for the first few weeks after placement. At other times, the additive assumption is likely to be conservative.

Table of Contents

List of Tables

List of Figures

List of Photographs

1. INTRODUCTION

FSA Consulting was engaged by the Poultry Cooperative Research Centre (CRC) to undertake Sub Project 2.2.4 – Odour Measurement and Impact from Spent Hen Composting. This report represents the final report for the project and includes a comprehensive review of the literature on odour emissions from composting (specifically animal composting), the results from odour measurements at two trial sites (Pittsworth and Tamworth), an impact assessment of the likely odour impacts of spent hen composting on-farm (prepared by Pacific Environment Limited) and a discussion of the research findings.

1.1. BACKGROUND TO THE RESEARCH

Composting is a suitable management tool for handling the solid wastes produced in layer hen facilities and is becoming a more common practice for managing spent hens and mortalities. The process is carried out with varying degrees of management input, from fairly basic stockpiling practices with occasional turning, through to fully managed composting that includes monitoring of temperature and moisture to ensure the process is completed.

Spent hens have traditionally been removed from farm and converted to human and animal food at processing facilities. The Australian egg industry is investigating other viable options to handle this by-product from the industry due to the potential lack of availability and capacity of these processing facilities to accept and process spent hens. Additionally, the cost and distance of transporting spent hens to processing facilities and the production losses from delayed shed destocking impacts on farm productivity. These facilities require that destocking occurs in a timely manner and delays in spent hen processing are not desirable. One option that has shown potential and is being adopted by industry is to compost the spent hens on-farm in windrows.

Composting spent hens on-farm is an option that has the potential to increase the flexibility of egg producer's production system by enabling timelier shed destocking however, the potential odour emissions from an on-farm composting facility may be a barrier to the adoption of this method of spent hen disposal. This research project provides some benchmarking data that will allow the potential impact of odour emissions from spent hen composting to be estimated using existing odour modelling techniques.

2. OBJECTIVES

The primary objective of the project was to quantify odour generation and emissions produced by composting spent hens on-farm and the likely impact these have on community amenity.

A further objective to determine if different cover materials, moisture levels or compost ages influence odour generation at the Pittsworth and Tamworth trial sites was added following an assessment of common carcass composting practices at layer farms.

3. Literature Review and Legislation

3.1. Overview

Carcass composting is an accepted disposal method of on-farm mortalities in livestock agriculture in countries such as Australia, New Zealand, United States and Canada (Akdeniz et al. 2010). Usually, carcass composting is utilised as a cost effective and bio-secure way of dealing with daily or weekly livestock mortalities that occur due to illness, accidents or other causes (Wilkinson 2007).

Spent hens, and other poultry, have been successfully euthanised using inert gas or water based foam and emergency flock depopulations have utilised these methods (Rankin 2010). Composting has been successful in the disposal of animal carcasses of all sizes such as laboratory test rodents (Sobrinho et al. 2011), small and large poultry (Flory & Peer 2010), sheep (Stanford et al. 2000), pigs (McGahan et al. 2007), cattle (Auvermann et al. 2006) and horses (Bonhotal et al. 2012). The material produced is stable, almost completely free of pathogens and plant seeds and is nutrient rich, making it suitable for land application (Haug 1993).

A management plan is needed to maintain proper temperature, oxygen and moisture levels in order to provide an environment that is conducive for microorganisms to thrive (Fonstad et al. 2003). Composting is reported to result in a 20% to 60% reduction in volume, 40% reduction in moisture content and 50% reduction in weight at the end of the process (Fonstad et al. 2003).

3.2. Carcass composting utilisation

Recently, composting has been utilised in dealing with large scale livestock mortalities. The culling of entire poultry flocks occurred during the avian influenza pandemic in 2002, where alternatives to more traditional methods, such as landfill, were sought (Flory & Peer 2010). Spent hens can be sent for processing into human or animal foodstuffs (Biswas et al. 2006, Jimenez et al. 2009, Karthik et al. 2010) or disposal through burial (Freeman et al. 2009).

High transport costs, low single-hen-unit value and livestock welfare issues have created a situation where the mass culling of spent hens, on-farm, is economically beneficial to the farmer and in-transit welfare issues are dealt with (Newberry et al. 1999, Turner et al. 2012). The closure of rendering and knackery services in the US and Australia has also forced livestock farmers to seek other methods of disposal (Wilkinson 2007). Also, on-farm composting can reduce the risk of disease transmission to other flocks off-site and to the human population (Wilkinson 2007). Composting of mortalities is becoming part of the regular farming cycle in poultry industries.

3.3. Recommended composting methods

Carcass composting requires sufficient and suitable substrate/cover material, adequate storage times, sufficient oxygen and moisture and an optimum carbon/nitrogen ratio of about 20/30:1 (Bagley et al. 1999, Bin 2010, Wilkinson 2007). Carcass composting can be conducted in concrete bays, or in windrows where large scale mortalities can be accommodated (Auvermann et al. 2006, Bonhotal et al. 2012, Wiedemann et al. 2008).

Sufficient cover material (Figure 1), such as sawdust/shavings, straw, plant husks or manure, allows for soakage of fluids and can prevent odours that pollute the surrounding environment and also attract scavengers (Bagley et al. 1999, Langston et al. 1997). McGahan et al (2007) recommended 6 m^3 of sawdust to compost 1000 kg of pig carcass and Bendfeldt et al (2005) successfully composted crushed turkey carcasses between two 125 mm layers of sawdust at about 5.65 kg of carcass weight, per 0.09 m^3 of cover material. After a certain period of time, the carcass compost heap or windrow is turned to allow for the secondary composting stage to take place.

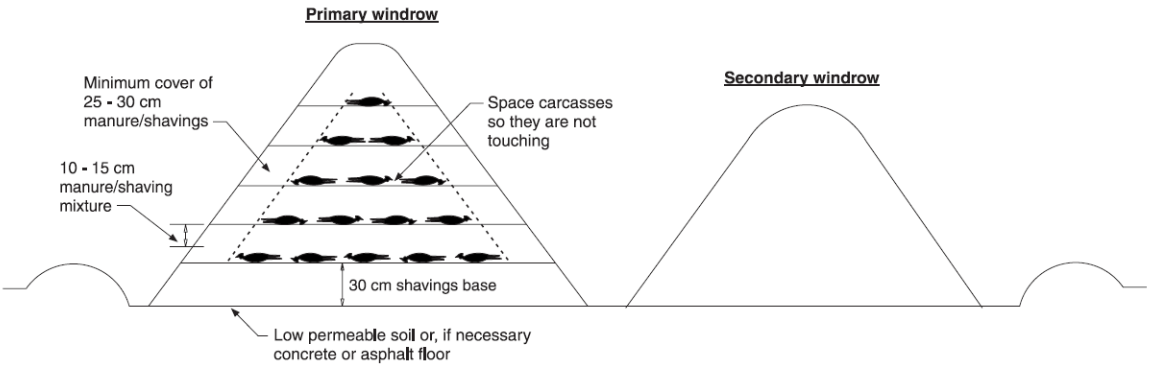

FIGURE 1 - CROSS SECTION OF NEW AND POST-TURNED WINDROWS USING RECOMMENDED GUIDELINES SOURCE: AARD (2004)

Carcass composting is an aerobic process, so there is an oxygen requirement at the carcass surface zone to drive the decomposition process (Gamroth 2012). The type of covering material used must promote aerobic digestion to achieve optimal thermophilic temperatures of 55 - 70°C (Glanville et al. 2006). High concentrations of moisture can cause the aerobic process to become anaerobic with the potential to create excess odours (Wilkinson 2007). High moisture also causes a slower and less thorough decomposition of carcasses (Price 2008) with the risk of leachate escaping to the environment (Ahn et al. 2008).

3.4. POULTRY FARMING AND ODOUR

The issue of odour is always present where intensive livestock operations exist and poultry operations, like other intensive industries, must comply with strict air pollution guidelines to achieve and maintain a licence to operate. Queensland government guidelines stipulate that proponents of new developments or modifications to existing facilities that may give rise to noxious or offensive odours need to determine the sensitivity of the receiving environment to such odours and demonstrate the use of best practice environmental management techniques to manage odours (EPA QLD 2004).

A Victorian Department of Primary Industries & Fisheries (DPI&F) survey in 2003 of the poultry industry found odour to be the leading cause of complaint and still remains a pollution issue (DPI Victoria 2010). Odours escape from housing, yards and paddocks, manure piles (used litter) and compost heaps and can become a nuisance or cause illness depending on the airborne gases or particulate matter (Morse & Division 2001). Almost all odour monitoring of poultry facilities available in the literature was conducted in or around meat chicken sheds. In Australia, meat chicken facilities are more likely to be located closer to urban areas than layer facilities. Odours and other gases are vented from housing sheds through extractor fans allowing for measurements to be easily taken before they are dispersed into the atmosphere (McGahan & Nicholas 2004).

Odour emissions from carcass composting of poultry, has been anecdotal and based on the personal observations of the monitor or researcher (Wilkinson 2007), rather than any recognised sampling procedure to provide accurate emission rates. Odours have usually been commented on as occurrences at different stages in the composting process without olfactory analysis being conducted. There have been odour studies carried out in the composting of other carcasses in Australia such as pigs (McGahan et al. 2007) and also in the composting of manure and litter from different types of livestock (McGahan et al. 2007, Smith & Watts 1994).

3.5. Odour sampling and analysis

Odour sampling in Australia is usually conducted in accordance with the Australian Standard/New Zealand Standard guidelines (Hudson et al. 2009). The two standard methods commonly used for collecting odour samples are the flux hood or flux chamber (static) and the wind tunnel (dynamic), however the flux chamber method is the stated method based on the Australian Standard AS4323.4. Samples of air collected using both methods are stored in non-porous bags and transported within the capture drums to an olfactometry lab for analysis. Sample analysis is conducted with dynamic olfactometry according to the standard AS/NZS 4323.3-2001 protocol and samples should be assessed within 30 hours of collection (Hudson et al. 2009).

The NSW Draft Policy 'Assessment and Management of Odour from Stationary Sources in NSW' (NSW-EPA 2001) notes that the flux hood is the preferred method for sampling odour emissions from area sources. However, the policy also notes that other sampling methods may be used where sufficient justification is provided regarding the method and protocols used for sampling. Direct comparisons of odour emission rates derived from flux hood (static) and wind tunnel (dynamic) samples are rare, with wind tunnels always resulting in apparently much higher odour emission rates and there are few published papers reporting the correlation between these devices (Nicholas et al. 2012). Reported differences are typically of at least one order of magnitude higher for wind tunnels (Nicholas et al. 2012).

The wind tunnel collects samples over a period in the range of 5 minutes, while the flux hood collects samples over a period in the range of 30–60 minutes. Consequently, the flux hood would represent a longer-term average odour emission rate, while the wind tunnel would more clearly reflect variations in emission rate over time (Boholt & Oxbol 2002). Nicholas et al, (2012) reported that the ratio of wind tunnel (dynamic) emission rates to flux hood (static) emission rates for feedlot pad and pond data varies from 15:1 to over 300:1. However, the ratio values did not show any consistent trends. Of late, the use of USEPA flux chambers for odour sampling has become more common, most likely due to their ease of use and their USEPA derived validation data (Jiang & Sands 2000).

3.6. Odour emissions from compost of various substrates

There is little published research on odour emissions from poultry carcass composting in windrows or heaps as many publications contain only personal site observations (Wilkinson 2007). There have been a number of other studies looking at composting larger animals (McGahan et al. 2007) and the co-composting of carcasses and other materials like manure, bedding and abattoir waste (Wilkinson 2007). As manure is a significant odour source in isolation, the results cannot be considered reflective of the composting of carcasses on their own.

McGahan et al (2007) demonstrated that composting of manure products and co-composting with pig carcasses produced more odour than carcasses that were composted on their own with a sawdust substrate (Table 1). The authors concluded that although there were variations between substrates, the emission rates overall were low (McGahan et al. 2007). This was the same conclusion reached by Nicholas et al (2006) when analysing odours from spent piggery litter composted with straw or rice hulls. According to Nicholas et al (2006), subjective observation of the character of the odour at each site by the same observer suggested that the odour intensity at the rice hull site was lower than at the straw site. However, insufficient measurements are available to draw valid conclusions other than the fact that emission rates are low at both sites compared to the overall emissions from the entire facility (McGahan et al. 2007).

Nicholas et al (2004), analysing the composting of beef feedlot manure and carcasses, found that disturbed samples generally had higher odour emission rates than the undisturbed samples. Also, the disturbed samples displayed a 50% reduction in odour generation within 24 hours of the initial disturbance and the odour emitted from the end of the wind tunnel was noted as being much less offensive in character than the other major odour sources at the feedlot (pond and feedlot pens). Table 1 gives a summary of the data from composting operations that include carcass composting and other organic waste materials, including manure. The average odour emission rate for manure (screened and unscreened) was 41 OU/m2.s while the average odour emission rate for carcass composting is 24 OU/m2.s.

TABLE 1 - ODOUR EMISSIONS FROM DIFFERENT SUBSTRATES SHOWING AGE, DISTURBANCE AND COLLECTION METHOD

Composting substrate	Age when sampled	Disturbed/ Undisturbed	Static hood/ Dynamic flow	Odour emission rate OU/m^2 s	Author/ Source
Grease trap waste,	7 days	Undisturbed	Static	34.1	PAE Holmes (Personal
green waste, bark,		Disturbed	Static	50.7	Communication)
zeolite & gypsum	20 days	Undisturbed	Static	28	
		Disturbed	Static	53.7	
	79 days	Undisturbed	Static	2.3	
		Disturbed	Static	1	
	120 days	Undisturbed	Static	N/A	
		Disturbed	Static	4.2	
Piggery screenings		Undisturbed	Dynamic flow	10.8 - 11.5	McGahan et al (2007)
only		Disturbed	Dynamic flow	22.3 - 41.8	
Piggery screenings &		Undisturbed	Dynamic flow	9 - 25.6	
pig carcasses		Disturbed	Dynamic flow	12.8 - 19.2	
Pig carcasses + sawdust		Undisturbed	Dynamic flow	6.8 - 17.8	
		Disturbed	Dynamic flow	5.1 - 7.4	
		Undisturbed	Static	0.023 - 0.036	
		Disturbed	Static	0.345 - 0.369	
		Undisturbed	Dynamic flow	9.9 - 25.1	
		Disturbed	Dynamic flow	9.6 - 11.6	
		Undisturbed	Static	0.082 - 0.132	
		Disturbed	Static	0.204 - 0.408	
Spent litter & straw	Stockpiled	Undisturbed	Dynamic flow	10.4 - 11.5	Nicholas et al (2006)
	Composted	Undisturbed	Dynamic flow	9 - 15.2	
	Semi-composted	Undisturbed	Dynamic flow	19.2	
	Stockpiled	Undisturbed	Dynamic flow	9 - 21.6	
Beef feedlot		Undisturbed	Dynamic flow	4.5 - 61	Nicholas et al, (2004)
manure (screened)		Disturbed	Dynamic flow	13 - 24	
Beef feedlot		Undisturbed	Dynamic flow	15.5 - 35	
manure (unscreened)		Disturbed	Dynamic flow	60 - 115	
Beef carcasses		Undisturbed	Dynamic flow	14 - 26	
		Disturbed	Dynamic flow	26 - 43	
Sewage sludge		Undisturbed	Static	3.5 – 6.7	Boholt & Oxbol (2002)
		Undisturbed	Dynamic flow	1.5 - 650	
Garden/ Park waste		Undisturbed	Static	49 - 91	
		Undisturbed	Dynamic flow	18 - 30	
Hen Manure	3 days	Undisturbed	Dynamic flow	205 - 289	Schmidt et al (2000)
	13 days	Undisturbed	Dynamic flow	38 - 71	
	28 days	Undisturbed	Dynamic flow	33 - 39	

Of note, Boholt and Oxbol (2002) compared dynamic and static methods on fresh sludge and on aged garden waste (Table 1), finding better correlations with the less odorous garden waste. The dynamic flux chamber was seen as delivering more reproducible results and able to identify periods of increased odour emissions (Boholt & Oxbol 2002). Overall, the comparison shows substantial scatter and does not suggest that a robust relationship exists between results collected with the two devices.

Schmidt and Bicudo, (2000), undertook an investigation into the changes in odour emissions associated with four different layer chicken manure / bulking agent compost mixtures. The bulking agent used was sunflower hulls. The varying emission rates measured was likely the result of the crust formation on the sides of the windrow and the venting gases through the top centre of the windrows. Schmidt and Bicudo (2000) also looked to determine if changes in the initial compost mixture (C:N ratio) affected odour and gas emissions during composting. The compost mixture consisted of sunflower hulls and layer hen manure at different ratios on a volume basis (Table 1). Odour emissions on day 3 of composting were 4 to 7 times higher than on day 13 or day 28. Schmidt and Bicudo (2000) reported on measurements of odour emission rates from composting caged layer manure using two different wind tunnels. They found that odour emissions were 80% to 90% lower on Day 28 compared to Day 2 of the composting process. On day 13, a notable decline was observed in the odour emission rate.

A recent review of public domain odour emissions data for commercial composting facilities by PAE Holmes (PAE Holmes 2012b) found that the majority of data was not supported by appropriately documented methodology or the data did not apply to the materials currently composted in Queensland. PAE Holmes collected samples from windrows at 7, 20, 79 and 120 days since placement (Table 1). Odour samples were collected from compost windrows that consisted of grease trap waste, green waste, bark, zeolite and gypsum. The USEPA flux chamber was used as the sampling device on the surface of the windrows and air was drawn from inside the flux chamber into a non-porous sample bag as detailed in Kienbusch (1986), cited in Galvin (2005), and Standards Australia (2001). The odour emissions appeared to rapidly decrease after the initial composting period (4 weeks). The disturbed 70 day old compost odour emission rate was less than the undisturbed emission rate. The odour emission data demonstrated that for the aged compost (80-120 days), the variation between the measured emissions was within the range associated with dynamic olfactometry. From this it was concluded that for compost at 80 to day 120 in age, the emission rate of odour from both disturbed and undisturbed compost is not significantly different.

PAE Holmes reported that in another study that undisturbed windrows had a higher emission rate than the disturbed windrows (PAE Holmes 2012b). This is somewhat counterintuitive as experience suggests that disturbed windrows have higher emission rates. An examination of the sample locations indicates that the flux chamber was placed onto the wet area of the undisturbed windrow. As such this would explain that the undisturbed sample had a higher emission rate. This demonstrates the need for uniformity in the sampling regime.

