6. Field vermiculture trial

6.1 Introduction

A vermiculture trial was conducted at Laureldale Research Station at the University of New England (UNE), Armidale, to determine if litter from a local integrator could be rapidly converted into odour free vermicast. The primary objective of this trial was to determine if the same methods that were used for the laboratory experiments were suitable for a commercial scale system, however the process was not quantified in detail. An integrated waste management vermiculture design was created in an attempt to utilise litter produced by 29,000 birds (average size broiler shed). This equated to 70 m^3 (35 T) of fresh litter, split into two commercial beds, each containing 35 m^3 of litter. As with the small laboratory experiments an emphasis was placed on watering heavily during the stabilisation phase.

An added complexity to this trial compared to the previous laboratory experiments was the utilisation of the hot leachate collected from the litter undergoing vermi-processing (commercial beds), during the stabilisation phase. In previous laboratory experiments the leachate was simply discarded, whereas in this experiment the liquid represented a new waste stream requiring utilisation and disposal. Vermi-filtration was the most feasible option as it has been shown to be useful in utilising some nutrient-rich liquid waste streams (White 1996, Bajsa et al. 2003). As a result drainage lines and terminal ponds were constructed around all beds to collect and recycle leachate on specially prepared vermi-filtration beds. The majority of leachate was directed onto these beds, but a small amount was also used for the production of inoculant (Figure 6.1).

Similarly to the inoculation experiment, leachate was also directed into inoculant tanks and oxygenated for a period of 48 hours. These liquids were then applied to the commercial beds in an attempt to enhance microbial populations in the earthworm substrate, and improve the conversion of litter into vermicast (Figure 6.1). This advice was obtained from a commercial vermiculturalist even though it conflicted with findings from experiment 5 (section 5.3.2).

A main constraint to the field trial was the requirement to use fresh litter, without composting or pre-washing. If this approach was successful it could represent an alternative waste management solution for hot organic wastes. A complete on-site integrated waste management system using *E. andrei* earthworms was developed (Figure 6.1), and could potentially utilise all organic wastes that a typical Australian broiler grower produces. This could include on-site

utilisation of dead birds; however this was not investigated in the current trial. Once established this system could recycle both vermicast and earthworms from one batch of litter to the next, and other than water, there would be no other inputs required to be brought on-site.

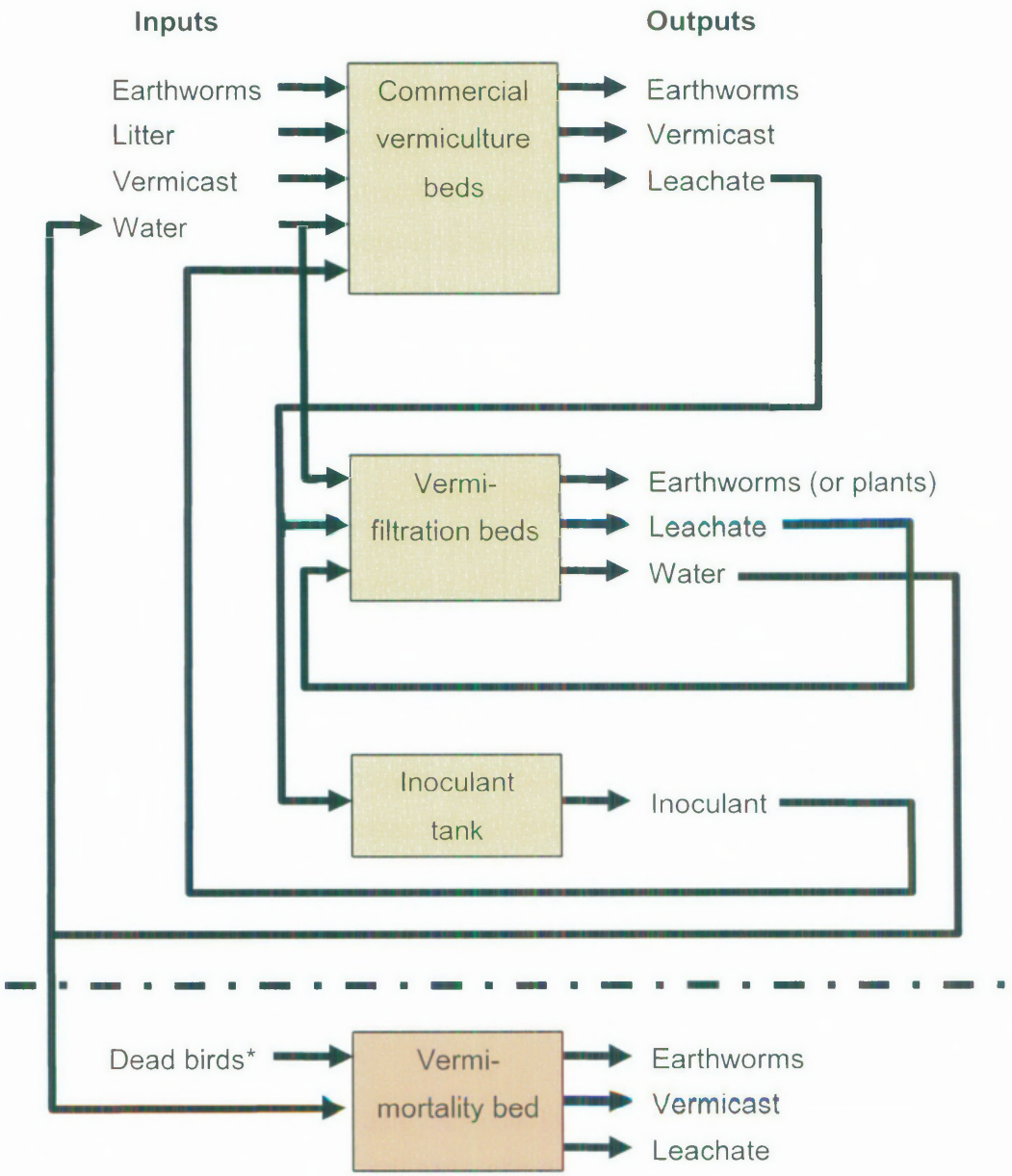


Figure 6.1 Processes involved in an integrated waste management system for broiler growers using a batch flow vermiculture system

*Other inputs for vermi-mortality beds not yet determined

6.2 Methods

6.2.1 Introduction

An integrated vermiculture system using litter was established at Laureldale Research Station, Armidale. This system included litter vermi-processing (commercial beds), vermi-filtration beds and inoculant tanks (Figure 6.1). A local broiler integrator supplied a total of 210 m^3 of fresh single batch rice hull based litter for the trial, of which 140 m^3 was used to produce vermicast and breed enough *E. andrei* to be used in the commercial trial. Vermicast derived from litter and earthworms grown in a litter substrate were the inputs to the commercial beds and were produced in advance.

There were three important considerations and restrictions placed on the design of this vermiculture system to make it suitable for adoption on-site. Firstly, litter had to be utilised fresh in a single batch to avoid storage and handling. Secondly, the system had to be capable of running without external inputs, self-sustaining from one cleanout of litter to the next. Thirdly, odour control was a key issue and would need to be addressed so as not to increase the odour footprint of the broiler operation.

