

An assessment of woodchip compost

Report 4

Woodchip for Livestock Bedding Project

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Mae'r Proiect Sglodion Pren ar gyfer Sarnau Da Byw a gyflenwir gan Hybu Cig Cymru yn derbyn arian cyfatebol gan y Comisiwn Coedwigiaeth, Asiantaeth yr Amgylchedd Cymru a Llywodraeth Cynulliad Cymru fel rhan o Cyswllt Ffermio.

INTRODUCTION

The first study undertaken during the Woodchip for Livestock Bedding Project examined the use of woodchip as animal bedding. That study (see [Report 1](#)) looked at three aspects of woodchip as bedding material, namely the effect of:

1. Initial moisture content of woodchips – ADAS Pwllpeiran (Pwllpeiran)
2. Livestock dietary inputs – IGER Aberystwyth (IGER)
3. Wood types (Hardwood or Softwood) - Glynllifon College

This report first describes the work undertaken to examine the environmental parameters; temperature, moisture content and oxygen levels of those woodchip composts and then goes on to analyse the changes in nutrient values over the first 6-7 months of composting with emphasis on variables introduced before and during the housing period.

Recommendations for maximizing the efficiency of woodchip as a reusable bedding material are made throughout.

METHODS - TEMPERATURE, WATER AND OXYGEN

1. Composts tested

Three demonstration sites tested key woodchip bedding-composting process variables:

1. Initial moisture content of woodchips at ADAS – Pwllpeiran (Pwllpeiran)
2. Livestock dietary inputs at IGER- Aberystwyth (IGER)
3. Wood types (Hardwood or Softwood) at Glynllifon College

The initial moisture contents of woodchip used at Pwllpeiran were 34%, 53% and 55%; these were used as bedding under sheep and cattle alongside a straw-only control under each, giving a total of 8 pens. Although the 53% and 55% woodchips had similar water contents, the 53% woodchip bedding was produced from fencing post points which resulted in a bias towards large, flat, splintered chip shapes, compared to the 55% (and 34%) stocks, which were chipped from rounds and gave a square, 'chunky' chip, even though the same make and model of chipper was used (see below).



Pwllpeiran: Woodchip compost with 53% initial moisture content



Pwllpeiran: Woodchip compost with 34% initial moisture content

IGER investigated the influence of two common winter feeds; hay and silage, on both straw and woodchip and under both sheep and cattle during an 8 week housing period.

Glynllifon College utilized 4 hardwoods and 4 softwoods, replicated under sheep and cattle. After 8 weeks housing, the bedding was combined to give 4 composts; sheep hardwoods and softwoods and cattle hardwoods and softwoods.

All 3 demonstration sites used a 'straw-only' bedding control under each type of livestock for comparison, which was composted at Pwllpeiran and IGER; however, Glynllifon didn't compost their straw bedding due to insufficient volume.

At the end of the animal housing period, Pwllpeiran and IGER undertook their composting indoors; Pwllpeiran maintained pyramidal heaps while IGER kept conventional windrows; both sites had ample ventilation. Glynllifon composted outdoors in open windrows.

2. Sampling protocol

Composts are most biologically active in their first two months; consequently, compost samples were collected at 2 weekly intervals for the first 2 months of composting, then every 4 weeks for a further 2 months and finally at 6 weekly intervals until the final sample collection.

At each sampling event, 4 replicate 1 kg samples were taken from each compost treatment at all 3 sites. The samplings undertaken are detailed below:

Pwllpeiran and IGER sampling dates 2006

22 nd Mar	Timepoint 0 (T0)	28 th June	Timepoint 5 (T5)
5 th April	Timepoint 1 (T1)	9 th Aug	Timepoint 6 (T6)
19 th April	Timepoint 2 (T2)	20 th Sept	Timepoint 7 (T7)
3 rd May	Timepoint 3 (T3)	25 th Oct	Timepoint 8 (T8)
31 st May	Timepoint 4 (T4)		

Glynllifon sampling dates 2006

20 th April	Timepoint 0 (T0)	29 th June	Timepoint 4 (T4)
4 th May	Timepoint 1 (T1)	27 th July	Timepoint 5 (T5)
18 th May	Timepoint 2 (T2)	7 th Sept	Timepoint 6 (T6)
1 st June	Timepoint 3 (T3)	18 th Oct	Timepoint 7 (T7)

In this report, Timepoints are referred to as 'T', followed by a number. For example, Pwllpeiran 'T0' or 'AT0' refers to samples collected from Pwllpeiran on 22nd March 2006. The dates are the same for IGER because sampling was done at both sites on the same day. Glynllifon started composting a month later than Pwllpeiran and IGER; hence, their timepoints 'T' are slightly different and only go up to GT7.

Pwllpeiran sheep and cattle woodchip treatments with pre-bedding moisture contents of 34%, 53% and 55% are just referred to as 34%, 53% and 55%. Woodchip/Manure compost is abbreviated to WM compost.

3. Compost turning

Turning was carried out either on the day of sampling or a couple of days before. This was only relevant to ensure that the samples collected, comprised of freshly mixed material. It is clear to see from the Pwllpeiran and IGER temperature graphs when the composts were turned, by the sharp periodic drops in temperature. The final two turns at IGER were made before 140 days and 180 days.

Method of turning the compost

Composts are turned with a front-loader by moving them to another location in the barn at Pwllpeiran and IGER or on the yard at Glynllifon.

Turning schedule

Pwllpeiran and IGER turned their composts every 2 weeks for the first 2 months, then every 4 weeks for a further 2 months and finally at 6 weekly intervals until the final sample collection. However, because Glynllifon started composting a month later than Pwllpeiran and IGER, the turning schedule was modified based on the evidence already gathered.

It can be seen from the data in Pwllpeiran and IGER's graphs (pages 5-8), that the WM composts are slow to heat up after turning, highest temperatures are recorded just before the next turn, as opposed to the straw based composts where the microbes burst into a frenzy of metabolic activity, and then gradually temperatures calm down until the next turn. Therefore, without straw based composts, it was decided Glynllifon should turn their WM composts only once a month for the first 4 months and then once every 6 weeks until the final sample collection. This modification to the turning protocol had a remarkable effect on both the actual temperatures recorded within the composts and the length of time the composts maintained temperatures above 60°C. However, because of the large quantity of wasted hay feed, particularly in the Glynllifon sheep treatments (approx 40% of the total volume), the lower turning frequency resulted in these composts turning anaerobic at GT3, see page 11.

4. Temperature (°C) – Target range: 50-55°C (pathogens are killed at 60-70°C).

Heat in compost is produced from the microbes breaking down the organic material – microbial metabolic activity. Temperature therefore provides a good general indicator that decomposition is taking place in an efficient way and that environmental conditions within the compost are optimal.

Measuring compost temperature

Pwllpeiran used Eltek thermocouple data loggers to take temperature readings from the centre of each compost heap at 30 minute intervals which were immediately relayed to a computer in the Pwllpeiran office. The data was periodically collated and sent to Bangor University.



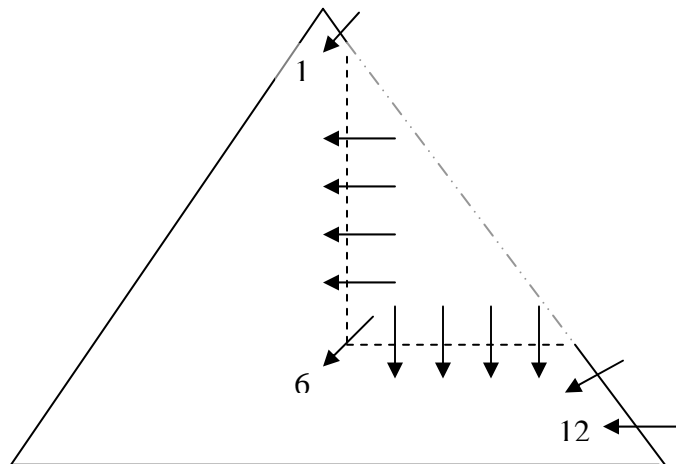
An electronic data logger was inserted into the centre of the 'Sheep 53%' WM compost on the end of a bamboo cane and marked with a yellow tag so it could be easily seen. The white lead relayed the temperature readings back to a central portal that was transmitted to a computer in the Pwllpeiran office.

IGER compost temperatures were recorded by similar data-loggers; Maxim DS1921G 'Thermochron iButtons' which also recorded temperature at 30 minute intervals, but the data was stored in the device's memory chip until it was downloaded in-situ at each sampling event.



Maxim 'Thermochron iButton'. Twine was tied through the hole in the fob and a metal tipped cattle stick used to push the device into the centre of the compost heap. When the data needed to be downloaded, the device was retrieved by pulling the twine.

The Glynllifon compost temperatures were isolated recordings taken at each sampling event. Although this method did not give a continuous record of temperature over time, it did deliver a detailed profile of temperature variance throughout the compost at specific points during the composting period. A 1 m "L" was dug into the heart of each windrow and temperature readings taken at 20cms intervals using a Hanna temperature probe, as illustrated in the diagram below.



5. Moisture content – Target range: 50-55%

Microbes need water to survive but also to assist with mobility. If the compost is too wet, then air cannot circulate and the heap becomes anaerobic. Compost moisture content analysis was carried out on all 4 replicate samples taken from every site and at every sampling event.

Measuring compost moisture content

Between 110 – 180 g of each compost sample was put in a pre-weighted aluminium tray and the fresh weight recorded, the trays were then oven baked at 80°C for no less than 22 hours. 16 hours is usually considered sufficient to achieve thorough desiccation but extra time given for certainty. After oven drying, the complete tray was weighted and the known weight of the aluminium tray removed to give the sample's dry weight. The percentage moisture loss was then calculated as a % of fresh weight.