3.7. Odour emissions from modern tunnel ventilated layer sheds

Layer hen sheds manage their manure through either mechanical removal on conveyor belts (tunnel ventilated housing) or through the utilisation of deep litter beds (barn systems and barns used in free range) to absorb excreta. Both types of housing systems require ventilation (either supplied by mechanical means or natural) and therefore act as an odour source with the potential to contaminate the surrounding environment. Odour data specific to layer hen facilities is very limited but a small number of odour emission tests have been carried out at layer facilities in Australia and in other parts of the world. However, changes in olfactometry standards and the designs and management of poultry facilities has rendered some older odour analysis irrelevant (Dunlop 2011a).

Pollock and Anderson (2004), cited by Dunlop et al (2011a), reported emission rates of 80 – 85 ou/s/1000 birds from a tunnel ventilated, multi-tiered, layer shed near Melbourne. A further study carried out by Enviroscan Industrial and Marine Surveys (2005), cited by Dunlop (2011a), found emission rates of 48 – 70 ou/s/1000 birds at a tunnel ventilated manure belt shed. Hayes et al (2006), researching a variety of poultry units in Ireland, measured 260 – 620 ou/s/1000 birds from a mechanically ventilated layer shed using a conveyor belt to remove manure. The same study also recorded 1060 – 1470 ou/s/1000 birds from a similarly ventilated deep litter facility. These results were found to be in line with previous studies for both shed types where 80 – 520 ou/s/1000 birds and 200 – 760 ou/s/1000 birds were found at manure belt and deep litter facilities respectively (Martinec et al. 1998, Ognik & Groot-Koerkamp 2001) cited by Hayes et al, (2006).

Dunlop et al (2011a) measured values of 58 – 512 ou/s/1000 birds at layer facilities in Victoria and Queensland that utilised manure belts. Unseasonal weather in Victoria prohibited a comparison between the odour analyses from both sites. It was found that odour emission rates increased with increasing ventilation and ambient temperatures whereas odour concentration tended to decrease (Dunlop 2011a).

Dunlop et al (2010) found higher rates of emissions at nine different broiler facilities in Queensland, Australia. Odour emissions ranged from 330 – 2960 ou/s/1000 birds, with a significant amount of variability found throughout the sampling batch and within sampling days. Changes in live weight and ventilation requirements were seen as primary causes of this variability (Dunlop et al. 2010). It was found that manually overriding the automatic ventilation system during sample collection may have influenced some of the measured emission rates while dust particles attracted to the sample bag material possibly affected the olfactometry analysis (Dunlop 2011b).

Hayes et al (2006) also measured odour emissions from broiler sheds recording an average of 450 – 550 ou/s/1000 birds from three different sized sheds using litter on a solid floor and naturally vented. An average of 430 ou/s/1000 birds was recorded in a broiler facility using a manure belt system that was mechanically ventilated (Hayes et al. 2006).

A recent report for a tunnel ventilated layer facility in southern Queensland reported odour emission rates of 43 – 53 ou/s/1000 birds from birds aged 21 weeks, and 88 – 125 ou/s/1000 birds aged 76 weeks (PAE Holmes 2012a). This facility operated a manure belt system and the odour emission rates were significantly lower than previously reported for the facility, when samples were collected during a different, potentially unrepresentative period.

Accurate and comprehensive data improves the outcomes from subsequent modelling. The emission of odours from a layer hen or other poultry facility creates an odour plume in the immediate vicinity and downwind of the sheds (Bunton et al. 2007). To determine the effect that this odour source has on its surroundings, dispersion modelling can be used to determine the extent of the distance required between the odour source and the receptor (Hudson et al. 2008, Schauberger et al. 2012). This requires the inputting of standard and/or measured emissions data along with meteorological data into modelling software such as CALPUFF or AERMOD (Vieira de Melo et al. 2012). These models are used to calculate the separation distance required to achieve odour impact criteria (Hudson et al. 2008). Gaussian models take the frequency of values for odour intensity over a time period and are able to consider the instantaneous characteristics of odour perception of human beings (Yuwono et al. 2012).

Odour analysis can be required by layers facilities and other livestock enterprises as part of their operational licence (McGahan et al. 2007) to assess whether offensive or noxious odours are polluting nearby residential or business area (Bunton et al. 2007). Any changes to farm management or practices that could extend the odour plume beyond its regulatory limit need to be assessed to determine if separation distances should be increased. The introduction of a composting facility for spent layer hens and regular on-farm mortalities could impact on the total odour emission rate from a production facility. To assess this scenario, modelling can combine the emission rates from layer sheds with those from compost windrows to create an overall profile for a production facility.

3.8. LEGISLATION REGARDING THE ON-SITE COMPOSTING OF SPENT HENS

Composting is strictly regulated within Australian states with some states requiring licences or permits in order to commercially produce compost. In relation to the on-farm composting of carcasses, there is less stringency if the product is confined to on-farm use. Following contact with regulatory bodies in each state or territory, it is evident that some states (with particular reference to the Northern Territory), have no standing on the topic as there is very little intensive poultry production within their jurisdiction. In the event that carcass composting is likely to take place on a farm, the local council and state government bodies (such as Department of Primary Industries, Department of Agriculture or similar) should be consulted as well as the state Environmental Protection Agency. The sections below outline information in relation to each state or territory.

3.8.1. AUSTRALIAN CAPITAL TERRITORY

There are no specific regulations for the composting of poultry carcasses in the Australian Capital Territory. Under the *Environmental Protection Act 1997* an environmental authorisation is required if a composting facility composts, or is intended by the operator to compost, more than 200 tonnes of animal waste per year. No exemptions for on-farm composting and use are mentioned.

3.8.2. NEW SOUTH WALES

During preparation of a development application, the application must either submit a Statement of Environmental Effect or Environmental Impact Statement (depending on the type, size, location etc. of poultry farm being proposed). Within this document, a producer is expected to address waste management – on-site waste water treatment, use and/or disposal, composting, growing media or crop residue disposal.

On-site composting needs to meet waste management provisions and odour management provisions. The Environmental Protection Authority requires that activities be carried out in a competent manner. This includes:

- the processing, handling, movement and storage of materials and substances used to carry out the activity; and
- the treatment, storage, processing, reprocessing, transport and disposal of waste generated by the activity.

The Environmental Protection Authority also requires that all plant and equipment installed at the premises or used in connection with the licensed activity:

- must be maintained in a proper and efficient condition; and
- must be operated in a proper and efficient manner.

All operations and activities occurring at the premises must be carried out in a manner that will minimise dust at the boundary of the premises.

3.8.3. Northern Territory

As there are no commercial poultry operations in the Northern Territory there are no specific regulations that relate to composting of poultry carcasses.

3.8.4. Queensland

Composting is regarded as an Environmentally Relevant Activity (ERA) in Queensland. However, if the composting activity is for purposes of the product generated onsite, then ERA 53 (composting and soil conditioner manufacturing) is not relevant. Other than ensuring the activity is carried out in a way that minimises environmental risk, there are no specific requirements.

3.8.5. South Australia

Intensive animal keeping enterprises require a licence for certain composting operations. The *Environmental Protection Act 1993* requires compliance with the general environmental duty. A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm. Further to the general environmental duty, in the event that over 200 tonnes of compost is produced, or is capable of being produced - then the activity is prescribed activity and triggers the need for a licence from the Environmental Protection Authority. The Environmental Protection Authority produced a composting guideline which relates to the conduct of a composting operation. It sets out the Environmental Protection Authority's expectations for the appropriate conduct of composting works in accordance with the *Environmental Protection Act 1993*. There are no specific regulations or legislation for the composting of poultry carcasses.

3.8.6. Tasmania

In Tasmania there are no specific regulations in relation to poultry carcass composting. However, any composting facility that processes over 100 tonnes of organic waste is classified as a Level 2 Activity and is then regulated by the Environmental Protection Agency, other than on-farm composting for use on agricultural land having the same owner as the land on which the compost is produced and is used in respect of silage on agricultural land.

Planning permission from a local council is normally required for the composting of waste materials at a farm if, those materials do not originate wholly within that farm or property; and / or the resulting compost is used anywhere other than on that farm or property.

3.8.7. Victoria

In Victoria, the Environmental Protection Authority prefers and recommends offsite disposal rather than on site composting. This is outlined in their farm waste management publication. If the compost operations are large enough to be scheduled then a works approval will need to be applied for.

All composting facilities must conform to the relevant State Environment Protection Policies and Environmental Regulations. If the compost is kept on the farm site and not removed offsite, there is no requirement for an Environmental Protection Authority approval. There are no specific regulations for composting chicken carcasses on farm.

When assessing an application for a poultry farm the Environmental Protection Authority would assess the composting process - check the size, method of composting etc. and if required assign relevant conditions. There are composting guidelines available to ensure the composting is correctly undertaken as well as recommended separation distances for compost facilities.

While there are no Environmental Protection Authority requirements, planning permission may be required from the local council

3.8.8. Western Australia

The Department of Environment Regulation considers composting to be a prescribed premise, which means it does require a works approval and license. The production/design capacity for composting for licensing is >1,000 tonnes/year.

Category 67A in the *Environmental Protection Regulations 1987* outlines the prescribed premises - Compost manufacturing and soil blending: premises on which organic material (excluding silage) or waste is stored pending processing, mixing, drying or composting to produce commercial quantities of compost or blended soils.

In Western Australian, whilst poultry sheds do not require a works approval or license from the Department of Environmental Regulation, the on-site composting of poultry carcasses would (if the capacity threshold of >1000 tonnes/year is met).

There are also regulations relating to the stable flies, again these are not specifically in relation to carcass composting but apply to the production of compost. The stable fly feeds on blood making it a destructive pest, especially for horses and cattle.

Stable flies breed in rotting vegetation including horticultural waste, livestock bedding and decomposing poultry manures in contact with the soil. With the shires and cities of Wanneroo, Swan, Joondalup, Gingin, Chittering, Kalamunda, Armadale, Rockingham, Cockburn, Harvey, Kwinana, Serpentine-Jarrahdale, and part of the Shire of Murray, the transportation of poultry waste and its use as horticulture manure are banned at all times of year unless it is treated to stop stable fly breeding - this may also be the case with carcass composting but as there are currently no known poultry producers composting >1,000 tonnes/year on-site, it has not been an issue.

In all cases it is recommended that anyone looking to compost spent hens carcases should always contact their local Council and EPA office first to confirm there are no other restrictions (ie. consent conditions or licence conditions) that need to be considered. In Western Australia the Department of Agriculture and Food should also be consulted in relation to stable flies.

4 METHODOLOGY

4.1 DESCRIPTION OF TRIAL SITES

Two sites were established at layer facilities in Pittsworth in Queensland and Tamworth in New South Wales, Australia. These facilities currently use windrow composting to manage their mortalities and/or spent hen carcasses. The managers at both facilities supplied sufficient hen carcasses for the construction of project-specific windrows using best practice guidelines from the literature. The site managers also made available staff and machinery, when required, to conduct the windrow management trials. Each site had two different windrow substrate cover materials. One was a manure material, which was either straight layer manure or a combination of layer manure and sawdust from barn sheds. The second was a sawdust based material, which was either straight sawdust or waste sawdust/wood shavings from stables used in the horse industry. This was based on a survey of common industry practice, where these were the most common substrates utilised. It was also hypothesised that the higher organic content manure substrate material would generate a higher odour emission rate than a more inert sawdust based substrate.

A description of the trial sites and their current management is provided below.

4.1.1 PITTSWORTH TRIAL SITE

The Pittsworth composting facility treats the daily mortalities from the caged and free range sections of the nearby poultry farm (Photograph 1). Spent hens are usually sent to a nearby processing plant, with some also composted along with the daily mortalities.

PHOTOGRAPH 1 – MORTALITY COMPOSTING WINDROW AND SPENT LITTER STOCKPILE, PITTSWORTH

This site currently uses spent litter from the barns at its free range operation as cover material, or substrate (Photograph 2). This is a mix of sawdust and hen excreta and was aged 1 – 3 years following removal from the shed. The compost trials were co-ordinated around when farm management could supply a sufficient quantity of hen carcasses to establish suitable sized windrows for specific use in the project. The services of the compost site manager were also supplied to construct the windrows to project specifications. Windrows using either clean sawdust (described as sawdust) or stockpiled layer manure (described as manure) were constructed. The current management practice is to turn the windrows every two weeks. However, the turning cycle for the project specific windrows was carried out to project specifications (described in section 4.2.1).

PHOTOGRAPH 2 – MORTALITY COMPOSTING WINDROW FOR DAILY/WEEKLY MORTALITIES, PITTSWORTH

Eight windrows in total were constructed at the Pittsworth trial site, four during the summer sampling period and four during the winter period. Of the eight windrows, four used a sawdust only substrate and four used the manure substrate. The windrows were similar in size and composition.

4.1.2 TAMWORTH TRIAL SITE

The facility at Tamworth composts all of its spent hens on-site at the end of a cycle of hens, thus the compost windrow establishment was based around the availability of hens from a shed destock. Spent hens are euthanised at 19 week intervals to coincide with shed destocking. The spent hens are composted in windrows about 100 metres long, 2 metres high and 4 metres wide at the start of the process (Photograph 3). The width and height decrease over time as a result of the composting process.

PHOTOGRAPH 3 – SPENT HEN COMPOSTING AREA, TAMWORTH

PHOTOGRAPH 4 – STOCKPILED MANURE AND SAWDUST COVER SUBSTRATES, TAMWORTH

The Tamworth site uses a mix of spent stable bedding (described as sawdust) and partially composted layer manure from previous carcass composting cycles, as cover material for windrows (described as manure) (Photograph 4, with manure in the foreground). A section of the large windrow was selected for the project. This section of the windrow was constructed to project specifications and managed in accordance with the requirements of the project team.

At the Tamworth site, six windrows were established. These included three sawdust substrate and three manure substrate windrows. The manure and sawdust windrows were established approximately 110 days apart in the summer trial. Two additional windrows (one sawdust and one manure) were established for the winter trial. Two of the summer compost windrows (one sawdust and one manure) were allowed to continue composting to provide winter odour sample data from mature carcass compost windrows.

4.2. ESTABLISHMENT OF COMPOSTING WINDROWS

4.2.1. PITTSWORTH TRIAL SITE

4.2.1.1. Pittsworth summer windrows: 1A and 1B

On the 7th of November 2012, two initial windrows were constructed at a site at the layer farm that had not been previously used for composting (Photograph 5). This site was a grass verge beside the existing composting facility. Some surface scraping was conducted to level the site, but this was minimal. The loader used for this operation had a telescopic arm and is the primary vehicle for the on-farm composting. The weather on the day was mostly sunny with a high of 26°C and there was no recorded rainfall on or 24 days prior to site establishment.

PHOTOGRAPH 5 – SITE OF WINDROWS 1A – 1F, PITTSWORTH

The two materials used as cover material were sawdust and aged poultry manure. The sawdust was clean and unused previously for any other purpose. There were some small rocks and clumps of clay and grass in the sawdust and these were removed during the windrow building process. The temperature of the sawdust in the stored pile was ~46°C.

The aged poultry manure used was from the stockpile that is utilised for composting the daily poultry mortalities from the farm. This manure is stockpiled for up to 3 years, with the material utilised as part of the composting trial being at least two years of age. Temperature readings from the manure source material were ~70°C where it was compacted and undisturbed and the temperature of the loose disturbed material was ~56°C, indicating that all the material was still actively composting.

The carcasses used for this project were supplied by the farm management from a caged facility on a nearby property operated by the producers. These hens were clean and did not have any manure or other material attached to their feathers when delivered.

The two windrows constructed on the 7th November are known as '1A', sawdust cover material, and '1B', manure cover material. A base layer of sawdust and a layer of manure substrate were laid down end to end with a two meter gap in between. The base layer of each windrow was levelled off to a depth of about 300 mm (Photograph 6).

The first layer of carcasses was laid with the birds side by side. Small gaps and low spots in the layer were obvious where the heads, necks and feet were positioned. The next set of carcasses was placed on top of the first whereby the torsos of second layer were on top of the heads, necks and feet of the first layer. This created a more level layer of carcasses, with a height roughly equivalent to about 1½ hens (~200 mm high).

The first layer of carcasses on the sawdust and manure substrate beds was covered with about 200 mm of substrate material (Photograph 7 and Photograph 9). The second layer of cover material was levelled off on both windrows using a hand shovel only. The second layer of carcasses were laid on top in the same manner as the lower layer and covered with the appropriate material (Photograph 10). The windrows were then topped off with cover material using the loader and excess cover material was pulled down the sides to ensure that all layers of carcasses were covered with at least 300 mm of cover material (Photograph 8 and Photograph 11). A spike was inserted all around the windrows to ensure the depth of the cover materials were at least 300 mm.

Figure 2 and Figure 3 provides a schematic representation of the cross section and overhead views of windrows 1A and 1B established at the Pittsworth site in November 2012.

A temperature probe was inserted into the two windrows immediately after construction to get a baseline reading before the composting process began. This was to be monitored when possible to ensure the composting process was achieving the high temperatures, 55 – 70°C, associated with successful anaerobic digestion. The temperature in the sawdust windrow ranged from 36.9 – 39.4°C about two hours after establishment, while temperatures in the manure windrow ranged from 41.5 – 46.5°C about an hour after completion.

