Environmental RTDI Programme 2000–2006

Production of Organo-mineral Fertilisers from Mixtures of Composted Pig Slurry Solids and Other Biodegradable Wastes

(2000-LS-1b-M2)

Final Report

Prepared for the Environmental Protection Agency

by

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Executive Summary

This project was one of the large-scale integrated projects undertaken in the Environmentally Sustainable Conversion Options for Large Volume Organic Wastes in Ireland, forming part of the Environmental RTDI programme of the National Development Plan 2000–2006. It was undertaken by a consortium of public organisations and private businesses with 50% co-funding from the Environmental Protection Agency and the Department of the Environment and Local Government.

The project examined a potential solution to some aspects of the problem of slurry disposal from large-scale intensive pig units and consisted of three distinct phases:

(i) Mechanical separation of pig slurry solids

(ii) Composting pig solids with other biodegradable wastes, and

(iii) Granulation of compost/mineral fertiliser mixtures to produce organo–mineral fertilisers.

It was co-ordinated by Mr. T.A. Stewart, Agricultural Consultant with Philip Farrelly & Co., Navan, Co. Meath, acting as the Lead Partner.

Project deliverables included:

- The production of up to 50 tonnes of separated pig slurry solids for composting with other locally available biodegradable wastes
- Composting eight batches of separated pig slurry solids with varying combinations of other wastes, each batch consisting of 4–10 tonnes
- Producing up to eight granulated fertiliser batches from the composts made
- Undertaking a market evaluation of the fertiliser products produced
- Carrying out a range of physical, chemical and biological tests on the composts and fertilisers produced, and
- Assessing the economic viability of the treatment process examined and its potential environmental impact.

A key output of this project was a report outlining the findings of the study describing the results obtained from mechanically separating pig slurry, composting the separated solids fraction with other locally available biodegradable wastes and combining the mature composts with mineral fertilisers to produce granulated organo–mineral fertilisers suitable for the amenity grassland market.

Mechanical separation of pig slurry was carried out on a commercial pig unit at Little Grange, Co. Meath, using a Carier Rotoscreen Model RS1000 separator, fitted with a 1.5-mm perforated drum screen.

A total of 43 tonnes of fresh pig slurry solids was produced and transported to a warehouse belonging to McCartney Contractors Ltd., located at Rosehill, Mullagh, Co. Cavan, where it was stored prior to mixing with other biodegradable wastes. The solids had a mean DM of 26.2%, a total N of 2.92% (43% as ammonia) and a C/N ratio of 24.

Mechanical separation removed 21% of the slurry dry matter but had a negligible effect on the volume of separated liquid produced. Solids removal reduced the total N of the liquid fraction by 13% but had no effect on the ammonia content of the liquid. Interestingly, the total P content of the liquid fraction was reduced by 49% on removal of the solids by mechanical separation while the soluble residual P content was reduced by only 5%. These findings are in line with published research on mechanical separation and have implications for intensive pig units struggling to find suitable land on which to spread their slurry.

The solids consisted mostly of undigested feed and pig hairs and had a low bulk density of 387 g/l. For composting purposes, the separated pig solids fell short of the preferred composting criteria of 50–60% moisture and a C/N ratio of 25:1–30:1. Consequently, they required the addition of suitable biodegradable materials capable of improving the porosity and increasing the carbon to nitrogen ratio of the mix.

A range of biodegradable agricultural and other wastes was acquired for mixing with the pig solids. These included poultry litter, spent mushroom compost, wood shavings, chopped straw, cocoa shells and shredded newsprint. The Northern Ireland Department of Agriculture's Horticultural Centre at Loughgall, Co. Armagh was engaged to prepare compost batch formulations and conduct analysis of compost components and resulting composts. Identification of pathogens present in the pig slurry was sub-contracted to the Northern Ireland Public Health Laboratory which also monitored their survival through the composting process.

A Keenan 170 FP Klassik 2 forage wagon was used to prepare a total of ten compost mixes which were gathered in piles ranging from 2 to 10 tonnes on the concrete floor of the McCartney warehouse. A daily record of compost temperatures was kept throughout the succeeding 9 months and the piles were turned approximately every 10–14 days during this time.

Conversion of the compost to a granular fertiliser was carried out in a small-scale pilot fertiliser plant supplied by Advanced Processes Inc., Pittsburgh, Pennsylvania, USA. The primary parts of this equipment consisted of a mixing unit known as a Turbulator that is used to mix the fertiliser ingredients, add a binding agent and initiate the agglomeration process. The partially formed granules from the Turbulator pass to a revolving disc that is used to grow the granules and determine their size. A drier is used to stabilise and harden the granules so formed.

Results from the present project suggest that satisfactory composts can be made from mixes containing widely varying proportions of pig solids and other biodegradable agricultural wastes, provided the basic composting parameters of C/N ratio, moisture and porosity are met. The compost mixes took 6–9 months to reach maturity (determined by a return to ambient temperature) which was longer than expected. However, a fully mature compost may not be necessary for conversion to granular fertiliser.

Poultry litter proved to be a useful amendment, acting as a source of N, increasing the dry matter content and improving the physical structure of the mix. Spent mushroom compost was a poorer amendment than the poultry litter but was still worth including in small amounts. Shredded newsprint proved to be the best carbon source when incorporated at around 10% of the mix by fresh weight. It promotes an early rise in compost temperature but must be moistened prior to inclusion. Wood shavings and chopped straw were of little benefit to the mixes where poultry litter made up a significant component. Cocoa shells are also an excellent source of carbon. They improve mix porosity and break down quickly. However, they suffer from a major drawback in being light and bulky and consequently very expensive to transport any distance.

The pig slurry used in the present project contained the pathogenic organisms *Salmonella*, *Campylobacter* and *Cryptosporidium* but was free of *Shigella*, *E. coli* 01257 and *Yersinia.* All the compost mixes tested achieved temperatures exceeding 55°C, with several rising to 70°C in the first few weeks of composting, with the result that all the composts made were found to be free of the range of pathogens for which tests were carried out.

The Turbulator and Disc Pelletiser was unable to properly granulate the mature compost without first reducing its moisture content from 40%+ to around 20% and removing all material with a particle size >2 mm from the compost.

The composts produced had a typical nutrient content of 2.33% total N, 1.63% P and 3.18% K which is much too low for direct use as an agricultural fertiliser and in nutrient terms could not bear the cost of granulation. Feather meal and dried blood were examined as possible N sources and, at a 50% inclusion rate, were found to lower the moisture content of the mix, making granulation easier. They also increased the organic N content of the mix.

Additional mineral fertilisers such as sulphate of ammonia, rock phosphate and sulphate of potash were needed in varying proportions to formulate suitable nutrient ratios for a range of applications, particularly amenity grassland where a slow release type fertiliser is desirable. It proved possible to granulate such compost/mineral fertiliser mixes but a question mark remains over the economic viability of commercially producing such products for the general agricultural market. Instead, any future commercialisation of the project outcomes should be targeted at the horticultural and amenity grassland market which attract substantially higher market prices than the agricultural market.

Granulated fertiliser produced during the project was tested on two Irish golf courses where it elicited favourable comment from greenkeepers. Granule size, colour, hardness and freedom from dust were considered to be equal, if not better than products currently available on the amenity grassland market.

1 Introduction

This project was carried out as part of the ERTDI programme of the National Development Plan 2000–2006. It was one of the large-scale integrated projects undertaken in the Environmentally Sustainable Conversion Options for Large Volume organic Wastes in Ireland, entitled Production of compost-based fertiliser products from pig manure as an alternative to land-spreading in slurry form (Ref. 2000-LS-1b-M2).

The project was developmental in nature rather than applied research. It was undertaken by a consortium of private and public organisations who provided 50% of the co-funding, the other 50% coming from the Environmental Protection Agency and the Department of the Environment and Local Government. It started officially on 1 September 2001 and had a life span of 18 months, but because of delays during the programme, it was not completed until November 2003.

1.1 Background

The disposal of manure from large-scale intensive pig units is a major problem in certain areas of Ireland where there are large concentrations of pigs. Counties Cork, Cavan and Tipperary have the greatest number of pig finishing units, accounting for almost 50% of the pig places available (Tuite, P., Teagasc Pig Census, personal communication, 2003). The Draft Waste Management Plan for the North East Region 1999–2004 identified pig slurry (501,590 tonnes), poultry manure (217,110 tonnes) and spent mushroom compost (SMC; 121,665 tonnes) as the main contributors to the 3.5 million tonnes of waste generated annually in the region (MC O'Sullivan & Co. Ltd., 1999).

Manure from pig units is universally handled in slurry form with land-spreading being the most common method of disposal. Few units have sufficient land attached to cope with the nutrient loading contained in the slurry, particularly nitrogen and phosphate, and insufficient land for spreading in the vicinity of the pig units has resulted in nutrient overload of the available land with the consequent loss of nutrients to local watercourses through leaching and surface run-off. A 1994 Teagasc study, for example, calculated the phosphorus surplus in Co. Monaghan farms to be 28 kg P/ha and this was regarded as an underestimate (MC O'Sullivan & Co. Ltd., 1999).

To date, alternative treatment processes commonly in use for the treatment of sludges and dirty water have not found much favour with farmers and intensive livestock producers. Capital and running costs associated with such treatment processes have been the main deterrent, along with a lack of expertise needed to operate the biological processes involved. Increasing pressure from EU and local environmental legislation is adding to the need to find alternative disposal methods that are less dependent on surface spreading on agricultural land. Prominent among the pieces of legislation affecting land-spreading of animal manures are The Nitrates Directive (CEC, 1991), The IPPC Directive (CEC, 1996), IPC Licensing (Oireachtas, 1992) and The Water Framework Directive (CEC, 2000).

1.2 Concepts Behind Project

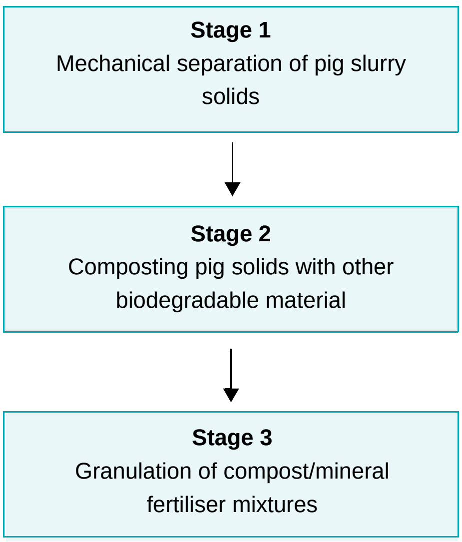
The thought process leading to the work carried out in this project was stimulated by a visit to a pig finishing unit in the Frazer Valley in British Columbia, Canada. In this novel unit, pigs are housed on solid floors in pens bedded with sawdust. The natural habit of the pig to keep its lying area clean is exploited in the pen design. Pigs are trained to dung and urinate at the end of the pen next the outer wall of the house and to use their snouts to push the manure-sodden sawdust out of the pen into a narrow passage between the pen wall and the outer wall. A mechanical scraper running in the dung passage removes the soiled bedding from the house; it is then transferred to a composting facility where it is converted into a growing medium for horticultural use. The usual problem of boredom encountered in pigs housed on slatted floors is alleviated by encouraging the pigs to spread the sawdust themselves around the pen floor. The sawdust absorbs the urine with the result that an ammonia-free atmosphere is produced resulting in improved growth rates compared with slatted-floor housing. All manure is handled in solid form eliminating the need for slurry tanks (Luymes, 1995, 1997).

Unfortunately, this unusual approach to pig housing could not be easily transferred to Ireland without major structural alteration to existing piggeries. It also depends on a readily available source of low-cost bedding such as sawdust as is the case in the Vancouver area of Canada but not here in Ireland. Thoughts then turned to what simple alternative treatment processes might be applied to slurry collected in tanks from conventional slatted-floor pig houses.

Mechanical separation of solids from the slurry is a well-documented option providing a solid material suitable for processing, for example, by composting with other biodegradable materials. The resulting compost could be regarded as a low-grade organic fertiliser, a soil amendment material, or a growing medium for plants if blended with other materials such as peat.

To take the process one step further, it should be possible to produce an organic-based fertiliser by adding additional nutrients to the compost and granulating the mixture in a manner that emulates mineral-based fertilisers currently available. Such an approach should be achievable by harnessing the agglomeration-type technology applied elsewhere to other fine particle solid wastes.

Consequently, a three-stage process was proposed as the basis for the present project, namely:



1.3 Project Consortium

A consortium of private organisations and government bodies were selected for the particular expertise and experience that they could bring to the project. They are listed in Table 1.1. A total of six private companies were involved along with the Northern Ireland Department of Agriculture and the Public Health Laboratory, Belfast. Three of the private companies were based in the Irish Republic, two in Northern Ireland and one in the USA. The contribution each made to the project is also detailed in Table 1.1.

1.4 Project Aims and Deliverables

The overall aim of the project was to develop and evaluate the market potential of a range of compost-based fertiliser products derived from mixtures of separated pig slurry solids and other biodegradable wastes.

The main deliverables listed in the project proposal were are follows:

- Produce up to 50 tonnes of separated pig slurry solids for composting with other locally available biodegradable wastes
- Compost eight batches of separated pig solids with varying combinations of other biodegradable wastes, each batch to be approximately 4 tonnes
- Produce up to eight granulated fertiliser batches from the composts made
- Undertake a market evaluation of the fertiliser products produced
- Perform a range of physical, chemical and biological tests on the composts and fertilisers produced
- Assess the economic viability of the treatment process examined and its potential environmental impact.

The project divided naturally into four distinct phases, namely:

1. Production of separated pig slurry solids
2. Composting of separated pig solids with other biodegradable wastes
3. Fertiliser manufacture
4. Evaluation of fertiliser products.

Table 1. 1. Private organisations and government bodies involved in the project.