6. Oxygen content – Target range: = 5-21% oxygen.

If the atmospheric oxygen content within a compost heap falls below 5%, obligate aerobic microbes die and the compost becomes dominated by anaerobic microbes that produce environmentally harmful gases such as methane and hydrogen sulphide, which also cause odour problems around the farm. The availability of oxygen (as a % of total atmospheric gases within the compost heap) was first recorded on 15th May 2006 and at each listed sampling event there after.

Measuring oxygen levels in the compost

Measuring the compost's atmospheric oxygen content was carried out using a handheld Minolta O₂ analyzer which comes with a long flexible tube attached. This was sheathed in a metal pipe, so it could be forced into the compost heap and allows measurements to be taken from the centre. As a result, wire gauze was fixed over the intake end of the pipe to stop compost debris from blocking the tube. The other end of the metal pipe was sealed with insulation tape to stop air from outside the compost being drawn in during sampling and corrupting the analysis. Once the pipe was inserted into the compost, the analyzer was switched on and left for approximately 2 minutes to make sure all the air trapped within the metal pipe had been removed before readings were recorded. This process was carried out on each compost before samples were gathered.

RESULTS – TEMPERATURE, WATER AND OXYGEN

Figure 1: Pwllpeiran **sheep** compost temperatures from 13th March to 21st Sept 2006. The dashed line - - - at 65°C indicates the UK PAS 100 pathogen guidelines, which require compost temperatures to reach 65°C for 7 days (not necessarily consecutively) for the compost to be deemed 'sanitized'. This is important if the compost is to be re-used as bedding the following winter. When the composts were turned is indicated by Turn.

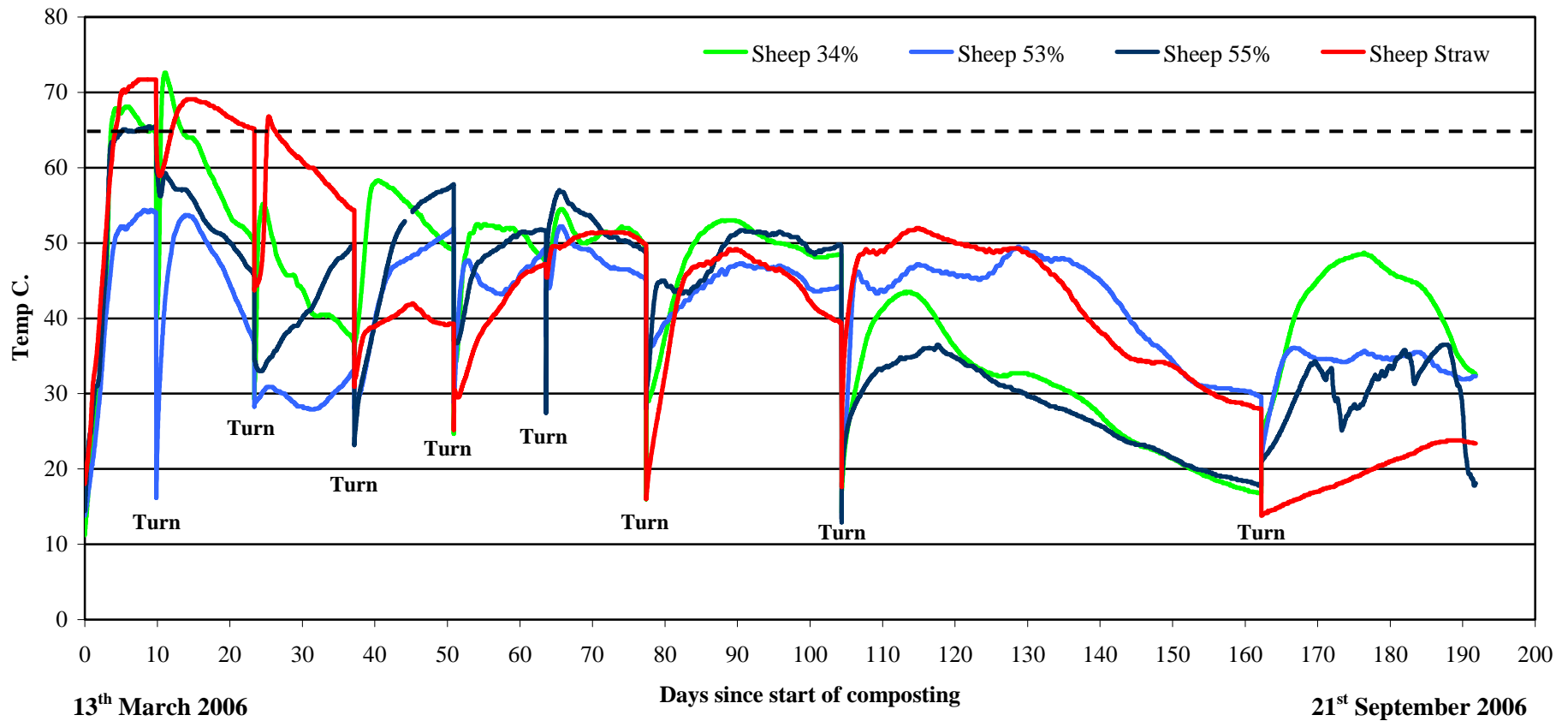


Figure 2: Shows **cattle** compost temperatures at Pwllpeiran from 22nd March to 21st Sept 2006. As above the dashed line - - - at 65°C indicates the UK PAS 100 pathogen guidelines, which is important if the bedding is to be re-used the following winter. Compost turning is indicated by **Turn**.

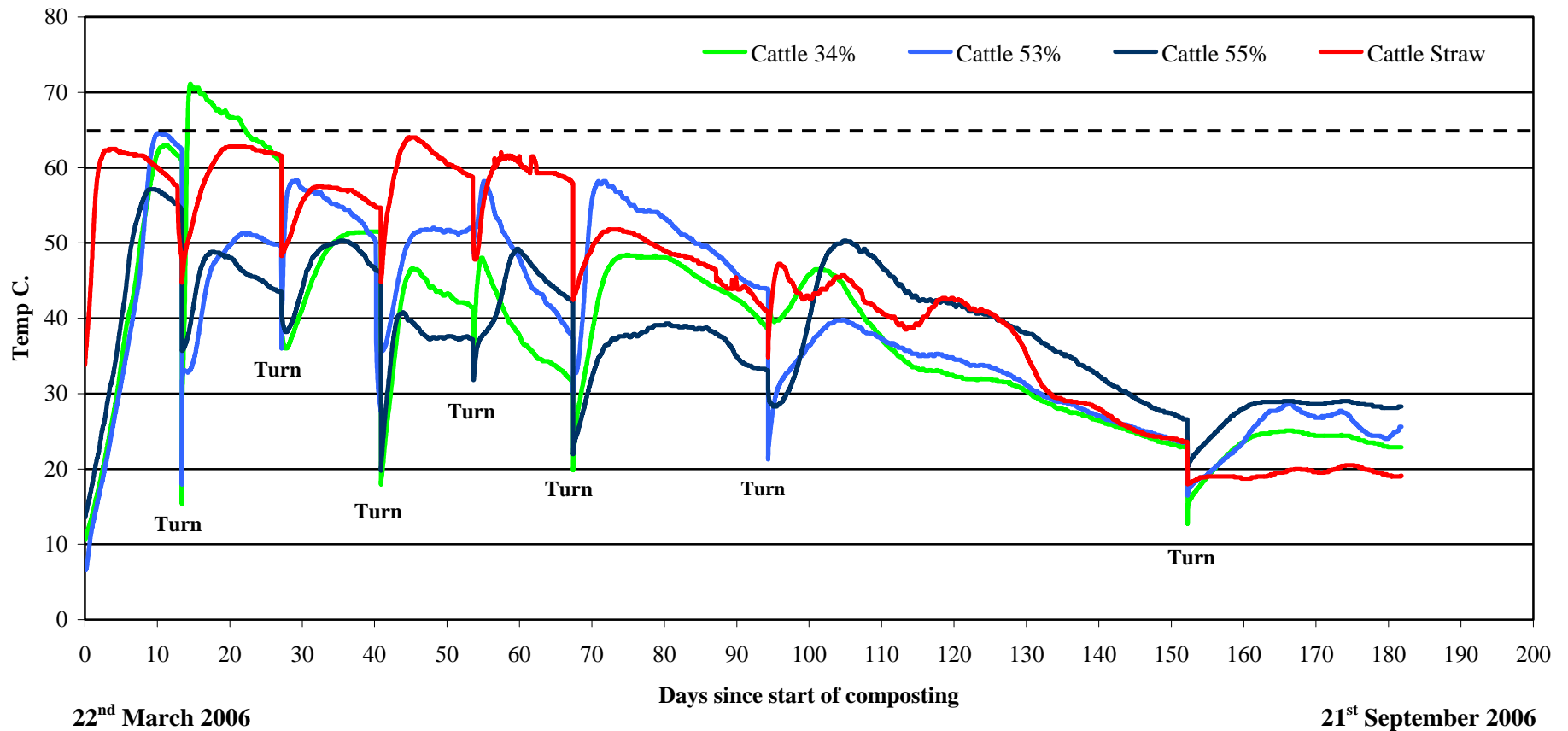


Figure 3: Shows **sheep** compost temperatures at IGER from 22nd March to 25th October 2006. As above the dashed line - - - at 65°C indicates the UK PAS 100 pathogen guidelines, which is important if the bedding is to be re-used the following winter. Compost turning is indicated by **Turn**.