PHOTOGRAPH 6 – BASE LAYER OF SAWDUST SUBSTRATE FOR WINDROW 1A, PITTSWORTH

PHOTOGRAPH 7 – APPLICATION OF SAWDUST SUBSTRATE ON FIRST LAYER OF SPENT HEN CARCASSES FOR WINDROW 1A, PITTSWORTH

PHOTOGRAPH 8 – COMPLETED WINDROW 1A WITH FULL COVERING OF SAWDUST SUBSTRATE, PITTSWORTH

PHOTOGRAPH 9 – BASE LAYER OF MANURE SUBSTRATE FOR WINDROW 1B, PITTSWORTH

PHOTOGRAPH 10 – WINDROW 1B ‘TOPPING-OFF’ WITH MANURE SUBSTRATE, PITTSWORTH

PHOTOGRAPH 11 – COMPLETED WINDROW 1B WITH FULL COVERING OF MANURE SUBSTRATE, PITTSWORTH

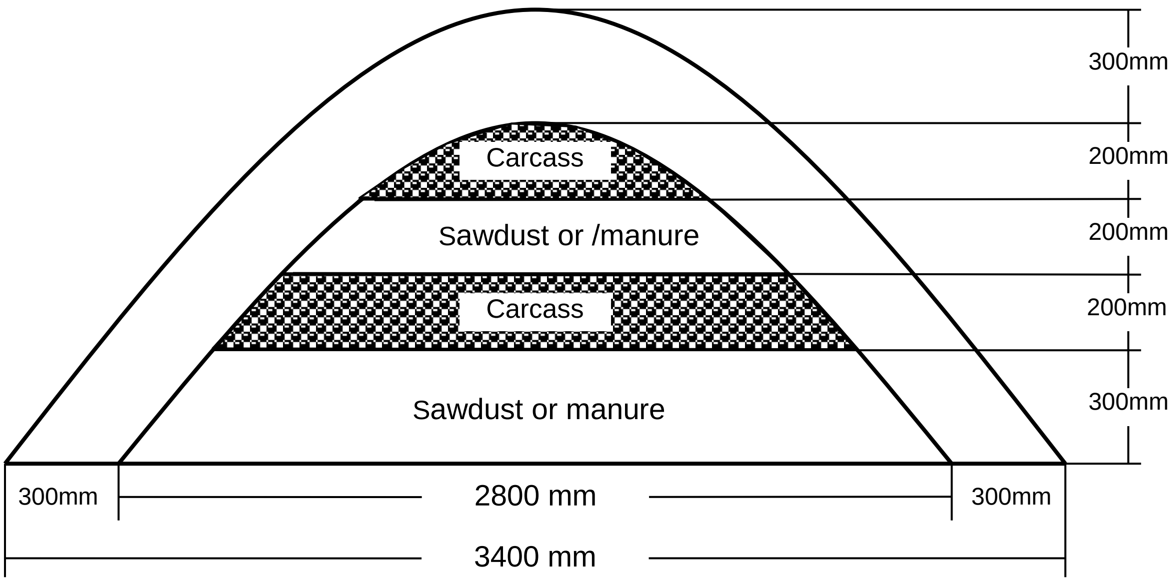

FIGURE 2 – CROSS SECTION OF WINDROWS 1A AND 1B, PITTSWORTH (APPROXIMATE DIMENSIONS)

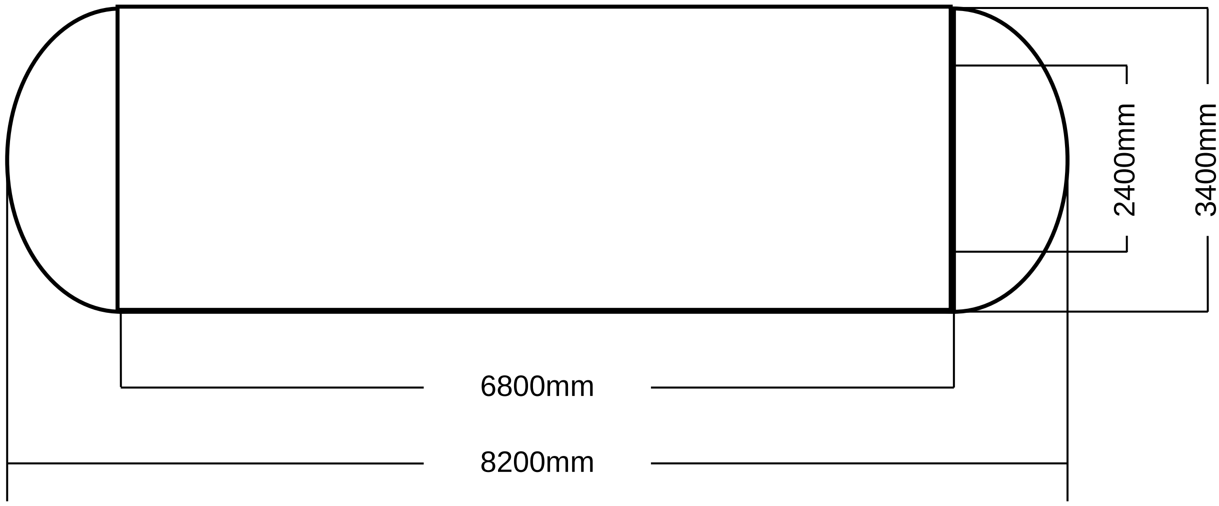

FIGURE 3 – OVERHEAD VIEW OF WINDROWS 1A AND 1B, PITTSWORTH

4.2.1.2. Pittsworth summer windrows: 1C and 1D

On the 29th November 2012, a second set of windrows, 1C & 1D were constructed with similar specifications as the first two windrows, 1A & 1B. These windrows were slightly shorter than the previous two, owing to the limit of 1200 hens available for composting (600 for each) compared to 1600 (800 for each) available for the first two windrows. These additional windrows, 1C and 1D, were offset by a three week time period from the first two windrows, 1A and 1B, to allow for odour sampling on a single day a week later with windrows of different ages.

One bed each of sawdust (windrow 1C) and manure (windrow 1D) were laid out 5 metres away from and parallel to the first set of windrows. The beds of cover material were smoothed out using a spade only and were at least 300 mm thick with some parts thicker to accommodate undulations in the ground. The cover material was of the same dry consistency as the first windrows and was taken from the same stockpiles.

The first layer of hens was placed onto each of the bed material using a bucket loader. The hens were levelled out to mimic the first windrows where the lower layer of hens were laid head to feet and the second were placed where the torsos lay upon the 'low' points creating a complete level about 1½ hens thick. These first levels were covered with the appropriate material to a thickness of about 200 mm and levelled off again using a spade.

The second level of hens was placed on top by hand in the same manner as the first level and the windrows were topped off with cover material. A probe was inserted at points all around both finished windrows to ensure a 300 mm thickness of cover material was provided on all sides of the birds. This probe was also used to record temperatures (Photograph 12).

PHOTOGRAPH 12 – MEASURING WINDROW TEMPERATURES, PITTSWORTH

On the 22nd February 2013, approximately 3 weeks after the first round of summer sampling, it was decided to reduce the number of summer windrows from four to two by combining 1A with 1C (sawdust) and 1B with 1D (manure), as these windrows had significantly reduced in volume. The windrows were turned with a front end loader onto a new section of the site and recovered with appropriate substrate material. As the windrows were being turned, water was sprayed over the material to replicate the conditions that windrows experience at a composting facility. The extra moisture added to the core of the windrow was to aid the composting process.

4.2.1.3. Pittsworth winter windrows: 1E and 1F

On the 22nd February 2013, FSA Consulting staff constructed two windrows, 1E (sawdust substrate) and 1F (manure substrate), at the Pittsworth trial site. These windrows were constructed to the similar specifications as the windrows established for the summer sampling, with only small variations in size and substrate due to the number of mortalities available. These were the first 2 of a total of 4 winter windrows to be constructed.

4.2.1.4. Pittsworth winter windrows: 1G and 1H

On the 20th March 2013, FSA Consulting staff constructed the final two winter windrows at the Pittsworth trial site. Windrows 1G (sawdust substrate) and 1H (manure substrate) were constructed using the same methods as previously described.

A summary of the windrow establishment timetable at the Pittsworth trial site is shown in Appendix A.

4.2.2. TAMWORTH TRIAL SITE

4.2.2.1. Tamworth summer windrows: 2A, 2B, 2C and 2D

On the 23rd September 2012 and 14th January 2013, windrows were constructed at a layer farm near Tamworth in New South Wales. These windrows were approximately 100 m long and consisted of a straw bed, on which the spent hens were laid. The spent hens were then covered with substrate material. The substrate material was either partially composted layer manure (manure windrow) or spent litter substrate from local horse stables (sawdust windrow). The trial component of the windrow was a designated 7 m section at the ends of the 100 m windrows. The windrows construction in both September 2012 and early January 2013 allowed for sampling of both 10 day old and 120 day old composting windrows during the period 22nd – 24th January 2013.

PHOTOGRAPH 13 – SPENT HEN COMPOSTING AREA, TAMWORTH

On the 13th and 14th January 2013, the sheds at the Tamworth site were cleared out with all spent hens euthanised with carbon dioxide (Photograph 14). The windrows were completed on the 14th January (Photograph 15).

The protocol for windrow construction at the Tamworth site was as follows.

- A layer of bedding straw about 4000 mm wide and 300 mm thick was laid out on hard compacted soil.
- The straw bed was wetted down and a layer of spent hens were laid on top at a rate of 100 birds per metre of windrow.
- The cover material was then applied up to a total windrow height of about 1500 mm.
- The windrows were further wetted using a fire truck with a spray adapter during the lifetime of the windrows as required by the farm manager to maintain sufficient moisture for active composting.

PHOTOGRAPH 14 – EUTHANISING CHAMBER (CO_2), TAMWORTH

PHOTOGRAPH 15 – WINDROW 2D, TAMWORTH

4.2.2.2. Tamworth winter windrows: 2E, 2F, 2G and 2H

On the 1st June 2013, new windrows were constructed at the Tamworth site by the owner. These were windrows 2G (sawdust substrate) and 2H (manure substrate) and were constructed using the same protocol as described for the windrows used in the summer trial site (2A, 2B, 2C and 2D). Two windrows that were established in January 2013 were allowed to continue to compost to allow for a staggered sampling of compost (fresh and complete) on the same day in mid-June 2013, 2E (sawdust substrate) and 2F (manure substrate). These windrows were previously known as 2C (sawdust substrate) and 2D (manure substrate) from the summer trial.

A summary of the windrow establishment timetable at the Tamworth trial site is shown in Appendix B.

4.3. ODOUR SAMPLING AND ANALYSIS METHODOLOGY

For each of the samples collected, a flux chamber was placed on an emitting surface that was representative of the sample source, as per the Australian Standard (Zealand 2009). To ensure no air leakage, the edges of the flux chamber were sealed by forcing it into the windrow surface (Photograph 16). A flow of instrument grade air at five litres per minute was allowed to flow into the flux chamber for 20 to 30 minutes until the device was stabilised. Sample bags were pre-conditioned by filling them with air from the flux chambers and releasing it again. The pre-conditioned sample bags were then allowed to draw air at a rate of two litres/min for approximately 45 minutes. Care was taken before, during and after collection to avoid exposing the drums and bags to direct sunlight, thus minimising excessive heating of the samples. A further description of this process can be found in Hudson et al (2009).

PHOTOGRAPH 16 – ODOUR SAMPLE COLLECTION USING FLUX CHAMBER

All samples collected at the two trial sites were transported and analysed within 20 hours of collection. Odour concentrations were determined using the eight panellist, triangular, forced choice dynamic olfactometry, located at the DAFF, Tor Street complex in Toowoomba. This complied with the Australian/New Zealand Standard for Dynamic olfactometry (Standards Australia/Standards New Zealand 2001). Each panellist was screened with a reference gas according to AS4323.3 to ensure their detection thresholds for the reference gas were at concentrations between 20 and 80 ppb (v/v).

Odorous samples were diluted with odour-free air and presented to the olfactometer panellists in one of three ports, while the other two ports emitted clean, odour-free air. The panellists were then asked to sniff from the ports and determine whether they could detect a difference between the three ports. Each panellist was allowed a maximum of 15 seconds to detect a difference. The panellists indicated via a keypad whether they were certain, uncertain or guessing regarding presence of an odour and from which port the odour (if detectable) was emitted.

This process was repeated, doubling the strength of the previous presentation each time, until each panellist had responded with certainty and correctly for two consecutive presentations. Each panellist's individual threshold estimate is determined by calculating the geometric mean of the dilution at which the panellist did not respond with certainty and correctly and the first of the two dilutions where the panellist responded with certainty and correctly. The complete dilution series is defined as a round and three rounds are completed for each sample provided sufficient sample is available. A further description of this process can be found in Hudson et al (2009).

4.4. ODOUR SAMPLE COLLECTION AND ANALYSIS

4.4.1. PITTSWORTH TRIAL SITE

4.4.1.1. Pittsworth summer sampling: 1A, 1B, 1C, 1D, 1SS and 1SM

On the 6th and 7th December 2012, summer odour sampling was conducted on all four windrows at the Pittsworth trial site (1A, 1B, 1C and 1D). Department of Agriculture Fisheries and Forestry (DAFF) Queensland staff collected two samples from each windrow using a static flux chamber. The weather on both sampling days was warm and sunny.

The sampling on the first day was conducted when the windrows were dry with no rainfall recorded in the previous 7 days. The flux chambers were placed near the top and on both sides of the sawdust substrate windrows and the duplicate samples were collected simultaneously from a single windrow (Photograph 17). This was repeated for the manure substrate windrows (Photograph 18)

PHOTOGRAPH 17 – FLUX CHAMBERS PLACED ON WINDROW 1C, SAWDUST SUBSTRATE, PITTSWORTH

Photograph 18 – Odour sampling manure substrate windrows, Pittsworth

The second day of sampling was conducted on the windrows after they were wet down. A 1500 litre water tanker was provided by the farm manager and was equipped with a petrol driven pump feeding a 25 mm hose. The windrows were wet down immediately prior to sampling to mitigate any evaporation that would occur. Approximately 250 litres of water was sprayed at a low pressure over the top of the windrows at a rate of ~10 l/min to replicate a rainfall event of about 10 mm. The length of time for each windrow wetting was based on the length and breadth of the windrows.

Photograph 19 – Wetting down of windrow 1D, manure substrate, Pittsworth

PHOTOGRAPH 20 – WINDROW 1C, SAWDUST SUBSTRATE, AFTER WETTING DOWN, PITTSWORTH

PHOTOGRAPH 21 – FLUX CHAMBER ON WETTED DOWN SURFACE OF MANURE SUBSTRATE, PITTSWORTH

Samples of the surface sawdust and manure were taken from the four windrows before both the dry and wet odour sampling to determine the moisture content. The purpose of this exercise was to a correlate odour concentration and moisture content of the surface.

After sampling, the samples were transported back to the olfactometry lab at DAFF Queensland, Tor Street, Toowoomba for analysis. The first four samples on each day arrived at the lab 1 – 3 hours after testing by means of a second transport vehicle on-site. The second set of samples arrived at the lab within the same timeframe meaning that all 8 samples on each day were tested within 5 – 8 hours of collection. This is well within the 24 hour recommendation set out in the Australian Standard AS/NZS 4323.3 – Stationary Source Sources, Part 3 – Determination of odour concentration by dynamic olfactometry (2001) (Photograph 22).

PHOTOGRAPH 22 – ODOUR SAMPLING ANALYSIS AT THE DAFF QLD OLFACTOMETER (PHOTOGRAPH COURTESY OF DAFF QLD)

In addition to the windrow samples collected at the site, odour samples were collected from the two substrate materials used to construct the windrows. One bucket of sawdust substrate (1SS) and one of manure substrate (1SM) from the stockpiles at site were transported to the DAFF Qld research facility and an odour sample was collected from each cover material and analysed using the DAFF Qld olfactometry laboratory as a blank reference sample (Photograph 23). This was done to compare the odour emission rates from 'clean' substrate material with windrow samples that contained composting carcasses.

PHOTOGRAPH 23 – FLUX CHAMBERS COLLECTING ODOUR SAMPLES FROM SUBSTRATE MATERIAL (SAWDUST AND MANURE)

After measuring the temperatures of each of the 4 windrows it was determined that 1A and 1B were no longer achieving the temperatures required for quick decomposition of the carcasses. Large cracks were evident on Windrow 1B and an exploratory hole was dug in windrow 1B, to observe the rate of decomposition of carcasses. Although most flesh was decomposed, there were feathers and bones remaining (Photograph 24). With low temperatures and a prolonged dry spell prior to sampling, it was possible that a lack of moisture within the core of the windrow was hindering the decomposition. It was decided that water would be injected at high pressure into windrows 1A and 1B in an attempt to raise the temperatures.

PHOTOGRAPH 24 – EVIDENCE OF DRY AND INACTIVE COMPOSTING, PITTSWORTH

On 29th January 2013, FSA Consulting and DAFF Qld staff collected further summer odour samples from windrows at the Pittsworth trial site. These were windrows 1C and 1D that were established on the 29th of November 2012 and were now approximately 60 days old and had previously been sampled as 7 day old windrows in early December 2012. The sampling was conducted about a day after the ex-tropical cyclone Oswald weather event moved from Queensland to New South Wales. The trial site received almost 130 mm of rainfall (recorded by staff) during this event.

The windrows were saturated to varying depths of between 10 and 100 mm with the most moisture stored at the top of the windrows. The surface of the sawdust windrow (1C) had begun to dry but this was only to a depth of <2 mm (Photograph 25). The surface of the manure windrow (1D) was still very wet at the surface (Photograph 26) but appeared drier at depth than in the sawdust windrow.

PHOTOGRAPH 25 – EVIDENCE OF WETTING OF SAWDUST SUBSTRATE WINDROW FROM LARGE RAINFALL EVENT, PITTSWORTH

PHOTOGRAPH 26 – EVIDENCE OF WETTING OF MANURE SUBSTRATE WINDROW FROM LARGE RAINFALL EVENT, PITTSWORTH

This allowed for odour samples to be taken from the wet surface of a windrow after a significant rainfall event, instead of creating one artificially, as with previous sampling. The flux hoods were placed each side of the windrows without any further wetting and samples were collected in line with the standard protocol.

Disturbed samples were then collected from each of the windrows 1C & 1D to mimic a turning or other disturbance event that usually occurs during a windrows lifetime. The surface of the sawdust windrow (1C) was broken up using a spade to a depth of 200 – 250 mm on both sides of the windrow. This was enough depth to reach the layer of spent hens. The flux hoods were immediately placed on the disturbed locations and the sampling was carried out. On the manure windrow (1D), the outer saturated crust was removed from areas about 750 x 750 mm on both sides of the windrow. The surface below this was disturbed to a depth of 200 – 250 mm and the flux hoods were placed on these areas immediately (Photograph 27 and Photograph 28). Sampling was conducted using the same standard protocol as discussed earlier.

PHOTOGRAPH 27 – CREATING DISTURBED WINDROW ON THE MANURE SUBSTRATE WINDROW, PITTSWORTH

PHOTOGRAPH 28 – FLUX CHAMBER SAMPLING ON THE MANURE SUBSTRATE WINDROW, PITTSWORTH

On the 20th March 2013, FSA Consulting and DAFF Qld staff collected further summer odour samples from the now mature windrows at the Pittsworth trial site. These windrows consisted of compost material that was combined 2 months earlier at the 60 day stage. The two sawdust windrows (1A and 1C) were combined to form a single sawdust windrow (1AC). The two manure windrows (1B and 1D) were combined to form a single manure windrow (1BD). This combining of windrows was done to ensure a sufficient quantity of material remained in a windrow to achieve active composting. The combining of windrows is common practice in the compost industry once degradation of the material has caused a sufficient volume reduction. The material in each windrow had an average age of approximately 120 days, with some material being about 130 days of age (1A and 1B) and some material being about 110 days of age (1C and 1D).