Organisation	Staff involved	Project duties	Partner background
Partner 1 Phillip Farrelly & Co. 2 Kennedy Rd., Navan, Co. Meath	Mr. P. Farrelly Mr. K. McEnteggart	• Lead Partner • Project financial management • Economic and environmental impact assessment	Leading Irish accountancy and environmental management company dealing mostly with farming community
Partner 2 Mr. Jack Marry, Little Grange, Co. Meath	Mr. J. Marry Mr. M. Carolin Mr. J. Carolin	• Provision of facilities on pig unit and slurry separation	Large-scale pig producer with several minimum-disease pig herds
Partner 3 ApT.Solutions, 2 Castle Manor, Antrim, Co. Antrim BT41 4PL	Mr. T.A. Stewart	• Project co-ordination • Technical expertise on waste management and fertiliser use	Agricultural consultant with wide experience of project management at EU and local level
Partner 4 McCartney Contractors Ltd., Rosehill, Mullagh, Co. Cavan	Mr. A. McCartney Mr. F. Corbally	• Provision of facilities, equipment and staff for composting and fertiliser production • Resourcing raw materials	Extensive experience in handling and disposal of agricultural wastes from poultry industry in Ireland
Partner 5 Dept. of Agriculture, N. Ireland, Horticultural Research Station, Loughgall, Co. Armagh	Dr. J.R. Rao Mrs. M. Kilpatrick Mr. S. Sturgeon	• Technical advice on composting and sampling • Analytical services	Provides specialist service to N. Ireland mushroom industry on compost preparation and mushroom production
Sub-Contract Northern Ireland Public Health Laboratory, City Hospital, Belfast.	Dr. J. Moore Dr. M. Watabe	• Animal and human pathogen analysis • Pathogen risk assessment	Main N. Ireland laboratory dealing with micro-organisms of concern to public health
Partner 6 Advanced Processes Inc., 2097 Duss Ave., Ambridge, PA 15003 Pennsylvania, USA	Mr. J. Zupanc Mr. K. Davis Mr. D.Werner (Enviro+Tech. Ltd.)	• Provision of agglomeration equipment • Technical expertise on granulation	US Company providing innovative solutions which add value to industrial wastes, particularly through application of agglomeration/granulation technology
Partner 7 James Coburn & Son Ltd., 32 Scarva St., Banbridge, Co. Down, BT32 3DD	Mr. B. Bell Mr. D. Redmond	• Evaluation of organic-based fertilisers for amenity grassland use	N. Ireland based company servicing the needs of the amenity grassland market in Ireland with particular emphasis on golf courses

2 Methods and Materials

2.1 Slurry Separation

There are a number of systems available for separating slurry into a nutrient/dry matter-rich fraction and a liquid fraction. These have been reviewed by Burton (1997) and range from simple sedimentation techniques, mechanical screen separators and centrifuges to biological treatment and reverse osmosis. Costs of the techniques employed vary widely reflecting the sophistication and efficiency of the technique. Sedimentation, mechanical screen separation and centrifugation are simple techniques that are cost effective, while biological treatments, evaporation, ultrafiltration and reverse osmosis are complex and expensive techniques (Burton, 1997).

The range of mechanical separators currently on the market is illustrated in Fig. 2.1 and include the bow sieve, double circle bow sieve, sieve belt press, sieve drum press (rotary screen), press screw/auger separator, sieve centrifuge and decanter centrifuge. Nutrient separation efficiency and technical data of common manure separators are given in Table 2.1 (after Burton and Turner, 2003). Costs range from €25,000 for basic screening packages to €100,000 or more for centrifuges (Burton and Turner, 2003).

The mechanical separator used in this project was the Rotoscreen type supplied by Carier (Model RS1000) and provided with a 1.5-mm perforated drum screen. This

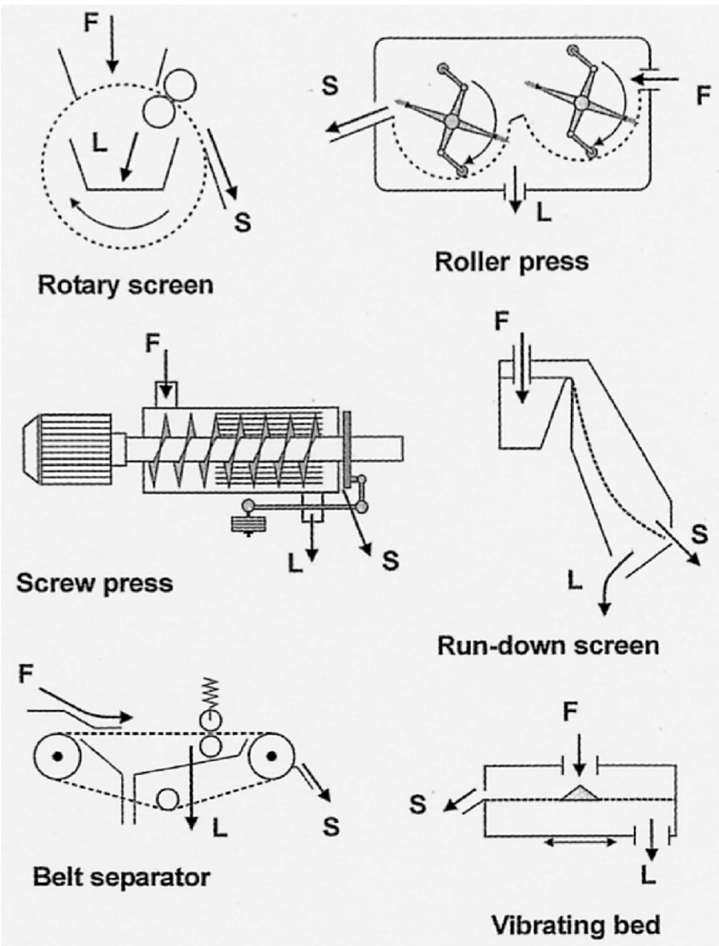


Figure 2.1. Selection of common separator designs (after Burton and Turner, 2003). F, feed manure; L, flow of screened liquid; S, flow of solids or concentrate.

Table 2.1. Nutrient separation efficiency and technical data of common manure separators (after Burton and Turner, 2003).

	Belt press	Sieve drum	Screw press	Sieve centrifuge	Decanter centrifuge
Flow rate (m^3/h)	3.3	8–20	4–18	1.9–5.5	5–15
Separation efficiency (%)					
Dry matter	56	20–62	20–65	13–52	54–68
Nitrogen	32	10–25	5–28	6–30	20–40
Phosphorus	29	10–26	7–33	6–24	52–78
Potassium	27	17	5–18	6–36	5–20
Volume reduction (%)	29	10–25	5–25	7–26	13–29
Energy required kWh/m^3	0.7	1	0.5–2.0	2.2–6.7	2.0–5.3

make was chosen because of its widespread use in the United Kingdom, its reputed reliability, its reasonable cost and the availability of a local representative to advise on its operation.

The separation equipment consisting of a mechanical separator mounted on a gantry and an electrically driven submersible slurry pump were located beside an underground slurry tank on a pig unit belonging to Mr. Jack Marry at Little Grange, Co. Meath (Photograph 2.1). Separated solids were held in a concrete bunker constructed beside the separation equipment and removed weekly to the composting facility. Separated liquid was stored in an overground metal slurry tank. It was removed periodically by local farmers and spread on nearby grassland.

2.2 Preparation of Composts

Composting is defined in a Scottish Agricultural College technical note on *Principles of Composting* as the production of humus from controlled aerobic decomposition of solid organic material (Szmidt, 1997). It depends on the degradation of the material by naturally occurring micro-organisms (bacteria, fungi and actinomycetes). Microbes growing at ambient temperature (mesophiles) begin the degradation process

Photograph 2.1. Project team visiting Marry Pig Unit to view mechanical separator mounted on gantry with submersible electric pump delivering slurry for separation, bunker to hold separated solids and overground tank to hold separated liquid.

within the compost stack. This is a metabolic process which produces heat causing the temperature to rise in the stack. The degradation process continues provided nutrients and oxygen are readily available. The C/N ratio, moisture content and particle size of the material are particularly important as is acidity which should be around 7 at the initial mixing stage (Szmidt, 1997). As the temperature of the stack rises above circa 45°C other microbes (thermophiles) that only grow at high temperatures are stimulated to multiply. These organisms generate further metabolic heat which can take the stack temperature as high as 80°C.

Temperatures in excess of 58°C for at least 12 h are widely considered essential for pasteurisation and elimination of pathogens to be complete (Szmidt, 1997; Epstein, 1997). Oxygen must be available to aid the degradation process which may be provided by mechanical turning or fan-assisted ventilation (Szmidt, 1997).

As the thermophilic action declines, the temperature will drop regardless of aeration. The process then enters a further mesophilic phase where enzymic degradation results in humification of the compost. When the compost returns to ambient temperature, it is typically regarded as mature, although what defines maturity is difficult to state (Szmidt, 1997).

A typical compost stack temperature profile of correctly pasteurised compost is shown in Fig. 2.2.

The biodegradable wastes mixed with the pig solids in this project were chosen from locally available wastes, mostly agricultural in origin. These included poultry litter, SMC, chopped straw, wood shavings, shredded newsprint and cocoa shells. Shredded green waste was not included because of the possible presence of stones and other extraneous material that could damage processing equipment during fertiliser manufacture.

The dry matter or moisture content, nitrogen content and C/N ratio were used to determine the quantity of each component added to an individual mix. The aim was to prepare each mix or batch with an initial moisture content in the preferred range of 50–60% and a C/N ratio of 25–30 as recommended in Rynk (1992).

The ingredients for each mix were homogenised by mixing in a Keenan Feeder Wagon (Photograph 2.2 – Keenan 170 FP Klassik II, Richard Keenan and Co. Ltd., Borris, Co. Carlow, Ireland). They were then stacked in separate piles on a concrete floor in a large enclosed building (28 m × 42 m × 7 m). Each batch or pile was turned periodically during the subsequent 9-month composting phase using a small industrial loader equipped with a mechanical shovel. Individual batches ranged from approximately 2 to 8 tonnes fresh weight.

The temperature of each pile was monitored continuously using temperature probes linked to a Fancom 765 multi-channel data logger (Photograph 2.3). Occasionally, additional water was added to the pile if moisture content measurements indicated that undue drying of the compost was taking place.

Sampling of the raw ingredients and the composts during the composting period for physical, chemical and

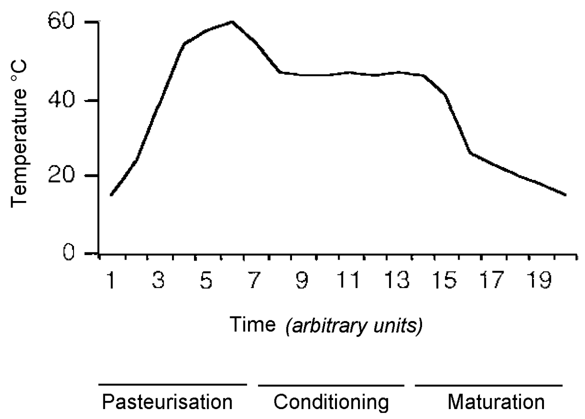


Figure 2.2. Typical compost temperature profile (after Szmidt, 1997).

Photograph 2.2. Keenan Feeder Wagon used to prepare compost mixes.

Photograph 2.3. Compost pile with temperature probe.

pathogen analysis was carried out following the procedures outlined in Leege and Thompson (1997) or those of the Composting Association (2000).

A 10-kg sample was collected from the raw materials and a 1-kg sample of each mix was taken at the start of composting and approximately at monthly intervals thereafter. All fresh samples were thoroughly mixed and duplicate sub-samples oven-dried at 105°C for 24 h to determine moisture content. The dried samples were then ground in a Cyclotec mill (Tecator-1093) to pass through a 0.5-mm mesh screen and used for further chemical analyses. The remaining fresh samples were used to determine ammonia, pH, electrical conductivity and bulk density (Hanson, 1973; MAFF, 1985; BSI, 1990).

The % carbon (C) was calculated using the formula recommended by the Composting Association (2000) namely:

$$\% \text{ C} = 100 - \% \text{ ash} \div 1.72$$

and the C/N ratio by:

$$\% \text{ C} \div \% \text{ total N.}$$

2.3 Microbiological and Molecular Tests

Samples of pig slurry and composts were subjected to standard protocols for identification of *Campylobacter*, *Cryptosporidium*, *E. coli* 0157, *Listeria*, *Salmonella*, *Shigella* and *Yersinia* using methods described in NIPHL (2001). Using cultural and DNA sequencing, the organisms were identified at strain level, depending on the availability of type strains and their data taken together with corresponding molecular database information. Details of methods used are outlined in Appendix 2.

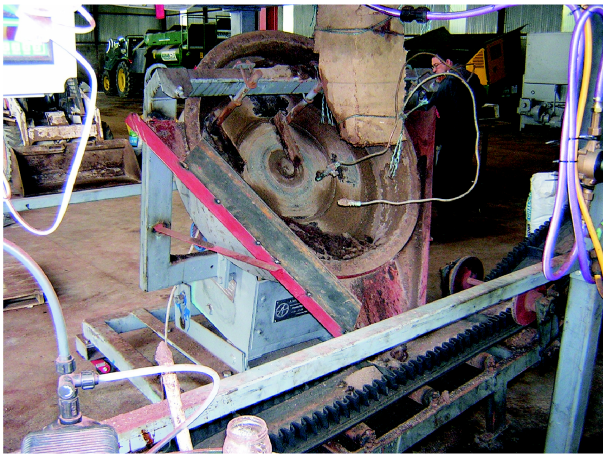
2.4 Fertiliser Manufacture

The process of converting compost into granulated fertiliser was carried out in a pilot fertiliser plant supplied by Advanced Processes Inc., Pittsburgh, Pennsylvania, USA. The plant comprised two key components – the API Turbulator and a shallow pan Disc Pelletiser, along with associated conveyers and a gas-fired moving chain-type drier.

The Turbulator or pin agglomerator is a horizontal stationary shell solids/liquid blender with a rotating agitator or rotor. The rotor consists of a shaft on which metal pins are mounted and which extends axially through the length of the shell with a small clearance between the ends of the pins and the shell. The rotor is driven at approximately 900 rpm which rigorously mixes the materials loaded into the Turbulator with a binding agent, if introduced at this stage, and initiates the agglomeration process.

Mounting the Turbulator on a gantry or platform allows the pellets to fall by gravity onto the shallow pan Disc Pelletiser (Photograph 2.4).

The disc is set at an adjustable angle and rotated slowly so that the feed material with its smaller agglomerates and the nuclei are sifted to the bottom of the tumbling load where, because of greater friction, they are carried to the



Photograph 2.4. Disc Pelletiser used to form fertiliser granules.

highest part of the disc before rolling down in an even stream. Larger agglomerates remain closer to the top layer where they travel shorter paths and are discharged over the rim of the disc. The smallest agglomerates are retained for further growth. Many factors influence the agglomeration process, including the nature of the solids to be pellitised, the particle size distribution, the moisture content of the feed material, the binding agent used and the pelletiser disc settings.

In the present project, a calcium lignosulphonate-type binding agent, Borresperse CAFN, was used during the fertiliser manufacturing process by spraying the binder onto the surface of the granules as they formed on the rotating disc.

This particular binding agent is a brown aqueous solution of moderate viscosity containing 7.0% reducing sugars which is derived from fermented spruce wood sulphate liquor. It is biodegradable and environmentally harmless. Typical applications include a plasticiser for concrete, a water reducer in gypsum board and a dispersant for pesticides.

3 Results

3.1 Slurry Separation

Initially, the slurry used for mechanical separation was drawn from a tank under a slatted weaner house on the pig unit. This slurry was found to be very dilute because of the frequent house washings between batches of piglets. Consequently, the yield of solids in relation to the volume of slurry available was insufficient to meet project requirements and an alternative supply of thicker slurry had to be obtained. This was taken from a tank under a slatted-floor house containing finishing pigs on the pig unit and represented the slurry accumulated over the winter period November to March. The analysis of this slurry, shown in Table 3.1, was typical of the slurry produced from pig units of this type in Ireland as reported by Teagasc (Coulter, 2001).