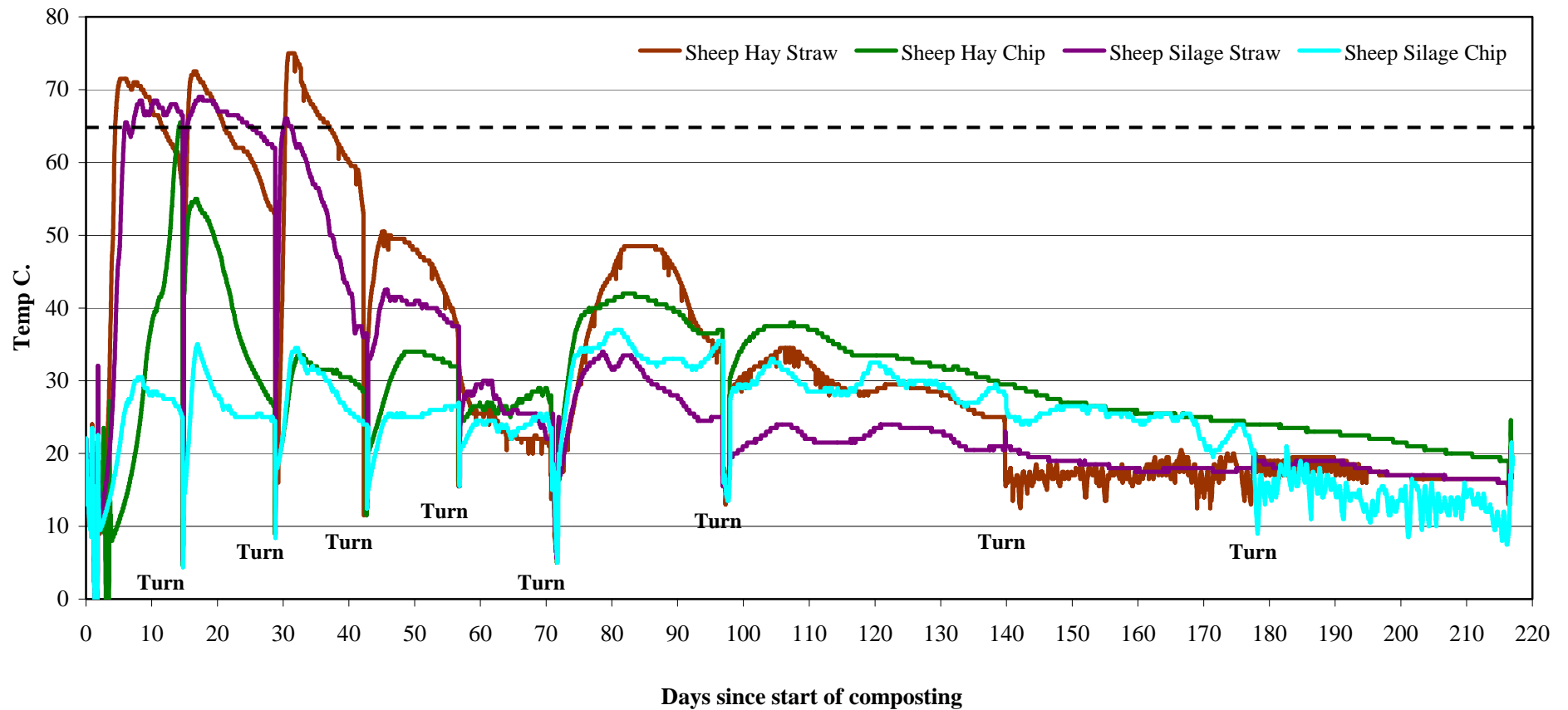


Figure 4: Shows **cattle** compost temperatures at IGER from 22nd March to 25th October 2006. As above the dashed line - - - at 65°C indicates the UK PAS 100 pathogen guidelines, which is important if the bedding is to be re-used the following winter. Compost turning is indicated by **Turn**.

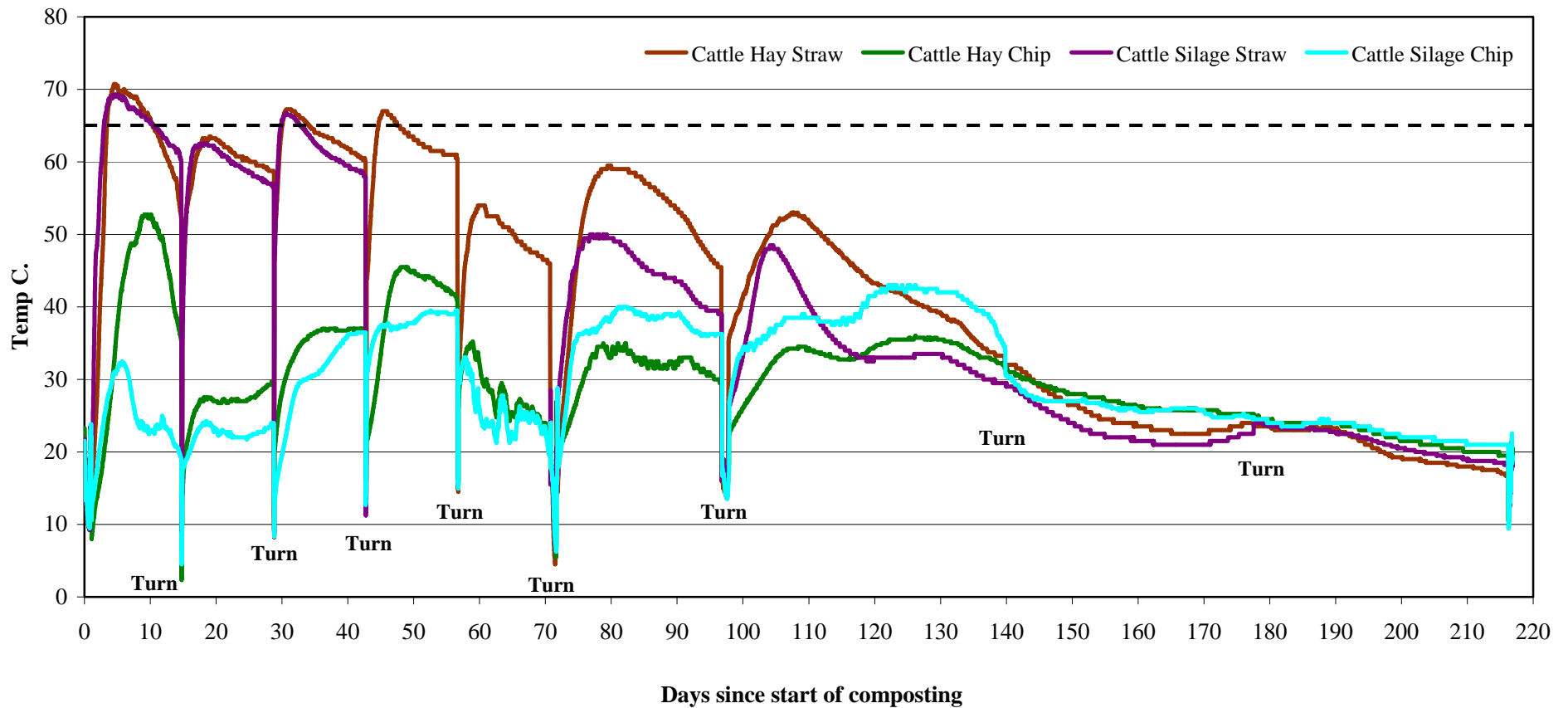
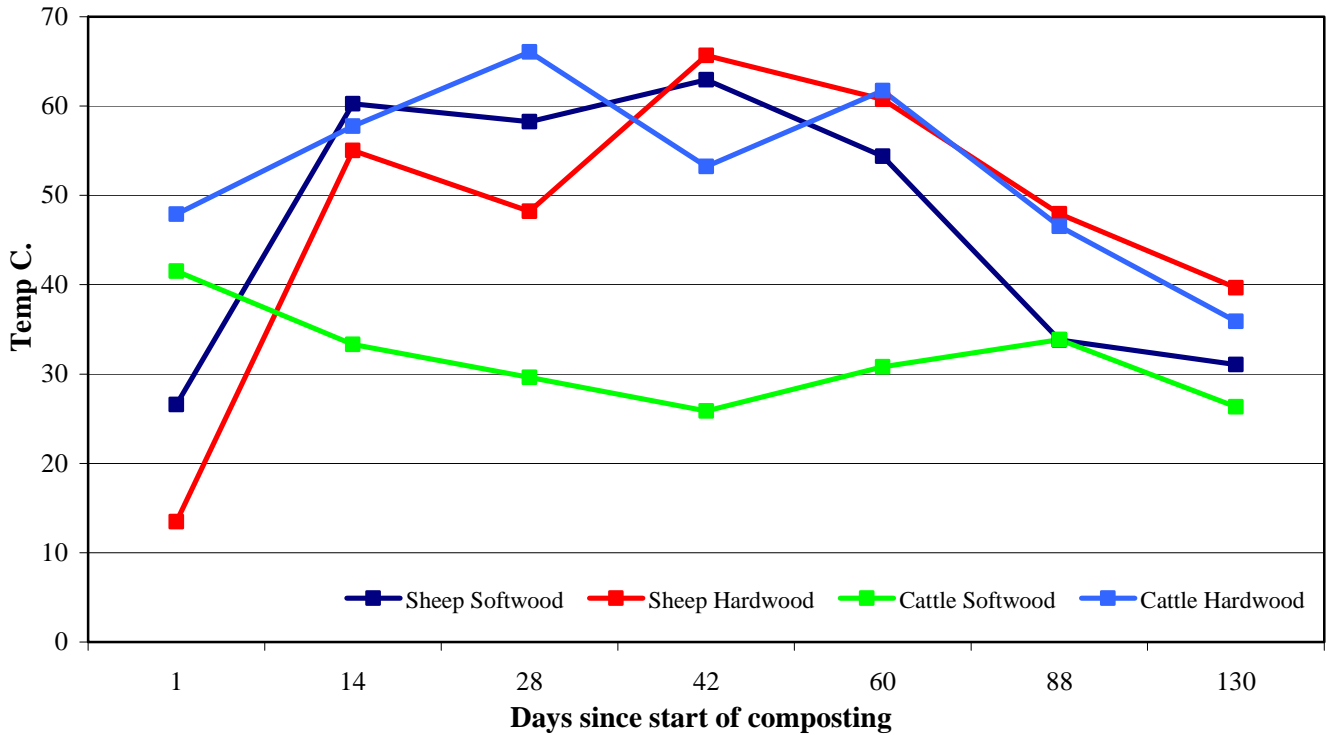


Figure 5: Glynllifon compost temperature readings. Each data point represents the average temperature of a compost profile (see diagram on page 4) recorded on sampling dates at Glynllifon and then plotted over time.