The term 'dead' windrow indicates that the composting process has ceased and there is no breakdown of the carcasses occurring, yet there is still a significant amount of organic matter remaining. On this day two 'dead' windrows were observed, both containing manure as a substrate. The windrows were a mature windrow (1BD) from the summer compost trial and a relatively new windrow that was established 28 days prior to the sampling (1F).

The inactivity was observed by probing the windrows with a temperature probe and by digging into the windrow to the carcass layer and comparing the level of carcass degradation with windrows of a similar age that had sawdust as a substrate material. It appeared that a 50 mm rainfall event had penetrated the outer surface of the windrow and a quick drying process sealed this outer layer. This would have the effect of starving the windrow of oxygen, a necessary component required for the composting process. It was noticed that there was some moisture near the carcass layer when digging into the windrow so composting should have continued. Also a considerable amount of moisture had been added during the windrow construction phase.

An opportunity to sample a well-constructed windrow (1F) that had ceased to function and also an aged windrow (1BD) that had been turned previously was provided. The corresponding sawdust windrows (1E and 1AC) that had gone through similar processes continued to generate temperatures above 55°C, demonstrating that the composting process and the corresponding breakdown of the carcasses was continuing. This was confirmed when the sawdust substrate windrows were dug into and they showed a far greater level of carcass decomposition than that observed in the 'dead' manure windrows.

Photograph 29 shows a close-up view of the 28 day old manure windrow with a distinct crust on the surface. Photograph 30 shows the temperature of the manure windrows has dropped to around 40°C, well below the 55°C required for active composting. Photograph 31 shows a comparison between the two 28 day old windrows with sawdust and manure, with the sawdust windrow having no evidence of surface crusting. This sawdust substrate windrow was still maintaining core temperatures above 55°C.

PHOTOGRAPH 29 – EVIDENCE OF SURFACE CRUSTING OF MANURE WINDROW, PITTSWORTH

PHOTOGRAPH 30 – EVIDENCE OF LOW CORE TEMPERATURES (~42°C) IN THE CRUSTED MANURE WINDROW, PITTSWORTH

PHOTOGRAPH 31 – DIFFERENCE IN CRUST OF UNDISTURBED SAWDUST AND MANURE WINDROWS, PITTSWORTH

In addition, two samples of 'clean' sawdust and 'clean' manure substrate that did not include carcass material was collected and analysed. This material was wet just prior to sampling, to provide emission data from wet substrate that did not include carcasses, as compared to the same material that was analysed previously on the 8th December 2012 when it was dry.

4.4.1.2. Pittsworth winter sampling: 1E, 1F, 1G and 1H

On the 20th and 21st March 2013, FSA Consulting and DAFF staff collected odour samples from winter windrows at the Pittsworth trial site. These windrows were constructed 7 days and approximately 28 days respectively prior to the sampling.

The odour sampling was conducted as previously outlined, with duplicate samples being collected for each of the manure and sawdust substrate windrows, but only single samples being collected for the sawdust and manure substrates without carcasses. The wetting down was done using the tanker and high-pressure hose as previously described.

Sawdust substrate windrow samples (windrow 1E) were also collected on the 21st March 2013 to investigate the emission rate generated from a simulated turning, with odour samples collected prior, immediately after, 1 hour and 3 hours post disturbance to investigate the increase / decay in odour following disturbance of the windrow. The process for collecting the disturbed samples was:

- After the undisturbed sample was collected, a large area, 750 x 750 mm, was dug out of the windrow until the carcass layer was reached.
- The carcass layer was also disturbed and the sawdust and carcasses were mixed up to mimic a turning event. No carcasses were left on the surface of the windrows where the samples were taken.
- The first samples were taken immediately after disturbance.
- The second samples were taken 1 hour after the disturbance at exactly the same spot on the windrow.

- The third samples were taken about 3 hours after disturbance at this same spot.

Photograph 32 shows the process used and flux chamber odour sampling of a disturbed sawdust substrate windrow (four weeks old) at the Pittsworth trial site.

PHOTOGRAPH 32 – DISTURBANCE PROCESS AND ODOUR COLLECTION FROM SAWDUST SUBSTRATE WINDROW, PITTSWORTH

All samples were transported to the DAFF Qld olfactometry laboratory and analysed within 6 hours of collection.

Further winter odour samples from the sawdust and manure substrate windrows were collected on the 24th April 2013, with these windrows being approximately 60 days of age. The sampling was conducted on un-wetted windrows only, 1E (sawdust) and 1F (manure), and a similar disturbance was conducted on windrow 1E as per the previous sampling, using the following procedure:

- After the undisturbed sample was collected, a large area, 750 x 750 mm, was dug out of the windrow until the carcass layer was reached.
- The carcass layer was also disturbed and the sawdust and carcasses were mixed up to mimic a turning event. No carcasses were left on the surface of the windrows where the samples were taken.
- The first samples were taken immediately after disturbance.
- The second samples were taken 1 hour after the disturbance at exactly the same spot on the windrow.

The preliminary results from the previous disturbance experiment were inconclusive so some clarification was needed. All samples were transported to the DAFF Qld olfactometry laboratory and analysed within 6 hours of collection.

On the 3rd and 16th July 2013, the final winter odour samples were collected from the Pittsworth trial site. These samples represented combined windrows, where the two sawdust substrate windrows established on 22nd February 2013 and 13th March 2013 were combined to a single windrow (1EG). Likewise, the manure windrows established on these dates were combined (1FH). The substrate material in these windrows had an age of 112 and 131 days (average of 122 days) for the 3rd of July sampling and an age of 125 and 144 (average of 135 days) for the 16th of July sampling day.

After a rainfall event immediately prior to 3rd of July, odour samples from naturally wet compost windrow surfaces were collected. No disturbance was caused to the windrows before sampling and both sawdust and manure covered windrows were sampled. Samples were transported to the DAFF Qld olfactometry laboratory and analysis was conducted within 8 hours of sampling. Dry samples were collected on the 16th July after a 14 day dry weather period. The same process was carried out as per all previous samples taken at the trial site.

4.4.2. Tamworth trial site

4.4.2.1. Tamworth summer sampling: 2A, 2B, 2C and 2D

On the 22nd and 24th of January 2013, odour samples were collected from the windrows at the Tamworth site from windrows. Weather conditions were dry and warm on both sampling days and sampling commenced at 7.00am EST each day (Photograph 33). The samples were returned to the DAFF Qld olfactometry laboratory in Toowoomba and were analysed between 12 and 18 hours of collection. This was well within the 24 hour time limit as recommended by the Australian Standard AS/NZS 43233.3.

Windrows 2A (sawdust substrate) and 2B (manure substrate) were constructed on the 12th of January 2013 and were approximately 10 days old when sampled. Windrows 2C (sawdust) and 2D (manure) were approximately 120 days old when sampled. All windrows were constructed with a straw base, about 4 metres wide, and the spent hens were laid out at about 100 birds per metre length of windrow. The single layer of spent hens on the straw base was covered with the substrate material.

Photograph 33 – Odour sample collection, Tamworth

Two replicate samples were collected from each windrow when they were dry. The windrows were then wet-down and sampled. All samples were conducted using the standard protocols as previously described. The prevailing weather conditions of the sampling day and a number of days previous meant that the windrows were dry at the surface and at depth.

The wetting down of a section of the windrows was done with a sprinkler hose that was gravity fed from a 25,000 L water truck. The amount of water used was similar to a 10 mm rainfall event and the sampling occurred immediately after the wetting down of the windrows. Samples of the wet and dry surface materials from all four windrow sites were collected and sent to the lab for moisture content analysis. Photograph 34 shows collection of odour samples from wet windrow sections at the Tamworth trial site.

PHOTOGRAPH 34 – ODOUR SAMPLE COLLECTION FROM WET WINDROW SECTIONS, TAMWORTH

On the 24th January 2014 substrate samples of the sawdust and manure collected from the Tamworth site were analysed for odour emission rate at the DAFF Qld laboratories in Toowoomba and the collected odour samples analysed in the olfactometer on site. These samples were only cover material and were used to compare the emission rate of the material with the compost windrows containing carcasses.

4.4.2.2. Tamworth winter sampling: 2E, 2F, 2G and 2H

On the 11th and 15th June 2013, staff from DAFF collected duplicate samples from manure and sawdust covered windrows at the Tamworth trial site. These windrows were both new (approximately 1-2 weeks of age) and mature (>120 days of age), with no disturbance caused to them. The rainfall before 11th June meant that wet samples were taken on this day and transported immediately to the laboratory at Tor St. Samples were analysed between 12 and 18 hours of post collection. After a dry period of 7 days, further samples were collected on the 18th June that had a dry surface and the same transport and analysis procedure was followed.

5. RESULTS AND DISCUSSION

5.1. ODOUR EMISSION RATES

As detailed in Section 3 (Literature review), the key factors that drive emissions from compost windrows include:

- the location of the site (i.e. climatic conditions)
- type of base material (manure vs sawdust)
- materials added to the windrows (base material vs material with spent hens vs turned material)
- management of the windrow (wet vs dry, turning vs unturned).

The odour emission rate data are reviewed with regard to these factors below.

5.1.1. LOCATION

Results of all odour samples from the Pittsworth (65 samples) and the Tamworth (34 samples) sites are detailed in Appendix C and Appendix D. This includes details of the substrate material, odour sample collection date, age of compost windrow from establishment date, windrow surface moisture content, windrow treatment (disturbed/undisturbed) and a description of the odour.

All emission data for both sites are summarised in Figure 4. Also included in the figure is the range of emissions for the substrate without and with carcasses present.

The emission rate data has been summarised as box and whisker plots. These plots allow the distributions of the data to be easily compared. The crossbar at the top of the line of each box represents the maximum value in the data set once outliers (as shown by the crosses) are removed. Outliers are 3 x the likely range of variation (interquartile range, IQR) above the third quartile, or 3 x IQR below the first quartile. Where outliers are 3 x the likely range of variation (interquartile range, IQR) above the third quartile, or 3 x IQR below the first quartile (The National Institute of Standards and Technology 2012). The top of the box is the third quartile (75% of data is below this) and the bottom of the box is the first quartile (25% of values are above this). The band inside the box is the median emission rate. The line with the crossbar at the bottom represents the minimum value.

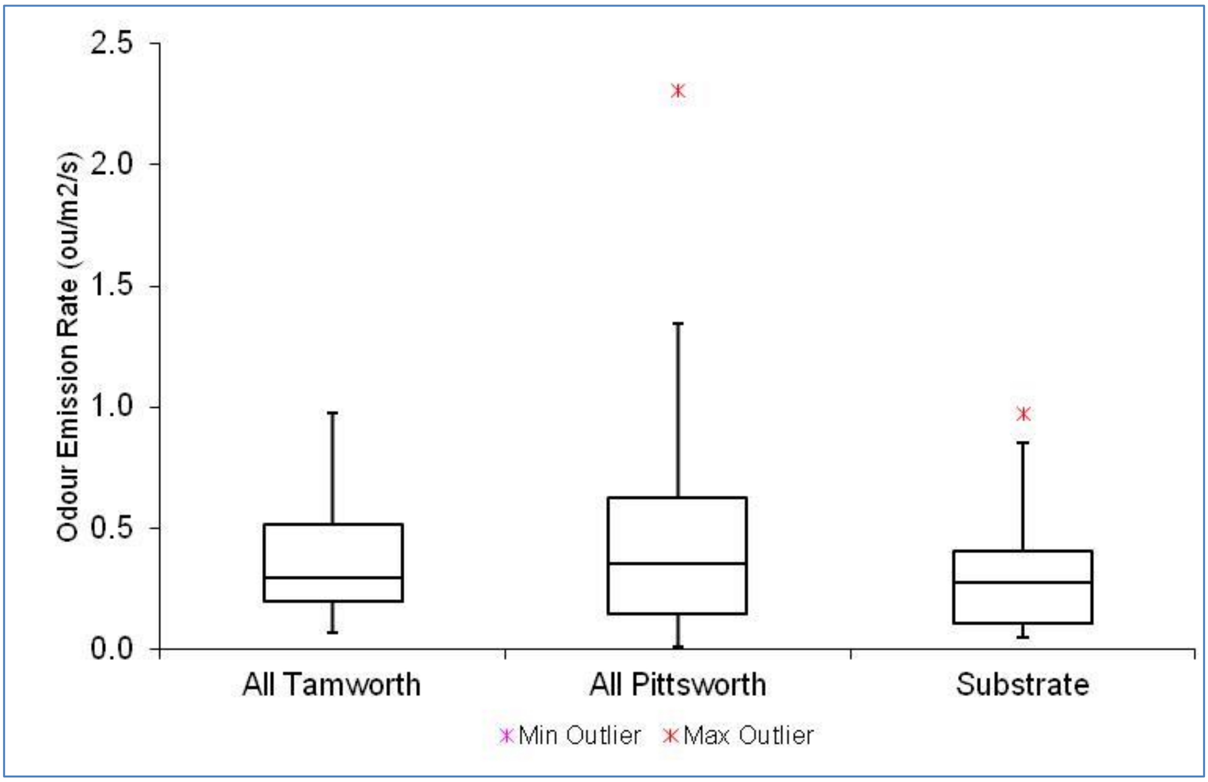

FIGURE 4 – EMISSION RATE BY SITE (INCLUDES SUBSTRATE MATERIAL)

Figure 4 shows that:

- The range of emissions is larger at the Pittsworth site than at the Tamworth site but the distributions are not significantly different as the boxes overlap.
- The general range of emissions by site (as shown by the box) is similar.
- The range of emissions for the substrate is similar to the site data.
- The distributions are skewed (i.e. the median does not lie in the middle of the box).
- The median emission rate for the sites is similar (0.3 vs 0.35 ou/m^2/s).
- The minimum emission rate for Pittsworth is lower than that at Tamworth.
- The maximum emission rate is higher at Pittsworth than at Tamworth.

5.1.2. SUBSTRATE MATERIAL

The next step focussed on assessing whether there was a difference between the range of emissions from sawdust and manure substrate material. The data are summarised below in Figure 5. Using the boxplots to assess the data, it can be seen that although there is some overlap between the boxes and the distributions are not statistically significantly different, they are sufficiently different to suggest that odour emissions from manure based systems will generally be higher than from sawdust based systems.

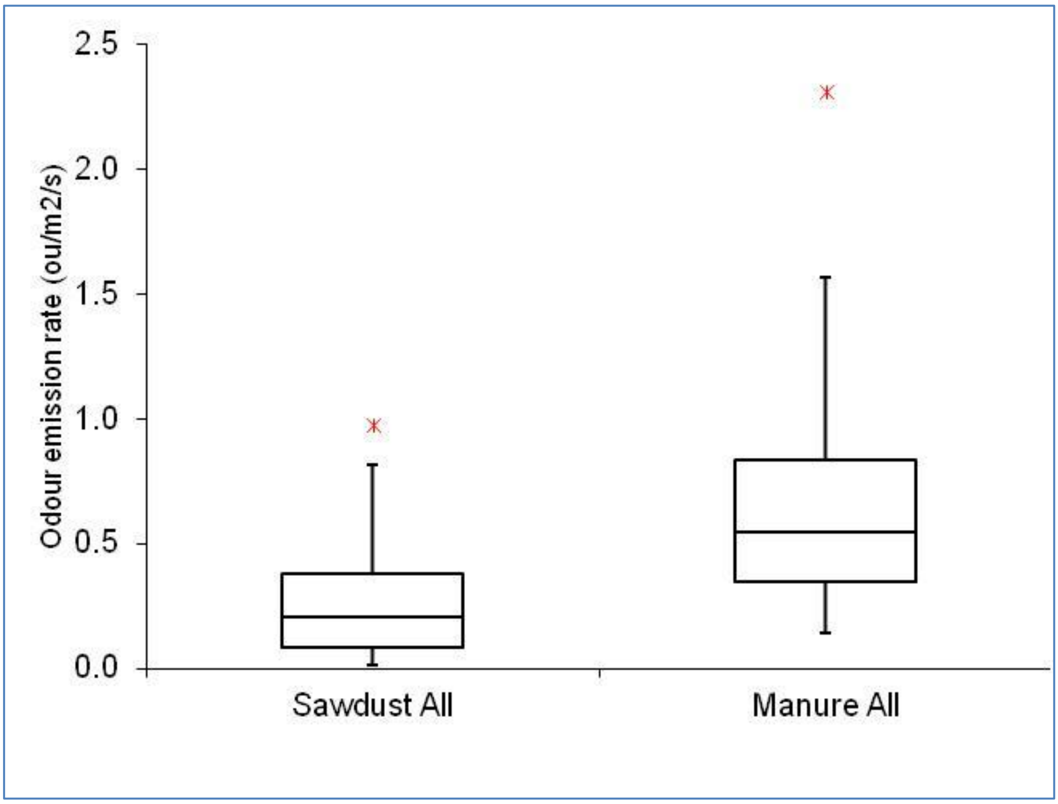

FIGURE 5 – EMISSION RATE BY SUBSTRATE MATERIAL (ONLY CARCASSES PRESENT)

Figure 5 shows that:

- The range of emissions associated with sawdust is less than that of manure.
- The distributions are skewed (i.e. the median does not sit in the middle of the box).
- The median emission rate for sawdust 2.7 times less than that of manure.
- The minimum emission rate for sawdust is 11 times lower than that for manure

5.1.3. EMISSIONS AS A FUNCTION OF WINDROW AGE

Schmidt and Bicudo (2000) looked at changes in odour emissions associated with four different chicken manure / bulking agent mixtures. With regard to age of windrow, odour emissions on day 3 of composting were 4 to 7 times higher than on day 13 or day 28. This is consistent with data held by Pacific Environment for municipal waste composting operations (which used meat chicken litter) showing that the emissions peak roughly a week after placement, and decrease over time. Logically this would occur as a function of the volatile compounds in the pile being depleted by the process.

However, key to this work is that the windrows are not managed like a commercial operation in that:

- the windrows are not actively turned at a high frequency (perhaps once per placement)
- water is not added to the windrows with turning
- the carbon to nitrogen ratio is not managed in that the operation is based on covering the dead birds with the base material. In contrast to this, traditional composting operations typically carefully manage the carbon to nitrogen ratio.

Accordingly, the manure data and sawdust data were analysed according to age since placed. The manure data are shown in Figure 6 (all data) and the sawdust data are shown in Figure 7. Figure 8 compares each base material by showing the average odour emission rate by age where carcasses were present in the windrows. It should be noted that the analysis of the odour results was grouped into five different windrow ages, with windrow age 6 – 8 days analysed as 7 days, windrow age 9 – 14 days analysed as 10 days, windrow ages 26 – 30 days analysed as 28 days and windrows ages 60 – 62 days analysed as 60 days. All mature and completed windrows (120 days and greater) were analysed as 120 days.