6.2.2 Site description and climate

Laureldale Research Station is a rural property owned by the UNE and adjoins the university at its NE boundary. Laureldale is located 30°51' south and 151°66' east, in the New England Tablelands, at an elevation of 950 m above sea level, part of the Great Dividing Range. The site was gently sloping (1%) with an easterly aspect and access to water and electricity. The site was orientated to capitalise on the slope for drainage and collection of runoff (vermi-filtration and inoculation). The climate at Laureldale is one of summer dominant rainfall, warm summers and cold winters (Figure 6.2 & Figure 6.3). The daily temperatures while the vermi-processing beds were running indicated overnight temperatures as low as -7°C (Figure 6.4).

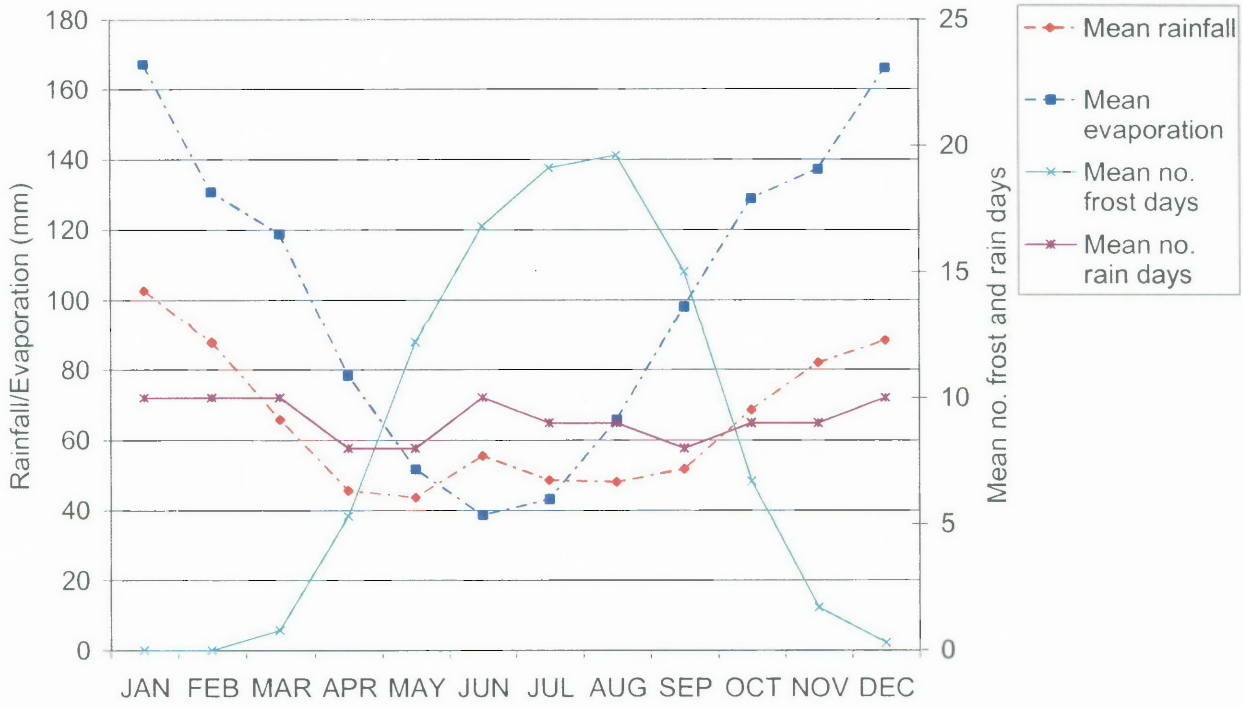


Figure 6.2 Long-term mean rainfall and number of rain days (1857-2006), and evaporation and frosts (1981-2006) for Armidale (University of New England 2007)

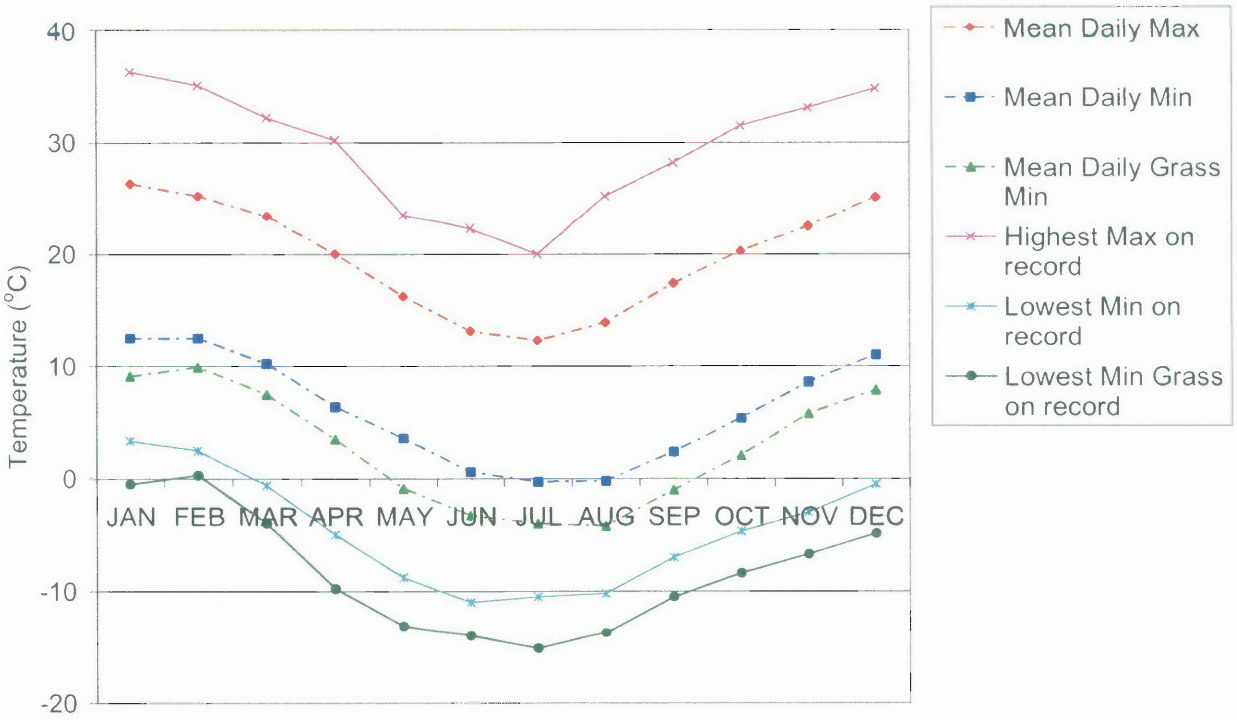


Figure 6.3 Long-term mean temperature information for Armidale from 1981 to 2006 (University of New England 2007)

