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2 year report on crop trials demonstrating use of compost and digestate in Irish Agricultural uses

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Demonstration of compost and digestate use in Irish agriculture, Years 1 and 2

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rx3 is funded by the Department of the Environment, Community and Local Government

Demonstration of compost and digestate use in Irish agriculture

Published by rx3

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Glossary of terms

ABP	Animal By-products
AD	Anaerobic Digestion
BMW	Biodegradable Municipal Waste
CAN	Calcium Ammonium Nitrate
Composting	Aerobic composting
CNU	Crop Nitrogen Uptake
CV	Coefficient of Variation
DAFM	Department of Agriculture, Fisheries and Marine
DECLG	Department of the Environment, Community and Local Government
Digestion	Anaerobic digestion
DM	Dry Matter
EPA	Environmental Protection Agency
Farm A (SB2)	Spring barley trial site for two years, north of Mullingar, County Westmeath
Farm B (SW1)	Spring wheat trial site for one year, west of Mullingar, County Westmeath
Farm C (GC2)	Grass/clover trial site for two years, Castlemahon, west County Limerick
Farm D (SB2)	Spring barley trial site for two years, Horse and Jockey, north County Tipperary
Farm E (WW1)	Winter wheat trial site for one season, Kilsheelin, southeast County Tipperary
LSD	Least Significant Difference
Morgans P	Method of measuring phosphorous content of soil
NDVI	Normalised Difference Vegetation Index
NIR	near Infrared Reflectants
NMP	Nutrient Management Plan
NSBW	National Strategy for Biodegradable Waste
OM	Organic Matter
PAS 110	Publicly Available Standard 110 - United Kingdom digestate standard
pH	Measurement unit for acidity/alkalinity of soil
s.e.	Standard error
SOM	Soil Organic Matter
UCC	University College Cork
UCD	University College Dublin

1. SUMMARY

This report presents the results of a two year crop demonstration trial at commercial scale on working farms, to compare the use of compost and digestate fertiliser products, made from biowaste, with the normal farming practices of artificial fertiliser or slurry use.

These trials have demonstrated that the available nutrients in compost or digestate, as quality fertiliser products, can directly replace nutrients conventionally supplied by artificial fertiliser. The use of compost or digestate, in these trials, brought agronomic and environmental benefits, proved to be possible to manage within a farming regime and did bring financial savings. The amount of benefit that can be achieved will depend on the individual situation

rx3[1] has funded these crop trials. Government policy is to reduce the volume of biodegradable municipal waste (BMW) being land filled and to increase volumes being composted and digested. This report provides information about, and results from, the crop trials over two growing seasons (2010 and 2011). These trials examined and compared the performance of four different fertiliser products in a commercial farming environment. The products were compost, slurry, artificial fertiliser and digestate. Digestate was used as either whole digestate, digestate fibre or digestate liquor.

There were five crop trial sites, located in Westmeath, Tipperary, Waterford and Limerick and on different soil types with different crops and weather conditions. Site variability was introduced to allow assessment of how the fertiliser products perform in different conditions.

The trial plots were large to facilitate the operation of standard farm machinery being used under normal farm conditions. The large size of the trial plots also reduced the risk of variation between and within plots. This approach was welcomed by the farmers who came to the open days, because it gave them confidence that they would be able to replicate the results on their own farms.

This crop trial was designed to observe the complex interaction of weather, soil, fertiliser and plant to identify the commonalities that would occur in different conditions when compost and digestate are used, compared to slurry or artificial fertiliser.

The wide variety of farming conditions in the trials means caution must be used when comparing the results of the trials from each farm. However, the conclusions that are drawn from this trial are those that can be expected to occur in most situations where and when compost or digestate are used to grow crops.

Four research projects were commenced in 2011 focusing on specific aspects of the complex interactions. However, further focused research is required in specific areas to explain why some of the observed effects occurred, and to determine how to maximise the benefits of using compost and digestate as fertilisers.

The key nutrients in compost are released slowly over time. The trials showed that the compost released about 20% of total nitrogen content during the growing season after surface application. Each of the three digestate products, whole digestate, digestate liquor and digestate fibre, is best suited to a particular use because of differing levels and ratio of available nitrogen and phosphorus and organic matter in each.