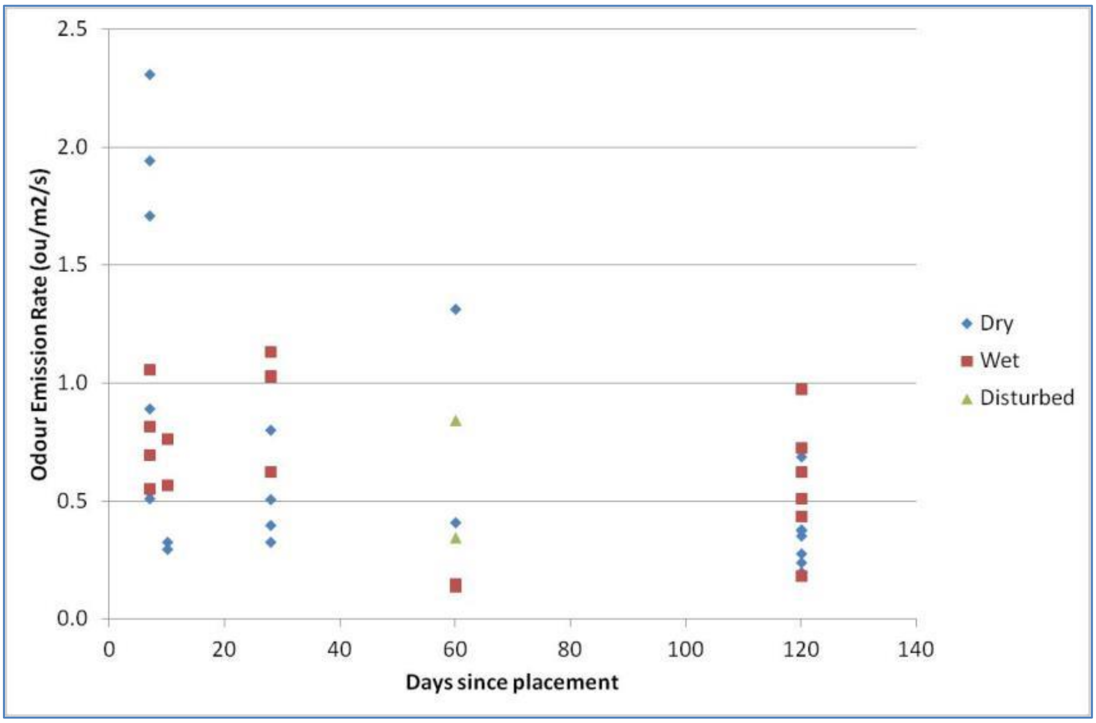

FIGURE 6 – EMISSION RATE – MANURE SUBSTRATE ONLY

As shown in Figure 6, the odour emissions (both wet and dry) are typically higher in the few weeks after the windrows are placed and then drop away with time (albeit with some variation at day 60). The data indicates that disturbing the windrows doesn't significantly increase the emissions, and the difference between wet and dry manure does not appear to be significant in the period close to placement. However, wet manure, when aged, appears to have higher emissions than dry manure.

The sawdust odour emission rate data are shown in Figure 7 and Figure 8 and also Table 2. It is important to note that the sawdust based emissions rose from day 7 to about day 28 and then decreased. The data indicated that wet windrows tended to have elevated emissions compared to dry windrows, at least in the first few weeks. In contrast, the manure emissions were highest at day 7, dropped at day 10, then rose slightly at day 28 before dropping away to a background value. Therefore, the trend lines shown in Figure 8 are indicative only. This is discussed further in Section 5.2.

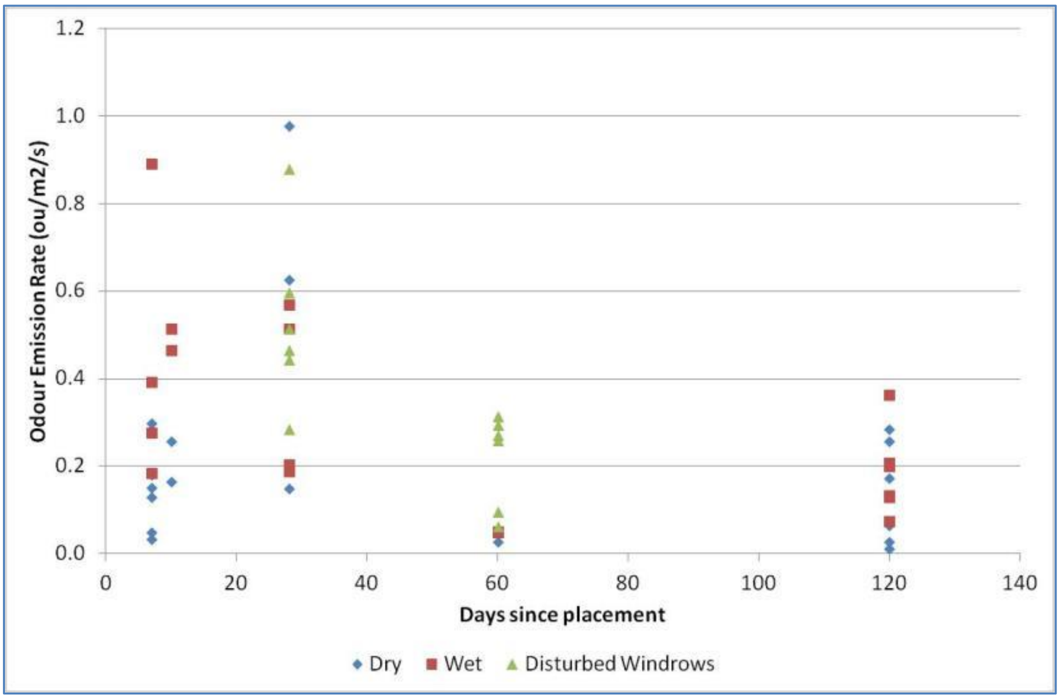

FIGURE 7 – EMISSION RATE – SAWDUST SUBSTRATE ONLY

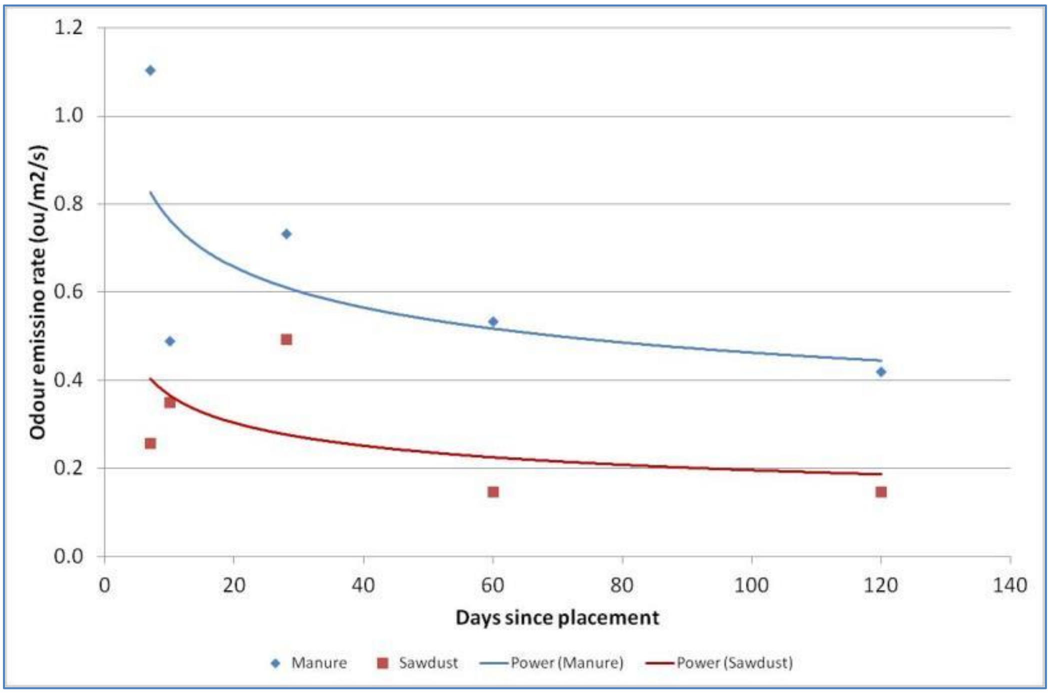

FIGURE 8 – EMISSION RATE – AVERAGE BY SUBSTRATE MATERIAL

TABLE 2 – AVERAGE ODOUR EMISSION RATE BY AGE (OU/M^2/SEC)

Age (days)	Manure	Sawdust
7	1.1	0.3
10	0.5	0.4
28	0.7	0.5
60	0.5	0.1
120 and greater	0.4	0.1

5.1.4. Emissions and Disturbance

Experience at other sites has shown that emissions can increase after the windrows are disturbed. A series of samples was collected at Pittsworth at 28 days and 60 days. The results are summarised in Figure 9. Emission rates were estimated immediately after turning (0 hours), 1 hour after turning, and 3 hours after turning. The data show that the emissions rose after turning but dropped off again rapidly. As expected, the 28 day windrow had higher emissions than the 60 day windrow.

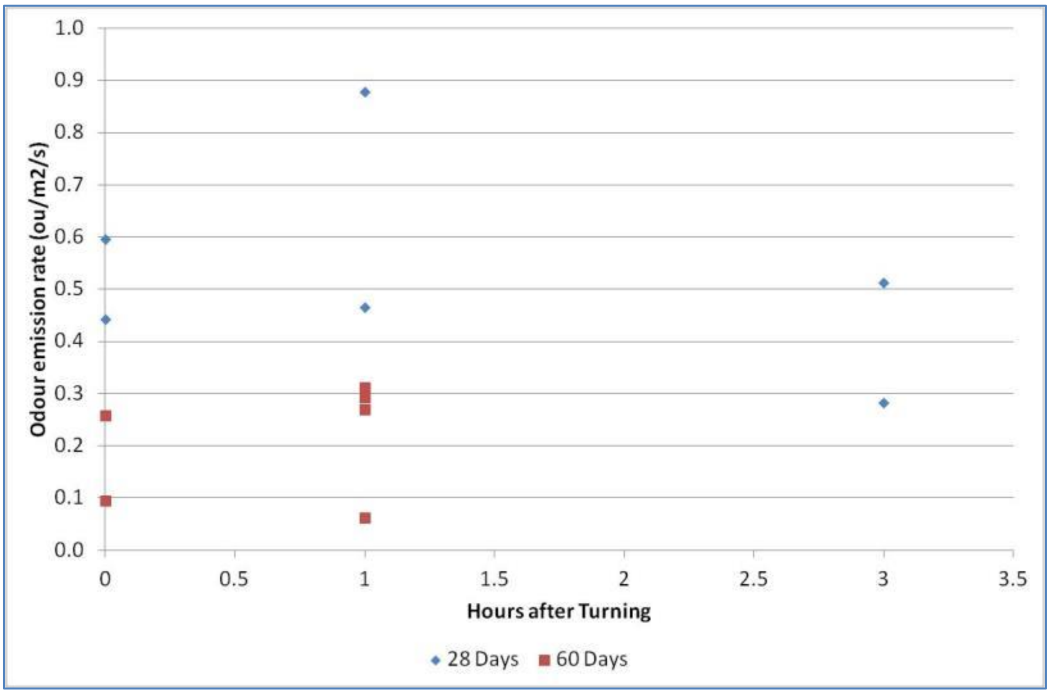

Figure 9 – Emission rate after disturbance

5.1.5. Odour Character and Age

Experience with composting has shown that the finished product is often far less odorous than the initial product. This might be expected as the initial material (dead birds in this case) is high in protein and fats, which decompose creating a wide range of odorous gases. Decomposition converts the original complex chemistry into simpler, less odorous breakdown products. The manner and rate of breakdown is affected by moisture, aeration and temperature. Different odour compounds are expected to be produced at different stages of composting.

Odour descriptors were collected for 56 of the odour samples using the odour panel. The results are summarised by age in Table 3. Whilst not conclusive, it can be seen that the general character of the odour changed from “decaying, putrid, pungent, dead chickens, chicken manure” for a new windrow to “silo smell, earthy, damp soil, vege patch” for a composted windrow.

TABLE 3 – SUMMARY OF ODOUR CHARACTER FROM SAMPLES

Sample	Age of Row	OER	Comment
Pittsworth	7	1.944	Chicken carcass, rotting veges, rotten, flatulence
Pittsworth	7	2.311	decomposing, sulfuric, rotten eggs
Tamworth	10	0.567	decaying, putrid; pungent; dead chickens; chicken manure
Tamworth	10	0.763	carrot cake; chicken manure pile; cabbage; rotting veges; rotten potato
Tamworth	10	0.329	earthen; damp; toast-like
Tamworth	10	0.298	sour; chiko roll; decomposing smell; dry/dusty
Pittsworth	28	0.329	mild compost smell
Pittsworth	28	0.508	mouldy, musty, decomposing, earthy
Pittsworth	28	0.627	molasses, syrupy, manure, more smelly than previous one
Pittsworth	28	1.134	musty, sour, rotten, feedlot?, rural, old manure - hard to pin down source
Pittsworth	60	0.410	rotten, cadavorous; dead chickens
Pittsworth	60	1.316	putrid, foul, dead chicken, cadavorous
Pittsworth	120	0.277	farmyard, chook-pen
Pittsworth	120	0.243	Dirt like smell; not compost
Pittsworth	120	0.514	earthy, dusty, burnt, shoe shop (Changes as it gets stronger)
Pittsworth	120	0.626	very musty, mouldy, smouldering
Pittsworth	120	0.353	feedlot smell, musty, mushroom compost, moister than previous sample
Pittsworth	> 120	0.378	wet, ashy, smoky
Tamworth	> 120	0.727	mouldy grain; earthy; bottom of silo; decomposing wood
Tamworth	> 120	0.978	silo smell, earthy, damp soil, vege patch
Tamworth	> 120	0.691	like previous but less pungent; ploughed paddock
Tamworth	> 120	0.382	wet dirt; humus; smell of "digging up peanuts"
Pittsworth	Substrate only	0.978	cheap dark Ghana chocolate, chickory, toasted peanut, Charlie Carp fertiliser

5.2. EMISSION PROFILE DEVELOPMENT

As shown in Figure 6, Figure 7 and Figure 8, there is a general trend with the emissions decreasing over time, but also there is considerable scatter about the curve. One way of incorporating the scatter is to apply the 3rd quartile value of the data for each age data point (for manure and sawdust samples). That is, the new curve is the level at which 75% of all measured emission rate values were below it.

As shown in Table 2, the emissions for manure samples follow a relatively straightforward power profile showing that the emissions decay over time. Here we have adopted a conservative approach and removed the day 10 values, which are lower. The result is the manure emissions profile by age shown in Figure 10. It should be used with the proviso that emissions before 7 days of age are assumed to be equal to the 7 day value. It may be appropriate for windrows older than 120 days to apply the median emission rate of 0.3 ou/m^2/s as shown in Figure 4

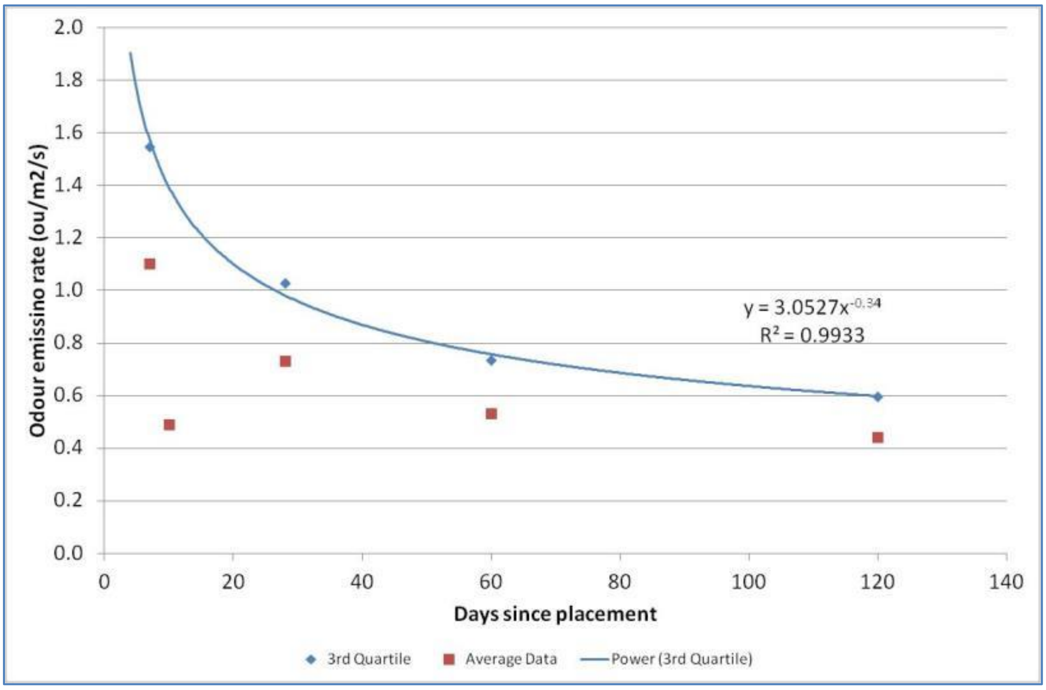

FIGURE 10 – 3RD QUARTILE AND AVERAGE EMISSIONS PROFILE – MANURE SUBSTRATE

The sawdust emissions were previously shown in Figure 7. To allow a prediction of emissions the emission profile has been broken into two sections, emissions up to day 59, and emissions 60 days and beyond. The emission profile for emissions up to day 59 is shown as Equation 1 where x is the age of the windrow in days and y is the predicted odour emission rate in ou/m^2/s. Any odour emissions prior to day 7 should be assumed to be the same as day 7.

EQUATION 1

$$y = -0.0004x^2 + 0.0279x + 0.174$$

For emissions at day 60 and beyond, we have applied the 3rd quartile value of 0.3 ou/m^2/s which is consistent with the measured data. A comparison of the 3rd quartile data and the proposed emissions profile is shown in Figure 11.