The unseparated slurry had a mean dry matter content of 4.80% and a range of 1.92–11.28% (Teagasc mean 3.20% DM). The mean total N content was 0.47% with a range of 0.33–0.64% (Teagasc mean 0.46%). Ammonia N made up 72% of the total N content of the slurry. The total P content of the slurry was 1253 mg/l with a range of 95–3130 mg/l (Teagasc mean 900 mg/l). Soluble residual P made up 24% of the total P in the slurry. The mean ash content was 1.22% with a range of 0.51–3.07%.

The separated solids mostly consisted of undigested animal feed and pig hairs. Detailed analyses are given in Table 3.2. The slurry solids had a mean dry matter content of 26.2% (range 23.7–28.5%), a mean pH of 8.62 (range 8.40–8.80) and a mean total N of 2.92% in DM (range 2.62–3.50), 43% of which was in ammonia form. The mean ash content was 13.9% in DM (range 10.9–21.5%) and the mean electrical conductivity (EC) was 1207 µS/cm (range 945–1461 µS/cm). Bulk density averaged 387 g/l (range 248–467 g/l) while the solids had a mean C/N ratio of 24 (range 20–26).

Table 3.2. Analysis of separated pig slurry solids (12 samples).

Determination	Mean	Range
Dry matter (%)	26.2	23.7–28.5
pH	8.62	8.40–8.80
Total N (% in DM)	2.92	2.62–3.50
Ammonia N (% in DM)	1.27	1.01–1.48
Ash (% in DM)	13.9	10.9–21.5
C/N ratio	24	20–26
EC (electricity cond., µS/cm)	1207	945–1461
Bulk density (g/l)	387	248–467

Detailed analyses of the liquid fraction separated from the pig slurry are given in Table 3.3. It had a mean dry matter content of 3.79%, a total N of 0.46% (of which 74% was ammonia N). The mean total P content was 637 mg/l (44% of which was residual soluble P). It had a mean BOD_5 of 7456 (range 5220–8030).

A composite sample of unseparated pig slurry and separated liquid was analysed for a range of minerals and

Table 3.1. Unseparated pig slurry analysis (10 samples).

Determination	Mean	Range	Teagasc*
Dry matter (%)	4.80	1.92–11.28	3.20
Total N (% in fresh weight)	0.47	0.33–0.64	0.46
Ammonia N (% in fresh weight)	0.34	0.31–0.39	–
Total phosphate (P in mg/l)	1253	95–3130	900
Soluble residual phosphate (P in mg/l)	298	151–594	–
Potassium (K in mg/l)	–	–	2600
Ash (% in DM)	1.22	0.51–3.07	–

***Coulter, 2001.**

Table 3.3. Analysis of separated liquid from pig slurry (10 samples).

Determination	Mean	Range
Dry matter (%)	3.79	1.74–5.77
Total N (% in fresh weight)	0.46	0.36–0.61
Ammonia N (% in fresh weight)	0.34	0.29–0.42
Total phosphate (P in mg/l)	637	58–1890
Residual soluble phosphate (P in mg/l)	282	172–397
Ash (% in DM)	1.12	0.45–1.79
BOD_5	7456	5220–8030

heavy metals. The results given in Table 3.4 indicate little difference between the two samples and that apart from copper and zinc derived from the animal feed, the levels of heavy metals in both samples were negligible.

The mineral content of the pig slurry solids is given in Table 3.5 and indicates that the solids were highest in calcium, magnesium and potassium and low in the other minerals measured.

Table 3.4. Mineral and heavy metal content of unseparated pig slurry and separated slurry liquid (composite sample).

Determination	Unseparated pig slurry	Separated slurry liquid
pH	7.9	8.0
Total solids (g/l)	11.6	11.4
Total nitrogen (g/l)	3.74	3.61
Ammonia-N (g/l)	3.31	3.30
Total phosphorus (P in mg/l)	175	178
Total magnesium (Mg in mg/l)	27.6	29.8
Total potassium (K in g/l)	1.81	1.74
Total copper (mg/l)	9.0	9.6
Chromium (mg/l)	<1.00	<1.00
Cadmium (mg/l)	<0.02	<0.02
Lead (mg/l)	<0.70	<0.70
Nickel (mg/l)	<0.50	<0.50
Total zinc (mg/l)	11.4	12.4
Mercury (mg/l)	<0.01	<0.01
Total ash (g/l)	5.8	5.6

Table 3.5. Mineral content of pig slurry solids (four samples).

Determination (g/kg)	Mean	Range
Copper	0.22	0.18–0.31
Manganese	0.73	0.63–0.93
Iron	1.67	1.11–2.69
Zinc	0.44	0.38–0.59
Calcium	63.7	53.4–78.1
Magnesium	7.05	5.78–10.02
Potassium	7.99	5.13–11.68
Sodium	0.99	0.86–1.28
Phosphorus	0.99	0.86–1.28

Assuming that mechanical separation of the solids from pig slurry has a negligible effect on the volume of liquid produced, mechanical separation in this project removed 21% of the slurry dry matter, 13% of the total N and had no effect on the ammonia N content of the liquid. Solids removal had a major effect on the total P content of the separated liquid reducing it by 49% while the soluble residual P was reduced by only 5%.

A total of 43 tonnes of fresh pig solids was produced during the separation phase of the project, all of which was utilised in the compost mixes. While it was not possible to accurately calculate the yield of fresh solids per m^3 of slurry separated, an approximate estimate assuming a pumping rate of 20 m^3/h suggested a yield of around 26 tonnes fresh solids per 1000 m^3 of slurry processed.

3.2 Compost Mixtures

A total of ten compost mixes were made containing pig slurry solids and varying proportions of other biodegradable wastes. These included poultry litter, SMC, straw, wood shavings, cocoa shells and shredded newsprint. The quantities of the individual components of each mix on a fresh weight basis are given in Table 3.6 and their proportions on a percentage basis are given in Table 3.7.

Mixes were formulated to achieve a moisture content in the range of 50–65%, a C/N ratio of 18 or higher and a bulk density of 400–600 g/l.

Individual batches ranged in size from 1877 kg to 8015 kg. All the batches contained pig solids, the fresh weight

Table 3.6. Quantities of biodegradable materials mixed with pig slurry solids in each of the composted batches (kg fresh weight).

Ingredient	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8	Batch 9	Batch 10
Pig solids	1500	3950	5010	2280	1475	1530	1570	1200	1200	3280
Poultry litter	325	960	710	400	–	570	2045	2000	1750	890
Spent mushroom compost	645	–	–	–	–	750	2085	430	–	–
Wood shavings	725	1193	1000	400	132	350	–	–	–	–
Shredded newspaper	–	–	–	–	170	500	815	570	532	365
Cocoa shells	–	–	–	755	–	–	1500	–	–	–
Straw	–	–	–	–	100	–	–	–	–	–
Total	3195	6103	6720	3835	1877	3700	8015	4200	3482	4535
Water added at start (l)	–	–	500*	300**	258	575	1150	705	957	600

*Added Day 14; ** added Day 10.

Table 3.7. Percentage of mix ingredients in compost batches (by fresh weight).

Ingredient	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8	Batch 9	Batch 10
Pig solids	47	65	75	59	79	41	20	29	35	72
Poultry litter	10	16	11	11	–	15	26	47	50	20
Spent mushroom compost	20	–	–	–	–	20	26	10	–	–
Wood shavings	23	19	14	10	7	10	–	–	–	–
Shredded newspaper	–	–	–	–	9	14	10	14	15	8
Cocoa shells	–	–	–	20	–	–	18	–	–	–
Straw	–	–	–	–	5	–	–	–	–	–
Total (%)	100	100	100	100	100	100	100	100	100	100

amounts ranging from 20 to 79%. Nine of the batches contained poultry litter at amounts ranging from 10 to 50% of the mix, while SMC was included in four of the batches in amounts ranging from 10 to 26%. Wood shavings and shredded newspaper were included in six of the ten batches, cocoa shells in two of the mixes and chopped straw in only one of the mixes.

Table 3.8 outlines the usual parameters recorded when making up compost mixes, i.e. dry matter, total nitrogen, pH, ash and C/N ratio. The dry matter of the pig solids ranged from 26.4 to 31.6%. Total N varied from 1.78 to 2.80%, pH from 8.3 to 8.9, ash from 15.2 to 23.3% and the C/N ratio ranged from 17 to 25.

All the pig solids used in the ten compost batches were drawn from a single pile of separated solids with a storage interval of 240 days between the preparation of the first and last compost mixes. The results in Table 3.8 suggest that some composting may have occurred within the separated solids stack itself during storage as evidenced by the loss of volatile N.

Five different loads of poultry litter were used during the preparation of the compost mixes. Each load was analysed separately and the results are shown in Table 3.8. Their DM ranged from 40.9 to 54.2%, total N from 2.12 to 4.64%, pH from 8.4 to 9.2 and ash from 16.1 to 21.2%. The C/N ratio on most occasions was from 10 to

Table 3.8. Composition of ingredients used in compost mixes.

Compost mix ingredient	Dry matter (%)	Total N (% in DM)	Non-volatile N (% in DM)	Ammonia-N (% of total N)	pH	Ash (% in DM)	C/N Ratio	Used in batch
Pig slurry solids	26.4	2.80	1.59	43.6	8.8	15.2	18	1,2
	28.0	2.71	1.55	42.8	8.9	15.5	18	3
	31.3	2.67	1.58	40.8	8.9	22.0	17	4
	31.2	2.49	1.74	30.0	8.3	23.3	18	5
	31.6	1.78	1.77	>1.0	8.6	22.5	25	6,7,8,9,10
Poultry litter	54.2	4.30	2.67	37.9	8.9	17.9	12	1,2
	43.3	4.54	2.57	43.4	–	16.1	11	3
	51.0	2.12	1.61	24.5	9.2	17.4	23	4
	40.9	4.41	2.86	35.1	8.4	21.2	10	6
	46.0	4.64	2.81	39.4	8.6	16.6	10	7,8,9,10
Spent mushroom compost	35.2	1.60	1.58	1.25	–	43.1	21	1
	33.7	2.49	2.46	1.20	7.8	35.1	15	6
	33.4	2.08	2.04	1.92	6.9	37.5	17	7,8
Wood shavings	83.8	0.10	0.10	–	5.8	0.35	579	1
	84.5	0.10	0.10	–	–	1.07	575	2,4,5
	88.1	0.15	0.13	13	6.3	0.45	386	3
	90.1	0.14	0.13	7	4.8	9.54	376	6
Straw	85.0	0.45	0.45	–	–	4.99	123	5
Shredded newspaper	90.2	0.07	0.07	–	6.48	0.85	823	5,6,7,8,9,10
Cocoa shells	85.7	2.33	2.33	–	–	7.29	23	4,7

12 except in one batch where it rose to 23 because of a low total N content.

The DM content of the SMC varied from 33.4 to 35.2%, the total N from 1.60 to 2.49, the ash content from 35.1 to 43.1% and the C/N ratio from 15 to 21 (Table 3.8)

The wood shavings were high in DM (83.8–90.1%) and very low in nitrogen content (0.10–0.15%). The ash content was also low except in one sample while the C/N ratio was high ranging from 376 to 579 (Table 3.8).

The shredded newspaper was very low in nitrogen (0.07%) and had a very high C/N ratio (823) while the chopped straw was also low in nitrogen but had a C/N ratio of 123. Cocoa shells were high in DM (85.7%), high in total N (2.33%) and ash (7.29%) and had a C/N ratio of 23, similar to the separated pig solids (Table 3.8).

Additional water was added to eight of the ten compost batches to ensure optimum composting conditions, i.e. Batches 3 to 10.

In Batches 3 and 4, the water was added 14 days and 10 days, respectively, after the start of composting while in the other Batches (5–10) the water was used to moisten the shredded newsprint before incorporation in the mix. The quantities of water added to each batch are shown in Table 3.6.

Table 3.9 summarises the main characteristics of the ten batches when set up to compost. Moisture contents ranged from 48.2 to 61.4%, total N from 1.49 to 2.70% and ash from 10.2 to 17.1%. The C/N ratio of the various mixes ranged from 18 to 33 with six of the mixes having a C/N ratio of 25 or over.

Table 3.9. Composition of batches at start of composting period.

Composition	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8	Batch 9	Batch 10
Total N (% in DM)	1.63	2.05	2.05	2.04	1.49	1.49	2.35	2.70	2.67	2.22
Non-volatile N (% in DM)	1.08	1.23	1.19	1.58	1.17	1.27	1.92	1.83	1.78	1.69
Moisture (%)	56.0	57.9	61.4	50.4	56.7	53.0	48.2	53.4	52.1	60.8
Ash (% in DM)	13.6	10.2	10.5	12.8	14.1	16.2	15.1	15.1	13.4	17.1
C/N ratio	31	26	25	25	33	33	21	18	19	22

3.3 Composting Temperatures

The batches or piles of compost were turned regularly at 7- to 14-day intervals throughout the composting period to control compost temperature and encourage uniform composting of the material. Temperatures within each pile were monitored continuously using temperature probes linked to a Fancom 765 multi-channel data logger. Mean daily temperatures for the first 4 weeks of composting are shown graphically in Figs 3.1–3.3 and are also detailed in Appendix 1, Table A1, while the mean weekly temperatures for the succeeding 28 weeks are shown graphically in Figs 3.4–3.6 and are also detailed in Appendix 1, Table A2. The sudden fall in temperature recorded on individual days was caused by turning the piles of compost.

The temperature in Batch 1 reached 55°C+ by Day 5 but rarely exceeded 60°C throughout the composting period. From Week 8 onwards, the temperature remained between 30 and 40°C falling to 21°C in the last week before recording ceased.

In Batch 2, the temperature reached 60°C by Day 3 and remained between 55 and 60°C for the next 12 weeks. Thereafter, it gradually fell to finish at 22°C when recording ceased.

The temperature was slow to rise in Batch 3 and did not exceed 55°C until Day 9. For the next 14 weeks the temperature fluctuated between 55 and 62°C and then gradually fell back to 25°C by the end of the recording period.

Batch 4 quickly heated up, reaching 65°C by Day 3 and remained between 65 and 70°C for the succeeding 4 weeks. In the next 14 weeks, it remained between 50 and 60°C, thereafter falling gradually to below 20°C by Week 27. By the end of the recording period it had fallen to 16°C.

The temperature in Batch 5 rose quickly by Day 3 to 66°C and for the following 15 days remained between 60 and 65°C. In the succeeding 6 weeks, it fluctuated between 50 and 60°C and then fell gradually over the next 15 weeks to 12°C. Recording was terminated at the end of Week 24 as there appeared to be no further biological activity taking place.