[1] rx3 is an initiative funded by the Department of the Environment, Community and Local Government (DECLG) to help develop Irish markets for Irish recycled materials

A number of methods were used, during this project, to publicise the results of the crop trials and to encourage farmers and other people to visit the crop trial sites to view the results of using compost and digestate as fertilisers[2]. The site visits were intended to provide information and to receive feedback. The main comments received in feedback can be found in section 4.3

It has been possible to draw clear conclusions from this crop trial and to provide specific recommendations regarding the use of compost and digestate as fertiliser products. These are provided in chapters 5 and 6. The main conclusions of the trial are

Arable Crops

Compost and digestate gave consistent positive crop growth benefits and grain yield responses from their use for growing spring wheat and barley and also winter wheat.

The surface applied and shallow incorporated compost applications showed strong visual effects on crop growth of cereal crops during the spring and summer, with improved crop nitrogen status and increased total crop nitrogen uptake being recorded. Favourable nitrogen utilisation levels were observed for the compost and the digestate products in the high nitrogen demanding wheat and barley crops.

While these natural fertiliser treatments did not significantly increase crop yield levels in these trials, relative to the artificial fertiliser, the trials clearly show that these nutrient rich compost and digestate products are a valuable alternative nutrient source which can replace substantial chemical fertiliser inputs in crop production.

The addition of compost, digestate fibre or whole digestate in arable soils, may increase soil organic matter (SOM), worm populations and other beneficial soil qualities, however the rate of any change, in SOM is slow.

Grassland

The trials show clearly that grass/clover swards respond well to the natural fertiliser programmes, increasing crop yields and SOM, compared to the artificial fertiliser use.

Compost use provides a slow release of nitrogen which is well suited to increasing output of clover-based grassland swards. However, when artificial nitrogen is added with the compost to supply the crop need for available nitrogen it inhibits the clover performance. Further work is therefore required to determine the best timing for application of both the compost and artificial nitrogen to maximise crop yield.

There is an indication that the addition of digestate or compost increases the pH, Morgan's P and total nitrogen levels in the soil, even when the off-take in the crop is more than the amount of available nutrient applied.

It would appear from the trials that although the nitrogen in the digestate is readily plant available it stimulates the grass/clover sward, rather than causing inhibition as with artificial fertiliser use. It also appears that the minor mineral crop uptake is increased with digestate.

[2] see Appendix 13 for full details

2. INTRODUCTION

rx3 **'rethink, recycle, remake'** (www.rx3.ie), is an initiative funded by the Department of the Environment, Community and Local Government (DECLG) to help develop Irish markets for Irish recycled materials. rx3 has a particular focus upon plastics, organics and paper. Accordingly, rx3 has funded these crop trials. The crop trial commenced in early 2010 to run for two years and has now been extended for a third season in 2012. This report relates to the two growing seasons (2010 and 2011).

Methanogen Ltd, with its partners of University of Reading Soil Science and Crop Research Ltd (a University College Dublin (UCD) campus company), were appointed to deliver this project to aid adoption of best practice in use of compost and digestate on commercial Irish farms. The crop trials have compared the natural fertiliser products of compost and digestate made from biowaste to the normal farming practices of using slurry and/or artificial fertiliser to grow grass/clover and arable crops (winter wheat, spring wheat and spring barley).

Purpose of the crop and grassland trials

- Increase awareness and understanding of how natural fertilisers in the form of compost or digestate made from biowaste, can be used in agriculture
- Gain better understanding of the environmental effects of using natural fertilisers
- Demonstrate how to use these natural fertilisers to best advantage on working farms
- Examine the practicalities of utilising existing farm equipment for spreading
- Investigate, where possible, the financial implications of using compost and digestate

These trials examined and compared the performance of four different fertiliser products. The products were compost, slurry, artificial fertiliser and digestate. Digestate was used as either whole digestate, digestate fibre or digestate liquor.

Compost and digestate are natural fertilisers[3] made by using processes of nature, aerobic composting (composting) and anaerobic digestion (digestion) to produce nutrient rich fertiliser products from biowaste and other biodegradable materials.

The five crop trial sites were located in different regions (see Table 1), and on different soil types with different crops and weather conditions. This facilitated identifying the influence these factors have on the use of compost and digestate. At the commencement of the trials each of the five sites had been under the same cropping regime for more than five years.

The trial plots were large (960m^2 for arable and 480m^2 for grassland), to facilitate the operation of standard farm machinery being used under normal farm conditions. This approach was welcomed by the farmers who came to the open days, because it gave them confidence that they would be able to replicate the results on their own farms. The large size of the trial plots also reduced the risk of variation between and within plots

This report provides all the data gathered during the trial and some additional background information within the Appendices. The body of the report highlights and discusses the important information arising from the trials, in relation to digestate and compost use on each farm.