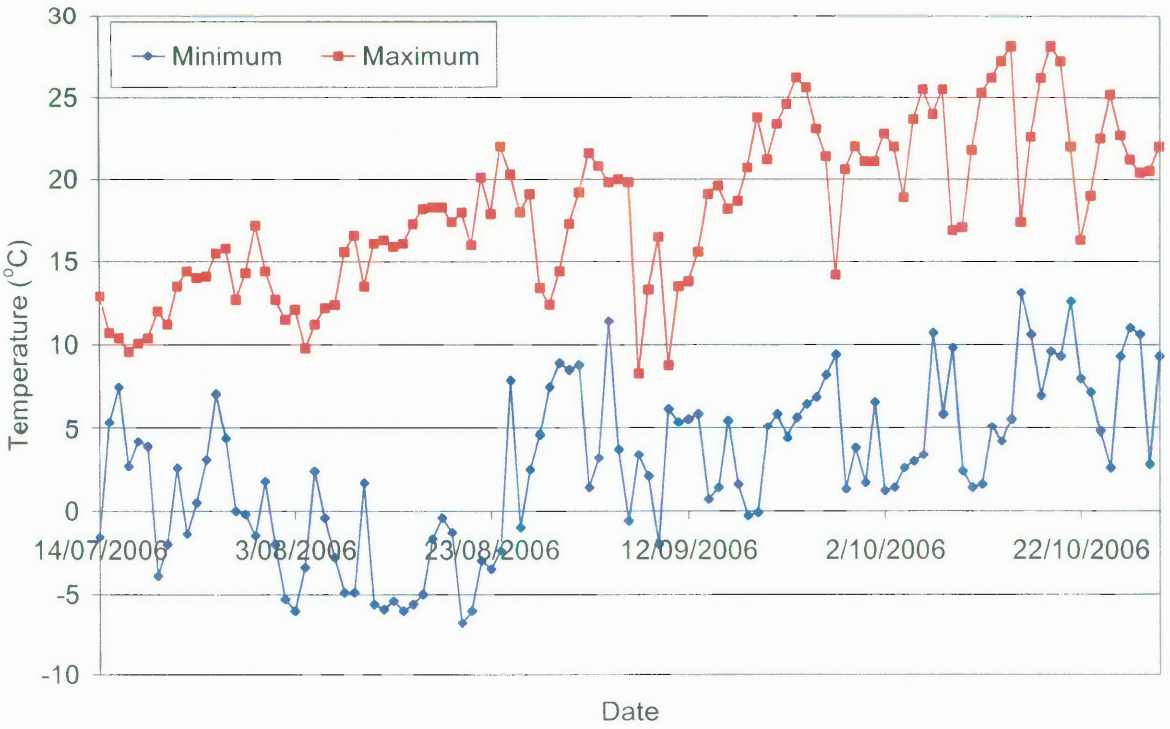


Figure 6.4 Daily maximum and minimum air temperatures during the commercial bed stage (BOM 2007)

6.2.3 Earthworm recruitment and bedding (vermicast)

Earthworm populations and vermicast were produced in three stages before the commercial trial started on the 14 July 2006. The first step was started on the 18 March 2005 and involved the production of vermicast and earthworms on the UNE campus, which then were transported to Laureldale. Two earthworm beds located on campus were made of hay and on the 24 March 2005 20 kg of chicken feed (pellets), 0.5 kg of pure *E. andrei* earthworms and 1 kg of vermicast were evenly spread on top of the wet hay. The beds were covered with shade cloth (Figure 6.5a) to avoid predation from wild birds, especially ibis (Figure 6.6), and then heavily watered.

Four times a week beds were watered and at the start of each week 10 kg of chicken feed and a further 0.5 kg of earthworms were added, paying attention to watering all areas of the bed. Adding protein in the form of chicken food to the surface of earthworm substrate is recommended when using a protein deficient food stock like hay (Murphy 1993). Within two weeks fungi had started to grow on the bed and the earthworms had completely moved into the hay (Figure 6.5b). After three months the earthworm population had increased and the majority of the hay had converted into vermicast, suitable for the next recruitment stage which was conducted at Laureldale Research Station.

(a) 24 March 2005

(b) 2 April 2005

Figure 6.5 (a) Establishment of recruitment beds and (b) fungi growth

Figure 6.6 Holes in edge of earthworm bed after an ibis' beak is withdrawn

The second production stage was initiated on the 10 July 2005 and involved the construction of a bed comprised of 5 T of hay and the earthworms and vermicast grown on campus. As with the on-campus breeding, chicken pellets were used to promote earthworm growth, at a rate of 40 kg/week. After three months there were enough earthworms and vermicast to start the final stage in earthworm and vermicast production.

The final stage involved breeding of earthworms using litter, which required the first two loads of fresh litter (Figure 6.7). Two beds each comprising 35 m^3 of litter were established in two windrows approximately (30 x 2 x 0.5 m) and were the final stage in the recruitment of earthworms and vermicast (Figure 6.8). The process generated enough vermicast (bedding) and earthworms derived from litter for the commercial beds, and replaced the hay-derived vermicast. This represented a commercial approach, where vermicast and earthworms generated from one cleanout of litter could be used to provide bedding for the following cleanout, without having to bring any organic materials like hay on-site. These beds were also eventually used for vermi-filtration of excess leachate from the commercial beds.

(a) 11 April 2006

(b) 11 April 2006

Figure 6.7 (a) Litter arrival and (b) bed establishment

(a) 29 May 2006

(b) 29 June 2006

Figure 6.8 (a) Earthworm recruitment beds at Laureldale using litter and (b) early morning frost on a recruitment bed

6.2.4 Commercial vermiculture beds

Two commercial litter vermi-processing beds were established within a fenced enclosure, each using 35 m^3 of litter and designed as though the vermiculture system was operating on a broiler farm. The volume of litter at the beginning and the volume of vermicast at the end were determined using the end area method (Natherson et al. 2006). Each bed contained fresh litter capped with vermicast and then earthworms were added that had been acclimatised in litter. All earthworm mass values were estimates only and were made by a commercial vermiculture operator. The litter to earthworm ratio was 35:1, based on wet weight of earthworms and fresh litter, which was equal to 500 kg of *E. andrei* per bed, equivalent to 3% earthworms (Table 6.1).

To avoid earthworm loss to birds (Figure 6.6) and maximise substrate utilisation by earthworms, shade cloth was again used to cover the beds. Runoff was collected in a terminal pond and

used on vermi-filtration beds or directed into two 1000 l inoculation tanks (Figure 6.9 a & b). The beds required daily watering and minor weekly maintenance, which included keeping the gutters clear and raking any fallen litter back under the shade cloth.