Batch 6 took 6 days to reach 60°C with a maximum of 62°C reached by Day 13. For the next 13 weeks the mean weekly temperature varied from 50 to 60°C and then fell to less than 20°C by Week 24. For some inexplicable reason, this pile of compost became active again, reaching a mean temperature of 67°C in Weeks 30 and 31. It still averaged 57°C in the week before temperature recording was terminated.

Batch 7 was the only compost to reach 70°C in the first week of composting (Day 6). It remained between 65 and 70°C on most days during the following 3 weeks and between 55 and 65°C for the subsequent 5 weeks. It then fell gradually to below 20°C by Week 23. Recording of temperature was terminated at the end of Week 26 as it had remained at 18°C for 3 weeks and the compost appeared inactive.

Batch 8 compost was slow to heat up initially reaching 60°C by Day 6. In the following 3 weeks, the temperature on most days was between 65 and 70°C. It then declined gradually to below 50°C by Week 14 and continued to fall over the succeeding weeks to 20°C by the end of the recording period.

Batch 9 was also slow to heat up initially taking 9 days to reach 60°C but by Day 16 the mean daily temperature had reached 70°C. It remained between 65 and 70°C on most days until the end of Week 4 and then fell gradually over the next 26 weeks to finish at 19°C by Week 31.

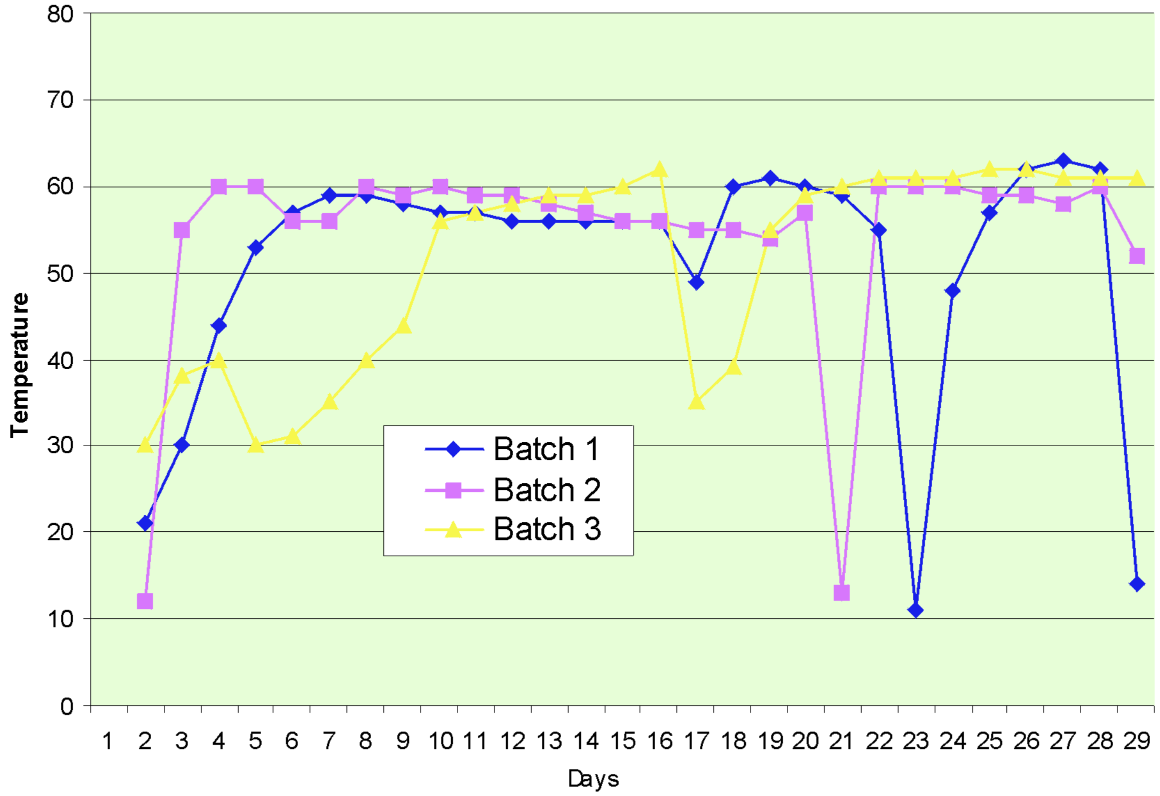


Figure 3.1. Mean daily temperatures (°C) over the first 28 days in compost Batches 1, 2 and 3.

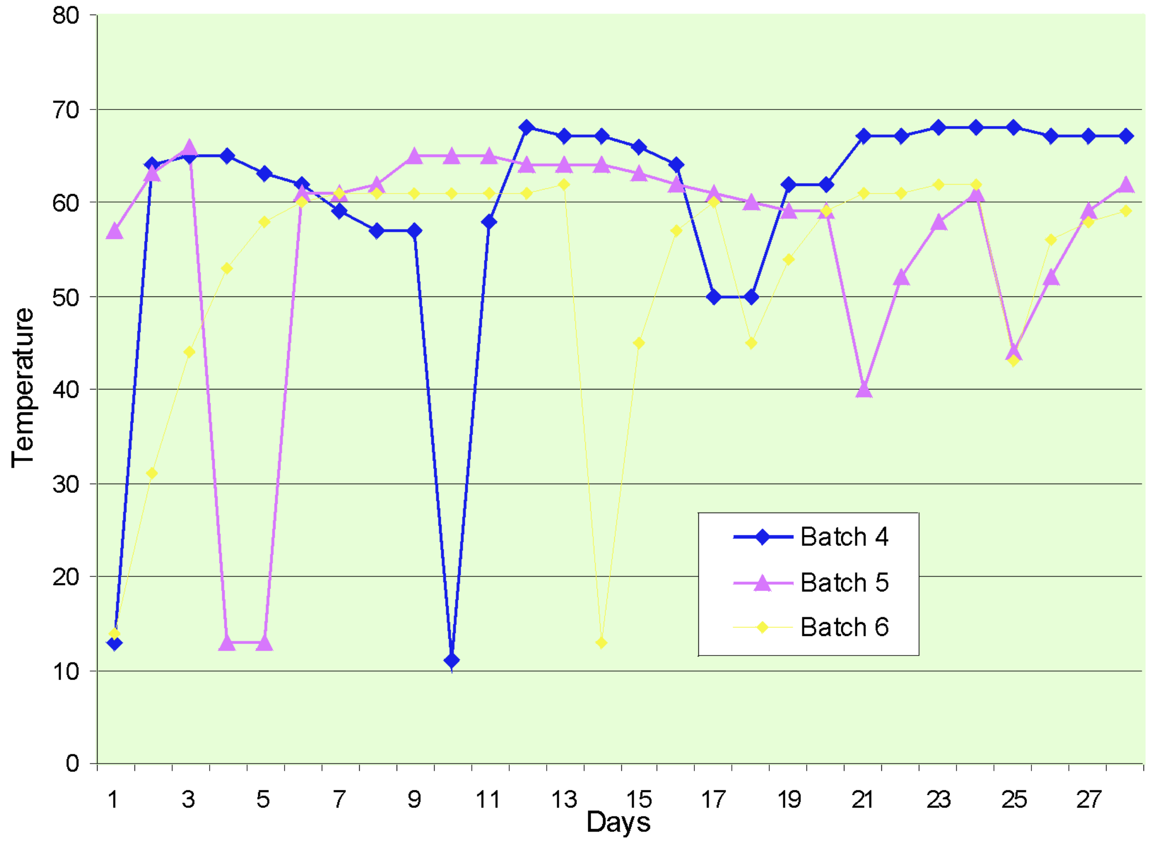


Figure 3.2. Mean daily temperatures (°C) over the first 28 days in compost Batches 4, 5 and 6.

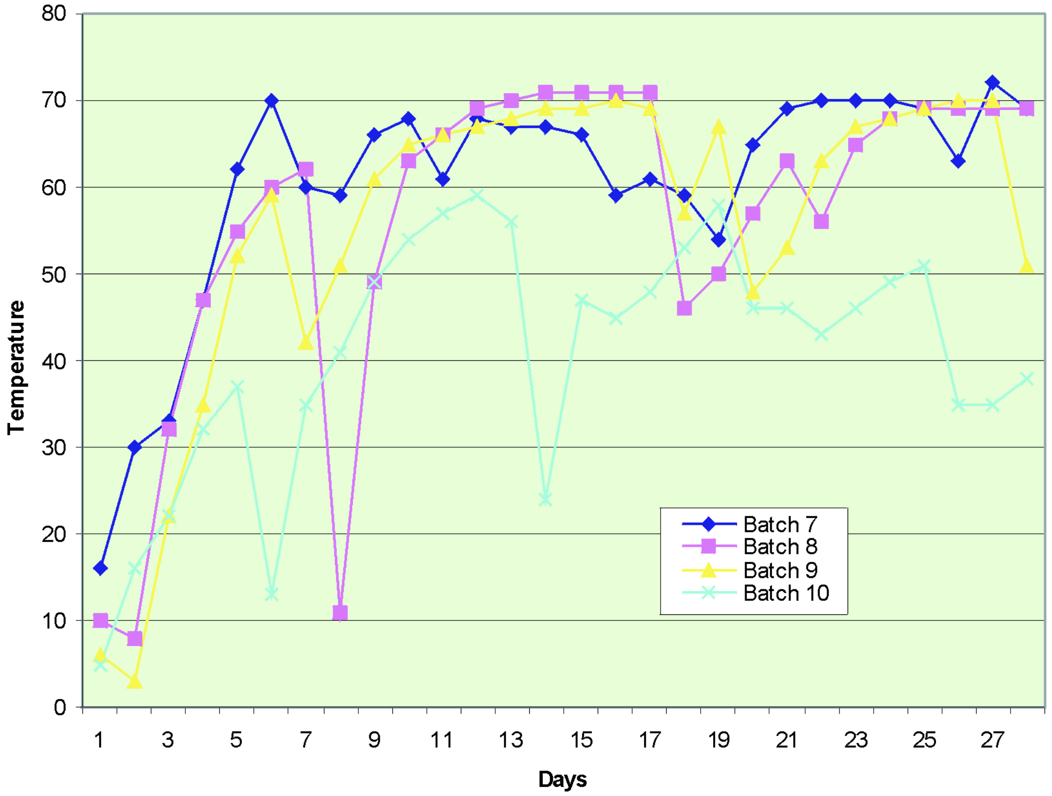


Figure 3.3. Mean daily temperatures (°C) over the first 28 days in compost Batches 7, 8, 9 and 10.

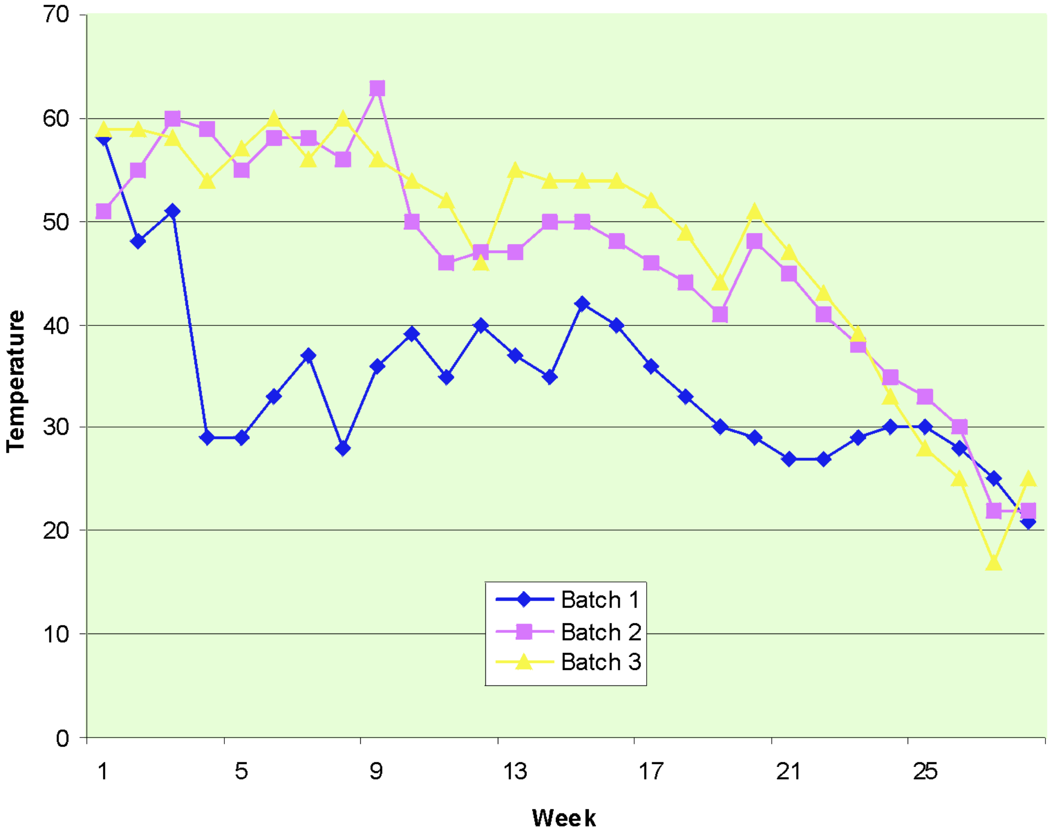


Figure 3.4. Mean weekly temperatures (°C) from Weeks 5 to 32 for compost Batches 1, 2 and 3.

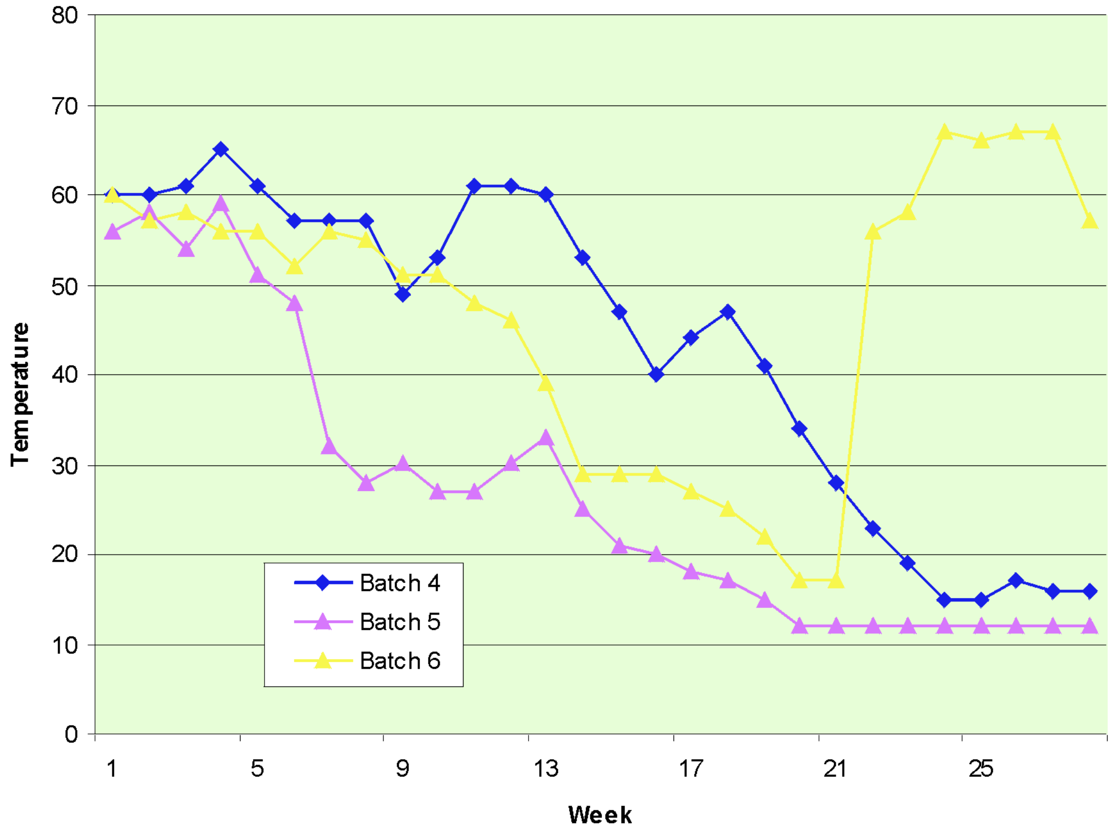


Figure 3.5. Mean weekly temperatures (°C) from Weeks 5 to 32 for compost Batches 4, 5 and 6.