[3] The term 'natural fertiliser' is used in this document in relation to slurry, compost and digestate.

Table 1: Location, year and crop types used for these trials

	Location	2010	2011	Notes
Farm A	Mullingar, County Westmeath	Spring barley	Spring barley	Minimum tillage[4]
Farm B	Mullingar, County Westmeath	No Trial	Spring wheat	Plough and till
Farm C	Castlemahon, West Limerick	Grassland	Grassland	Dairy farm
Farm D	Horse and Jockey, County Tipperary	Spring barley	Spring barley	Plough and till
Farm E	Kilsheelan, County Tipperary	No Trial	Winter wheat	Plough and till

The trial locations are shown in the map below, which is available in interactive form from www.rx3.ie/Organics

Figure 1: Location of crop trial sites

2.1. BACKGROUND

Previous research results regarding compost and digestate use in agriculture are available from other European countries. Germany is leading in research on the use of compost in soils. Denmark has the most research on the use of digestate in agriculture. Switzerland, Sweden, Austria and the UK have also undertaken research projects on one or both of the natural fertilisers, compost or digestate. Although this research provides significant information, it cannot always be used for comparison or as guidance for what will occur in Irish conditions.

[4] Minimum tillage is a soil conservation system with the goal of minimum soil manipulation necessary for a successful crop production. It is a tillage method that does not turn the soil over, unlike ploughing, which disturbs the soil structure and activity.

2.1.1. Government policy

Government policy is to reduce the volume of biodegradable municipal waste (BMW) land filled and to increase volumes composted and digested. This policy is driven by a series of measures including primary legislation, regulatory and fiscal measures. These crop trials are part of the market development strategy instigated by the Government to encourage the use of the compost and digestate produced by processing the BMW.

In 2010, 269,200 tonnes of waste materials of which 127,674 tonnes was source-separated BMW was processed at 45 Irish composting facilities. The National Strategy for Biodegradable Waste (NSBW) set BMW composting targets of 250,000 tonnes by 2010, 320,000 tonnes by 2013 and 330,000 tonnes by 2016. Figure 2 shows that BMW recycling by composting and anaerobic digestion must increase significantly to meet targets set.

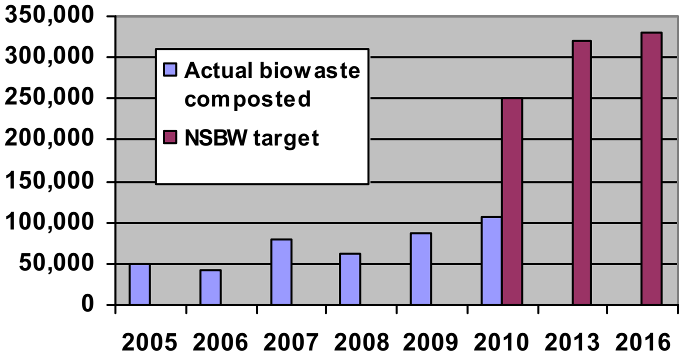


Figure 2: BMW recycled tonnage and targets by year

2.1.2. Changes in food production methods

Since 1950 the cost of food has reduced, relative to the cost of living. The use of artificial fertiliser has contributed to this cost reduction by increasing the amount of food produced per hectare. Where the intensification of agricultural production relies entirely on artificial fertiliser, to produce crops, it tends to reduce soil organic matter. Reduced soil organic matter contributes to soil compaction, water logging, and low water retention in times of drought. On some intensively farmed land, crop output has begun to decrease, despite chemicals being added. Minor mineral deficiencies can be found in the food produced intensively. Minor minerals contribute to good health in plants, animals and humans.

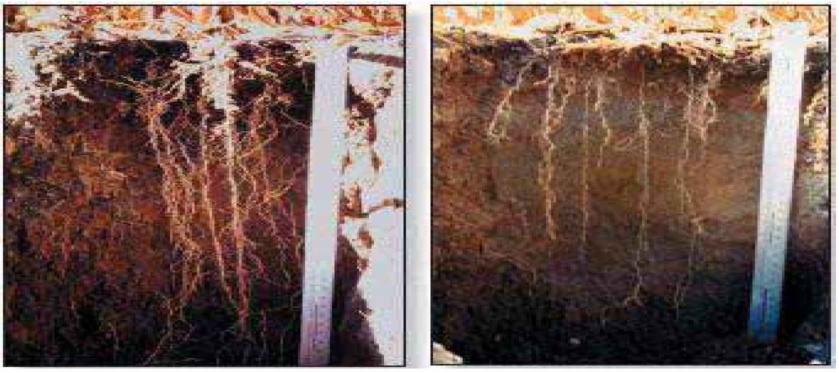


Figure 3: Corn roots in (left) non-compacted and compacted (right) soil

The use of a natural fertiliser, which brings organic matter, major and minor minerals and helps to stimulate soil activity and health, could help restore depleted land and improve good land.