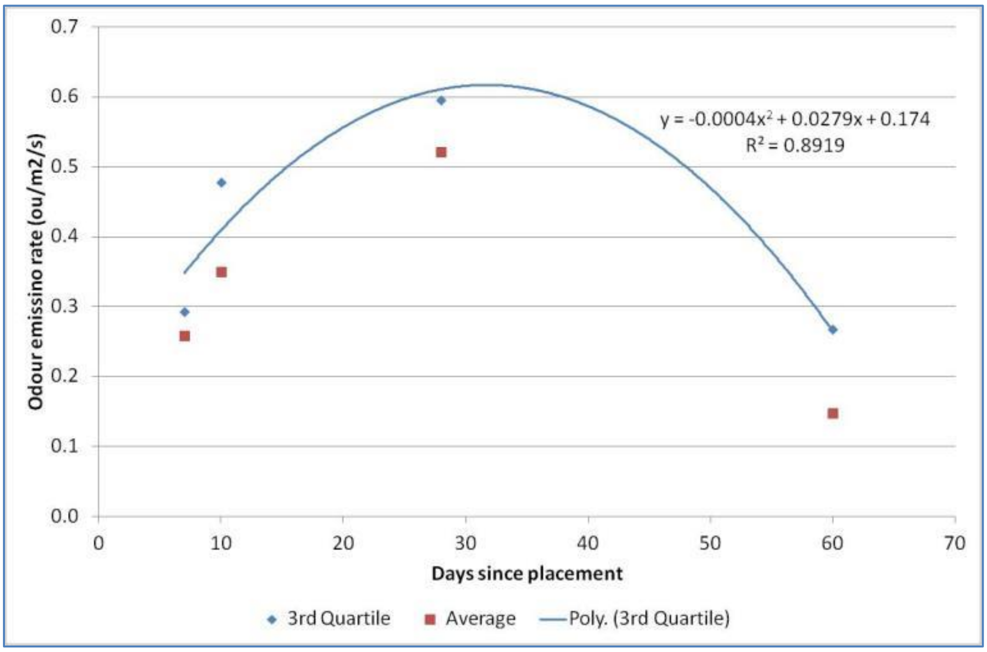

FIGURE 11 – 3RD QUARTILE EMISSIONS PROFILE AND AVERAGE EMISSIONS – MANURE SUBSTRATE

A full analysis of the development of the odour emission profile of spent hen composting can be found in the milestone report for the project: *Odour Emission Profile Development – Odour Measurement And Impact From Spent Hen Composting* (Pacific Environmental Limited 2013b).

5.3. ODOUR MODELLING

Odour modelling was performed at two example sites:

- Pittsworth region
- Tamworth region

The aim of the modelling was to assess the impact of introducing spent hen composting on a typical egg laying facility.

5.3.1. MODELLING METHODOLOGY

The size of the farms was based on what might be considered a medium sized modern tunnel ventilated facility with a total of six sheds: one rearer shed and five layer sheds. The capacity of each shed was assumed to be 50,000 birds. It was also assumed that all sheds run their manure belts regularly and that manure was removed from the site on each run. Farm operation was based on a 47 week laying cycle, with the rearer sheds holding birds for 16 weeks. To ensure conservatism, it was also assumed that all sheds were continuously full.

Spent hens were assumed to be placed in windrows with dimensions of 1.75 m high and 3.5 m wide (178 hens per linear metre), with a total windrow length of 280 metres on site. These data were based on Composting By-Products on Egg Farms (DAFF N/A).

Both farms modelled were at arbitrary locations within the model domain and were not selected based on any proposed operation.

The air dispersion modelling conducted for this study has been based on the use of the models TAPM and CALMET/CALPUFF. This system substantially overcomes the basic limitations of the steady-state Gaussian plume models such as AUSPLUME. These limitations are most severe in very light winds, in coastal environments, and where terrain affects atmospheric flow. CALMET/CALPUFF is often used for odour-related assessments as it can cover the effect of impacts under low wind speed conditions.

The modelling system works as follows:

- TAPM is a prognostic meteorological model that generates gridded three-dimensional meteorological data for each hour of the model run period.
- CALMET, the meteorological pre-processor for the dispersion model CALPUFF, calculates three-dimensional meteorological data based upon observed ground and upper level meteorological data, and/or modelled upper air data generated for example by TAPM.
- CALPUFF then calculates the dispersion of plumes within this three-dimensional meteorological field.

5.3.2. ESTIMATION OF EMISSIONS

The windrow emissions were taken from the higher overall emission data (manure substrate) and were calculated as $y = 3.0527 \times x^{-0.34}$, where y is the emission rate (ou/m^2/s) at a point in time x, in days.

Shed emissions were based on the emission rate data detailed in the report: Dust and Odour Emissions from Layer Sheds (Dunlop 2011a). The emissions were based on the Queensland data as there was a good relationship between ambient temperature and ventilation rate, and between ventilation rate and odour emission rate. The NSW data returned a poor relationship between ambient temperature and ventilation rate and ventilation rate and odour emission rate and therefore were not used.

The basic factors determining odour emissions are ventilation rate and odour concentration. Ventilation is driven by a number of other factors. For meat chickens, bird age and target temperature are critical. However, as the bird mass in layer sheds essentially remains constant over time (compared to the rapid growth in chicken sheds), the relationship between ambient temperature and ventilation rate can readily be evaluated. This is shown in Figure 12. The red markers represent summer data, and the blue, winter data.

Figure 12 shows that with increasing temperature, the ventilation rate in the sheds increases exponentially to a maximum of approximately 100 m^3/s. Ventilation will not increase at temperatures higher than shown because the fan capacity is limited. Departures from the trend line represent the effects of short-term ventilation changes, the use of cool pads on the sheds and possibly other minor factors.

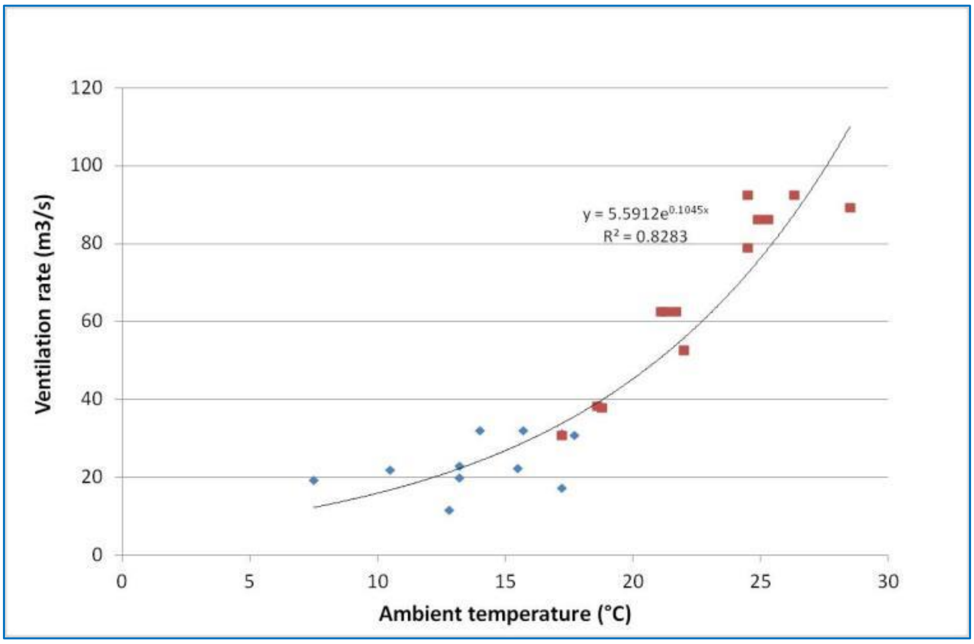

FIGURE 12 – AMBIENT TEMPERATURE VS SHED VENTILATION RATE (DUNLOP 2011A)

Figure 13 below shows the relationship between ventilation rate and odour emission rate. The red markers represent summer data, and the blue markers represent winter data. The variation around the trend line in Figure 13 is due to the use of both summer and winter data, which includes measurements immediately after and leading up to the manure belt running.

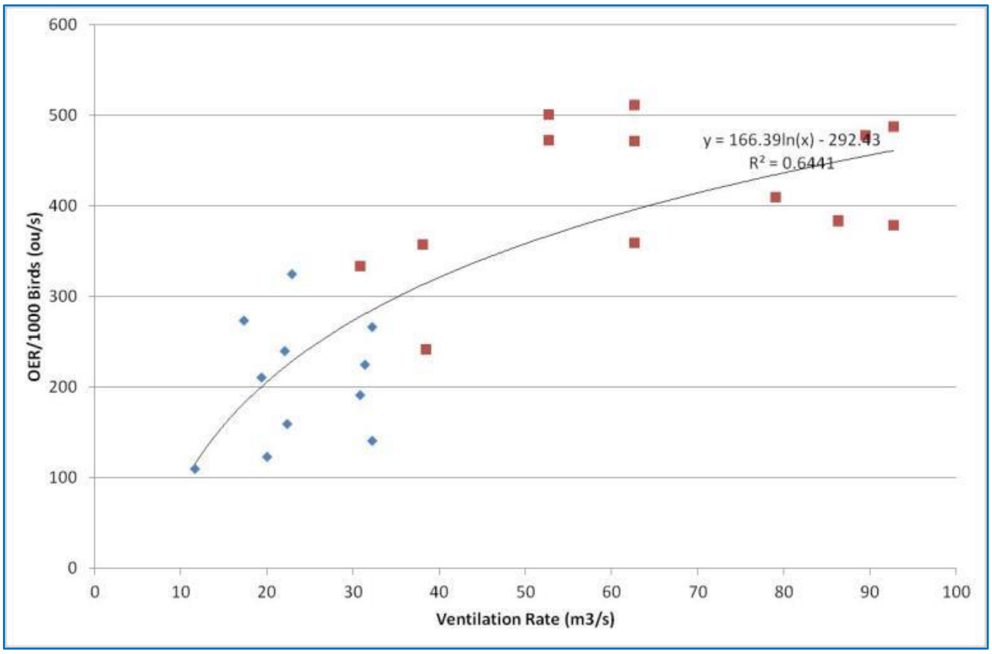

FIGURE 13 – VENTILATION RATE VS ODOUR EMISSION RATE (OER) FOR A SHED (DUNLOP 2011A)

Emissions were estimated based on the data in Figure 12 and Figure 13. Using the ambient temperature predicted by CALMET, the ventilation rate (using Figure 12) was calculated and then emission rate at a point in time for a given number of birds (using Figure 13). For conservatism, the rearer shed was treated as a layer shed, which gives a higher bird mass than would occur.

An example of the estimated emissions is shown for the Queensland site in Figure 14. The figure shows that composting would contribute around 2% of total site emissions, based on the maximum rate from the sheds.

5.3.3. METEOROLOGICAL DATA

The first meteorological datasets used in the modelling was for the 2008 year at a site located near Pittsworth in southern Queensland. This dataset is characterised by light wind from most directions, with prevailing winds from the east most common. During the morning, the wind speeds generally are light, and increase through the day. Easterly, east-north-easterly and east-south-easterly breezes are common throughout the morning and increase until midday. In the afternoon, wind speeds continue to increase and while on most days winds continue from the east, westerly and south-westerly winds are also common. Following sunset, wind speeds decrease and light easterly and east-north-easterly winds return.

The second meteorological data set is for the 2004 year at a site just south of Tamworth in northern New South Wales. At this site, the climate is characterised by a predominance of winds from the east and south-east and a secondary maximum from the west and north-west. The wind roses show that there is a strong tendency in the early morning for light winds from the east and southeast, followed as the day progresses by increasing wind speeds and typically an afternoon wind from the west or north-west. By late at night, winds have normally decreased and are typically again from the east. This behaviour reflects a dominant downslope-upslope flow pattern caused by heating and cooling combined with regional-scale terrain effects, and is typical of areas on the western slopes of the Great Dividing Range.

A full analysis of these meteorological sites can be found in the detailed odour modelling report for this project (Pacific Environmental Limited 2013a). This includes detailed wind roses, a breakdown of the stability class and mixing height for each site.

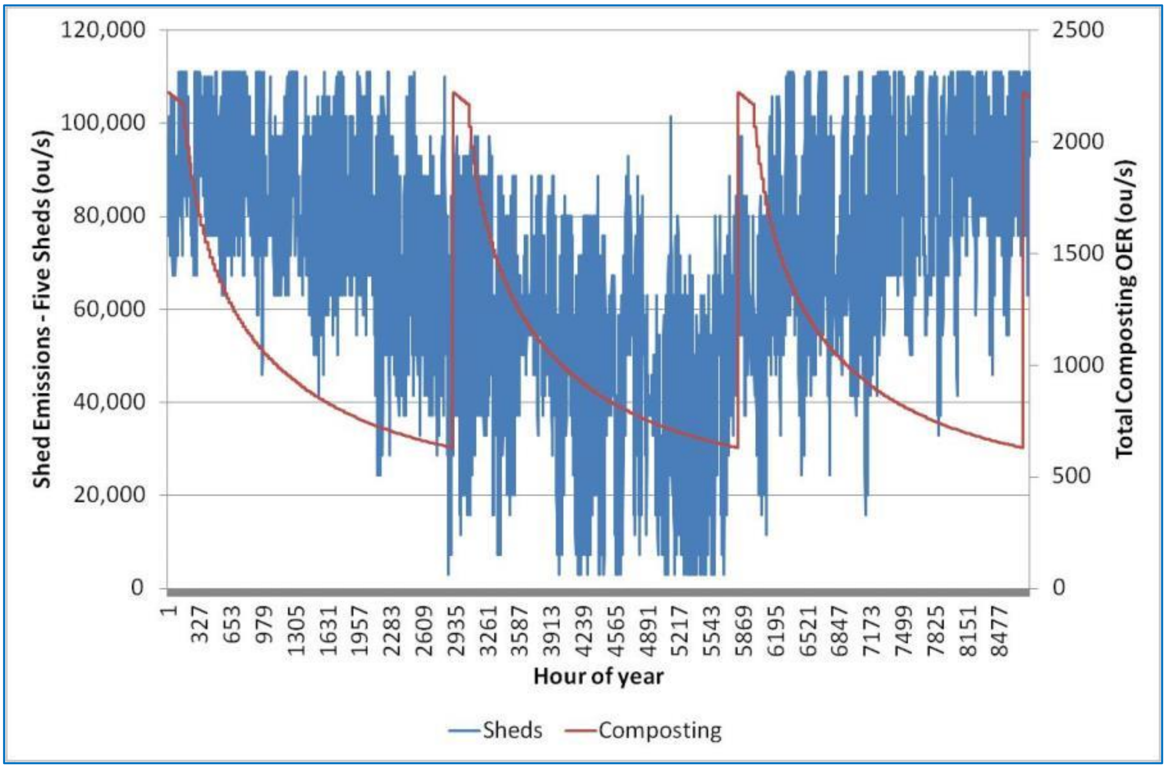

FIGURE 14 – EXAMPLE OF PREDICTED EMISSIONS (QUEENSLAND SITE)

5.3.4. ODOUR IMPACT CRITERIA

For the purposes of the modelling exercise conducted in this project, the Queensland regulatory odour impact criteria of 2.5 odour unit, 99.5 percentile, 1 hour average odour concentration ($C_{99.5\ 1hr\ avg}$ = 2.5 ou) was chosen. This represents 99.5% of the time that the odour impact criteria of 2.5 hours is not exceeded, or conversely 0.5% of the time that the odour impact exceeds 2.5 ou at a particular location. Thus, for one year of odour modelling on an hourly basis (8766 hours), then the 2.5 ou criteria is exceeded for 44 hours in a year.

5.3.5. MODELLING RESULTS

A primary objective of the project was to quantify odour generation and emissions produced by composting spent hens on-farm and the likely impact these have on community amenity. To assess this, three odour modelling scenarios were run for each meteorological site. These were:

1. composting emissions only
2. sheds emissions only
3. shed and composting emissions combined.

To provide a direct comparison of the two sites, a single odour impact criteria needed to be chosen ($C_{99.5\ 1hr\ avg}$ = 2.5 ou). The results of this odour modelling are shown below in Figure 15, Figure 16 and Figure 17 (Queensland site) and Figure 18, Figure 19 and Figure 20 (NSW site), with the red line representing the $C_{99.5\ 1hr\ avg}$ = 2.5 ou impact criteria.