The Cattle Softwood compost temperature never rose above 45°C except at the very start of composting. It is considered that the compost was too wet for viable microbial populations to get established, compounded by the compost being positioned in a corner, restricting air circulation. However, above optimal moisture contents are often corrected as microbes begin metabolising the material, water is lost by evaporation. The Cattle Hardwood compost moisture content mirrored the Cattle Softwood's until GT2 when its moisture content dropped, while the Cattle Softwood stayed high.

Percentages of water and oxygen at each site are presented together because of their relationship.

Pwllpeiran moisture content and oxygen results during 7 months composting:

Table 1: % moisture contents of raw bedding, soiled bedding and WM compost at Pwllpeiran

Treatment	Before bedding (%)	After bedding, before composting (%)	After composting (%)	Means during composting (%) ± se
Sheep 34%	34	43.3	47.5	46.4 ± 1.6
Sheep 53%	53	58.8	56.4	53.5 ± 2.4
Sheep 55%	55	47.5	52.0	49.2 ± 2.0
Sheep Straw	11	61.1	39.1	54.0 ± 3.4
Cattle 34%	34	67.2	53.5	61.8 ± 2.1
Cattle 53%	53	68.5	61.2	65.3 ± 1.4
Cattle 55%	55	69.4	60.1	65.3 ± 1.7
Cattle Straw	11	75.1	56.3	71.2 ± 2.7

The ‘Cattle Straw’ compost was the only treatment at Pwllpeiran that became anaerobic (see oxygen table below), thought to be due to the treatments high moisture content and compounded by the necessity of having a standardized turning schedule for all the composts; 2 weeks for the first 2 months then every 4 weeks for the following 2 months, was too infrequent for very wet straw in the early stages.

As the composts were stored indoors, it was considered prudent to give the driest of the Pwllpeiran composts additional water during the summer to maintain optimal moisture contents.

Table 2: Additional watering (litres) at Pwllpeiran during summer 2006

Treatments	Total Litres Added 5/5/06 – 23/8/06
Sheep 34%	726
Sheep 53%	540
Sheep 55%	573
Cattle 34%	216

Overall, the WM composts achieved high oxygen levels throughout the sampling period, primarily due to the rigidity of the woodchip maintaining good structural porosity and airflow through the composts. Table 3 shows % oxygen levels in Pwllpeiran composts, starting from 16th May. The red squares indicate when the composts turned ‘anaerobic’ a *fatal lack of oxygen for aerobic microbes*. Pink squares indicate oxygen deficient conditions. Ideally, all composts should always have over 10% oxygen.

Table 3: Pwllpeiran compost oxygen content (% of total air volume)

Treatment	T3.5	T4	T5	T6	T7
Sheep 34%	17.4	18.6	18.6	18.4	19.7
Sheep 53%	19.4	20.4	19.5	20.4	20.1
Sheep 55%	15.9	19.6	19.8	20.5	20.2
Sheep Straw	15.5	17.3	17.2	17.7	19.8
Cattle 34%	14.5	18.8	18.9	19.8	19.9
Cattle 53%	19.5	17.4	20.1	20.1	20.2
Cattle 55%	17.7	19.9	18.6	19.9	20.1
Cattle Straw	5.1	0.9	3	0.9	8.8

IGER moisture content and oxygen results during 7 months composting:

Table 4: % moisture contents of raw bedding, soiled bedding and WM compost at IGER

Dietary inputs	Before bedding (%)	After bedding, before composting (%)	After composting (%)	Mean during composting (%) ± se
Animals fed Hay on Woodchip	54.1	58.7	49.1	56.8 ± 1.7
Animals fed Hay on Straw	8.1	59.4	60.4	63.8 ± 2.2
Animals fed Silage on Woodchip	54.1	68.9	43.5	53.8 ± 2.4
Animals fed Silage on Straw	8.1	64.6	49.3	60.1 ± 2.7

IGER had a 2nd delivery of woodchip midway through housing, which had + 0.5 % higher water content; 54.1 % is the mean of the two stocks. There was no additional watering at IGER, but like Pwllpeiran, the cattle straw treatments turned anaerobic. This was probably due to the turning regime being too infrequent.

Table 5: IGER compost oxygen content (% of total air volume)

Treatment	T3.5	T4	T5	T6	T7
Cattle fed Hay on Straw	5.5	7.9	1.6	1	7.7
Cattle fed Silage on Straw	4.6	6.7	15.8	1.2	6.2
Cattle fed Hay on Chip	19.1	20	17.9	19.7	19.1
Cattle fed Silage on Chip	19.6	20.2	18.9	19.8	19.5
Sheep fed Hay on Straw	16.9	18.9	19.7	19.8	19.5
Sheep fed Hay on Chip	19.2	19.1	18.7	18.3	19.2
Sheep fed Silage on Chip	20.2	20.4	20.4	20.4	20.7
Sheep fed Silage on Straw	18.2	20.3	20.9	20.4	20.4

Anaerobic = less than 5 % (highlighted in RED), 5 – 10 % oxygen is borderline (highlighted in PINK).

Glynllifon College moisture content and oxygen results during 7 months composting:

Table 6: % moisture contents of raw bedding, soiled bedding and WM compost at Glynllifon

Treatment	Before bedding (%)	After bedding, before composting (%)	After composting (%)	mean during composting (%) ± se
Softwood	50	62.5	64.7	61.5 ± 1.7
Hardwood	40.4	64.3	52.5	57.4 ± 1.8

It is apparent from the early 'cattle softwood' oxygen data there was very little aerobic respiration depleting oxygen levels in the compost.

Table 7: Glynllifon compost oxygen content (%)

Treatment	T2	T3	T4	T5	T6
Sheep Softwood	20.7	1.4	16.6	15	19.4
Sheep Hardwood	21.2	3.8	15.3	15.2	17.5
Cattle Softwood	21.2	19.5	19.5	16.1	18.9
Cattle Hardwood	20.8	8.3	12.6	19.3	19.3

CONCLUSIONS – TEMPERATURE, WATER AND OXYGEN

Analysis of temperature, water and oxygen shows that WM composting performance is reduced if the woodchip’s pre-bedding water content is above 30%.

If the soiled woodchip is NOT going to be re-used as bedding the following winter, then adding a labile carbon supplement may help the microbes decompose the woodchips quicker. This is a carbon based material like paper (newspaper or pulp), dead leaves, reeds etc and ‘labile’ means it is easier for the microbes to breakdown than wood and therefore enables them to mineralise more of the available N in the manure. There are a number of ways this can be achieved; either during housing, by using a mix of straw and woodchip together or by leaving any waste hay feed to integrate into the bedding or after housing, by adding paper, reeds, dead leaves or other non-toxic plant material. If shredded newspaper is selected, if possible avoid using colour print as the chemicals may be toxic to microbes so could adversely affect decomposition. Perhaps the easiest and most efficient way of introducing a labile carbon supplement is by adding any rotten, musty bales of straw or hay to the soiled woodchip after the livestock have been turned out in spring; break up the bales and shake them out evenly over the dirty bedding just before it is piled up for composting.

Careful consideration should be given to the model of chipper used because along with thickness, age and moisture content of the wood being chipped, it has a direct effect on the physical qualities of the chips produced.

Table 8: A brief summary of the benefits of using dry woodchip bedding under livestock.

Wet Woodchips	Dry Woodchips
<ul style="list-style-type: none"> • Pwllpeiran found more bedding is needed if the initial moisture content of the woodchips is high... increasing the cost of bedding. • Furthermore, IGER used large volumes of woodchip bedding which resulted in a high ratio of woodchip to manure in the compost, which may reduce composting performance. 	<ul style="list-style-type: none"> • Pwllpeiran found that less of the drier woodchips were needed when topping up the beds. <ul style="list-style-type: none"> - Pwllpeiran also found the rounded chips were kicked around more by the animals. This turning and mixing during housing better utilizes the chip between top-ups and importantly for the composting; thoroughly distributes the manure within the chip.
Straw	<ul style="list-style-type: none"> • Drier woodchips produce a higher composting temperature, indicating that the environmental conditions are more optimal for microbial decomposition and necessary to sanitize the compost and meet UK PAS 100 regulations. • Greater absorbency potential <ul style="list-style-type: none"> - Trapping more effluent run-off. - Greater nutrient holding capacity.

PART 2

METHODS - CHEMICAL ANALYSIS

Compost temperature, moisture content and oxygen are good environmental indicators of composting performance. Chemical analyses indicate the agronomic value of the compost if it was applied to land at that point in its decomposition.

In some cases, it was not necessary to analyse samples in all the time series; the table below shows which analyses were carried out on which bedding and or compost samples.

Analyses	Raw Bedding	T0	T2,T4 and T6	T8
pH & EC	✓	✓	✓✓✓	✓
K, Na, Ca	✓	✓	✓✓✓	✓
NO ₃ ⁻ & NH ₄ ⁺	✓	✓	✓✓✓	✓
DOC & TSN	✓	✓	✓✓✓	✓
Contaminants				✓
Available P	✓	✓	✓✓✓	✓
Total P	✓			✓
Cu & Zn	✓			✓
Total C and N	✓	✓		✓

International Standard Methods used:

1. Determination of compost pH and electrical conductivity (EC)

1. Measure out 20 cm³ of soil/compost into labelled plastic beaker.
2. Add 20 ml of distilled water.
3. Mix with a glass stirring rod and let stand for 30 minutes.
4. Calibrate pH meter with pH 4 and 7 standard buffers.
5. Measure pH after calibration of pH meter.
6. Calibrate EC meter with a 0.01 M KCl solution. It should be set to 1410 μ S cm⁻¹.
7. Put electrode in extract and measure EC.