Commercial pressure means that a farmer has to be certain of what the outcome will be if they using different techniques or inputs. These crop trials were conducted to ascertain whether these natural fertilisers would be able to improve the soil quality, maintain output and be manageable in modern agricultural systems at an affordable cost, and to demonstrate to farmers how to use them.

Significant amounts of energy, typically natural gas (about 4 tonnes of oil equivalent[5]), is required to make one tonne of artificial nitrogen. All artificial fertiliser is made outside Ireland and transported many miles. Rock phosphate, used to produce phosphorus fertiliser, is a limited and diminishing natural resource, extracted, processed and then imported into Ireland. A lower cost fertiliser produced and supplied locally, and that is less influenced by international energy prices could help to provide farm production cost stability.

2.1.3. Why an integrated assessment of compost and digestate is necessary

Typically a crop research project is designed to limit variable factors that might affect the aspect that is being researched. This approach means the results of that research can generally be relied upon to be replicated if the same conditions are applied. However, when the conditions vary, or the situation is different the results of the research may then not be applicable.

Performance trials using artificial fertiliser can focus on only the crop growth response, and the outcome is considered to be reliable relative to each type of crop, even if location and other growing conditions vary. This is because the nutrients in artificial fertiliser are in a standard mineral form that plants can utilise relatively directly, if there are growing conditions, without significant interaction with the soil or other factors.

However, the use of compost, digestate or other natural fertilisers stimulates the complex interaction within the soil and between the soil and plant. Soil activity and the plants interaction with the soil, releases nutrients from the organic matter added and from the soil particles. This complex interaction varies depending on the qualities of digestate and compost[6], the level of organic matter, soil health and type, previous land use, weather conditions etc.

This crop trial identifies the commonalities that occur in different conditions and has demonstrated to farmers the effects of using compost or digestate at farm level, compared to normal farming practices.

Caution must be used when comparing results between farms, due to wide variation in farming conditions. However, the conclusions drawn from this trial are those that can be expected to occur in most situations where and when compost or digestate are used to grow crops.

2.2. ADDITIONAL RESEARCH

In 2011, additional research was commenced under controlled conditions to add clarification and further understanding to results observed in the field. This additional research continues in 2012 and will be published in the second half of 2012.

[5] As advised by senior process engineer at IFI (Irish Fertiliser Industries)
[6] dependant on criteria such as materials used to make them, the process management, degree of maturation

- **Additional research project 1**; incubation trials at Teagasc Kinsealy investigating nitrogen and phosphorus availability of compost and digestate when mixed with soil.
- **Additional research project 2**; pot-plant growth trials at Teagasc Kinsealy using grass are ongoing to determine relative availability of organic nitrogen and phosphorus relative to inorganic nitrogen and phosphorous.
- **Additional research project 3**; detailed characterisation of the compost and digestate used in the main crop trial. A comparison of results of this research will be made to another characterisation which is underway at Teagasc of 25 compost and digestate materials from another EPA funded project.
- **Additional research project 4**; three factorial design trial studies were conducted at the UCD Lyons Farm using the compost on research plots of established clover only, grass only and grass/clover areas, to monitor both the rate of release of nitrogen from the compost and the relative nitrogen uptake levels by the respective crops. [7]
- **This crop trial project has been extended** for an additional year, for the 2012 growing season. The same trial plots were maintained on two of the host farms, Farm C (GC2[8]) on Farm D (SB2[9]). This additional year is expected to provide further insight into the long term effects of using compost or digestate.