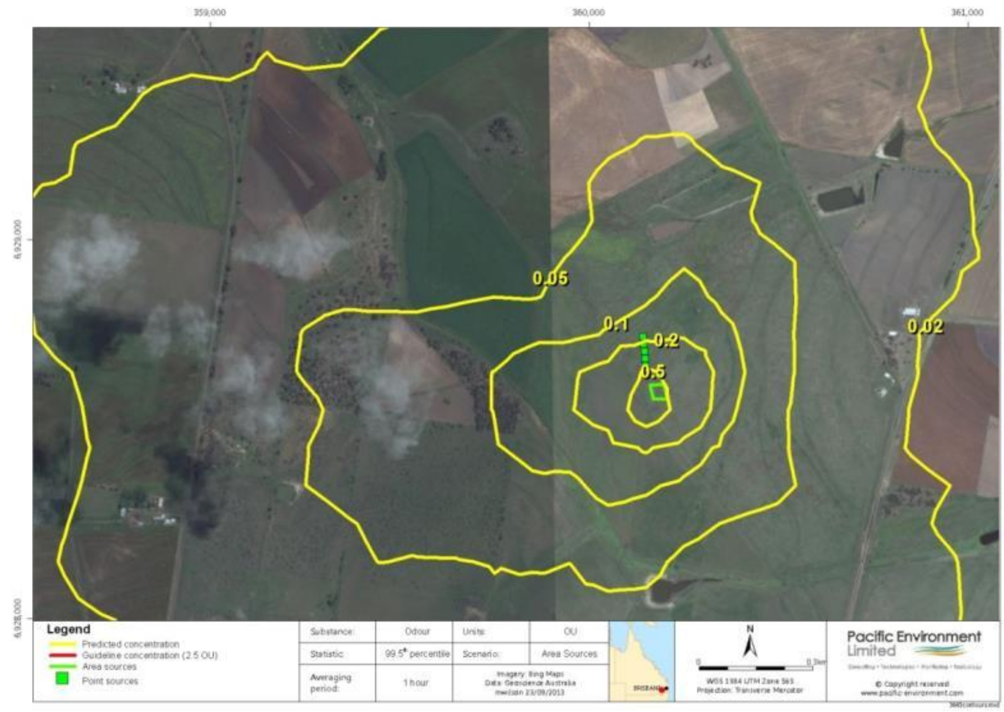

FIGURE 15 – QUEENSLAND CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – COMPOSTING ONLY

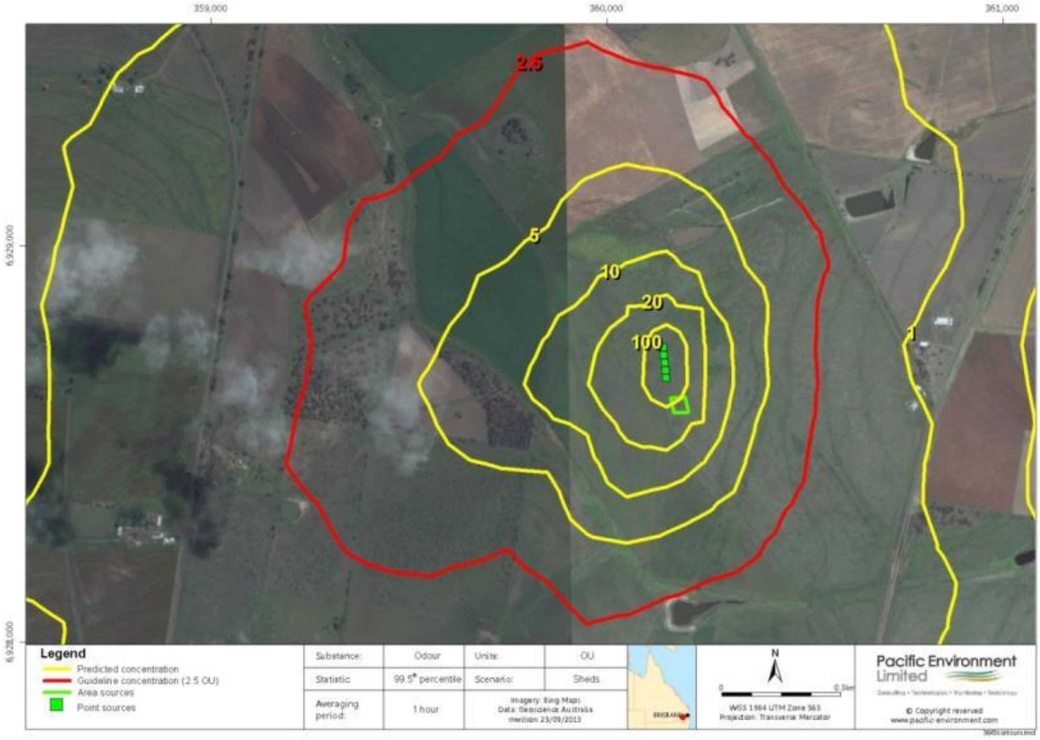

FIGURE 16 – QUEENSLAND CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – SHEDS ONLY

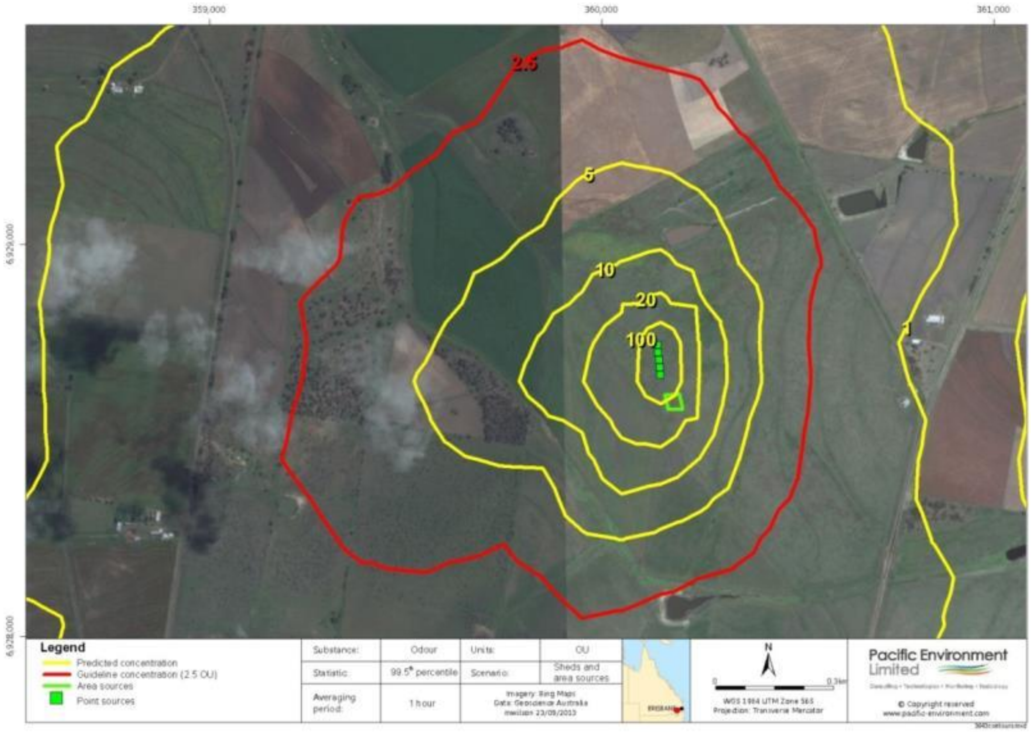

FIGURE 17 – QUEENSLAND CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – SHEDS AND COMPOSTING

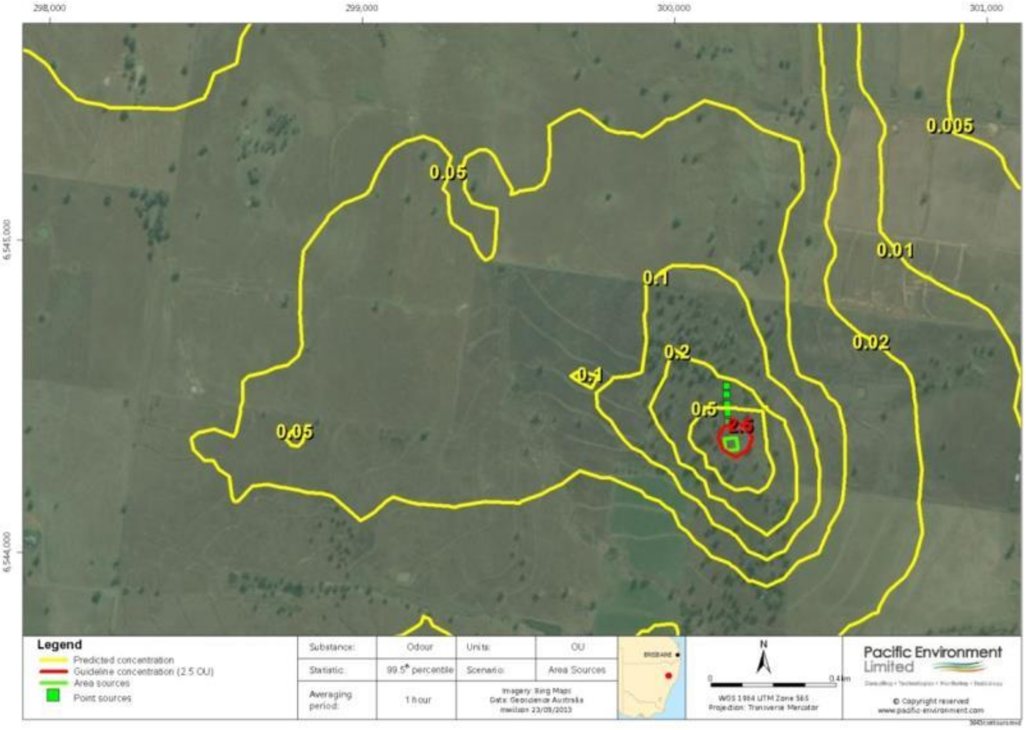

FIGURE 18 – NSW CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – COMPOSTING ONLY

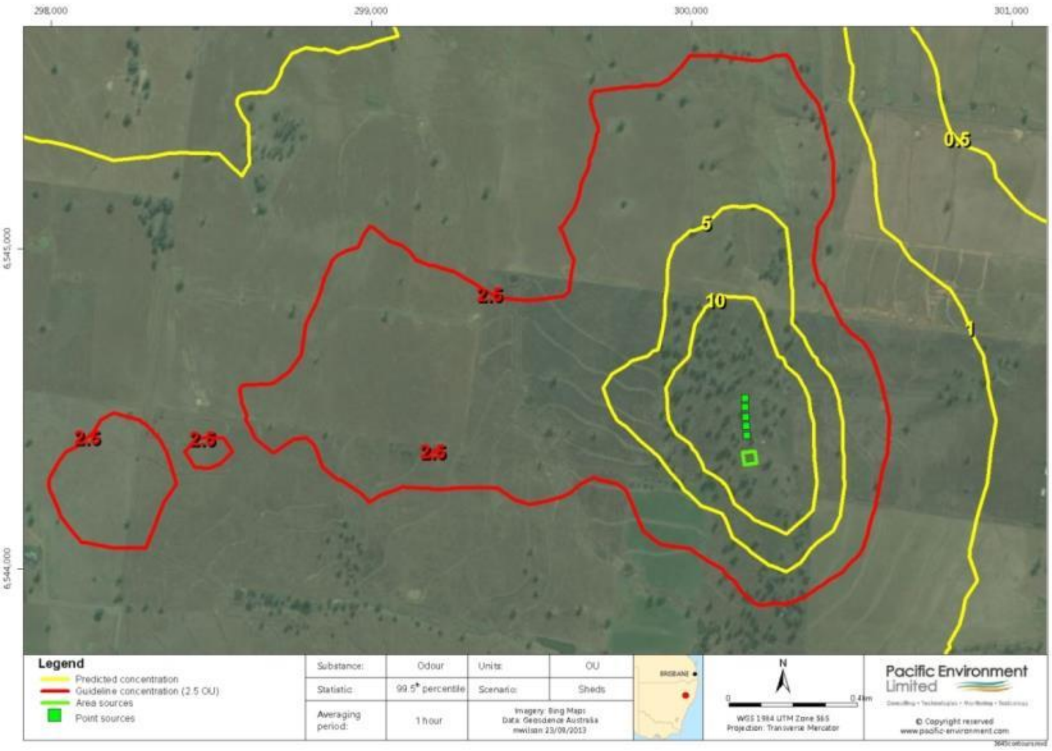

FIGURE 19 – NSW CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – SHEDS ONLY

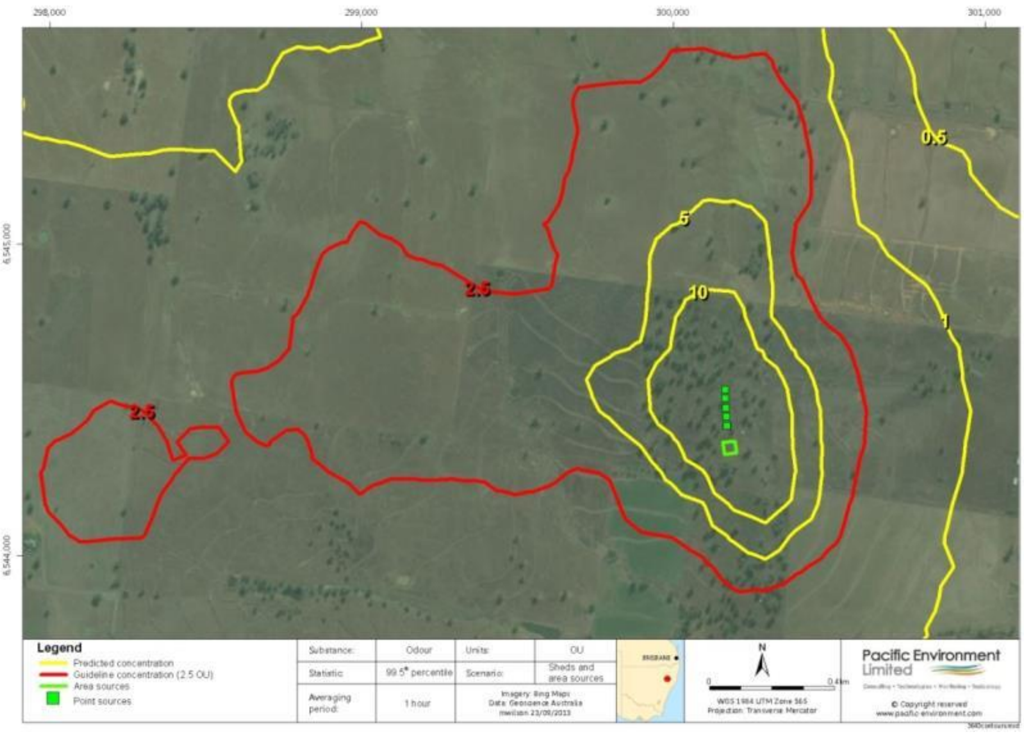

FIGURE 20 – NSW CASE: PREDICTED $C_{99.5\ 1HR}$ = 2.5 OU CONTOUR – SHEDS AND COMPOSTING

5.3.6. ODOUR MODELLING DISCUSSION

The odour modelling impact assessment (Section 5.3.5) shows that the addition of composting operations to a typical farm (based on flux chamber measured emission rate data) would have a negligible impact on overall emissions. However, this is based on the assumption that the windrows would be placed and then disturbed infrequently, and managed appropriately.

One item not factored into the assessment is the character of the odour from the windrows. The data shows (Section 5.1.5) that the character of the odour changes over time from more offensive to less offensive. The modelling performed above assumes that the odour is additive to that from other sources. In reality, compost odour is less offensive than shed odour (if covered and managed appropriately) and therefore the assumption that it is additive is only likely to be relevant for the first few weeks after placement. At other times, the additive assumption is likely to be quite conservative.

Although the flux chamber method complies with the AS4323.4 standard for area source measurement, research such as that reported by Parker et al. (2009) and Jiang & Kaye (1996) has highlighted that for gas phase controlled odorants, such as some of those found in composting, the flux chamber can under-predict the release of these odorants and, therefore, emissions. This was highlighted by Pollock and Braun (2009) who found that the use of flux chambers on green waste windrows could underestimate impacts.

However, even if the emissions were to increase by a factor of two or three, the modelling indicates that the influence of the composting emissions would be minimal compared to the shed emissions.

6. Conclusions

Composting has long been used as a suitable management tool for handling the solid wastes produced in layer hen facilities and is now becoming a more common practice for managing both hen mortalities and spent hens. Spent hens have traditionally been removed from farm and converted to human and animal food at processing facilities. The Australian egg industry is investigating other viable options to handle this by-product from the industry due to the potential lack of availability and capacity of these processing facilities to accept and process spent hens. Additionally, transport costs and the loss in farm productivity while a shed is being destocked has made this traditional method less financially viable.

Composting spent hens on-farm is an option that has the potential to increase the flexibility of an egg producer's production system however, the potential odour emissions from an on-farm composting facility may be a barrier to the adoption of this method of spent hen disposal. There is very little odour emission data from animal carcass composting available in the literature, particularly where the emission rate data was collected using flux chambers to the Australian Standard.

Measurements of odour emission rates were collected from two spent hen composting sites (Pittsworth and Tamworth). The odour samples collected included two different compost substrate materials, sawdust and manure. Samples were also collected for both wet and dry windrow surfaces; and disturbed and undisturbed windrows. Additionally, testing was conducted to investigate the decay in odour emission rate, three hours post disturbance of a windrow. Some of the samples were also assessed for odour character to determine if aged compost produced a different type of odour to freshly placed windrows. Both summer and winter compost trials were conducted at each trial site.

A total of 99 odour emission samples were collected (65 at Pittsworth site and 34 at the Tamworth site) using a flux chamber and then analysed at the Department of Agriculture, Fisheries and Forestry olfactometer in Toowoomba, using the AS/NZS 4323.3 standard. It was found from the collected odour emission data that the general range of emissions at each site was similar, with the median emission rate being 0.3 ou/m^2/s (Pittsworth) and 0.35 ou/m^2/s (Tamworth). These odour emission rates were in the order of what has been previously measured from pig carcass composting using flux chambers. The range of emissions associated with sawdust is less than that of manure, with the median emission rate for sawdust being 2.7 times less than that of manure and the minimum emission rate for sawdust being 11 times lower than that for manure.

In relation to windrow age, the odour emissions for both wet and dry compost windrows were typically higher in the few weeks after the windrows are placed and then drop away with time and the difference between wet and dry manure does not appear to be significant in the period close to placement. However, wet manure, when aged, appears to have higher emissions than dry manure. The sawdust based emissions rose from day 7 to about day 28 and then decreased. The data indicated that wet windrows tended to have elevated emissions compared to dry windrows, at least in the first few weeks. In contrast, the manure emissions were highest at day 7, dropped at day 10, then rose slightly at day 28 before dropping away to a background value. The odour decay experiment, where emission rates were estimated immediately after turning, 1 hour after turning, and 3 hours after turning showed that the emissions rose after turning but dropped off again rapidly.

Using the collected odour emission data, a typical emissions profile (by windrow age) was developed for sawdust and manure based windrows. The emission rate as a function of age for manure based windows can best be described as:

$$y = 3.0527 \times x^{-0.34}$$

Where:

y is the odour emission rate (ou/m^2/s) and
x is the age of the windrow in days.

The emission rate for sawdust based windrows up to day 59 can be described as:

$$y = -0.0004x^2 + 0.0279x + 0.174.$$

For windrows older than 60 days, a constant odour emission rate of 0.3 ou/m^2/s can be applied.

To quantify odour generation and emissions produced by composting spent hens on-farm and the likely impact these have on community amenity, three odour modelling scenarios were run for two meteorological sites: composting emissions only; sheds emissions only; and shed and composting emissions combined. The meteorological sites were locations near Pittsworth in Queensland and Tamworth in New South Wales.

The odour modelling impact assessment showed that the addition of composting operations to a typical farm (based on flux chamber measured emission rate data) would have a negligible impact on overall emissions. However, this is based on the assumption that the windrows would be placed and then disturbed infrequently, and managed appropriately.

One item not factored into the assessment is the character of the odour from the windrows. The data collected during the study indicates that the character of the odour changes over time from more offensive to less offensive. The modelling impact assessment modelling assumed that the odour is additive to that from other sources. In reality, compost odour is less offensive than shed odour (if covered and managed appropriately) and therefore the assumption that it is additive is only likely to be relevant for the first few weeks after placement. At other times, the additive assumption is likely to be conservative.

Although the flux chamber method complies with the AS4323.4 standard for area source measurement, research such as that reported by Parker et. al. (2009) and Jiang & Kaye (1996) has highlighted that for gas phase controlled odorants, such as some of those found in composting, the flux chamber can under-predict the release of these odorants and, therefore, emissions. This was highlighted by Pollock and Braun (2009) who found that the use of flux chambers on green waste windrows could underestimate impacts.

However, even if the emissions were to increase by a factor of two or three, the modelling indicates that the influence of the composting emissions would be minimal compared to the shed emissions.