Note: Sometimes the compost soaks up all the water. If this happens then increase the amount of water added from 20 to 40 ml (i.e. 1:2 compost-to-water v/v).

International Standard Method References

Smith, J.L. and J.W. Doran. 1996. Measurement and use of pH and electrical conductivity. p.169-186. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Rhoades, J. D. 1982. Soluble salts. p. 167-179. In: A. L. Page et al. (ed.) Methods of soil analysis: Part 2: Chemical and microbiological properties. Monograph Number 9 (Second Edition). ASA, Madison, WI, USA.

2. Determination of exchangeable cations: potassium (K), sodium (Na) and calcium (Ca) in composts

Sample preparation:

1. Mix 30 g of compost sample with 150 ml of distilled water in a 300 ml polythene bottle.
2. Shake for 1 hour.
3. Drain the solution through a 200 μm gorse filter.
4. Pour 50 ml into a polythene centrifuge tube.
5. Centrifuge for 10 mins at 8000 rpm.
6. Pour (approx 45 ml) slowly into another vial to avoid any sediment carry.

Concentrations of K, Na and Ca in the compost samples were measured using a flame emission photometer and compared against a range of standards, which were prepared from a 1000 mg l⁻¹ stock solution.

Preparation of standards:

K	0-20 mg l ⁻¹	0, 5, 10, 15, and 20 mg l ⁻¹
Na	0-20 mg l ⁻¹	0, 5, 10, 15, and 20 mg l ⁻¹
Ca	0-100 mg l ⁻¹	0, 25, 50, 75, and 100 mg l ⁻¹

International Standard Method References

Rowell, D. 1994. *Soil Science: Methods and Applications*. Longman UK Ltd.

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3. Determination of extractable nitrate (NO₃⁻) and ammonia (NH₄⁺) in composts

1. Mix 30 g of compost sample with 150 ml of distilled water in a 300 ml polythene bottle.
2. Shake for 1 hour.
3. Drain the solution through a 200 μm gorse filter.
4. Pour 50 ml into a polythene centrifuge tube.
5. Centrifuge for 10 mins at 8000 rpm.
6. Pour (approx 45 ml) slowly into another vial to avoid any sediment carry.
7. Store samples in fridge at 4°C.
8. Prepare 0-10 mg l⁻¹ standards of NO₃⁻ and NH₄⁺.
9. Determine NO₃⁻ and NH₄⁺ in samples and standards on Skalar autoanalyser.
10. Standard curves should give a straight line and r² value above 0.995.
11. Perform baseline correction in software if required (normally only required if samples are extremely close to baseline i.e. 0.0 to 0.1 mg l⁻¹).

International Standard Method Reference

Mulvaney, R.L. 1996. Nitrogen-Inorganic forms. In: *Methods of soil analysis. Part 3. Chemical methods* (D. L. Sparks et al., ed.). SSSA Book Ser. 5. Soil Science Society of America, Madison, WI. pp. 1123-1184.

Analyzer Manufacturer details: <http://www.skalar.com>

4. Determination of dissolved organic carbon (DOC) and total soluble nitrogen (TSN) in composts

1. Mix 30 g of compost sample with 150 ml of distilled water in a 300 ml polythene bottle.
2. Shake for 1 hour.
3. Drain the solution through a 200 μm gorse filter.
4. Pour 50 ml into a polythene centrifuge tube.
5. Centrifuge for 10 mins at 8000 rpm.
6. Pour (approx 45 ml) slowly into another vial to avoid any sediment carry.
7. Store samples in fridge at 4°C.
8. Prepare 10 mg l⁻¹ mixed standards of KNO₃⁻ and DOC (K-phlatate) by adding 1 ml of each to a 100 ml flask and top up with distilled water.
9. Determine DOC and TSN on a Shimadzu analyser with autosampler with a distilled water blank and a 10 mg l⁻¹ standard every 10 samples.

Nitrate (NO₃⁻) and Ammonium (NH₄⁺), are DIN, Dissolved Inorganic Nitrogens; the sum of these plus any DON, Dissolved Organic Nitrogen = TSN, Total Soluble Nitrogen content of the sample. DOC means Dissolved Organic Carbon. Consequently, the DOC:TSN ratio is the 'available C:N ratio'.

The DOC and TSN values from the analyser are produced in mg C l⁻¹. To get DON, subtract the NO₃⁻ and NH₄⁺ values from the TSN value. To convert to mg/kg⁻¹ then multiply by 10. This gives values on a wet weight basis. For a dry weight basis, the moisture content must be accounted for.

International Standard Method Reference

D.L. Jones, A.G. Owen, J.F. Farrar, *Simple method to enable the high resolution determination of total free amino acids in soil solutions and soil extracts*, Soil Biology & Biochemistry 34 (12) (2002) pp. 1893-1902.

Jones DL, Willett VB (2006) *Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil*. Soil Biology & Biochemistry 38 (5): 991-999

Analyser Manufacturer details: <http://www.shimadzu.com>

5. Determination of contaminants in composts

1. Weigh 1000 g of compost into a tray.
2. By hand, separate out the plastic, metal and stone contaminants.
3. Weight each contaminant fraction
4. Calculate the % weight of each contaminant fraction.

Contaminant (% of total weight) = [Contaminant weight (g) / total weight (g)] × 100

International Standard Method Reference: Not applicable.

6. Determination of available and total phosphorus in composts

Sample preparation for available P:

1. Mix 30 g of compost sample with 150 ml of distilled water in a 300 ml polythene bottle.
2. Shake for 1 hour.
3. Drain the solution through a 200 μm gorse filter.
4. Pour 50 ml into a polythene centrifuge tube.
5. Centrifuge for 10 mins at 8000 rpm.
6. Pour (approx 45 ml) slowly into another vial to avoid any sediment carry.
7. Store samples in fridge at 4°C.

Sample preparation for total P:

1. Dry the compost samples in an oven at 80°C for a minimum of 24 hours.
2. Grind the samples to obtain a homogenous sample.
3. Weight out 0.2 g into a graduated 15 ml test tube.
4. Place the tube in a digestion block and add 1.6 ml nitric acid, followed by 0.4 ml perchloric acid.
5. Place marbles on top of tubes and leave to stand in backwashed fume hood overnight.
6. Turn on the digestion block in morning, set to 100°C / 212°F and leave for 1 hour.
7. After 1 hour, increase temperature to 133°C / 275°F.
8. After another hour, increase temperature to 150°C / 302°F, leave for 5 hours.
9. Complete digestion by increasing temperature to full (200°C / 392°F) for the final hour.
10. Leave to cool overnight.
11. Remove marbles and place in beaker in acid bath.
12. Top up test tubes to the graduated line with distilled water.
13. Filter using W541 filter paper or equivalent into 20 ml scint vial and store.
14. Rinse all funnels and scrub under tap water before leaving to soak overnight in acid.
15. Rinse tubes using distilled water.

Phosphate Analysis

1. Prepare 0 to 20 mg l^{-1} P standards using P stock solution stored in the fridge (1000 mg l^{-1}).
2. Add 2 ml of this to a 100 ml flask and make up to the mark with distilled water to give 20 mg l^{-1} standard.
3. Make up 10 ml of 10 % (w/v) ascorbic acid (i.e. 1 g of ascorbic acid dissolved in 10 ml of distilled water). Do this in a 20 ml polypropylene vial.
4. Add 80 μl of sample or standards to all the wells required in a 96 well plate.
5. Add 180 μl of Ames Reagent (kept in fridge) to all the wells required in a 96 well plate.
6. Add 30 μl of ascorbic acid to all the wells required in a 96 well plate. Do this final step as quickly as possible so that the colour development in the wells all starts at the same time.
7. Measure absorbance at 820 nm in Versamax plate reader after 15 minutes.

The microplate reader delivers P values in mg P l^{-1} . To convert to mg kg^{-1} then multiply by 10. This gives values on a wet weight basis. For a dry weight basis, the moisture content must be accounted for.

International Standard Method Reference

Murphy J. and Riley JP 1962. *A modified single solution method for the determination of phosphate in natural water*. *Analytica Chimica Acta*, 27, 31-36

Analyzer Manufacturer details: www.moleculardevices.com/pages/instruments/versamax.html

7. Determination of total copper (Cu) and zinc (Zn) in composts

Sample preparation:

1. Dry the compost samples in an oven at 80°C for a minimum of 24 hours.
2. Grind the samples to obtain a homogenous sample.
3. Weight out 0.2 g into a graduated 15 ml test tube.
4. Place the tube in a digestion block and add 1.6 ml nitric acid, followed by 0.4 ml perchloric acid.
5. Place marbles on top of tubes and leave to stand in backwashed fume hood overnight.
6. Turn on the digestion block in morning, set to 100°C / 212°F and leave for 1 hour.
7. After 1 hour, increase temperature to 133°C / 275°F.
8. After another hour, increase temperature to 150°C / 302°F, leave for 5 hours.
9. Complete digestion by increasing temperature to full (200°C / 392°F) for the final hour.
10. Leave to cool overnight.
11. Remove marbles and place in beaker in acid bath.
12. Top up test tubes to the graduated line with distilled water.
13. Filter using W541 filter paper or equivalent into 20 ml scint vial and store.
14. Rinse all funnels and scrub under tap water before leaving to soak overnight in acid.
15. Rinse tubes using distilled water.