Figure 4: Grass/clover trials at UCD

[7] More detailed report of this trial held at UCD is in Appendix 12
[8] GC2 means that the grass/clover trial was hosted by this farm for two years to date
[9] SB2 means that a spring barley trial was hosted by this farm for two years to date

3. METHODOLOGY AND MATERIALS USED

3.1. THE TRIAL LOCATIONS

There were five crop trial sites located in different regions and on different soil types. In the 2010 growing season, there were two spring barley and one grass/clover trials. In 2011 two additional trial sites were added one of winter wheat and the other spring wheat. Table 2 provides details of the location, crop and natural fertiliser used

Table 2: Crop trial locations, crop grown and product used in 2010 & 2011

	Location	2010	Product	2011	Product	Plot size
Farm A	Mullingar, Westmeath	Spring barley	W, C	Spring barley	W, L, C	960 m^2
Farm B	Mullingar, Westmeath	-	-	Spring wheat	W, L, F, C	960 m^2
Farm C	West Limerick	Grass/clover	W, C	Grass/clover	L, C	480 m^2
Farm D	Horse & Jockey Tipperary	Spring barley	W, C	Spring barley	W, L, C	960 m^2
Farm E	Kilsheelin, Tipperary	-	-	Winter wheat	W, L, C	750 m^2

W = whole digestate L = Liquor F = Fibre C = Compost

3.1.1. Summary of conditions at the four arable sites

The trial plots, at each site, were laid out randomly in one block within a larger field of the same crop, with the tram tracks running up the middle of each plot. The plots were sized to the width of equipment used on that farm and were sufficiently long to facilitate using a combine harvester. On Farms A (SB2)[10], B (SW1)[11], and D (SB2) each plot was 960m^2 (24m x 40m) and at Farm E (WW1)[12] were 750 m^2 (15m x 50m). Crop management, other than fertiliser, was the same as the rest of the field.

Figure 5: Plots at Farm A (SB2) showing tram tracks running up the middle of trial plots

- Farm A (SB2), in County Westmeath - spring barley grown using minimum tillage in both 2010 and 2011. The bedrock geology is Westmeath Limestone overlain by deep deposits of glacial drift. The soil loam/clay loam texture with moderate organic matter (4.5%) and slightly acidic pH (6.1 pH units). It is free draining, with a weak structure and high silt content. Soil P was index 2 and soil N was index 1.

[10] SB2 means that a spring barley trial was hosted by this farm for two years
[11] SW1 means that the spring wheat trial was hosted by this farm for one year
[12] SW1 means that the winter wheat trial was hosted by this farm for one year

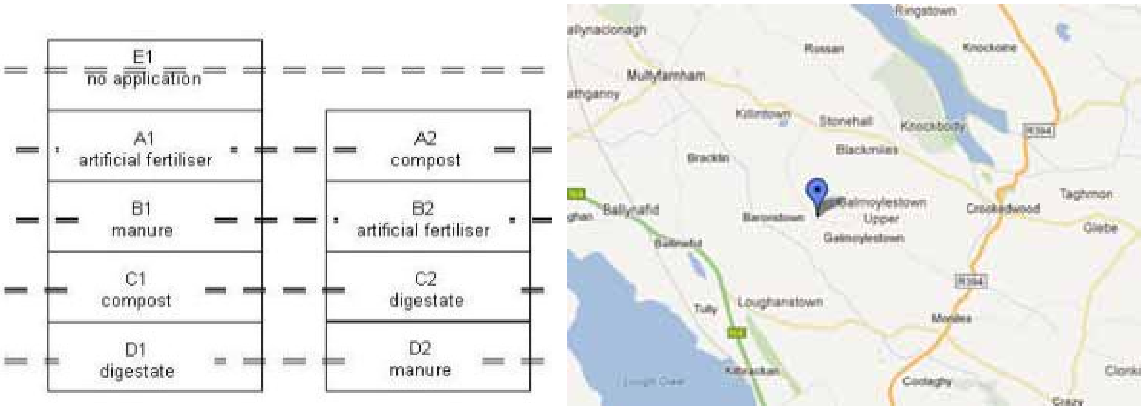


Figure 6: Spring barley plot layout (left) and location (right) in Westmeath of Farm A (SB2)

- Farm D (SB2), Horse and Jockey, Tipperary, Spring barley grown using plough and till in both 2010 and 2011. The bedrock geology is Visean limestone and calcareous shale. The soil is well-drained, well structured and shows a friable dark brown gravely loam surface. Soil analysis determined a loam texture with high organic matter status (5.3 - 7.2%) and neutral pH (6.7 pH units). Soil P was index 2 and soil N was index 1