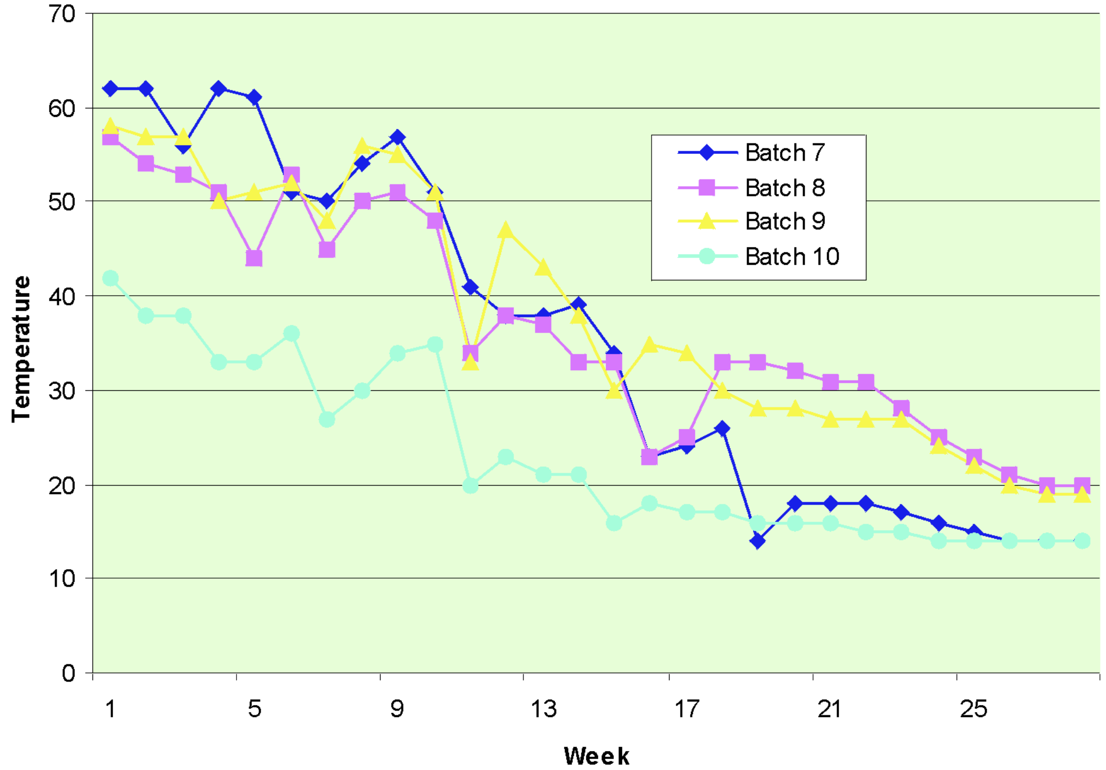


Figure 3.6. Mean weekly temperatures (°C) from Weeks 5 to 32 for compost Batches 7, 8, 9 and 10.

Batch 10 was very slow to heat up and by Day 12 had reached its maximum of 59°C. It remained between 45 and 50°C over the next 2 weeks and between 30 and 40°C for most of the following 10 weeks. By Week 18 the mean weekly temperature had fallen below 20°C and remained so until the end of the recording period. Overall, this particular compost batch exhibited the lowest temperatures of any of the compost mixtures examined.

A notable feature of most of the compost mixes tested was the length of time required for them to become inactive with some batches still showing signs of biological activity after an 8-month composting period. While the composting period varies according to the feedstock used and the degree of process control, for a simple composting system, such as that used in this project, the active composting phase is usually around 2 months with a further 1–2 months for the compost to cure. For in-vessel systems, where greater process control is possible, the active composting period can be significantly reduced allowing a cured/stable compost to be produced within 3 months (Gilbert *et al.*, 2001).

3.4 Chemical Composition and Bulk Density of Mature Composts

Details of the nutrient content of the final four batches of compost made are given in Table 3.10. These were chosen as the most suitable composts for further processing into granular organo–mineral fertilisers as they represented the most likely mixes to be adopted commercially at some future date. The nitrogen content ranged from 2.1 to 2.9%, phosphorus from 1.3 to 2.2% and potassium from 2.5 to 4.0% in the DM. Bulk density of the composts ranged from 325 to 480 g/l.

Table 3.10. Nutrient content and bulk density of compost Batches 7 to 10.

Analysis	Compost batch				Mean
	7	8	9	10	
Dry matter (%)	52.3	43.8	47.9	38.5	45.6
Total N (% in DM)	2.9	2.1	2.1	2.2	2.3
Total P (% in DM)	2.2	1.4	1.3	1.6	1.6
K (% in DM)	2.9	4.0	3.3	2.5	3.2
Bulk density (g/l)	375	380	325	480	390

3.5 Particle Size Analysis of Composts

Table 3.11 gives details of the particle sizes of the material in each compost batch. Particle size was determined by hand-shaking a sample of compost from each batch through a set of Endecott test sieves carrying the BS 410 kite mark. Sieve sizes ranged from 16 mm to 75 µm.

From 92 to 100% of compost particles in all batches passed through an 8-mm sieve whereas from 50 to 84% of particles passed through a 2-mm sieve. Composts with a high proportion of poultry litter contained a larger proportion of coarser material (e.g. Batches 8 and 9) compared with those containing a high proportion of pig solids (e.g. Batches 2 and 3).

Only three composts (Batches 2, 3 and 7) had more than 30% of their particles passing through a 600-µm sieve and only one compost had more than 15% of particles passing through a 300-µm sieve. Less than 10% of particles in all composts passed through a 150-µm sieve.

3.6 Pathogen Analysis

A detailed description of the pathogen work carried out during the project is given in Appendix 2. Samples of pig slurry and other biodegradable wastes used in the compost batches were subjected to standard protocols for the identification of *Campylobacter*, *Cryptosporidium*, *E. coli* 0157, *Listeria*, *Salmonella*, *Shigella* and *Yersinia.*

The tests carried out cover the usual range of pathogens that might be routinely encountered in pig slurry and other organic wastes of animal origin. In this project, the separated pig solids came from a 'minimum-disease' herd, i.e. a pig herd where hygiene is maintained at a high level. In such circumstances, pathogen levels are likely to be lower than in normal commercial herds, but may still be present without causing a noticeable effect on animal health.

It was found that 58% of the pig slurry samples tested contained *Salmonella* species that exhibited intermediate to high-level resistance towards the tetracycline antibiotic. Some of the *Salmonella* species also showed multiple resistance to moderate doses of ampicillin, kanamycin and cipromycetin (modified Stalk Test).

The tests also revealed the presence of *Campylobacter* species in 21% of the pig slurry samples and the presence of oocysts of *Cryptosporidium* were also detected.

Table 3.11. **Percentage of particles in each compost batch passing through test sieves ranging in aperture size from 16 mm to 75 µm.**

Compost batch no.	Test sieve aperture size													DM (%) of sieved sample
	16 mm	8 mm	4 mm	2 mm	1.7 mm	1 mm	710 µm	600 µm	425 µm	300 µm	212 µm	150 µm	75 µm	
1	100	100	88	66	58	40	30	24	16	10	7	4	0.6	57.6
2	100	100	95	80	73	53	41	35	24	15	11	7	2.1	64.0
3	100	99	95	84	77	57	44	38	26	16	11	7	1.9	70.5
4	100	100	93	72	64	46	36	30	20	13	9	5	1.4	58.5
5	100	95	82	66	60	44	35	30	19	13	8	6	1.1	52.2
6	100	99	91	74	67	46	33	27	18	12	8	5	1.6	41.0
7	100	99	83	68	61	45	36	31	23	15	10	7	2.0	55.8
8	100	94	76	51	42	26	20	16	11	6	3	2	0.4	47.8
9	100	96	76	50	42	27	20	18	12	7	4	2	0.3	51.0
10	100	92	77	56	49	36	26	20	11	6	3	1	0.2	39.8

However, it was not possible to determine the viability of the *Cryptosporidium* oocysts.

The microbiological and molecular tests confirmed the absence of *Shigella*, *E. coli* 01257 and *Yersinia* species in the pig slurry samples tested.

A similar range of tests was carried out on the mature composts to detect the presence or absence of the pathogens described.

All compost batches were found to be free of the pathogens for which tests were carried out. Furthermore, no oocysts of *Cryptosporidium* were found in the composts examined.

Laboratory challenge tests were carried out to determine the survival rate of a range of pathogens likely to be encountered in agricultural wastes when exposed to a given temperature regime. A sample of compost (Batch 14) was first irradiated to kill off any organisms present and then inoculated with *Salmonella* species (*S. typhimurium*, *S. manhattan*, *S. stanley*, *S. heidelberg* and *S. derby*), *Campylobacter coli*, *Campylobacter lali*, *E. coli* 01257 12900, *E. coli* 01257 9001, *Yersinia enterocolitica* and *Listeria monocytogenes.*

The challenge test showed that all the pathogens examined were killed by incubation at 70°C for 1.5 h.

3.7 Fertiliser Manufacture

The aim in attempting to granulate the composts produced in this project was to produce an organic-based fertiliser suitable for use on amenity grassland such as golf-course fairways and greens. Here the requirement for spring and summer fertiliser application is to release nitrogen and other nutrients slowly to give an even growth of grass. A compound fertiliser containing an approximate analysis of 10% nitrogen (50–75% from an organic source) 3% phosphorus (P) and 6% potassium (K) with sulphur added as an optional nutrient, is a popular fertiliser mix for use during the growing season while a low N-, high P- and K-type compound fertiliser, e.g. 3% N, 5% P and 10% K, is commonly used as an autumn dressing. Consequently, fertiliser manufacture concentrated on producing products that fell into these two categories.

A pellet diameter of 2.0–2.5 mm is required for fertilisers applied to golf-course fairways while a diameter of 1.0–1.5 mm is required for finer turf areas such as golf and bowling greens.

Compost Batch 7 was chosen as the base material for all the fertiliser batches manufactured because of the volume available and the maturity of the compost. The first test involved attempting to pelletise the ungraded compost by passing it through the Turbulator, adding binder and observing the resulting agglomeration process. It quickly became obvious that the compost contained an excessive amount of coarse material (32% of which failed to pass through a 2-mm aperture sieve) that would not efficiently pelletise (Table 3.11).

The extent to which the compost particles were broken down by the action of the Turbulator pins on passage through the Turbulator was measured. Results shown in Table 3.12 indicate that passage through the Turbulator *per se* reduces the particle size of the compost. However, this grinding action within the turbulator was insufficient to reduce all particles to a suitable size for effective commercial pelletisation, i.e. particle sizes of 1.5 mm or less.

Crude roughly shaped pellets were formed from the smaller particles but, because of the low density of the compost, the resulting pellets were too light and unsuitable for application by conventional fertiliser spreaders.

The moisture content of the compost at 48% was also too high for satisfactory processing through the pilot plant, resulting in frequent blockages and difficulties with the pelletising process.

It was therefore decided as a consequence of these tests to pass the compost over a 2-mm screen to remove the coarser material and only use the finer material passing through the screen for the manufacture of fertilisers.

The nutrient content of Batch 7 compost was also determined and reported in Table 3.13. This showed that screening had only a minor effect on compost composition resulting in a small increase in the ash and potash content of the finer (under 2 mm) material.

It was also evident from the chemical analysis of the compost (total N 3.0%, total P 2.1% and total K 3.0%) that supplementation by nutrients from other sources was necessary in order to achieve the target nutrient ratio of the proposed granulated fertilisers. Consequently, two sources of organic nitrogen were obtained for blending with the screened compost, namely dried poultry feather meal and dried animal blood. The composition of these two products along with the inorganic fertilisers used in the fertiliser mixes is given in Table 3.14.

Table 3.12. Quantity of compost particles retained on sieves before and after passage through turbulator.

Sieve aperture size	Percentage by weight of particles retained on sieve	
	Raw compost	After Turbulator pass
4.75 mm	15	2
3.35 mm	9	2
2.36 mm	17	7
1.18 mm	30	32
783 µm	15	30
Pan	14	26

The first mix tested consisted of 29% compost, 29% feather meal, 17% sulphate of ammonia, 15% rock phosphate and 10% sulphate of potash (Table 3.15). Adding drier materials, such as feather meal and the mineral fertilisers, to the compost resulted in a mix with a moisture content of 21.1% which passed through the Turbulator without causing blockages and proved relatively straightforward to pelletise. The mix had a bulk density of 670 g/l compared with 330 g/l for the compost on its own.

The mix, when granulated and dried, produced a fertiliser containing 5.1% moisture, 7.9% total N, 2.3% P, 4.4% K and 8.0% S. This was slightly less concentrated than the target 10:3:6 fertiliser planned but was still within an acceptable range for use on golf-course fairways. Granule

Table 3.13. Nutrient content of unscreened and screened Batch 7 compost.

Determination	Unscreened compost	Screened coarse compost >2 mm	Screened fine compost <2 mm
Dry matter (%)	52.3	51.5	52.5
Ash (% in DM)	34.1	27.3	37.4
Organic matter (% in DM)	65.9	72.7	63.6
Total N (% in DM)	2.9	2.5	3.0
Total P (% in DM)	2.2	2.4	2.1
Total K (% in DM)	2.5	2.5	3.0

Table 3.14. Nutrient content of amendments mixed with compost (Batch 7) when formulating fertilisers.