Table 6.1 Bed dimensions and loading rate for commercial beds 1 and 2

	Length (m)	Width (m)	Height (m)	Litter (m^3)	Vermicast (m^3)	Worm (kg)
Bed 1	19	2.7	0.7	35	4	500
Bed 2	9.4	5.5	0.7	35	4	500

(a) 14 July 2006 (b) 29 July 2006

Figure 6.9 (a) Establishment and layout of the vermiculture system and (b) shade cloth covered beds

For the first four weeks each bed was watered daily with 500 l of fresh and inoculated water. The frequency of watering was based on the results from the laboratory experiments and the water volume (500 l) enabled full saturation of the entire bedding surface. Water was applied using a sprinkler hose that ran the length of the bed, and inoculated water was pumped (centrifugally) onto the beds using a fire hose, further details in section below (Figure 6.10). For the following four weeks both beds received 500 l of fresh and inoculated water every third day, and then once every five days until completion. During times of rain and when excessive leachate was collected the volume was reduced to either 250 or 125 l of both fresh and inoculated water. Effort was made to recycle all the leachate from the beds however some small losses did occur, especially when a drainage line became blocked.

(a) 29 July 2006

(b) 29 July 2006

Figure 6.10 (a) Water application using sprinkler hoses (b) and application of inoculated water

After two weeks, a channel 20 cm deep was dug approximately halfway up the side of each bed so that it formed a loop around the bed. This channel was then filled with vermicast and earthworms from the recruitment beds, which were now acting as vermi-filtration beds (Table 6.1). The channel encouraged further penetration of earthworms into the litter and also served as a haven for any earthworms that migrated from the top of the beds before becoming exposed to birds. In week 4 the surfaces of the beds were lightly turned using a garden fork to promote water infiltration. Surface mixing was then implemented every 15 days until completion. Where compaction occurred, a series of holes were dug down into the beds and filled with vermicast. This was implemented in an attempt to promote water and oxygen infiltration and the penetration of earthworms deeper into the beds. This also coincided with weekly measurements of litter conversion.

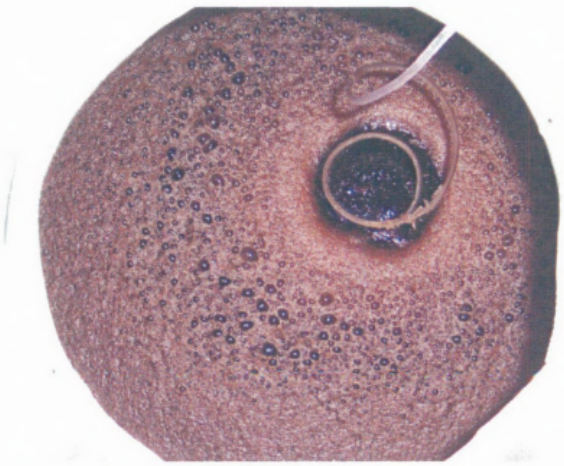
Every 7 days two small cores were dug down through the vermicast layer in both commercial beds, to determine how fast conversion was occurring. Cores were dug in different locations due to the possibility that previous inspections would have improved oxygenation, misrepresenting the conversion of litter. By using the maturity of vermicast derived in the laboratory experiments as an example, the height of remaining un-processed litter could be determined. This was achieved by running a horizontal string line out from a steel post of a known height and then measuring down from the string to the pale unprocessed litter. The system was concluded when a commercial vermiculturalist examined the vermicast and found it suitable for sale (odour free).

6.2.4.1 Leachate, inoculation tanks and vermi-filtration

Each commercial bed had a gutter around it to promote leachate to flow either into the inoculation tanks or the vermi-filtration beds (Figure 6.1, Figure 6.9 a & b and Figure 6.11 b). The tanks were fitted with a large aquarium air pump to continuously oxygenate the leachate

and promote aerobic microbial populations (Figure 6.11 a). Initially, 50 l of leachate was collected in each tank, then filled with fresh water and oxygenated. Excess leachate was pumped onto the vermi-filtration beds and was effectively used instead of chicken pellets to continue earthworm breeding. After 6 weeks the volume of leachate collected in the tanks increased to 200 l and by week 10 the leachate could be used without having to dilute it with fresh water. From this time vermi-filtration was not required as all liquids were then re-used on the commercial beds.

The inoculant supplied by The Worm Man® was the same as that used in the laboratory experiments. The inoculant was added directly to the tanks using the same approach as the smaller inoculation experiment. To avoid clogging the pump, the inoculant was first added to a bucket of water, mixed for 5 minutes, strained and the liquid then added to the tanks. Approximately 20 l of liquid was left remaining in the tank so as to inoculate the next batch of leachate. Inoculation attempted to encourage microbial populations in the substrate; however detailed microbial analysis of the liquid inoculant was not investigated.



(a) 29 July 2006

(b) 29 July 2006

Figure 6.11 (a) Oxygenating inoculation liquids, and (b) tanks, centrifugal pump (foreground) and commercial beds that are slightly elevated and draining back towards the tanks (background)

6.3 Results

Commercial grade odour free vermicast was generated from litter in 108 days, and was visually and chemically similar to vermicast generated in the laboratory experiments (Figure 6.12 a, b & c and Table 6.2). The conversion rate of litter into vermicast was slower at the beginning and end of the process (Figure 6.13) and the lower 10-15 cm of each bed were not fully processed when the trial concluded. A total of 39 m^3, including 4 m^3 of bedding and 35 m^3 of litter (Table 6.1) was reduced in volume to between 27-29 m^3, showing a reduction in litter volume between 25-30%. It was estimated that approximately 1000-2000 kg of *E. andrei* were available for harvest from each bed at the time of completion, as well as a large quantity of unhatched cocoons (Figure 6.12 d and Figure 6.14).

(a) 30 October 2006

(b) 30 October 2006

(c) 30 October 2006

(d) 30 October 2006

Figure 6.12 (a) Friable vermicast at completion, (b) moisture difference with surface, (c) weeds on bed surface and (d) vermicast densely populated with *E. andrei*

Table 6.2 Comparison of the mean chemical concentrations in litter before and after conversion into vermicast based on dry weight

	N	P	Ca	K	Mg	S	Na	Fe	Al	Zn	Mn	Cu
						g/kg						
Litter	30.2	24.4	34.5	18.0	7.6	5.9	5.3	0.66	0.73	0.51	0.46	0.11
Vermicast	20.8	33.1	53.8	4.4	12.3	4.6	1.8	3.43	2.23	0.75	1.24	0.19
Laboratory vermicast*	21.1	34.2	48.2	5.2	10.1	5.1	2.3	2.9	2.01	0.69	1.12	0.18

*Laboratory vermicast was not derived from the same batch of litter used to produce commercial vermicast at Laureldale