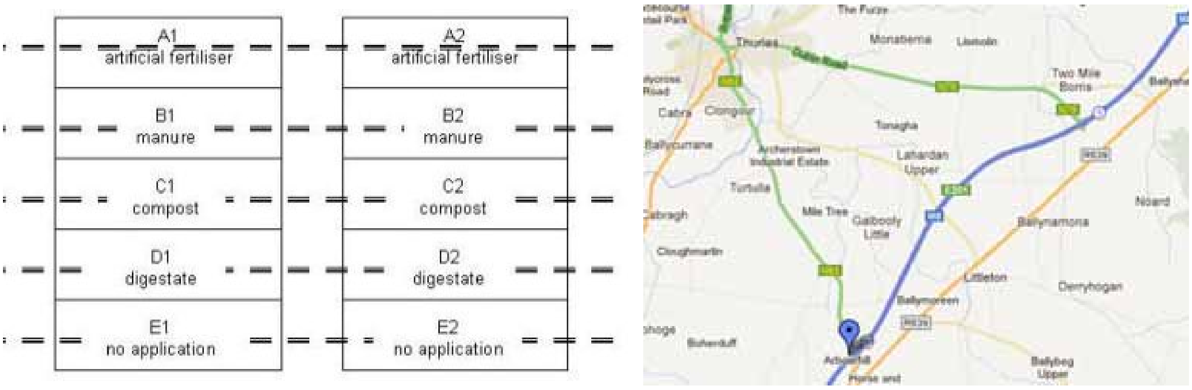


Figure 7: Spring barley plot layout (left) and location (right) in Tipperary of Farm D (SB2)

- Farm B (SW1), in County Westmeath - spring wheat grown using plough and till in 2011 only. The soil is a clay loam, free draining, with good organic matter (5.8%) and a neutral-alkaline soil (6.8 pH units). The previous crop was spring rapeseed so SI 610 dictates that soil nitrogen is index 2. The soil P was index 1.

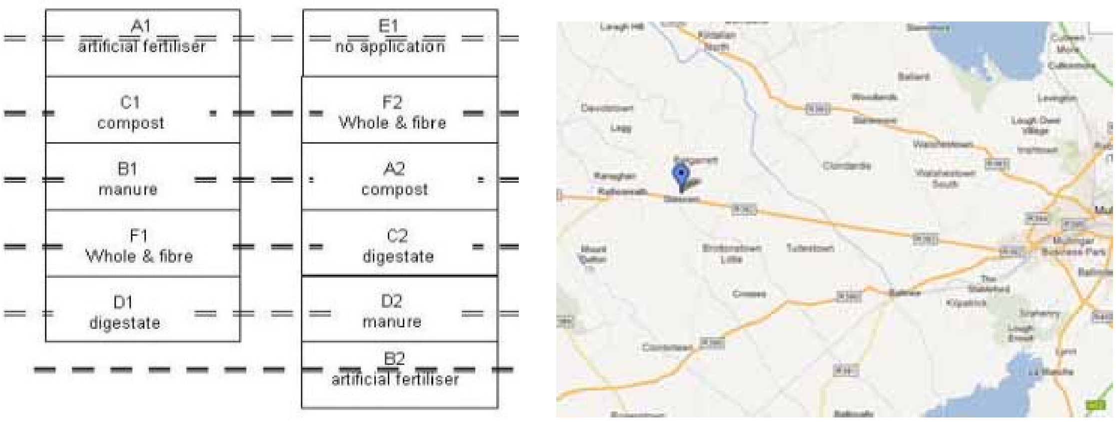


Figure 8: Plot layout for wheat sites and location in Westmeath of Farm B (SW1)

- Farm E (WW1), Kilsheelan, Clonmel County Tipperary. Winter wheat grown using plough and till, planted in 2010 and cropped in 2011. There is a system of a five year rotation of a variety of crops. The soil is medium loam, with good organic matter (5.8%) and high alkalinity (7.5 pH units) and fine particles. Last year, peas were grown so SI 610 dictates that the soil nitrogen is index 2. The soil phosphorous was index 3.