Nutrient source	Dry matter(%)	Nutrient content (% in material as supplied)			
		Total N	Phosphorus (P)	Potash (K)	Sulphur (S)
Feather meal	89.6	12.8	0.41	0.22	–
Dried blood	96.6	16.0	0.22	0.25	–
Sulphate of ammonia	–	21.0	–	–	24.0
Nitro-chalk	–	27.5	–	–	–
Rock phosphate	–	–	11.8	–	–
Superphosphate	–	–	21.0	–	–
Sulphate of potash	–	–	–	42.0	18.0
Compost (Batch 7) screened, <2 mm	52.5	1.57	1.10	1.58	–

Table 3.15. Nutrient content of Mix 1.

Mix 1 ingredients	Quantity mixed (kg)	Proportion in mix (%)	Nutrients supplied (kg)			
			N	P	K	S
Compost (Batch 7)	500	29	7.9	5.5	7.9	–
Feather meal	500	29	64.0	2.1	1.1	–
Sulphate of ammonia	300	17	63.0	–	–	72.0
Rock phosphate	250	15	–	29.5	–	–
Sulphate of potash	175	10	–	–	73.5	31.5
Total	1725	100	134.9	37.1	82.5	103.5

size was also within an acceptable range for its intended use and 53% of its nitrogen content was derived from organic sources.

The product, however, suffered from one possible drawback related to its odour, brought about by the inclusion of the feather meal. There was a strong poultry-type odour from the freshly made fertiliser which it was feared could offend potential end-users and jeopardise future sales.

A second mix was therefore formulated, leaving out the feather meal and replacing sulphate of ammonia (21% N) with nitro-chalk (27.5% N) and rock phosphate (12% P) with superphosphate (20% P) because of their higher nutrient contents. The mixture contained 53% compost, 27% nitro-chalk, 10% superphosphate and 10% sulphate of potash. This proved disastrous resulting in a strong heat-intensive chemical reaction within the Turbulator, causing the mix to form large lumps that clogged the Turbulator outlet bringing the operation to a standstill for several days.

A third mix was formulated substituting dried blood for the feather meal. The use of dried blood derived from non-ruminant animals for the manufacture of organic-type fertilisers is permitted under the EU Animal By-Products Regulation No. 1774/2002 (CEC, 2002). Details of this mix are given in Table 3.16. Adding dried blood and the other mineral fertilisers to the compost reduced the moisture content of the mix to 13.7% and increased the bulk density to 700 g/l.

The dried blood was a difficult messy material to handle because of its very fine particle size and tendency to clump together when in contact with water. The granules produced were reddish brown in colour and not as well formed or spherical as the mix containing feather meal. It was also more difficult to produce uniform-sized pellets or granules. However, there were no odour problems associated with this mix. The resulting fertiliser, when dried, contained 4.4% moisture, 8.9% total N, 2.7% P and 6.3% K.

The fourth mix was designed to produce a low N, high P and K fertiliser for autumn use with a target N:P:K ratio of 3:5:10. It was composed of 50% compost (Batch 7), 8% nitro-chalk, 21% superphosphate and 21% sulphate of potash. The mixture had a moisture content of 25% and a bulk density of 700 g/l (Table 3.17).

Table 3.16. Nutrient content of Mix 3.

Mix 3 ingredients	Quantity mixed (kg)	Proportion in mix (%)	Nutrients supplied (kg)		
			N	P	K
Compost (Batch 7)	500	29	7.9	5.5	7.9
Dried blood	500	29	80.0	1.1	1.3
Sulphate of ammonia	300	17	63.0	–	–
Rock phosphate	250	15	–	29.5	–
Sulphate of potash	175	10	–	–	73.5
Total	1725	100	150.9	36.1	82.7

Table 3.17. Nutrient content of Mix 4.

Mix 4 ingredients	Quantity mixed (kg)	Proportion in mix (%)	Nutrients supplied (kg)		
			N	P	K
Compost (Batch 7)	1050	50	16.6	11.6	16.6
Nitro-chalk	150	8	41.3	–	–
Superphosphate	450	21	–	94.5	–
Sulphate of potash	450	21	–	–	189.0
Total	2100	100	57.9	106.1	205.6

On this occasion, problems with overheating and clumping of the mix, when passing through the Turbulator, did not materialise, but the mix proved difficult to pelletise and grow into large enough granules. Consequently, a high proportion of fine granules in the 1–2 mm category was produced.

When pelletised and dried, this mix resulted in a fertiliser containing 4.4% moisture, 2.9% N, 4.8% P and 10.5% K which was close to the intended target formulation.

The particle sizes of the materials used in each mix was determined along with the particle size distribution within the mixes themselves. The granule size distribution of a sample of the unscreened fertiliser produced from each mix was also measured. Results are given in Tables 3.18 and 3.19. It should be noted when examining these results that the compost and feather meal had already been passed over a 2-mm screen to remove the coarser material and that the mineral fertilisers had been crushed by passing through the rollers of a corn mill.

The particle size distribution of Mix 1 showed a larger proportion of material in each of the sieve aperture sizes between 2.0 mm and 600 µm compared with Mix 2. However, there was little difference in the proportion of fertiliser granules over 2 mm in size or between 1 and 2 mm in size. Slightly over 50% of the granules produced exceeded 2 mm (Table 3.19).

The inclusion of dried blood had a striking effect on particle size distribution in Mix 3 with over 50% of the mix passing through a 600-µm aperture sieve and 28% passing through the finest 75-µm sieve used in these tests. Despite the finer make-up of this mix compared with the others, approximately half of the granules produced were over 2 mm in size (Table 3.19).

Mix 4 had a higher proportion of particles passing through the 710-, 600- and 425-µm aperture sieves than Mixes 1 and 2. This may have contributed to the difficulties encountered in making large (over 2 mm) granules from this mix. Consequently, only 37% of the Mix 4 fertiliser granules were over 2 mm in size (Table 3.19).

A concern was expressed during the fertiliser manufacturing process that the nutrients in each mix might not be evenly distributed between fertiliser granules of different sizes. Consequently, fertiliser from Mixes 3 and 4 were graded into a number of size categories and the nutrient content of each grade category was compared with the ungraded fertiliser. The results are shown in Tables 3.20 and 3.21.

Table 3.18. Percentage by weight of particles passing through sieves with apertures ranging from 2.0 mm to 75 µm.

Test sieve aperture size	Materials used in fertiliser mixes					
	Screened compost (Batch 7)	Feather meal	Dried blood	Sulphate of ammonia	Rock phosphate	Sulphate of potash
2.0 mm	98	95	100	100	94	91
1.7 mm	90	92	100	100	93	87
1.0 mm	49	64	100	89	81	58
710 µm	28	19	100	63	65	44
600 µm	15	9	100	51	58	40
425 µm	4	2	100	31	47	32
300 µm	1	0	100	14	40	26
212 µm	0.7	0	100	5	34	21
150 µm	0.3	0	100	2	28	16
75 µm	0	0	88	0	14	4

Table 3.19. Percentage by weight of compost particles and fertiliser granules passing through sieves with apertures ranging from 2.0 mm to 7.5 µm before and after granulation.

Test sieve aperture size	Mix 1		Mix 2		Mix 3		Mix 4	
	Before	After	Before	After	Before	After	Before	After
2.0 mm	95	47	81	44	93	50	88	63
1.7 mm	90	34	74	34	89	39	83	53
1.0 mm	62	12	49	12	73	11	61	23
710 µm	38	7	30	5	61	4	56	9
600 µm	23	7	18	4	54	2	48	6
425 µm	8	4	5	2	45	0.9	33	2
300 µm	2	3	1	1	42	0.6	9	1
212 µm	1	0	0	0	38	0.5	3	0.5
150 µm	0	0	0	0	36	0.4	1.5	0.3
75 µm	0	0	0	0	28	0.2	0	0

Some variation in nutrient content was noted in the Mix 3 fertiliser fractions with the granules under 1.18 mm in size showing a slightly higher N content and a lower P and K content then the larger granules.

In the Mix 4 fertiliser, there was little or no variation in the nutrient content of the various granule sizes examined.

3.8 Application of Fertiliser to Golf Greens

There was insufficient time during the course of the project to carry out extensive field trials on the fertiliser products produced. However, Mix 3 fertiliser was applied in late summer to a number of golf greens in two contrasting golf courses in Ireland – one situated on a heavy clay soil in Co. Fermanagh (Castle Hume) and the other located on a sandy soil in Co. Donegal (Bundoran Golf Club).

The fertiliser was applied at a rate of 25 g/m² and appeared to break down easily in 3–4 days. Visual greening up of the grass was seen within 5 days and the colour remained consistent for another month after application. Weather conditions favoured grass growth following fertiliser application and a notable increase in shoot density was observed. Photograph 3.1 shows a green on the Fermanagh golf course that was treated with Mix 3 fertiliser. (Note the colour difference between the green and the untreated area surrounding the green.)

Table 3.20. Nutrient content of a range of granule sizes from Mix 3.

Product	Dry matter (%)	Nutrient content (% in fresh material)				
		Ash	Organic matter	Total N	Phosphorus (P)	Potassium (K)
Mix 3 before granulation	86.3	29.6	56.7	9.5	2.2	4.3
Fertiliser – ungraded granules	95.6	37.0	58.6	8.9	2.7	6.3
Fertiliser – granules 1.18 mm or less	96.1	30.2	65.9	11.2	2.4	3.9
Fertiliser – granules 1.19–3.35 mm	96.4	33.1	63.3	9.9	2.6	4.8
Fertiliser – granules 3.36 mm and over	94.8	33.0	61.8	10.0	2.5	4.7

Table 3.21. Nutrient content of a range of granule sizes from Mix 4.

Product	Dry matter (%)	Nutrient content (% in fresh material)				
		Ash	Organic matter	Total N	Phosphorus (P)	Potassium (K)
Mix 4 before granulation	75.1	45.1	30.0	2.2	3.7	8.8
Fertiliser – ungraded granules	95.6	56.3	39.3	2.9	4.8	10.5
Fertiliser – granules 1.18 mm or less	98.6	57.8	40.8	3.1	5.0	11.3
Fertiliser – granules 1.19–2.36 mm	98.6	57.1	41.5	2.9	4.9	11.6
Fertiliser – granules 2.37–3.35 mm	98.6	56.5	42.1	3.0	5.0	11.5
Fertiliser – granules 3.36 mm or over	97.9	56.3	41.6	3.0	5.2	11.3

Greenkeepers were asked to comment on the acceptability of the fertiliser when compared with fertiliser products currently used. There was general agreement that the granule size and hardness was satisfactory and that the colour, smell and dustiness of the product was acceptable. Greenkeepers found the fertiliser products manufactured during this project to be equally acceptable or better than those available to them at present.

Photograph 3.1. Golf green treated with Mix 3 fertiliser at Castle Hume Golf Course, Co. Fermanagh.

4 Discussion

4.1 Slurry Separation

Research carried out in the 1970s (Grundey, 1980) suggested that the belt press separator was capable of producing a high dry matter fibre of 25–30% DM which composts very readily. In the present project, the rotary screen separator used produced pig slurry solids with a mean DM content of 26.2%. An approximate estimate of solids and nutrient removal during separation suggested that 21% of the slurry DM, 13% of the total N and 49% of the total P were removed, while the ammonia N and soluble residual P found in the liquid fraction was similar to that of the unseparated slurry. These findings are in line with published results obtained under more stringent conditions than applied in the present project.

For example, a study by Moller *et al.* (2000) showed that the most informative index of separation is the "reduced separation efficiency index" where an index value of 0 indicates that the nutrients are distributed equally between the solid and liquid fractions and a value of 1 indicates that the nutrients are concentrated in the solid fraction.

In separation studies using pig slurry, they found that simple mechanical screen separators gave a "reduced separation efficiency" of 0.07–0.5 for DM, 0.01–0.1 for total N and 0–0.2 for total P. Practically speaking, half to three-quarters of the solids, and a little over half the total N and total P were removed in the solid fraction.

In comparison, Moller *et al.* (2000) found that decanting centrifuges were very efficient in removing DM (index 0.36–0.74) and total P (index 0.4–0.82) but not in separating total N (index 0.11–0.19).

Burton and Turner (2003), in reviewing the performance of mechanical separators, state that the best nutrient separation results are achieved with decanter centrifuges, especially concerning phosphate reduction, while relatively high throughput rates are possible using simple sieve drum presses or press auger separators. With suitable technologies, a nutrient removal rate of up to 80% for phosphorus and 50% for nitrogen can be achieved (Burton & Turner, 2003).

It is interesting to note the reaction and observations of local farmers when given the separated pig slurry liquid to spread on their grassland. After spreading several tanker loads, they refused to take any more from the pig unit on the grounds that they could not see where it had been applied to the grass. Their perception was that the separated liquid could not be, in nutrient terms, any better than dirty water.

This reaction is contrary to trial work which has shown improved responses in grass yields from use of separated slurry liquid. For example, trials comparing applications of the same rates of cattle slurry and separated cattle slurry liquid to grassland resulted in increases of 25–35% grass DM over two cuts despite the separated liquid containing only 68% of the total N content of the unseparated cattle slurry (Grundey, 1980).

Clearly, an educational programme would be required to convince farmers of the nutrient value of the separated liquid should separation become a common practice in Ireland.

4.2 Composting

The physical and chemical characteristics of the pig slurry solids produced by mechanical separation during this project fall outside the preferred range in terms of the C/N ratio, moisture content and bulk density as defined by Rynk (1992) and set out in Table 4.1. The pig solids, when stored on their own, did show signs of heating indicating some microbial activity, and nitrogen determinations suggested loss of ammonia during storage. However, it may be concluded that the microbial activity was insufficient to result in a satisfactory compost and that the addition of amendments are necessary to assist the degradation process and achieve the temperatures needed to pasteurise the material.

Poultry litter proved to be a useful amendment in plentiful supply, acting as a source of nutrients, particularly nitrogen, reducing the moisture content and improving the physical structure of the mix.

Some SMC in the mix was also advantageous but, because it has already been partially composted, the remaining carbon is likely to be less biodegradable.

Table 4.1. Characteristics of pig slurry solids compared with desired characteristics of raw material mixes for composting purposes (after Rynk, 1992).

Characteristic	Preferred range	Reasonable range	Project mechanically separated pig solids
Carbon to nitrogen ratio	25:1–30:1	20:1–40:1	17:1–25:1
Moisture content (%)	50–60	40–65	68–74
pH	6.5–8.5	5.5–9.0	8.4–8.8
Bulk density (g/l)	<640	–	248–467

The addition of wood shavings gives a more open structure to the mixes tested and are a good source of carbon. However, they are slow to break down and need to be screened out of the mature compost if conversion to a granular fertiliser is intended. Furthermore, where a wood shavings based poultry litter is incorporated in the mix, there should be no need for the addition of further wood shavings.

Chopped straw was used in only one of the mixes tested (Batch 5). It appeared to have little impact on the compost process at the inclusion rate chosen and was relatively expensive to use.

Cocoa shells are an excellent carbon source and improve the porosity of the mix. They also break down readily in the composting process. While a plentiful supply exists in the Dublin area, the cocoa shells suffer from the major drawback of being light and bulky, incurring high transport costs if moved any distance.