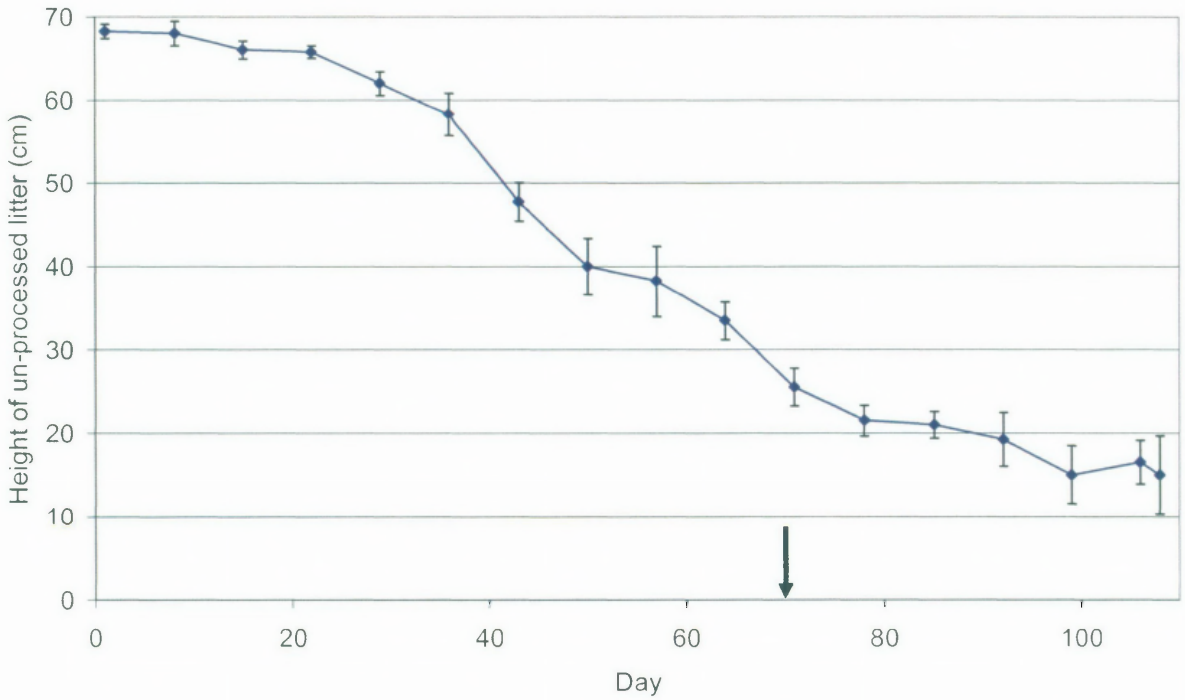


Figure 6.13 Mean height of visually un-processed litter over the 108 days the system ran (±SE)
Arrow indicates when vermi-filtration was concluded

Parameters which may affect the commercial viability of this on-site vermiculture trial ranged from the control of wild birds and weeds, odour control and seasonal effects like temperature. Ibis and magpies were particularly destructive when covers were moved during windy days, as they scratched material into the gutters when searching for earthworms. Also, as the beds matured the amount of weeds germinating on top of the beds increased, even under the shade cloth (Figure 6.12 b & c). It was speculated that the inoculated water reduced the odour of leachate in gutters that surrounded the commercial beds. While both cold nights (frost) and hot days resulted in the earthworms occupying regions lower in the substrate.

Figure 6.14 Unhatched cocoons on surface of commercial beds at completion

6.4 Discussion

Using the same vermiculture techniques developed in the laboratory experiments, litter from a commercial shed (70 m^3) was converted into 52-58 m^3 of vermicast in 108 days. This was two months longer than the fastest litter conversion time reached in the laboratory experiments (Section 4.3.3). The reasons for this increase in time could have been due to a number of factors. Firstly, the greater depth of litter (compaction) as the distance earthworms had to penetrate was 70 cm as apposed to 6-7 cm in the laboratory experiments. Secondly, the proportionally smaller percentage of *E. andrei* earthworms used reducing vermi-processing, and finally starting the trial in winter.

It was evident from observations that compaction of litter occurred towards the base of the bed, and could have been responsible for litter conversion becoming retarded towards the end of the trial. It was possible that compaction limited the amount of oxygen reaching deeper into the bed, which in turn would have reduced the proliferation of aerobic microbes (earthworm food). It was also difficult to determine the depth of un-processed litter towards the end of the trial as colour differentiations could not be accurately made between the vermicast and litter. This was why the lower 10-15 cm of the commercial beds was not considered to be fully processed (Figure 6.13).

The issue of compaction was overcome to some extent by digging a series of columns in the bed which were then filled with vermicast so as to allow the vertical movement and subsequent sideways penetration of earthworms. This procedure was unpleasant and could be easily avoided by placing 30 cm (diameter) x 1 m long 'aeration piping' into the beds before the litter was applied (Figure 6.15). A more expensive approach could be the use of forced aeration (Figure 6.15), similar to approaches used by composting facilities (Tiquia and Tam 2002). Without minimising the effects of compaction the depth of litter may have to be reduced, therefore the surface area of the beds would increase, which in turn increases the area of land required to process the same volume of litter.

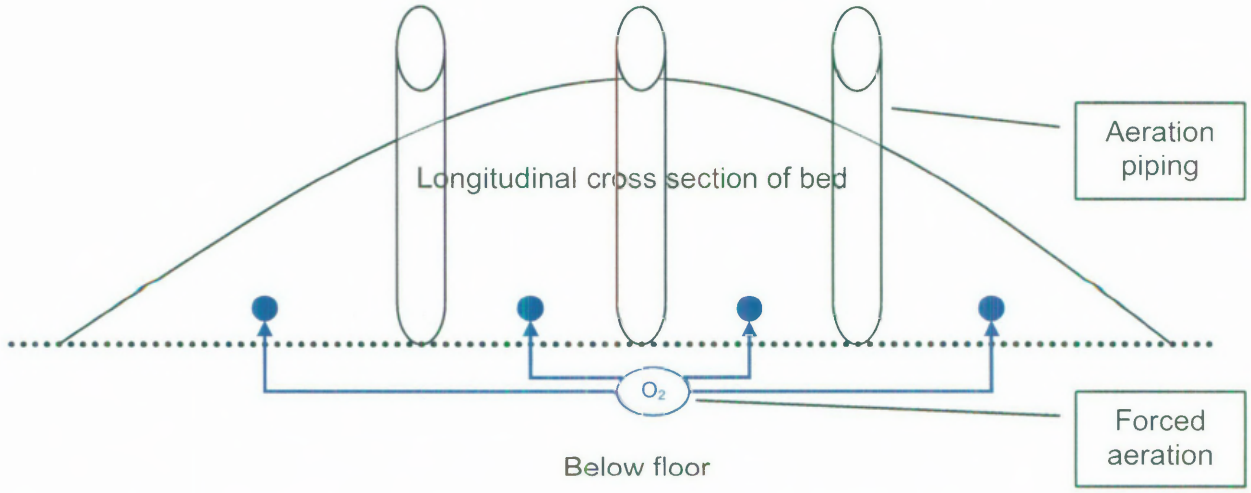


Figure 6.15 Diagrammatic example of aeration piping and forced aeration suitable for this batch flow system

Not only did using a deeper layer of litter lead to compaction but using proportionally less earthworms than in the laboratory experiments was also a factor. The litter to earthworm loading rate in laboratory experiments was 5.3:1 (19%) in contrast to 35:1 (3%) in the field trial. Initially it was indented to use proportionally the same quantity of earthworms in the field trial as the laboratory experiments. However due to logistical issues of producing the required quantity in the timeframe of this study, the proportion was reduced. Both the mechanical and microbial affects of earthworms (vermi-processing) were less in the field. By increasing the mass of earthworms either initially or once the system became more stable, the litter conversion rate could be increased. This is not unreasonable as a commercial operation should have excess earthworms and cocoons at the end of each cycle (Figure 6.19 & Figure 6.14).