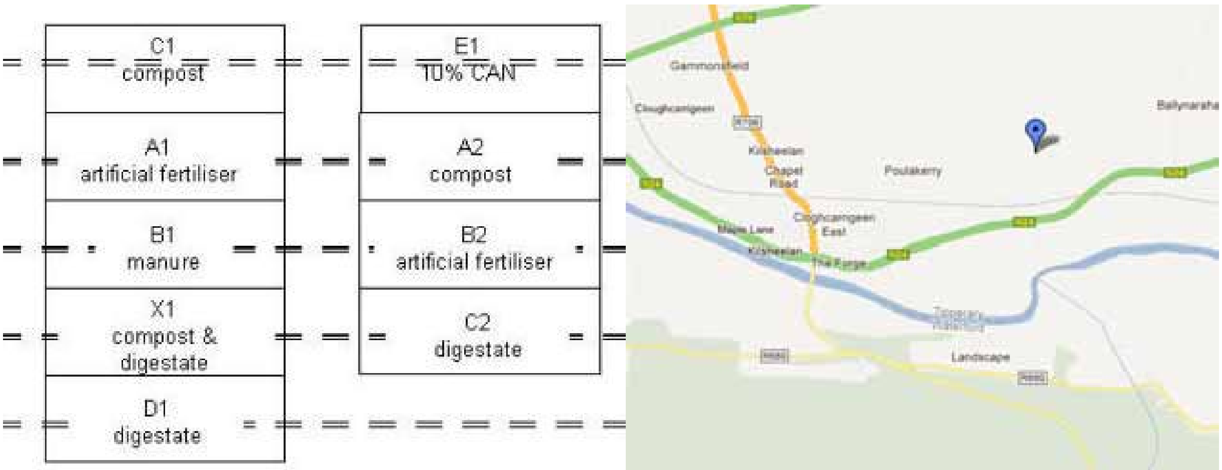


Figure 9: Plot layout (left) and location (right) and location in Tipperary of Farm E (WW1) (winter wheat)

3.1.2. Summary of conditions at the grass/clover trial site

The field used for the grass/clover crop trial was on Farm C (GC2), in West Limerick part of a dairy farm with 100 milking cows. The land is heavy, rarely dries out fully and naturally has high molybdenum and low potassium content. The field used for the trials was permanent pasture and white clover had been stitched into all the fields on the farm in 2007, to reduce the need for additional nitrogen. This clover has established well. There were two replicates for each treatment and each trial plot size was 480m^2 (12m wide and 40m long).

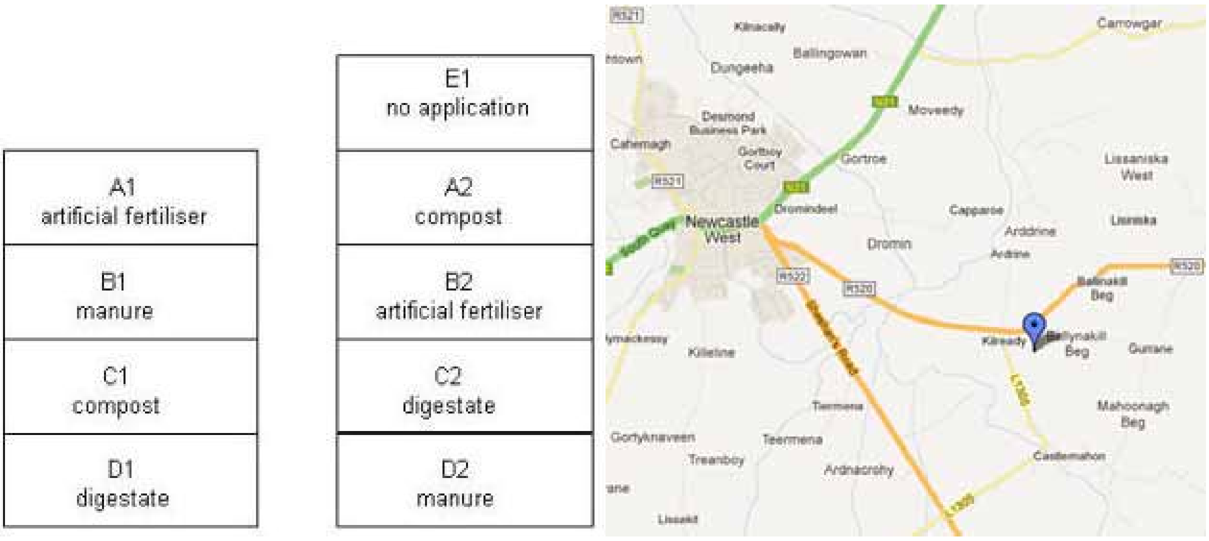


Figure 10: Plot layout (left) and location (right) in County Limerick of Farm C (GC2) grass/clover trial

3.2. FERTILISER INPUTS AND THEIR MANAGEMENT

Compost as a fertiliser

The key nutrients in compost are released slowly over time. In artificial fertiliser products, the nutrients are available on application. Therefore the effects are not directly comparable. Nutrient availability of compost varies depending on the materials used in making the compost and its level of maturation. Further research is required to determine the exact nutrient release and availability from compost when incorporated with soil.