Shredded newspaper proved to be the best carbon source tested in this project. It breaks down quickly in the mix provided it is moistened prior to inclusion. If pre-soaking is not practised, the benefits of adding shredded paper are much reduced and its presence in the mix can be detected after several months of composting. Used newspaper is expensive to purchase in the shredded state, but because of its desirable attributes in the compost mix, on-site shredding would need to be considered in a commercial operation.

Results from the present project suggest that satisfactory composts can be produced from mixes derived from widely varying proportions of biodegradable agricultural wastes provided the basic composting parameters are met.

A total of six of the ten mixes tested met the ‘preferred’ range of characteristics for composts outlined by Rynk (1992) while eight of the ten fell into the ‘reasonable’ range. The last four test mixes to be made had lower C/N ratios than the other mixes because they were all made using the same 4-month-old separated pig solids which had already begun to compost during storage. All mixes composted satisfactorily; however, the time taken to reach maturity (as indicated by a return to ambient temperature in the pile) was much longer than expected. This may be a reflection of the small-scale nature of the composting process used and should be significantly shortened when composting is carried in a modern temperature-controlled in-vessel composting facility. Furthermore, for the conversion of compost to a granular fertiliser, it may not be necessary to fully mature the compost, as would be required for marketing compost *per se.*

4.3 Temperature and Pathogen Control in Composts

A rapid rise in compost temperature in the first couple of days to 60°C+ is desirable to ensure proper sanitation of the compost and to initiate the thermophilic phase of the process. This was generally achieved in mixes containing less than 70% pig solids on a fresh weight basis and containing another readily biodegradable carbon source in the mix.

Recent EU legislation concerning animal by-products not intended for human consumption – Regulation (EC) No. 1774/2002 – states that the placing on the market of processed manure and processed manure products is subject to the following conditions:

(a) they must come from a technical plant, a biogas plant or a composting plant approved by the competent authority, in accordance with this regulation;

(b) they must have been subjected to a heat treatment process of at least 70°C for at least 60 minutes or to an equivalent treatment in accordance with rules laid down under the procedure referred to in article 33 (2);

(c) they must

(i) be free from *Salmonella* (no *Salmonella* in 25 g treated product), and

(ii) be free from *Enterobacteriaceae (*based on the aerobic bacteria count <1000 cfu per gram of treated products), and

(iii) have been subjected to reduction in spore-forming bacteria and toxic formation, and

(iv) be stored in such a way that, once processed, contamination or secondary infection and dampness is impossible.

Under the conditions prevailing in this project, only Batches 7, 8 and 9 reached temperatures of 70°C. These mixes contained 20–35% pig solids, 26–50% poultry litter and 10–15% shredded paper (by fresh weight). Two of the mixes also contained SMC. All mixes, however, reached temperatures of 55°C+ by the end of the second week of composting and 60°C+ by the end of Week 3 (except Mix 10 which never reached this temperature at any time during the composting process).

The prevalence of selected pathogens in fresh manure from livestock in the UK is shown in Table 4.2. This shows *Campylobacter* and *Cryptosporidium* to be the most common pathogens encountered in pig manure. In the present study, the presence of *Salmonella*, *Campylobacter* and *Cryptosporidium* was detected in the pig slurry while the samples tested were free from *Shigella*, *E. coli* 01257 and *Yersinia.*

In a comprehensive review of strategies to reduce the disease risk from livestock manures, Burton and Turner (2003) reported work by Pereira-Neto (1998) that composting effectively eliminates pathogens provided the temperature reaches 55–60°C for a minimum period of 3 consecutive days. Proper turning is important as it will result in all compost material being exposed to these temperatures. The static pile method and particularly in-vessel composting are most effective in providing proper mixing and pathogen inactivation.

Jones and Martin (2003), in a further extensive review of the literature on the occurrence and survival of pathogens of animals and humans in green compost, concluded that most pathogens are inactivated by the composting process and a composting procedure with a residence time of 3 days at a temperature greater than 55ºC results in a sanitised compost. Sanitation standards for compost have been developed in the UK by the Composting Association (2000) which specify minimum compost temperatures of 55–65ºC for periods of 3–14 days, depending on the composting process (turned windrow, in-vessel, static aerated piles). The US EPA established criteria for composts made from biosolids (Composting Association of the United States, 1993). According to the Federal Biosolids Technical Regulations, a windrow must reach a minimum temperature of 55ºC for 15 days with a minimum of five turnings. For an in-vessel or static pile system, a minimum temperature of 55ºC for 3 days is required.

As already noted, only three of the compost mixes tested reached the more stringent temperature target of 70ºC set by the new EU regulations for composting wastes which include animal by-products. However, all the composts produced in the present project from the various mixes examined were found to be free from the range of pathogens for which tests were carried out. Consequently, it would seem reasonable to assume that composting wastes of animal origin to the standards set by the new EU Animal By-Products Regulations should

Table 4.2. Prevalence of selected pathogens in fresh manure from livestock in the UK (after Nicholson *et al.,* 2000).

Pathogen	% Prevalence in manures from			
	Cattle	Pig	Poultry	Sheep
Salmonella	<0.1	<0.1	<0.1	<0.1
Listeria	>75	<5	8	<35
***E. coli* 0157**	16	0.4	0	2.2
Campylobacter	89	95	>75	>75
Cryptosporidium	48	<50	<0.1	<50

result in the production of organic material which is safe to handle and use for further processing.

It is interesting to note that Jones and Martin (2003) in their review stated that there was no information on the survival of *Campylobacter* in composting systems. The present study has shown that *Campylobacter* was detected in the separated pig slurry solids incorporated in the compost mixes but was absent from the mature compost arising from these mixes, the inference being that the organism was rendered inactive by the composting process.

4.4 Granulation of Compost

The project results have highlighted a number of key problem areas to be addressed and how they might be resolved if composts are to be successfully processed into granular form using the equipment chosen, i.e. the Turbulator and disc pelletiser. These are compost moisture content, compost particle size and compost nutrient content.

The Turbulator and disc pelletiser combination works best when the moisture content of the material to be agglomerated is below 25% and preferably around 20%. Particle size is also important and should be less than 2 mm and preferably under 1 mm with a range of smaller particle sizes making up the bulk of the material.

The composts produced in the present project were too wet and coarse to be granulated directly without further conditioning. Moisture could be removed by artificially drying the compost but this adds additional cost to the process. Similarly, screening to remove larger particles (e.g. over 2 mm as carried out during the project) or grinding to produce a finer material are possible ways of preparing the compost for granulation. Both add additional costs to the process. In the case of screening, about one-third of the compost would have to be removed and put to other uses whereas grinding would allow all the compost to undergo the granulation process.

As a result of the experience gained in this project, the American company supplying the pilot fertiliser plant is currently investigating the feasibility of reconstructing the Turbulator to incorporate a grinding mechanism that would break up the compost as it passes through the machine.

The nutrient content of the composts produced in this project exceed those found in normal composts sold to the public as general purpose growing media but fall far short of what is currently available in granulated fertiliser products offered to the amenity grassland or agricultural markets (Table 4.3). Consequently, it is necessary to boost the nutrient content of composts when targeting the granulated fertiliser market by the addition of other organic nutrients and mineral fertilisers.

In the present project, both feather meal and dried blood were found to be excellent sources of organic N and had the advantage of reducing the moisture content of the compost to the desired level when added at around 30% of the compost fertiliser mix. The addition of mineral fertilisers, such as rock phosphate and sulphate of potash, also contributed to a reduction in the moisture content of the final compost/fertiliser mix. More importantly, the addition of these organic N sources and the mineral fertilisers had a significant impact on improving the particle size distribution of the mix and the ease with which the resulting mix could be granulated.

While time and budgeting constraints prevented operation of the pilot fertiliser plant on a continuous basis for a sustained period, sufficient information was obtained about the process parameters necessary to design and operate a commercial plant.

Initial reaction from greenkeepers to the fertiliser batches produced was sufficiently promising to warrant

Table 4.3. Comparison of N, P and K contents of locally sourced composts.

Analysis (% in DM)	Compost source		
	Green wastes	Agricultural wastes (present project)	Commercial peat-based general purpose
Total N	1.94	2.33	1.20
Total P	0.14	1.63	0.15
Total K	0.86	3.18	0.19

consideration of scaling up the process to that needed for commercial operation.

It is also interesting to note that the addition of mineral fertilisers to the compost increased the bulk density of the mix compared with an equivalent volume of the compost on its own. The resulting fertiliser is still 30–40% lighter than conventional mineral fertilisers. This weight difference is not likely to be of significance when operating small-scale fertiliser applicators but could be important when operating large agricultural fertiliser spreaders, particularly in windy conditions.

4.5 Practical Implications

The mechanical separation of coarse solids from liquid manure is practised to a varying extent in most European countries. For example, figures published by Burton and Turner (2003) indicate that 90% of pig slurry in Greece is mechanically separated, 10% in Spain, and in Italy 15% of cattle slurry and 40% of pig slurry are mechanically separated. No figures were given for the Netherlands or the UK where the practice of mechanical separation is known to be widespread.

The benefits of mechanical separation are best achieved in livestock units where the technology forms an integral part of the slurry handling process and not an add-on to an existing slurry collection system. An ideal scenario would involve the use of frequently emptied shallow channels under slatted floors flowing into a small holding tank. The solids are removed from this relatively fresh slurry by mechanical separation and the liquid fraction stored in an overground tank. Part of the separated liquid may also be recycled to flush out the channels. In piggeries, such an arrangement leads to an improved house atmosphere, easier slurry to pump and spread, and a reduction in odours from the liquid fraction when land-spread.

Unfortunately, most piggeries in Ireland have been designed with underfloor tanks and would require extensive modification to facilitate efficient mechanical separation of slurry solids.

By selecting the most appropriate mechanical separation equipment, it should be possible to maximise the removal of solids from the raw slurry and reduce the phosphate content of the liquid fraction by at least 50%. While the volume of liquid to be disposed of is not likely to be reduced by more than 20% by mechanical separation, reduction of the phosphate loading when land-spreading the liquid fraction could have a significant impact on land requirements.

The extent to which mechanical separation of pig slurry from intensive pig units could contribute to easing land disposal problems is outside the scope of the present project. Nevertheless, the topic merits closer scrutiny and should be examined more fully in the context of developing new strategies for handling manure from such units.

It is estimated that a 1000-sow unit finishing its own progeny will produce approximately 30,400 m^3 slurry per year. Assuming a yield of 26 tonnes fresh solids per 1000 m^3 of raw slurry processed, a pig unit of this size would produce around 790 tonnes fresh solids per year if all the slurry is mechanically separated. This quantity of solids would be too small to justify construction of a composting facility on site. As the present project has shown, pig solids are best mixed with other biodegradable wastes if commercial composting is to be pursued.

A further important factor to be considered is the lack of recognised gate fees associated with the present methods of agricultural waste disposal. It is generally agreed that a commercial composting facility of circa 20,000 tonnes annual throughput requires wastes attracting a gate fee of around €30/tonne to cover the costs of composting. Consequently, it can be concluded that composting pig slurry solids could only be contemplated in a centralised unit located in close proximity to a number of large-scale pig units and also close enough to other sources of biodegradable waste, such as food and green waste, that attract sizeable gate fees. In such circumstances, it would be possible to charge for the mature compost used as a base for organo–mineral fertiliser production at a nominal price of around €10/tonne. If reasonable gate fees are not obtained for a sizeable part of the compost mix, then the viability of producing granulated fertiliser from the resulting compost would be in considerable doubt.

The key factors influencing the cost per tonne of fertiliser produced following the processes examined in this project, are the capital cost of the fertiliser plant, the cost of the mineral components of the mix, and the operating costs particularly energy. It is unlikely from present estimates that the proposed organo–mineral fertilisers could be produced for under €150/tonne (Table 4.4). If

Table 4.4. Likely cost of producing organo–mineral fertiliser (€/tonne).

Cost component	€
Fertiliser plant – capital depreciation	12
Fertiliser plant – electricity usage	4
Fertiliser ingredients	104
Fertiliser drying costs	16
Labour (3 man units @ €20/hour)	12
Maintenance/insurance (20% of capital costs)	2
Total	150

Notes:
Fertiliser plant costs based on output of 5 tonnes/h with a capital cost of €1 million depreciated over 10 years at 7% interest.
Electricity consumption: 150 kW/hour at €12/kW.
Fertiliser mix: 0.5 tonne compost at €8 and 0.5 tonne inorganic fertilisers at €96.
Drying costs: 50 litres propane/tonne at 32 cents/litre.

this is the case, then the decision taken during the project to focus on fertilisers for the specialist amenity grassland market (where it is possible to obtain product retail prices double those obtainable in the general agricultural fertiliser market) was the correct approach to pursue.

The amenity grassland market also prefers to work with less concentrated fertilisers than commonly on offer in the agricultural market. This is fortuitous as it would be difficult to achieve high nutrient concentrations and still include a reasonable proportion of compost in the fertiliser mix considering the low inherent nutrient value of composts.

4.6 Environmental Considerations

As already pointed out, removal of the solids from pig slurry by mechanical separation could offer a number of environmental benefits, particularly to the larger pig units, provided the technology is properly incorporated into the design of the slurry handling system on the unit. Benefits in terms of improved pig house atmosphere and odour control during slurry spreading are possible coupled with a significant reduction in the phosphate content of the liquid fraction. This could lead to a smaller land area requirement for a given volume of effluent applied.

The separated liquid still contains a sizeable proportion of the soluble nitrogen and most of the soluble phosphate found in the raw slurry and thus could pose a pollution risk through leaching when applied to land under unfavourable weather conditions or in excessive amounts.

The diversion of the solids fraction to other uses rather than direct application to agricultural land could be beneficial in preventing excessive build-up of organic matter in grassland soils, leading to a deterioration in the stock-carrying capacity and sward composition.

Composting, if carried out in windrows or uncovered bunkers, can lead to a significant loss of ammonia to the atmosphere. As ammonia emissions are now the subject of impending EU legislation and given that agriculture accounts for 80–95% of these emissions across Europe (De Kluizenaar and Farrell, 2000), it is imperative that composting involving animal manures is carried out in totally enclosed in-vessel type composting units. However, provided these units are fitted with atmospheric scrubbers to remove ammonia, which is reabsorbed within the compost mass, there should be no particular risk to the atmosphere from composting such wastes.

4.7 Towards a Complete Treatment System for Pig Slurry

The work reported here can only offer a partial solution to the disposal of slurry from intensive pig units as it has not dealt with the liquid fraction arising from the removal of solids by mechanical separation.

Several attempts have been made in recent years to develop a complete treatment process that removes solids from the slurry and extracts any remaining nutrients from the liquid fraction, the aim being to greatly reduce or eliminate the necessity to land-spread slurry.