Considering that over night temperatures were as low as -7°C and that grass temperatures were on average 4°C lower still (Figure 6.3 & Figure 6.4), this might explain the slow litter conversion at the start of the trial (Figure 6.13). As discussed previously, the gut retention time for *E. andrei* can double with a 10°C decrease in temperature (Jager et al. 2003). Therefore, this system should also be evaluated in warmer climates or initiated during warmer months of the year to determine if the processing time could be shortened. However, these results were encouraging for overseas broiler production operating in cold climates as the system was resilient to low overnight temperatures. Most of Australia's broiler production occurs in warmer climates than Armidale and it is unlikely that this system would normally have to operate in such low temperatures. Importantly, it was evident that the occasional frost (Figure 6.8d) did not affect the viability of this approach as it was observed that earthworms simply move deeper into the more insulated regions of the substrate.

Temperature could have influenced the conversion rate of litter initially, however laboratory experiments showed a necessity for a stabilisation phase. This stabilisation phase required irritants like N and other salts to be washed out of the earthworm's bedding layer, otherwise mortality could occur. Also, time is required for microbial populations to establish (Edwards 1995), and it was speculated that N may also impact on microbial growth (earthworm food). With research into inoculants for vermi-processing the stabilisation phase may be reduced.

For this trial it was not possible to determine if inoculation had an effect on conversion rate of litter into vermicast. However, an important effect the inoculated water had was in reducing the odour of leachate both in the receiving channels and the terminal ponds, which was observed on a number of occasions (Figure 6.9 and Figure 6.11). It was envisaged that a small flush of inoculant, approximately every 20 minutes could alleviate malodour coming from the leachate channels, which was the system's most odorous zone. Further work needs to be conducted in this area as odour control will be a fundamental component of an on-site integrated waste management system's success.

During the first 10 weeks leachate collected from the commercial beds was in excess of requirements, and during this time vermi-filtration beds received and utilised these excessively hot liquids (Figure 6.13). This proved to be a very effective way of utilising the odorous liquids and reiterates how an on-site operation would require enough space and infrastructure for dedicated vermi-filtration beds. Importantly, most of the processes involved including watering (fresh and inoculated) and leachate collection and utilisation, could be automated.

Other issues encountered with the field trial included birds trying to access earthworms and weeds growing on the beds. Both ibis and magpies tried to access the earthworms and in doing so scratched substrate into the leachate channels, which then required removal (Figure 6.6). This could be simply overcome by improving the use of the shade cloth or weed-mat, and ensuring that the whole bed was covered, including the edges which were not covered in this trial. The weeds however only became a problem toward the end of the trial once enough vermicast was available for plants to take root. If the conversion process could be accelerated then this problem with weeds may be reduced.

Although broiler carcasses were not incorporated into this trial it is possible that this vermiculture approach could easily use dead birds as protein for earthworm food, thereby utilising them onsite. One way this could be achieved would be by using some of the aeration pipes (Figure 6.15) as mortality pipes, by inserting birds and back filling with vermicast and then sliding the pipes out. Empty pipes could be left in place and the grower could use them whenever necessary. To achieve complete decomposition of birds a separate mortality bed

may be required, however it could be possible to include this process into the vermi-filtration beds (Figure 6.9).

Results from the trial suggest that a 25-30% reduction in litter volume could be achieved with this vermiculture system. Ndegwa and Thompson (2000) found that one of many advantages of using an on-site vermiculture system is that litter volume is significantly reduced by the time it is converted into vermicast. A greater volume reduction might be possible if the process was allowed to continue, however the end point of this trial was simply when the substrate became suitable for sale (odour free). Further, it can be expected that the longer the substrate is occupied by earthworms, the more likely that the vermicast would contain fewer nutrients, due to microbial consumption and increased earthworm biomass. Since the vermicast would be destined for plant production it may be more important to maintain higher levels of nutrients than reduce its volume further. However, with interest growing in vermimeal production it may be desirable to maximise the mass of earthworms, resulting in their occupation of the substrate for longer periods, which should lead to a finer and more compact vermicast product. Therefore, further studies are required to investigate these issues.

The chemical composition of the commercial and laboratory vermicast was similar (Table 6.2). Nitrogen, P and Na were less concentrated in the vermicast compared to the litter, which was expected due to their high solubility. Removal is likely to have occurred via vertical flow with possible transferral to the vermi-filtration beds. All other elements tested were either similar to litter or slightly more concentrated in the vermicast. For example, P, Ca, Mg, Fe, Al and Mn appeared to be more concentrated in the vermicast (Table 6.2). This may be explained due to the reduction in substrate volume during the process, resulting in a concentration effect of elements with lower solubilities. Iron was shown to be highly variable in litter and may explain why Fe appeared excessively concentrated in vermicast, indicating that an improvement in sampling may be required. The concentration of N in vermicast would be expected to decrease if large quantities of earthworms (protein) were produced and harvested from the same input of litter (Murphy 2005).

Some concerns have been raised over the affect of antibiotics and the broiler industry's operation cycles (time between litter cleanouts) may have on the system. Antibiotics used in animal production and subsequent residue in litter may have a sterilising effect on microbial growth or a direct affect on the earthworms (Murphy 1993). However, experiments using broad spectrum antibiotics in paunch did not inhibit the conversion of paunch into vermicast or earthworm biomass (Dynes 2003). This is encouraging as it is unlikely that the type and concentration of antibiotics in litter would be of concern to *E. andrei* and the efficiency of this vermiculture system. Another important consideration in the trial was the time it would take to

process litter, as the typical broiler is grown out in 6-8 weeks, possibly limiting the vermiculture process to a similar time constraint. This may be less of a concern for the future broiler industry as it is investigating and expected to move towards litter reuse (Runge et al. 2007). Also, if greater space for the on-site vermiculture system was available then the number of beds could be increased, and conversion time would be less important.

Finally, there seems to be a movement away from ground based vermiculture systems due to environmental concerns and infestations of flatworms that are thought to prey on earthworms (Edwards and Steele 1997, Murphy 2005). Therefore installing concrete floors on which the substrate is then placed would eliminate both of these issues. This would however substantially increased capital infrastructure costs and require appropriate engineering designs and relevant regulatory approvals.

6.5 Model

The purpose of the following section was to attempt to predict the likely variation in production of both vermicast and earthworms from a larger commercial vermiculture operation. This model was derived from both the laboratory experiments and the Laureldale field trial results. The first three models describe production from laboratory data which were then extrapolated for a commercial or field scale scenario (Figure 6.16, Figure 6.17 & Figure 6.18). Both water use and bedding choice have been shown to be important for the conversion of litter into vermicast and the quantity of earthworms produced. Therefore, the final model predicted the likely variation in production at a commercial level when varying both watering interval and bedding type (Figure 6.19).