Preparation of standards:

1. Prepare a range of 0, 1.5, 3, 4, 5, 6, 7.5 mg l⁻¹ Cu standards using Cu stock solution (1000 mg l⁻¹) and a range of 0, 0.25, 0.5, 0.75, 1, 2, 3 mg l⁻¹ Zn standards using Zn stock solution (1000 mg l⁻¹)
2. Add 0.75 ml of Cu and 0.3 ml of Zn to a 100 ml flask and make up to the mark with ultra pure water to give a top standard of 7.5 mg l⁻¹ Cu and 3 mg l⁻¹ Zn. Repeat for all expect standard 4 which is made up in a 1000 ml flask as this standard is used to monitor drift every 10 samples.
3. Analyze the samples on a Varian Techtron AA-975 Atomic Absorption Spectrophotometer.

Due to expectedly high Zn content, the digested sample solutions were diluted by 20:1 with distilled water. However, Cu content was analysed without the need for further dilution.

Determination of compost total Carbon (C) and Nitrogen (N)

1. Dry the compost samples in an oven at 80°C for a minimum of 24 hours.
2. Grind the samples to obtain a homogenous sample.
3. Put a tin foil cup on a 4 decimal point balance and zero the weight.
4. Weigh out 50-200 mg into the tin foil cups and record the weight to 4 decimal places.
5. Wrap the foil into a cigar shape. Be careful not to lose sample when wrapping.
6. Place the samples in a labelled holding tray
7. Analyze the samples on the automated LECO CHN2000 Analyzer

The analyzer gives results in % N and % C. To convert to g kg⁻¹, simply multiply the % values by 10 (i.e. 3% C = 30 g kg⁻¹).

International Standard Method Reference

Method 972.43. Official Methods of Analysis of AOAC International, 16th Edition (1997), AOAC International, Arlington, VA.

Analyzer Manufacturer details: <http://www.leco.com/>

RESULTS - CHEMICAL ANALYSIS

pH

Concerns were raised by farmers at a number of the demonstration farm open days, that the WM compost would be very acidic and need lime adding. However, the results clearly show that although the woodchip is acidic before bedding, the pH is dramatically increased with the addition of manure during housing.

Table 9: Pwllpeiran pH before and after composting

Treatment	Before bedding	After bedding, before composting	After composting
Woodchip 34%	3.4	8.3	8.1
Woodchip 53%	4.2	8.3	8.5
Woodchip 55%	4.0	8.1	8.6
Straw	7.7	8.2	8.5

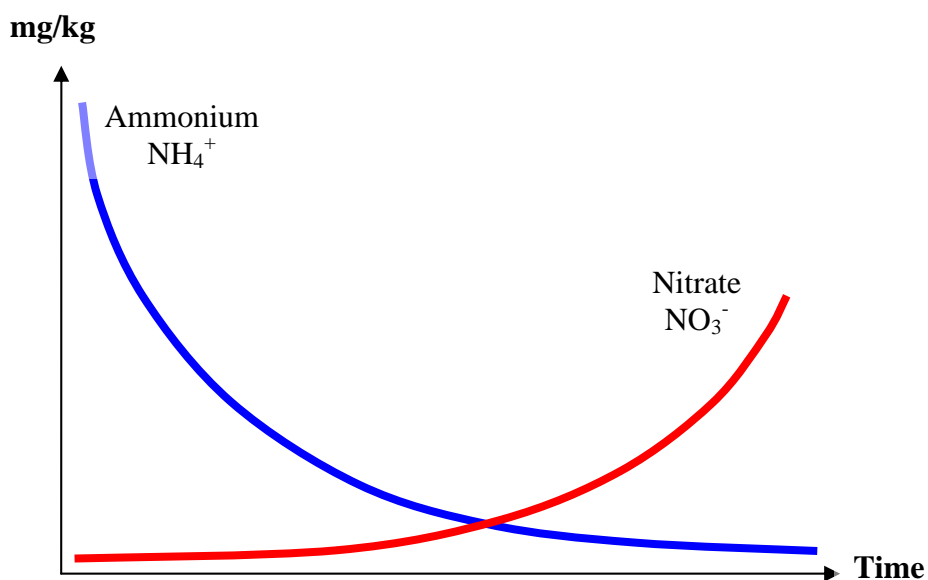
All woodchip treatments at IGER and Glynllifon showed the same pH pattern.

Electrical Conductivity (EC)

Electrical conductivity (EC) is a means of measuring the soil's total soluble salt content and is used to assess the potential risk of salt injury to plants. Salts found in these composts include Nitrate (NO_3^-) Potassium (K^+), Calcium (Ca^{2+}), Sodium (Na^+), Sulphate (SO_4^{2-}) and Magnesium (Mg^{2+}) etc. EC readings of up to 8.5 mS/cm were found in the composts, but it must be remembered these concentrations will be greatly reduced when dispersed onto land. The values were similar to those of conventional manure based composts.

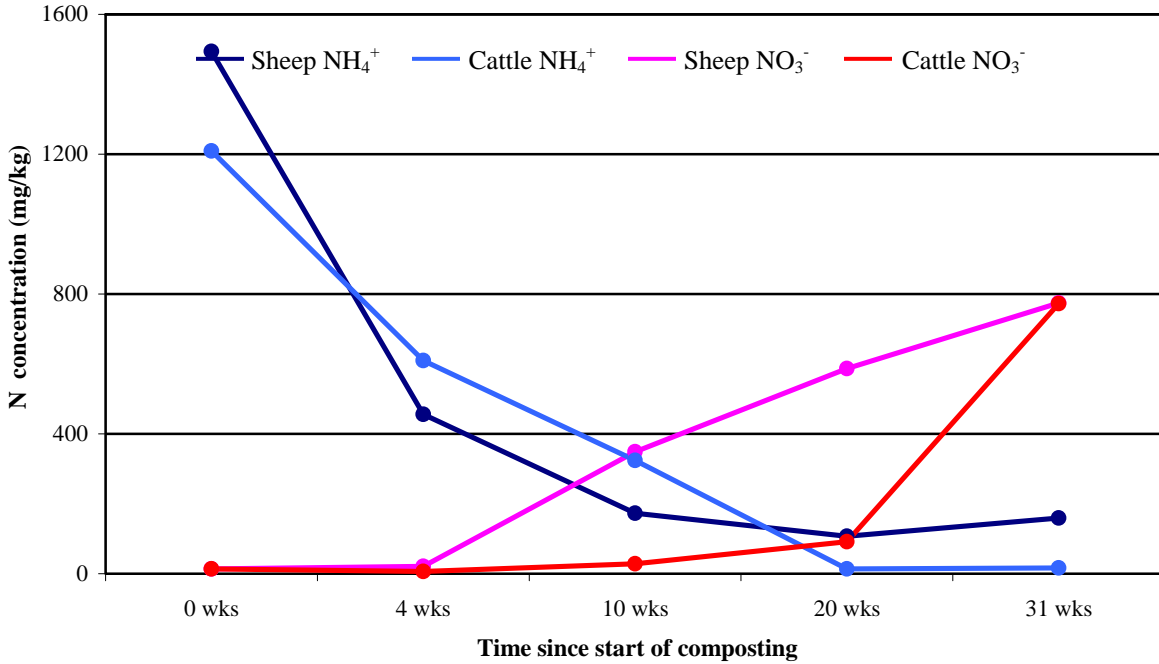
Available Nitrogen (N)

At the start of composting, ammonium-N levels are high and nitrate-N levels are low. Over the first few months, microbes convert ammonium-N into nitrate-N. This conversion over time results in a 'ship's hull' shape to the graph, typified by the illustration below.



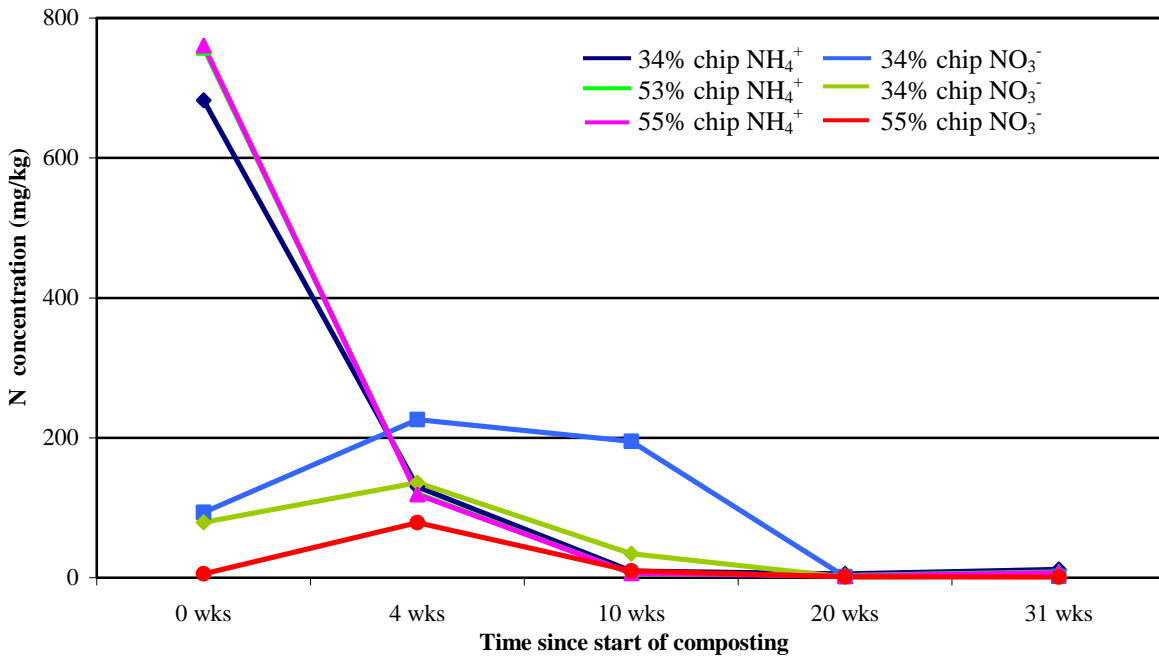
This pattern is evident in both the sheep and cattle straw composts featured in the graph below. Where ammonium NH_4^+ levels decrease from 1209 and 1494 mg/kg to nearly zero and nitrate NO_3^- levels increase from zero mg/kg at the start, to just under 800 mg/kg by week 31.