One such system is described by Burton and Turner (2003) which produces an organo–mineral fertiliser and no effluent for disposal. In that process, pig slurry is collected in shallow channels under slatted floors and flushed regularly to a holding tank from where it is pumped to overground reactor tanks and mixed with chemicals and polymers to produce a magnesium–ammonium–phosphate (MAP) complex known as ‘struvite’ plus a sludge. This struvite/sludge mix settles to the bottom of the tanks and the liquid is siphoned off to be recycled for flushing out the manure channels. The sludge, at around 25% DM, is removed to a central fertiliser manufacturing plant and subjected to an exothermic chemical reaction between a base (e.g. anhydrous ammonia) and an acid (e.g. sulphuric, nitric, or phosphoric acid) which produces sufficient heat to evaporate the water contained in the manure/sludge. Other wastes which attract a gate fee, such as food waste, can be added at the central plant to reduce manufacturing costs. The process can be fully automated and nutrient ratios of resulting fertilisers altered by adjusting the feedstock used. Obviously, the viability of such a process will depend on the scale of the operation, its location in close proximity to a number of large pig units, the availability of a local gate fee paying biodegradable waste and the cost of non-organic chemicals added.

The annual cost of land-spreading slurry from IPPC-regulated pig units located in non-arable areas is currently estimated at around €150/sow plus finished progeny or around €150,000/year for a 1000 sow unit (Farrelly, P., Cost of land-spreading slurry from IPPC-regulated pig units, personal communication, 2003). Several such pig units working together could convert their slurry into organo–mineral fertilisers for sale within Ireland or for export to Mediterranean and Middle East countries where such products are in much demand. In doing so, the environment in the neighbourhood of the fertiliser factory could be greatly enhanced by reducing nitrate and phosphate leaching from local soils and by lowering atmospheric ammonia emissions.

5 Conclusions

1. Mechanical separation of pig slurry collected during the winter months (November–March), in a tank under a slatted-floor house containing finishing pigs, resulted in the production of a solid fraction with a DM content of 26.2%, a pH of 8.6, a total N of 2.92% in DM, of which 43% was in ammonia form. The mean ash content of the solids, which consisted mostly of undigested feed and pig hairs, was 13.9%, the EC was 1207, and the bulk density was 387 g/litre. It had a C/N ratio of 24 with a range of 20–26.

2. Mechanical separation removed 21% of the unseparated slurry dry matter but had a negligible effect on the volume of liquid produced. Solids removal reduced the total N of the liquid fraction by 13% but had no effect on the ammonia content of the liquid. Total P in the liquid fraction was reduced by 49% on removal of the solids while the soluble residual P was reduced by only 5%.

3. The characteristics of the pig solids produced by mechanical separation in this project fell outside the preferred criteria for composting on their own. Consequently, the addition of other biodegradable wastes was required to reduce the moisture content to the preferred range of 50–60% in DM and to adjust the C/N ratio to the preferred range of 25:1–30:1 to facilitate satisfactory composting.

4. Other biodegradable wastes added to the pig solids included poultry litter, SMC, wood shavings, chopped straw, cocoa shells and shredded newsprint.

   Poultry litter proved a useful amendment, which is in plentiful supply, acting as a source of N, reducing the moisture content and improving the physical structure of the mix.

   Wood shavings gave a more open structure to the compost mix but were slow to break down and had to be screened out of the mature compost. Their inclusion was found to be unnecessary where poultry litter made from wood shavings was already incorporated in the mix. Chopped straw appeared to add little benefit to compost mixes and was expensive to use.

   Cocoa shells proved an excellent carbon source and improved the porosity of the mix. They suffer from a major drawback of being light and bulky, incurring high transport costs if moved any distance.

   Shredded newsprint proved to be the best carbon source tested when incorporated at around 10% of the mix by fresh weight. It breaks down quickly in the mix, provided it is moistened prior to inclusion, and promotes an early rapid rise in compost temperature. It is expensive to purchase in the shredded state and on-site shredding would need to be considered in a commercial operation.

5. Results from the present project suggest that satisfactory composts can be made from mixes composed of widely varying proportions of pig slurry solids and other biodegradable agricultural wastes provided the basic composting parameters are met.

6. It took 6–9 months for the compost mixes containing pig solids to reach maturity as determined by a return of the mix to ambient temperature. This was longer than expected and may have been influenced by the small batch sizes composted (less than 10 tonnes). However, a fully mature compost may not be necessary for conversion to granular fertiliser.

7. *Salmonella*, *Campylobacter* and *Cryptosporidium* were the pathogens found in the pig slurry used in this project, while the samples tested were free from *Shigella*, *E. coli* 01257 and *Yersinia*. All the composts produced were found to be free from pathogens at the end of the composting process.

8. Research elsewhere has shown that composting effectively eliminates pathogens provided the temperature reaches 55–60°C for a minimum of 3 consecutive days and that the composting piles have been properly mixed to ensure that all material in the pile has been exposed to these temperatures. These temperatures were achieved in all mixes (except Batch 10) in the first couple of days.

9. Compost mixes containing 20–35% pig solids, 26–50% poultry litter and 10–15% shredded paper by fresh weight achieved temperatures of 70°C in the first fortnight of composting. Current EU legislation concerning the composting of animal by-products requires that the material be subjected to a heat treatment process of 70°C for at least 60 minutes. Laboratory challenge tests, involving a wide range of pathogens, carried out using sterile compost from the present project showed that all were eliminated at an incubation temperature of 70°C for 1.5 hours.

10. The composts produced in the present project were too wet and coarse to be granulated directly by the equipment employed, namely a Turbulator and Disc Pelletiser. For effective granulation, it was necessary to reduce compost moisture content from 40%+ to circa 20% and particle size to under 2 mm and preferably under 1 mm with a range of smaller particles making up the bulk of the material.

11. The composts produced were too low in nutrient content to justify conversion to granular fertiliser and required to be supplemented with high N type organic materials such as feather meal and dried blood and mineral N, P, K fertilisers.

12. The addition of these nutrient sources to the compost greatly improved the agglomeration characteristics of the compost mix, resulting in the production of organo–mineral fertilisers of particular interest to the amenity grassland market.

13. Sufficient information was collected during the operation of the pilot fertiliser plant to allow decisions to be made concerning the design, sizing and viability of a commercial fertiliser plant to produce organo–mineral fertilisers targeted at the horticulture and amenity grassland market.

14. The application of fertiliser, produced during the project, to greens on two golf courses in Ireland elicited favourable responses from the greenkeepers involved. Granule size, colour, hardness and freedom from dust were considered to be equal to, if not better than, products currently on the market.

6 Publications Arising from Project

Kilpatrick, M., Sturgeon, S., Rao, J.R., Moore, J.E., Watabe, M. and Stewart, T.A., 2003. *Composting Pig Slurry Solids and Physico–Chemical and Microbiological Tests Prior to its Formulation to Granulated Fertiliser*. Symposium No. 13, Paper 2320, 17th WCSS, 14–21 August 2002, Thailand.

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Appendix 1

Table A1. Mean daily temperature (°C) recorded in each compost batch over the first 28 days of composting.

Day	Compost Batch Number									
	1	2	3	4	5	6	7	8	9	10
1	21	12	30	13	57	14	16	10	6	5
2	30	55	38	64	63	31	30	8	3	16
3	44	60	40	65	66	44	33	32	22	22
4	53	60	30	65	13	53	47	47	35	32
5	57	56	31	63	–	58	62	55	52	37
6	59	56	35	62	61	60	70	60	59	13
7	59	60	40	59	–	61	60	62	42	35
8	58	59	44	57	62	61	59	11	51	41
9	57	60	56	57	65	61	66	49	61	49
10	57	59	57	11	65	61	68	63	65	54
11	56	59	58	58	65	61	61	66	66	57
12	56	58	59	68	64	61	68	69	67	59
13	56	57	59	67	64	62	67	70	68	56
14	56	56	60	67	64	13	67	71	69	24
15	56	56	62	66	63	45	66	71	69	47
16	49	55	35	64	62	57	59	71	70	45
17	60	55	39	50	61	60	61	71	69	48
18	61	54	55	–	60	45	59	46	57	53
19	60	57	59	62	59	54	54	50	67	58
20	59	13	60	–	59	59	65	57	48	46
21	55	60	61	67	40	61	69	63	53	46
22	11	60	61	67	52	61	70	56	63	43
23	48	60	61	68	58	62	70	65	67	46
24	57	59	62	68	61	62	70	68	68	49
25	62	59	62	68	44	43	69	69	69	51
26	63	58	61	67	52	56	63	69	70	35
27	62	60	61	67	59	58	72	69	70	35
28	14	52	61	67	62	59	69	69	51	38

Table A2. Mean weekly temperature (°C) recorded in each compost batch in Weeks 5–32.

Week	Compost Batch Number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
5	58	51	59	60	56	60	62	57	58	42
6	48	55	59	60	58	57	62	54	57	38
7	51	60	58	61	54	58	56	53	57	38
8	29	59	54	65	59	56	62	51	50	33
9	29	55	57	61	51	56	61	44	51	33
10	33	58	60	57	48	52	51	53	52	36
11	37	58	56	57	32	56	50	45	48	27
12	28	56	60	57	28	55	54	50	56	30
13	36	63	56	49	30	51	57	51	55	34
14	39	50	54	53	27	51	51	48	51	35
15	35	46	52	61	27	48	41	34	33	20
16	40	47	46	61	30	46	38	38	47	23
17	37	47	55	60	33	39	38	37	43	21
18	35	50	54	53	25	29	39	33	38	21
19	42	50	54	47	21	29	34	33	30	16
20	40	48	54	40	20	29	23	23	35	18
21	36	46	52	44	18	27	24	25	34	17
22	33	44	49	47	17	25	26	33	30	17
23	30	41	44	41	15	22	14	33	28	16
24	29	48	51	34	12	17	18	32	28	16
25	27	45	47	28	–	17	18	31	27	16
26	27	41	43	23	–	56	18	31	27	15
27	29	38	39	19	–	58	–	28	27	15
28	30	35	33	15	–	67	–	25	24	14
29	30	32	28	15	–	66	–	23	22	14
30	28	30	25	17	–	67	–	21	20	14
31	25	22	17	16	–	67	–	20	19	14
32	21	22	25	16	–	57	–	–	–	–

Appendix 2 Summary of Microbiological Methods Employed

1 Microbiological Tests on Pig Slurry

1.1 Materials used

Forty-three pig slurry samples obtained between 13 February 2002 and 5 April 2002 were used in this study.

1.2 Microbiological method used in this study

The pig slurry samples were tested for the presence of *Salmonella* sp., *Shigella* sp., *Campylobacter* sp., *E. coli* 0157, *Yersinia enterocolitica* and *Cryptosporidium*.

The methods followed are described in NIPHL (2001).

1.3 Salmonella sp. sensitivity test

1.3.1 Salmonella *sp. used in this study*

Twenty-six *Salmonella* sp. isolated from pig slurry were tested for their sensitivity against 12 antibiotics.

1.3.2 Method

1. Suspend a colony in saline.
2. Calibrate the solution to 0.5 McFarland using turbidometer.
3. Spread the solution onto Nutrient Agar using swabs.

2 Microbiological Test for Spent Mushroom Compost

2.1 Materials used

Thirty-two spent mushroom compost samples collected between 31 October 2001 and 14 December 2001 were used in this study.

2.2 Microbiological tests

The spent mushroom compost samples were tested for the presence of the following bacteria: *Salmonella* sp., *Campylobacter* sp. and *Listeria monocytogenes*.

The methods followed are described in NIPHL (2001).

3 Microbiological Test for Samples of Materials and the Mixture for Granulated Fertiliser

3.1 Materials used

Forty-five samples of materials and the mixture for granulated fertiliser obtained between 10 April 2002 and 2 September 2002 were used in this study.

3.2 Microbiological tests

Samples of materials and the mixture for granulated fertiliser samples were examined for the presence of *Salmonella* sp., *Shigella* sp., *E. coli* 0157, *Campylobacter* sp., *Yersinia enterocolitica*, *Cryptosporidium* and *Listeria monocytogenes*.

4 Microbiological Test for Samples of Materials and the Mixture for Fertiliser (Second Final Mixture)

4.1 Materials used

Fourteen samples of the second final mixture collected on 11 April 2003 were used in this study.

4.2 Microbiological tests

The second final mixture samples were tested for the presence of *Salmonella* sp., *Shigella* sp., *E. coli* 0157, *Campylobacter* sp., *Yersinia enterocolitica*, *Cryptosporidium* and *Listeria monocytogenes*.

5 Microbiological Test for Samples of Materials and the Mixture for Fertiliser (Final Mixture)

5.1 Materials used

Twenty-one samples of the final mixture for fertiliser obtained on 7 July 2003 were used in this study.

5.2 Microbiological tests

Final mixture fertiliser samples were tested for the presence of *Salmonella* sp., *Shigella* sp., *E. coli* 0157, *Campylobacter* sp., *Yersinia enterocolitica*, *Cryptosporidium* and *Listeria monocytogenes*.

6 Challenge Test

6.1 Materials used

The sample used for the challenge test was taken from the second final mixture.

6.2 Method

The challenge test method is shown in Section 8 below.

7 Final Bacterial Count

7.1 Material used

Four samples of each of the granulated fertilisers made from the final mixtures were used in this study.

7.2 Method

Using a range of serial dilutions, the number of culturable colony-forming units was evaluated using a spiral plate technique as described in Section 8.2 (iii).

8 Challenge Test Procedure

8.1 Preparation for challenge test

1. Take 10 g sample and mix with 90 ml saline (10^{-1}). Plate onto MH. Incubate at 37°C for 48 h.

2. Take 10 g sample and mix with 90 ml TSB. Incubate at 37°C for 48 h. Plate onto MH. Incubate at 37°C for 24 h.

8.2 Challenge test

1. Preparation of bacterial suspension (10^{7}).

   (i) Subculture *Salmonella* sp., *C. jejuni*, *E. coli*, *Yersinia enterocolitica*, *Listeria monocytogenes*, *E. coli* 0157 and *E. coli* 9001 onto blood agar. Incubate following the methods described in NIPHL (2001).

   (ii) *C. jejuni*, *C. coli*, *Salmonella* sp. were suspended in 9 ml saline. Other bacteria were enriched accordingly for 24 h.

   (iii) Make 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} dilutions of each bacterial suspension. Use the 10^{-4} dilution for counting the colony (use a spiral plate). Incubate at 30°C for 48 h.

2. Challenge test

   (i) Put 25 g radiated fertiliser sample into a honey jar. Incubate at 70°C, overnight.

   (ii) Add 1 ml of each bacterial suspension to the jar. Mix well.

   (iii) Incubate all at 70°C for 1 h.

   (iv) Enrichments:
   Salmonella – Mix 2(Sal) and 225 ml BPW.
   Campylobacter – Mix 2(Camp) and 225 ml *Camp* broth.
   Listeria – Mix 2(Lis) and 225 ml half strength Fraser, then full strength Fraser.
   Yersinia – Mix 2(Yer) and 225 ml TSB.
   E. coli – Mix 2(*E. coli*) and 225 ml TSB.