6.5.1 Laboratory experiment model (effect due to water interval)

The following model predicted the likely reduction in litter conversion due to inadequate watering events (Figure 6.16). It was derived from experiment 1, which used 200 ml watering volumes over 23 days of vermi-processing (not to completion). The inputs of earthworms, volume of litter, and coconut husk were constant, however watering interval varied. The output in question was the percentage of litter converted at the end of 23 days.

Input calculations include:

- Earthworms mass = 0.17 kg
- Litter volume = 0.2 x 0.2 x 0.06 = 0.0024 m^3
- Coconut husk bedding volume = 0.2 x 0.2 x 0.05 = 0.002 m^3
- Watering intervals and total water applied over 23 days
    - 0.5/day = 9.2 l
    - 1/day = 4.6 l
    - 2/day = 2.3 l
    - 3/day = 1.5 l
    - 4/day = 1.1 l
    - 5/day = 0.9 l

Output calculations include:

- Percentage conversion of litter after 23 days

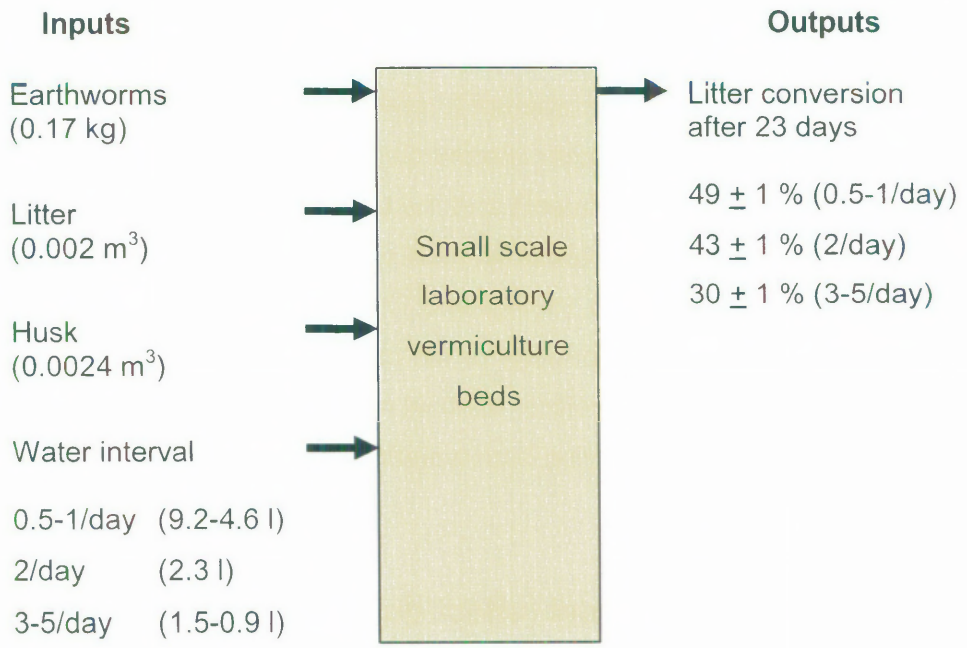


Figure 6.16 Model of inputs used to maintain the system and the conversion of litter as a result of increasing watering interval, derived from the 200 ml treatments in experiment 1 (± SE)

6.5.2 Laboratory experiment model (less than optimum)

The following model showed the effect earthworm bedding had on the conversion of litter and the production of *E. andrei* (Figure 6.17). The data were derived from experiment 4, and was based on results from treatment 2 and ran for 78 days. The input mass of earthworms, volume of litter, coconut husk (bedding), and the volume of water were constant for this and the following model. The variation in the mass and volume of outputs was represented by the SE.

Input calculations include:

- Earthworms mass = 0.17 kg
- Litter volume = 0.2 x 0.2 x 0.06 = 0.0024 m^3
- Coconut husk bedding volume = 0.2 x 0.2 x 0.05 = 0.002 m^3
- Total water added over 78 days = 5.8 l

Output calculations include:

- Earthworms mass = 0.236 ± 0.012 kg
- Vermicast volume = 0.2 x 0.2 x 0.09 = 0.0036 ± 0.0002 m^3
- Total leachate collected over 78 days = 4.9 ± 0.007 l

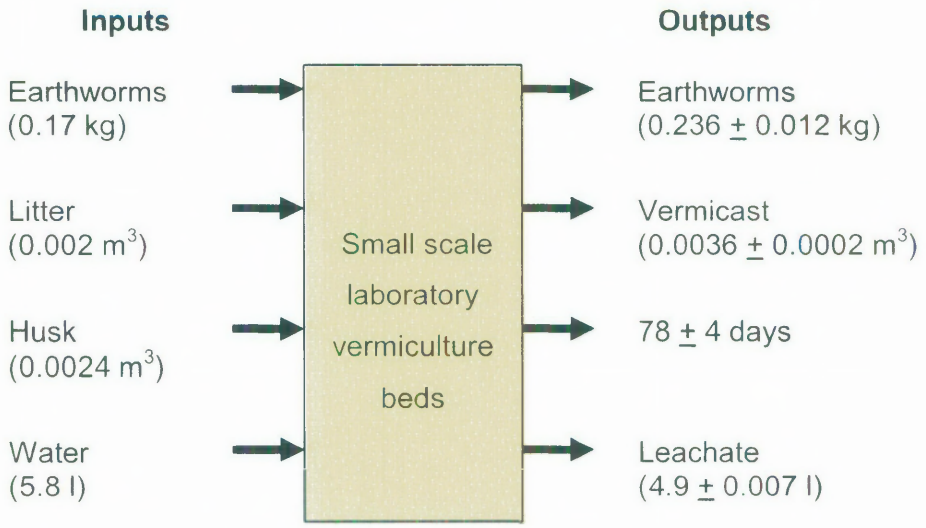


Figure 6.17 Model of inputs and outputs from experiment 4 using coconut husk bedding over 78 days (± SE)

6.5.3 Laboratory experiment model (optimum)

The final laboratory model highlights that selecting the right earthworm bedding could improve litter conversion and earthworm production (Figure 6.18). The data were also derived from experiment 4, however this time it was based on treatment 7. This treatment produced the maximum biomass of earthworms recorded in all of the laboratory experiments, and ran for 44 days. The variation in mass and volume of outputs was represented by the SE.