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APPENDIX A: SUMMARY OF WINDROW ESTABLISHMENT AND ODOUR SAMPLING AT THE PITTSWORTH TRIAL SITE.

Date	Action	Details of windrow construction & odour sampling
7 Nov 2012	Summer windrow establishment: 1A & 1B	Windrow 1A, sawdust substrate, >8 metres long Windrow 1B, manure substrate, >8 metres long
29 Nov 2012	Summer windrow establishment: 1C & 1D	Windrow 1C, sawdust substrate, >8 metres long Windrow 1D, manure substrate, >8 metres long
6 Dec 2012	Summer windrow sampling: 1A,1B, 1C & 1D	1A, 29 days old, sawdust substrate, dry surface, 2 replicates 1B, 29 days old, manure substrate, dry surface, 2 replicates 1C, 7 days old, sawdust substrate, dry surface, 2 replicates 1D, 7 days old, manure substrate, dry surface, 2 replicates
7 Dec 2012	Summer windrow sampling: 1A,1B, 1C & 1D	1A, 30 days old, sawdust substrate, wet surface, 2 replicates 1B, 30 days old, manure substrate, wet surface, 2 replicates 1C, 8 days old, sawdust substrate, wet surface, 2 replicates 1D, 8 days old, manure substrate, wet surface, 2 replicates
8 Dec 2012	Substrate sampling: 1SS & 1SM	1SS, sawdust only, dry surface, 1 replicate 1SM, manure only, dry surface, 1 replicate
29 Jan 2013	Summer windrows sampling: 1C & 1D	1C, 62 days old, sawdust substrate, wet surface, 2 replicates 1D, 62 days old, manure substrate, wet surface, 2 replicates 1C, 62 days old, sawdust substrate, wet, disturbed, 2 replicates 1D, 62 days old, manure substrate, wet, disturbed, 2 replicates
**After the sampling on 29 Jan 2013, windrows 1A & 1C and windrows 1B & 1D were turned and combined to form 1AC & 1 BD*		
22 Feb 2013	Winter windrow establishment: 1E & 1F	Windrow 1E, sawdust substrate, >7 metres long Windrow 1F, manure substrate, >8 metres long
13 Mar 2013	Winter windrow establishment: 1G & 1H	Windrow 1G, sawdust substrate, >8 metres long Windrow 1H, manure substrate, >8 metres long
20 Mar 2013	Summer windrow sampling: 1AC & 1BD	1AC, <134 days old, sawdust substrate, dry surface, 2 replicates 1BD, <134 days old, manure substrate, dry surface, 2 replicates
20 Mar 2012	Winter windrow sampling: 1E,1F, 1G & 1H	1E, 26 days old, sawdust substrate, wet surface, 2 replicates 1F, 26 days old, manure substrate, dry surface, 2 replicates 1G, 7 days old, sawdust substrate, dry surface, 2 replicates 1H, 7 days old, manure substrate, dry surface, 2 replicates
21 Mar 2012	Winter windrow sampling: 1E & 1F	1E, 27 days old, sawdust substrate, dry surface, 2 replicates 1E, 27 days old, sawdust substrate, dry surface, disturbed, 2 replicates 1E, 27 days old, sawdust substrate, dry surface, 1 hours after disturbance, 2 replicates 1E, 27 days old, sawdust substrate, dry surface, 3 hours after disturbance, 2 replicates 1F, 27 days old, manure substrate, wet surface, 2 replicates
21 Mar 2012	Substrate sampling: 1SS & 1SM	1SS, sawdust only, wet surface, 1 replicate 1SM, manure only, wet surface, 1 replicate
24 Apr 2013	Winter windrows sampling: 1 E & 1F	1E, 61 days old, sawdust substrate, dry surface, 2 replicates 1E, 61 days old, sawdust substrate, dry surface, disturbed, 2 replicates 1E, 61 days old, sawdust substrate, dry surface, 1 hours after disturbance, 2 replicates 1F, 61 days old, manure substrate, wet surface, 2 replicates
**After sampling on 24 Apr 2013, windrows 1E & 1G and windrows 1F & 1H were turned and combined to form 1EG & 1 FH*		
3 Jul 2013	Winter windrow sampling: 1EG & 1 FH	1EG, <134 days old, sawdust substrate, wet surface, 2 replicates 1FH, <134 days old, manure substrate, wet surface, 2 replicates
16 Jul 2013	Winter windrow sampling: 1EG & 1 FH	1EG, <150 days old, sawdust substrate, dry surface, 2 replicates 1FH, <150 days old, manure substrate, dry surface, 2 replicates

APPENDIX B: SUMMARY OF WINDROW ESTABLISHMENT AND ODOUR SAMPLING AT THE TAMWORTH TRIAL SITE.

Date	Action	Details of windrow construction & odour sampling
10 Sep 2012	Summer windrow establishment: 2A & 2B	Windrow 2A, sawdust substrate, >10 metres long Windrow 2B, manure substrate, >10 metres long
14 Jan 2013	Summer windrow establishment: 2C & 2D	Windrow 2C, sawdust substrate, >10 metres long Windrow 2D, manure substrate, >10 metres long
21 Jan 2013	Summer windrow sampling: 2A, 2B, 2C & 2D	2A, 133 days old, sawdust substrate, dry surface, 2 replicates 2B, 133 days old, manure substrate, dry surface, 2 replicates 2C, 9 days old, sawdust substrate, dry surface, 2 replicates 2D, 9 days old, manure substrate, dry surface, 2 replicates
23 Jan 2013	Summer windrow sampling: 2A, 2B, 2C & 2D	2A, >135 days old, sawdust substrate, wet surface, 2 replicates 2B, >135 days old, manure substrate, wet surface, 2 replicates 2C, 11 days old, sawdust substrate, wet surface, 2 replicates 2D, 11 days old, manure substrate, wet surface, 2 replicates
24 Jan 2013	Substrate sampling: 2SS & 2SM	2SS, sawdust substrate only, dry surface, 1 replicate 2SM, manure substrate only, dry surface, 1 replicate
1 Jun 2013	Winter windrows establishment: 2G & 2H	Windrow 2G, sawdust substrate, >10 metres long Windrow 2H, manure substrate, >10 metres long
Windrows 2C & 2D, sampled in January (10 days old), have become 2E & 2F (>134 days old).		
11 Jun 2013	Winter windrow sampling: 2E, 2F, 2G & 2H	2E, 150 days old, sawdust substrate, wet surface, 2 replicates 2F, 150 days old, manure substrate, wet surface, 2 replicates 2G, 10 days old, sawdust substrate, wet surface, 2 replicates 2H, 10 days old, manure substrate, wet surface, 2 replicates
15 Jun 2013	Winter windrow sampling: 2E, 2F, 2G & 2H	2E, 154 days old, sawdust substrate, dry surface, 2 replicates 2F, 154 days old, manure substrate, dry surface, 2 replicates 2G, 10 days old, sawdust substrate, dry surface, 2 replicates 2H, 10 days old, manure substrate, dry surface, 2 replicates

APPENDIX C: RESULTS FROM ALL ODOUR SAMPLES TAKEN AT THE PITTSWORTH TRIAL SITE.

Substrate	Wet/ dry	Age (days)	Date	Code (From Table 1)	(OU/m²/s)	Odour conc. (OU)	Moisture content %	Sampled after disturbance	Odour descriptors from olfactometry panellists
Sawdust	Dry	7	06 Dec 2012	1C	0.032	50		No	
Sawdust	Dry	7	06 Dec 2012	1C	0.179	279		No	
Manure	Dry	7	06 Dec 2012	1D	1.710	2656		No	
Manure	Dry	7	06 Dec 2012	1D	0.893	1387		No	
Manure	Dry	29	06 Dec 2012	1B	0.802	1248		No	
Manure	Dry	29	06 Dec 2012	1B	0.401	624		No	
Sawdust	Dry	29	06 Dec 2012	1A	0.149	232		No	
Sawdust	Wet	8	07 Dec 2012	1C	0.392	609		No	
Sawdust	Wet	8	07 Dec 2012	1C	0.891	1387		No	
Manure	Wet	8	07 Dec 2012	1D	0.818	1272		No	
Manure	Wet	8	07 Dec 2012	1D	1.060	1649		No	
Manure	Wet	30	07 Dec 2012	1B	1.032	1599		No	
Manure	Wet	30	07 Dec 2012	1B	1.029	1599		No	
Sawdust	Wet	30	07 Dec 2012	1A	0.514	799		No	
Sawdust	Wet	30	07 Dec 2012	1A	0.568	883		No	
Sawdust	Dry	365	08 Dec 2012	1SD	0.061	95	35.1	No, Sawdust only	
Manure	Dry	500	08 Dec 2012	1MA	0.254	395	25.1	No, Manure only	
Sawdust	Wet	62	29 Jan 2013	1C	0.270	420	39.9	Yes (immediately after)	
Sawdust	Wet	62	29 Jan 2013	1C	0.313	487	39.9	Yes (immediately after)	
Manure	Wet	62	29 Jan 2013	1D	0.843	1312	37.6	Yes (immediately after)	
Manure	Wet	62	29 Jan 2013	1D	0.346	538	37.6	Yes (immediately after)	
Manure	Wet	62	29 Jan 2013	1D	0.149	232	51.3	No	
Manure	Wet	62	29 Jan 2013	1D	0.140	218	51.3	No	
Sawdust	Wet	62	29 Jan 2013	1C	0.051	80	56.9	No	
Sawdust	Wet	62	29 Jan 2013	1C	0.049	77	56.9	No	
Manure	Dry	26	20 Mar 2013	1F	0.329	512		No	mild compost smell
Manure	Dry	26	20 Mar 2013	1F	0.508	790		No	mouldy, musty, decomposing, earthy
Sawdust	Wet	26	20 Mar 2013	1E	0.188	292		No	dank, wet grass/straw odour
Sawdust	Wet	26	20 Mar 2013	1E	0.204	318		No	not as strong as previous, drier smell, pickles
Sawdust	Dry	120	20 Mar 2013	1AC	0.064	99		No	dry, rubbish tip, burnt (not earthy, not compost)
Sawdust	Dry	120	20 Mar 2013	1AC	0.072	112		No	very weak, chicken-pen, dusty paddock
Manure	Dry	120	20 Mar 2013	1BD	0.277	431		No	farmyard, chook-pen
Manure	Dry	120	20 Mar 2013	1BD	0.243	378		No	Dirt like smell; not compost
Sawdust	Dry	7	20 Mar 2013	1G	0.151	235		No	mushroomy, compost, under-house, feedlot/piggery
Sawdust	Dry	7	20 Mar 2013	1G	0.049	76		No	Mild manure-like,dry,dirty,dusty
Manure	Dry	7	20 Mar 2013	1H	1.944	3025		No	Chicken carcass, rotting veges, rotten, flatulence
Manure	Dry	7	20 Mar 2013	1H	2.311	3597		No	decomposing, sulfuric, rotten eggs
Sawdust	Dry	27	21 Mar 2013	1E	0.978	1522		No	mild sour chicken odour
Sawdust	Dry	27	21 Mar 2013	1E	0.627	975		No	mild; bbq gas smell, vinegar on hot chips
Sawdust	Dry	27	21 Mar 2013	1E	0.443	689		Yes (immediately after)	dusty, dirt smell; hard to describe
Sawdust	Dry	27	21 Mar 2013	1E	0.596	927		Yes (immediately after)	weak; dry dirt smell, like outer layer of previous sample
Manure	Wet	27	21 Mar 2013	1F	0.627	975		No	molasses, syrupy, manure, more smelly than previous one
Manure	Wet	27	21 Mar 2013	1F	1.134	1765		No	musty, sour, rotten, feedlot?, rural, old manure - hard to pin down source
Sawdust	Dry	27	21 Mar 2013	1E	0.878	1367		Yes (1 hour after)	dusty, fermented, paddock odour
Sawdust	Dry	27	21 Mar 2013	1E	0.465	724		Yes (1 hour after)	burnt, smoky, earthy
Sawdust	Dry	27	21 Mar 2013	1E	0.513	799		Yes (3 hours after)	toasted peanuts, Charlie Carp, burnt wood chips
Sawdust	Dry	27	21 Mar 2013	1E	0.283	441		Yes (3 hours after)	like previous, toasted peanuts, mild sour compost
Sawdust	Wet	1000	21 Mar 2013	1SD	0.443	689		No, Sawdust only	weak, dry compost, dirt
Manure	Wet	365	21 Mar 2013	1MA	0.978	1522		No, Manure only	cheap dark Ghana chocolate, chickory, toasted peanut, Charlie Carp fertiliser
Sawdust	Dry	60	24 Apr 2013	1E	0.055	85	22.7	No	weak earthy
Sawdust	Dry	60	24 Apr 2013	1E	0.027	42	22.7	No	weak, sweet earthy smell
Sawdust	Dry	60	24 Apr 2013	1E	0.095	148	49.8	Yes (immediately after)	musty, mouldy; unaired room; damp, earthy
Sawdust	Dry	60	24 Apr 2013	1E	0.259	403	49.8	Yes (immediately after)	earthy; wet dirt; tannin

Manure	Dry	60	24 Apr 2013	1F	0.410	638	13.6	No	rotten, cadavorous; dead chickens
Manure	Dry	60	24 Apr 2013	1F	1.316	2048	13.6	No	putrid, foul, dead chicken, cadavorous
Sawdust	Dry	60	24 Apr 2013	1E	0.293	456	46.2	Yes (1 hour after)	weaker (half as strong) as previous; putrid
Sawdust	Dry	60	24 Apr 2013	1E	0.062	96	46.2	Yes (1 hour after)	earthy, dusty
Sawdust	Wet	122	03 Jul 2013	1EG	0.128	200	48.9	No	dry, dusty, burning peat moss
Sawdust	Wet	122	03 Jul 2013	1EG	0.074	116	48.9	No	mulch
Manure	Wet	122	03 Jul 2013	1FH	0.514	799	35.6	No	earthy, dusty, burnt, shoe shop (Changes as it gets stronger)
Manure	Wet	122	03 Jul 2013	1FH	0.626	975	35.6	No	very musty, mouldy, smouldering
Sawdust	Dry	135	16 Jul 2013	1EG	0.012	18	27.1	No	wet dirt in a shaded area; inoffensive earthen smell
Sawdust	Dry	135	16 Jul 2013	1EG	0.027	42	27.1	No	compost, mulch, vege patch, composting bale of hay
Manure	Dry	135	16 Jul 2013	1FH	0.353	549	11.5	No	feedlot smell, musty, mushroom compost, moister than previous sample
Manure	Dry	135	16 Jul 2013	1FH	0.378	588	11.5	No	wet, ashy, smoky

APPENDIX D: RESULTS FROM ALL ODOUR SAMPLES TAKEN AT THE TAMWORTH TRIAL SITE

Substrate	Wet/ dry	Age (days)	Date	Code (From Table 2)	(OU/m²/s)	Odour conc. (OU)	Moisture content %	Sampled after disturbance	Odour descriptors from olfactometry panellists
Sawdust	Dry	7	21 Jan 2013	2A	0.298	464	17.8	No	
Sawdust	Dry	7	21 Jan 2013	2A	0.129	200	17.8	No	
Manure	Dry	7	21 Jan 2013	2B	0.540	840	22.2	No	
Manure	Dry	7	21 Jan 2013	2B	0.513	799	22.2	No	
Sawdust	Dry	120	21 Jan 2013	2C	0.173	269	20.8	No	
Sawdust	Dry	120	21 Jan 2013	2c	0.067	105	20.8	No	
Manure	Dry	120	21 Jan 2013	2D	0.200	312	20.4	No	
Manure	Dry	120	21 Jan 2013	2D	0.191	297	20.4	No	
Sawdust	Wet	9	23 Jan 2013	2A	0.277	431	59.7	No	
Sawdust	Wet	9	23 Jan 2013	2A	0.184	287	59.7	No	
Manure	Wet	9	23 Jan 2013	2B	0.553	861	44.9	No	
Manure	Wet	9	23 Jan 2013	2B	0.697	1085	44.9	No	
Sawdust	Wet	122	23 Jan 2013	2C	0.208	323	56.7	No	
Sawdust	Wet	122	23 Jan 2013	2C	0.134	208	56.7	No	
Manure	Wet	122	23 Jan 2013	2D	0.184	287	54.5	No	
Manure	Wet	122	23 Jan 2013	2D	0.439	683	54.5	No	
Sawdust	Dry	365	24 Jan 2013	2SD	0.298	464	12.6	No, Sawdust only	
Manure	Dry	500	24 Jan 2013	2MA	0.050	78	14.4	No, Manure only	
Sawdust	Wet	150	11 Jun 2013	2E	0.201	312	46.0	No	Hippy compost; organic compost, moist grass; musty
Sawdust	Wet	150	11 Jun 2013	2E	0.363	565	46.0	No	same as above, dry grassy
Manure	Wet	150	11 Jun 2013	2F	0.727	1131	46.0	No	mouldy grain; earthy; bottom of silo; decomposing wood
Manure	Wet	150	11 Jun 2013	2F	0.978	1522	46.0	No	silo smell, earthy, damp soil, vege patch
Sawdust	Wet	10	11 Jun 2013	2G	0.465	724		No	earthy
Sawdust	Wet	10	11 Jun 2013	2G	0.514	799		No	compost; grain; dry, dusty
Manure	Wet	10	11 Jun 2013	2H	0.567	883		No	decaying, putrid; pungent; dead chickens; chicken manure
Manure	Wet	10	11 Jun 2013	2H	0.763	1188		No	carrot cake; chicken manure; cabbage; rotting veg; rotten potato
Sawdust	Dry	154	18 Jun 2013	2E	0.284	441	31.6	No	dirt, poultry-like
Sawdust	Dry	154	18 Jun 2013	2E	0.257	400	31.6	No	dirty, poultry; jaffa; old hay
Manure	Dry	154	18 Jun 2013	2F	0.691	1076	31.7	No	like previous but less pungent; ploughed paddock
Manure	Dry	154	18 Jun 2013	2F	0.382	594	31.7	No	wet dirt; humus; smell of "digging up peanuts"
Sawdust	Dry	14	18 Jun 2013	2G	0.257	400	55.4	No	dank; mushroom compost,
Sawdust	Dry	14	18 Jun 2013	2G	0.165	256	55.4	No	damp; decomposing hay
Manure	Dry	14	18 Jun 2013	2H	0.329	512	44.7	No	earthen; damp; toast-like
Manure	Dry	14	18 Jun 2013	2H	0.298	464	44.7	No	sour; chiko roll; decomposing smell; dry/dusty