Figure 6: Pwllpeiran Straw: NO_3^- and NH_4^+ levels during composting



However, **all** 14 WM composts, regardless of treatment variables, demonstrated the following nitrate pattern.

Figure 7: Pwllpeiran Cattle Woodchip: NO_3^- and NH_4^+ levels during composting



The Pwllpeiran cattle WM composts show good early NO_3^- development, but after 4-10 weeks decline to near 0 mg/kg.

This pattern persists in all of the WM composts after 31 weeks.

mean NO₃⁻ mg/kg

- Pwllpeiran sheep woodchip = 94
- Straw comparison = 775

- Pwllpeiran cattle woodchip = 2
- Straw comparison = 772

Similarly,

- IGER sheep woodchip = 89
- Straw comparison = 698

- IGER cattle woodchip = 4
- Straw comparison = 415

Glynllifon didn't have a straw compost comparison, but NO₃⁻ levels can be gauged against straw composts at IGER and Pwllpeiran

- Sheep Softwood = 19
- Sheep Hardwood = 15
- Cattle Softwood = 6
- Cattle Hardwood = 13

It is considered, after about 4-10 wks the microbes began immobilizing the nitrate-N to balance their cellular C:N ratio while continuing to break down the C rich woodchips after the small quantity of available nitrogen in the cellulose material had been used up; resulting in the very low levels of available nitrate-N at the end of the first season's composting.

It is therefore reasonable to expect that if this 'unfinished' compost were applied to the field at this stage, the microbes within the woodchips would continue to source available N from the surrounding soil. In short, the WM composts would become a nitrogen sink not a nitrogen source, potentially resulting in N deficient plant growth. On this evidence, it's recommended that farmers should either re-use the woodchip as bedding the following winter or compost the annual beddings each year in individual heaps for up to 3 years or until the woodchip has decomposed sufficiently.

The aim is to reduce the volume of wood in the compost whilst maximising the quantity of manure, so if the feeding area is scared clean on a regular basis during housing, the manure should be stored and remixed into the bedding material before composting, providing the microbes with a suitable balance of nutrients to breakdown the woodchip in the shortest possible time and at the same time, save money.

Table 10: Nutrient quantities in all treatments after 7 months composting if 10 metric tonnes was applied to a hectare of land. (10t/ha)

ADAS Treatment	Total K kg/ha	Total Na kg/ha	Total Ca kg/ha	Total P kg/ha	Available P kg/ha	Nitrate kg/ha	Ammonium kg/ha	TSN kg/ha	DOC:TSN	Total N kg/ha	pH
Sheep 34%	103	33.9	69.4	22.0	0.44	2.60	0.30	3.57	3.34	115	8.21
Sheep 53%	115	35.4	70.2	25.3	0.66	0.17	0.16	1.59	10.2	106	8.50
Sheep 55%	117	30.4	75.6	20.8	0.65	0.04	0.16	1.52	9.72	96.9	8.72
Sheep Straw	146	58.2	112	44.6	4.03	7.75	1.60	16.8	6.27	223	8.81
Cattle 34%	90.1	37.2	33.4	20.7	1.41	0.02	0.12	0.62	10.4	94.3	8.03
Cattle 53%	88.0	38.8	32.0	23.1	1.98	0.03	0.08	0.56	9.22	91.5	8.54
Cattle 55%	96.1	39.5	37.2	25.2	2.05	0.01	0.07	0.44	9.53	99.3	8.37
Cattle Straw	157	61.9	117	59.2	1.77	7.73	0.17	10.0	3.11	287	8.16

IGER Treatment	Total K kg/ha	Total Na kg/ha	Total Ca kg/ha	Total P kg/ha	Available P kg/ha	Nitrate kg/ha	Ammonium kg/ha	TSN kg/ha	DOC:TSN	Total N kg/ha	pH
Sheep fed Silage on Straw	81.8	95.9	40.6	47.7	6.33	7.59	2.73	15.0	5.87	246	9.05
Sheep fed Silage on Chip	67.2	46.0	16.8	19.8	3.03	0.41	0.28	1.53	7.20	82.1	8.19
Sheep fed Hay on Straw	107	87.8	41.7	44.1	2.40	6.36	1.74	10.2	3.91	277	7.67
Sheep fed Hay on Chip	73.8	46.9	16.1	17.9	3.00	1.36	0.45	2.82	4.47	100	6.94
Cattle fed Silage on Straw	78.0	102	54.5	60.5	3.38	4.91	1.01	16.5	5.67	333	9.06
Cattle fed Silage on Chip	70.0	42.0	14.3	14.2	2.24	0.05	0.13	0.96	11.3	73.9	7.95
Cattle fed Hay on Straw	74.7	86.9	66.8	52.9	1.33	3.39	0.53	7.25	5.40	335	8.33
Cattle fed Hay on Chip	91.3	45.6	18.3	17.5	1.32	0.04	0.08	0.58	10.9	89.3	7.09

Glynllifon College Treatment	Total K kg/ha	Total Na kg/ha	Total Ca kg/ha	Total P kg/ha	Available P kg/ha	Nitrate kg/ha	Ammonium kg/ha	TSN kg/ha	DOC:TSN	Total N kg/ha	pH
Sheep Softwood	86.9	62.3	244	60.8	1.53	0.19	0.24	3.34	9.14	223	8.47
Sheep Hardwood	68.2	57.5	231	63.8	1.91	0.15	0.42	3.61	8.81	216	8.42
Cattle Softwood	74.2	28.1	55.9	26.4	1.42	0.05	0.06	0.93	9.57	104	8.65
Cattle Hardwood	78.3	64.1	210	67.1	2.28	0.13	0.49	4.50	8.44	218	8.08

K = Potassium, P = Phosphorus, the 'available P' column is just the proportion of Total P that's extractable in water, this also applies to TSN – Total Soluble Nitrogen in relation to Total N.

Nitrate (NO₃⁻) and Ammonium (NH₄⁺), are dissolved inorganic nitrogens; the sum of these plus any dissolved organic nitrogens = the TSN Total Soluble Nitrogen content of the sample.

DOC = Dissolved Organic Carbon, TSN = Total Soluble Nitrogen. Consequently, the DOC:TSN ratio is the 'available C:N ratio'.

Alternatively, farmers may wish to apply the compost by % rate as opposed to weight. Table 10 below uses an application rate of 150–50–80 NPK and shows dependant % rates of P and K (kg/ha) based on a standardized N application of 150kg/ha. For example, if 150kg/ha of N in the *Sheep fed Silage on Chip* compost was applied, then 36kg/ha P (instead of 50kg/ha) and 123kg/ha K (instead of 80kg/ha) would actually be applied.

Table 11: IGER % rates of P and K (kg/ha) based on applying 150kg/ha N (150/50/80 NPK)

Target application rate/ha	150kg	50kg	80kg	Tonnes/ha
Actual application rates based on 150kg/ha N	N	P	K	required
Sheep fed Silage on Straw	150	29	50	6
<i>Sheep fed Silage on Chip</i>	150	36	123	18
Sheep fed Hay on Straw	150	24	58	5
Sheep fed Hay on Chip	150	27	111	15
Cattle fed Silage on Straw	150	27	35	4
Cattle fed Silage on Chip	150	29	142	20
Cattle fed Hay on Straw	150	24	33	4
Cattle fed Hay on Chip	150	29	153	17

The best way to assess the quality of the WM composts is to compare them to their corresponding straw treatments.

Overall, nutrient levels are lower (by weight) in woodchip than straw based composts. The most significant finding to have emerged from these analyses, is the microbial sequestration of nitrate (NO₃⁻), leaving little or no available N in the WM composts. This is the reason why the app. rates of K are relatively high; approx 4 times as much WM compost is needed to supply 150 kg/ha of N than straw based equivalents, as the 'Tonnes/ha required' column clearly shows. See [Report 6](#) for further information.

The aim of fertilizing is to replenish the soil with whatever nutrients were used up by the growth of the previous years off-take and then increase them by the amount needed for the following years growth, depending on crop type, whilst taking into account the various baseline nutrient levels in the soil at any given time, hence the need for regular soil analysis tests.

Heavy Metals

Total Copper (Cu) and Zinc (Zn) levels were analysed in all raw bedding materials and T8 compost samples; both groups of samples conformed to PAS100 regulations. Glynllifon results below illustrate the content levels found.

Table 12: Copper and Zinc (mg/kg) in raw bedding and composts after 7 months at Glynllifon

Treatment	Cu mg/kg raw bedding	Cu mg/kg composts	PAS 100	Zn mg/kg raw bedding	Zn mg/kg composts	PAS 100
Sheep on Softwood	2.09	29.5		8.64	270	
Sheep on Hardwood	3.53	43.2	upper limit	23.0	374	upper limit
Cattle on Softwood	2.09	23.2	200mg/kg	8.64	155	400mg/kg
Cattle on Hardwood	3.53	49.5		23.0	381	

Consistent variations in metal contents are seen between hard and softwoods in the Glynllifon trials above and were also evident between sheep > cattle and straw > woodchip at both Pwllpeiran and IGER.

Total carbon:nitrogen (C:N) ratios

C:N ratio is the total amount of carbon relative to the total amount of nitrogen present in composts at any given point in time. A ratio of '100' means there's 100 grams of carbon for each gram of nitrogen. To establish whether the microbial sequestration of NO_3^- discussed earlier, devalues the productive potential of the decomposed material, samples were sieved through a 2 mm riddle. A 2 mm gauge is clearly not practical for on-farm operations, but was necessary for the purpose of these analyses.