Input calculations include:

- Earthworms mass = 0.17 kg
- Litter volume = 0.2 x 0.2 x 0.06 = 0.0024 m^3
- Vermicast bedding volume = 0.2 x 0.2 x 0.05 = 0.002 m^3
- Total water added over 44 days = 4.7 l

Output calculations include:

- Earthworms mass = 0.413 ± 0.005 kg
- Vermicast volume = 0.2 x 0.2 x 0.08 = 0.0032 ± 0.0002 m^3
- Total leachate collected over 44 days = 3.8 ± 0.0045 l

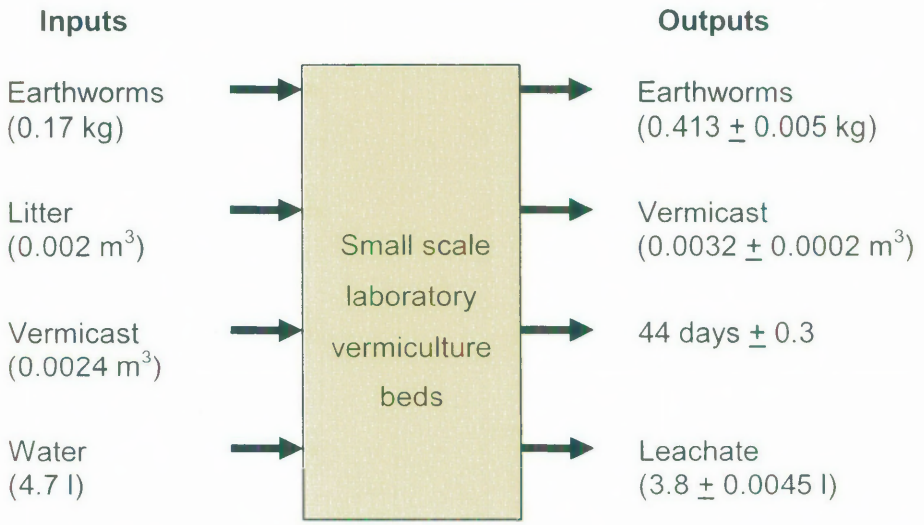


Figure 6.18 Model of inputs and outputs from experiment 4 using vermicast bedding over 44 days (± SE)

6.5.4 Commercial field scale model (based on half a shed)

The commercial field scale model was extrapolated from the laboratory models and results from the Laureldale field trial (Figure 6.19). It showed that conversion of litter into vermicast and the production of earthworms was highly variable. However, if operating at a similar efficiency as achieved in the best performing laboratory systems, vermimeal production could also become a viable option.

There were three assumptions, firstly that by initially using a proportionally similar mass of earthworms as the laboratory experiments (5.3:1 litter:earthworm), the same production levels of *E. andrei* could be achieved at a commercial scale. Secondly, the volume of vermicast at the end of the process was similar irrespective of the time it took to reach completion and was based on using 4 m^3 of earthworm bedding. Thirdly, a yet to be determined quantity of vermicast bedding could provide a suitable environment for the larger input of earthworms used in this model, compared to the quantity used in the field trial. This could also influence the volume of vermicast at the end.

Input calculations include:

- Earthworms mass = 0.17 kg / 0.9 kg x 17500 kg = 3306 kg
- Litter volume = 35 m^3
- Vermicast bedding volume = 8 m^3
- Total water added
    - Husk - over 216 days = 28.3 kl
    - Vermicast - over 108 days = 19.5 kl

Output calculations include:

- Earthworms mass
  - Husk = 0.236 kg / 0.9 kg x 17500 kg = 4585 kg
  - Vermicast = 0.413 kg / 0.9 kg x 17500 kg = 8031 kg
- Vermicast volume
  - 25-30% reduction = 27-29 m^3 (end area method)
- Conversion rate difference
  - Vermicast relative to husk = 100 - (44 days/78 days x 100)
    = 44% faster litter conversion

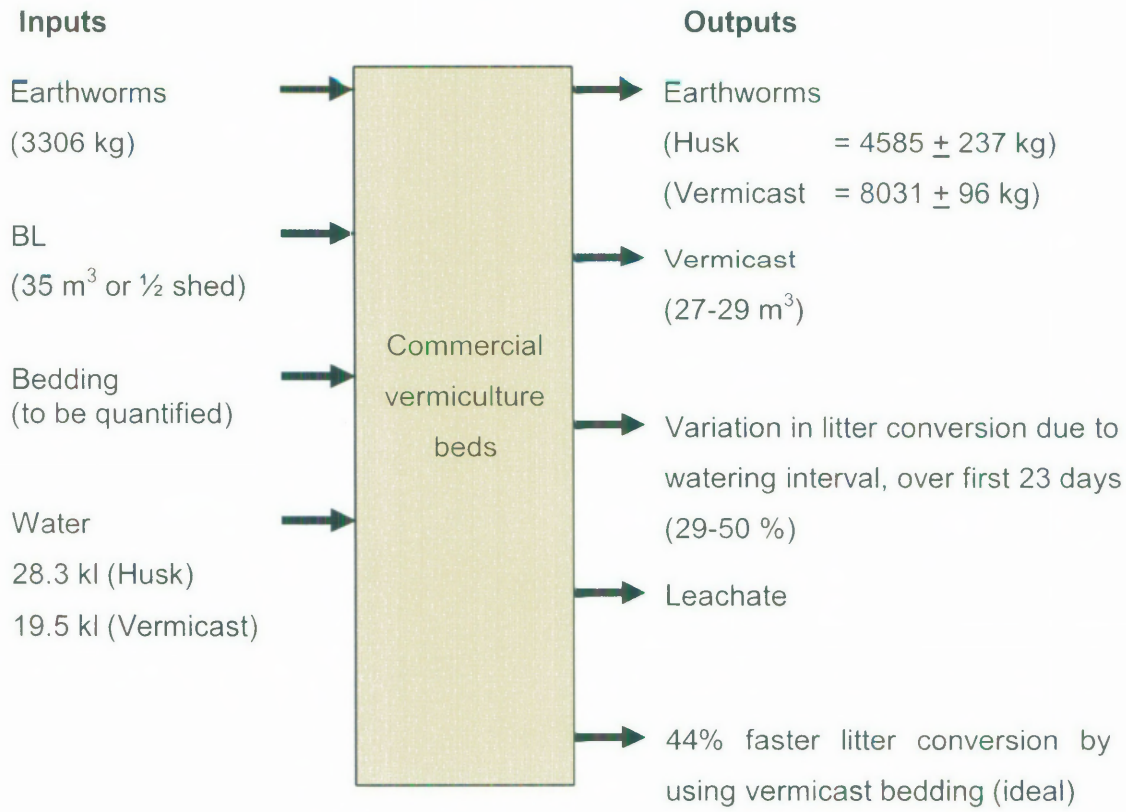


Figure 6.19 Commercial field scale model of the inputs and the likely variation of outputs by combining optimal parameters from both laboratory experiments and the Laureldale field trial

This model predicted that when the system was operating at optimal production levels, 8031 kg of earthworms would be available for harvest after 35 m^3 of litter is vermi-processed (Figure 6.19). Therefore if the starting earthworm input for the system was 3306 kg, then there would be 4725 kg of earthworms available for sale off-site, which could then be processed into vermimeal. This prediction was not unreasonable as it was estimated that 1000-2000 kg of earthworms were available for harvest from the trial (35 m^3 of litter), which was a first attempt at processing fresh litter at this large scale.

There were 27-29 m^3 of vermicast available which should have a similar value as a composted product which complements the vermimeal value-adding opportunity. However, the proportion of vermicast required for preparation of the earthworm bedding layer for the following batch of litter was not determined. In conclusion, these were encouraging outcomes from a waste management perspective as they improve the economic viability of using vermiculture to process litter. It was envisaged that Australian integrators could use this model to determine the economic viability of this approach. For example, if fish and beef meal were comparable in value to vermimeal then the model could help formulate the likely income integrators could expect from vermimeal production.