Table 13 shows total N g/kg in the small and large fractions in IGER's WM composts, independent of the % at which they occurred, as well as the total C and N in all the unsieved treatments.

Table 13: C:N ratio of IGER's raw bedding

Raw Bedding	C:N ratio
Woodchip 1st Load	318
Woodchip 2nd Load	365
Straw	81

Table 14: Total C and N in > < 2 mm WM fractions and straw composts after 7 months at IGER

Treatments	N g/kg in <2mm	N g/kg in >2mm	Straw	Total N g/kg	Total C g/kg
Sheep fed Silage on Straw			24.6	25.0	367
Sheep fed Silage on Woodchi	16.1	7.57		8.26	431
Sheep fed Hay on Straw			27.7	28.0	363
Sheep fed Hay on Woodchip	19.5	7.56		10.1	425
Cattle fed Silage on Straw			33.3	33.6	343
Cattle fed Silage on Woodchip	13.5	6.95		7.42	436
Cattle fed Hay on Straw			33.5	33.7	335
Cattle fed Hay on Woodchip	17.9	7.27		8.94	436

The small fraction has a far greater N content than the large chunks, but constitutes a smaller quantity of the combined mass; hence, Total N contents are a sum of the proportionate inputs from each fraction.

Table 15: shows the % of small and large material found in each site's composts after 7 months.

Trial Site	% < 2mm	% > 2mm
ADAS	22	78
IGER	13	87
Glynllifon	37	63

Manure provides plenty of available N in the early stages of composting, but the C in woodchip is bound up in lignin complexes so cannot be made available in the short term. Hay is a good supplementary source of available C to compliment the N rich manure. However, silage has a lower C:N ratio than hay and therefore, lacks the necessary levels of available C to fully utilize the wealth of N during the first few months. As a result, the more optimal balances of available C:N present in hay composts, allows higher levels of microbial metabolism and respiration, so more C is lost to the atmosphere as CO₂.

The disparity seen in Table 14 above, between the amounts of small material in IGER and Glynllifon's composts, is thought to have resulted from a combination of 'over-bedding' at IGER and a large amount of wasted hay feed at Glynllifon, which gave the microbes a biased but beneficial balance of available C to N, resulting in a greater amount of decomposition. Pwllpeiran's 22:78 split of small vs. large material is considered a representative ratio of decomposition in WM composts after the first 7 months.

Over the 7 months, after the initial frenzy of microbial activity died down the protracted task of decomposing the woodchip began. Some of the available N was lost to the environment but most was used by the microbes, evident by the steep reduction in % C to N. Wood (chip) has a C:N ratio of between 300-500:1; far higher than the microbe's cellular ratio of 15:1, so N becomes the limiting factor to decomposition in the longer term, hence the benefit of adding N rich manure by annually re-using the bedding over 3 years. After each season, the additional N remains in the bio-reserve and is continually recycled through generations of organisms.

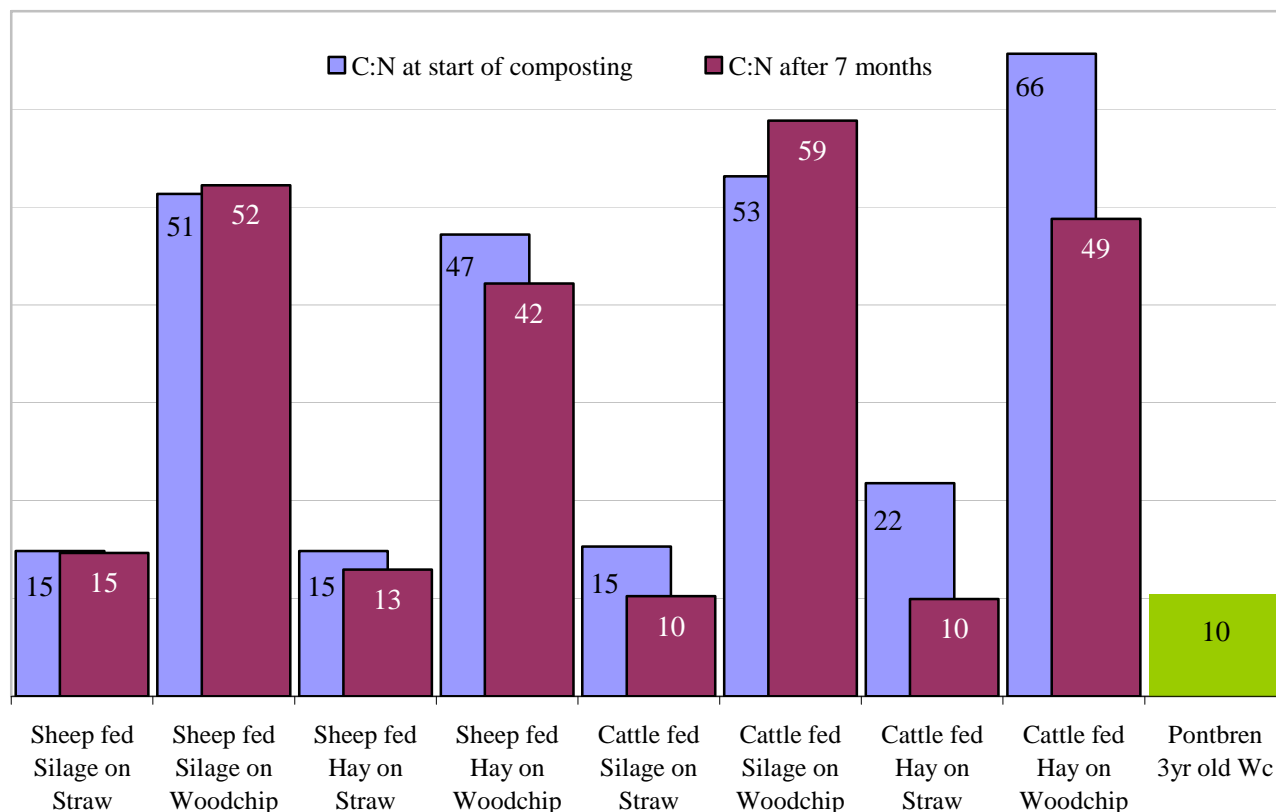
The reduction in C:N ratios seen in most of the IGER treatments below, broadly demonstrates the proportion to which the WM composts have broken down after 7 months. Comparison to the mature Pontbren 3 year old WM compost, featured in green, gives further support to the recommendation that woodchip as livestock bedding is best utilized over a number of years.

Over the composting period, the net g/kg of carbon in the heaps does *actually* decrease, but N does not *actually* increase; a net increase of N could only be achieved by N fixation, which would require anaerobic conditions and Table 5 shows these conditions did not occur in the WM composts at IGER.

The two cattle straw composts reduced in bulk by approx 40-50% over 7 months, in contrast to the sheep straw composts which hardly reduced at all over the same period. Similarly, but to a lesser extent, the four 'hay-fed' composts with their more microbe-friendly quantities of available C and N, will have enabled a greater reduction of bulk material than the 'silage-fed' composts and therefore concentrated the N in a smaller volume of material. Increases in C:N seen in the 'silage-fed' composts, shows that during the 7 months, a greater 'proportionate' percentage of N was lost to the environment than C via microbial metabolism and respiration.

The graph below compares the C:N ratios in the fresh composts with C:N in composts after 7 months. Ammonium levels in T0 and T8 samples (analysed separately) were added to total N, to correct for any loss of N as ammonia.

Figure 8: IGER C:N ratios before and after 7 months composting



Similar factors caused minor variations in the Pwllpeiran treatments, where otherwise the moisture content was the dominant variable in sheep composts but which had little bearing on the wetter, manure-laden cattle loads. However, there was also an enduring effect from the disparity of C:N in the woodchip bedding stocks seen in Table 15 below.

Table 16: Total C:N g/kg and ratios in Pwllpeiran raw bedding

ADAS: Raw Bedding	N g/kg	C g/kg	C:N
Woodchip 34%	1.20	486	407
Woodchip 53%	0.81	479	590
Woodchip 55%	1.10	478	437
Straw	4.49	433	96

It is interesting to note the lower N content of the 53% stock which was chipped from fence 'points' and therefore constituted by mostly older wood from the centre of the bough, whereas the 34% and 55% stocks were cut from rounds and so contain a broader age range of growth rings. This, in combination with the different physical properties of the 53% stock, had a significant impact on its composting performance and nutrient values in conjunction with the different inputs from cattle and sheep manure.

PRESCRIPTIONS FOR THE USE OF WOODCHIP AS BEDDING AND TREATMENT OF WM COMPOST RESULTS

If **compost** is the farmer's priority...

1. Use smaller woodchips.
2. Pre-bedding woodchip water content should be between 5 -30%.
3. Use the minimum viable quantity of woodchip – 4” base layer and 2” top-ups thereafter.
4. Any rotten or musty bales should be broken up and strewn over the soiled bedding before composting.
5. If a scraped feeding area system is used, the manure must be stored and remixed into the bedding material before composting.

If **bedding** is the farmer's priority...

1. Use larger woodchips.
2. Pre-bedding woodchip water content should be between 5 -30%.
3. Use the minimum viable quantity of woodchip – 4” base layer and 2” top-ups thereafter.
4. Do not leave the woodchip bedding down in the barn over the summer; always store it in heaps whether it is going to be re-used the following winter or not.

After the woodchips final use as bedding, follow points 4 and 5 in the adjacent box.



Mae'r Prosiect Sglodion Fren ar gyfer Samau Da Byw a gyflerwir gan Hybu Cig Cymru yn derbyn arian cyfatebol gan y Comisiwn Coedwigaeth, Asiantaeth yr Amgylchedd Cymru a Llywodraeth Cynulliad Cymru fel rhan o Cyswllt Ffermio.



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