During these crop trials the nutrient availability was taken to be as shown in table 3 below, based on the research[13] available when the trials commenced. However, the analysis of the compost and the crop performance, in 2011, would indicate, that the available nitrogen in the compost was closer to 20% than the 10% assumed for the trials.

Table 3: Nutrient content and availability in a typical compost used (62%DM) (units kg/t of DM)[14]

Nutrient	Nitrogen	Phosphorous	Potassium
Total	19.3	4.4	6.5
Available	1.9	3.3	5.2
Availability	10%	75%	80%

Process of Composting

Composting is a process that utilises a natural self-heating aerobic biological process which causes decomposition of the material by micro-organisms (mainly bacteria and fungi) into a humus rich product. Food or catering waste is composted in enclosed systems with stringent process controls.

Food waste can be collected with green waste for composting because either woodchip or green waste (50% of mix) is needed to aid air access. The compost mixture is placed in piles, which are aerated and turned regularly, to allow the material to fully process. Initially the process is conducted indoors, in a monitored and controlled environment, and then matured outside (humification stage) for about 60 days. The compost is graded to the particle size required, and physical contaminants (e.g. plastic), if present, can be removed. The compost is then a fertiliser product, ready for use, with a high content of lignin, a soil conditioner.

[13] Wrap (2009) using quality compost to benefit cereal crops and Prasad (2009) A literature review on the availability of nitrogen from compost in relation to the Nitrate Regulations SI 378 of 2006: Small-scale study report prepared for the Environmental Protection Agency by Cré – Composting Association of Ireland

[14] Full analysis results of all inputs used in the trials are available in Appendix 4

Figure 11: Compost maturing indoors and outdoors

Digestate as a fertiliser

Whole digestate[15] is the fully digested material that is unloaded from a digester. Whole digestate can be passed through a separator to remove the coarse fibres (digestate fibre) from the liquid (digestate liquor). Each digestate product has different properties and nutrient content which depend on the feedstock quality, the duration and type of digestion process and other conditioning used.

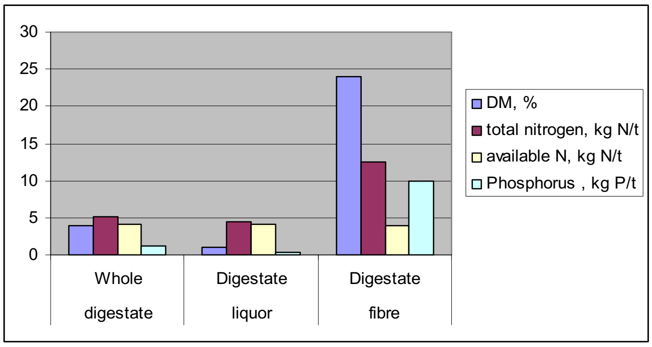
Each type of digestate product is best suited to a particular use.

- Whole digestate is best applied prior to silage or arable crop sowing
- Digestate fibre is best applied when phosphorous and organic matter is needed
- Digestate liquor is best applied on growing grass or for top dressing on crops, as it does not soil the crop and nearly all the nitrogen is readily plant available.

This is because of the difference in the level and ratio of available nitrogen and phosphorus and whether or not organic matter is needed. It can be seen from Table 4 that the available nitrogen content is similar for all three products, but the total nitrogen, phosphorous and dry matter content vary significantly in each product.

Table 4: Comparison of the selected characteristics[16] of the different forms of digestate

As an example	Whole digestate	Digestate liquor	Digestate fibre
DM	4.0%	1.0%	24.0%
Total nitrogen, kg/t	5.2	4.5	12.5
Available nitrogen kg/t	4.1	4.1	4.0
Available nitrogen	81%	91%	32%
Phosphorous, kg/t	1.2	0.4	10.0
Available N : P ratio	3.5 : 1	11 : 1	0.5 : 1



The anaerobic digestion process

Anaerobic digestion is a natural microbial process that can occur when air is excluded from organic matter. One method of processing food waste is to utilise a controlled wet digestion process, which takes about 60 days processing to produce a fertiliser. A digester is a tank which is heated and mixed, and from which air is excluded. A by-product of the process is biogas which can be captured and used as a renewable fuel.

Food waste for anaerobic digestion is best collected as a separate waste stream, in small dedicated bins excluding physical contaminants such as plastics or glass and excluding woody materials which are not generally suitable for anaerobic digestion.

Food waste is best co-digested with manure or sewage sludge to improve process stability.

[15] typically 4-12% DM (dry matter content)
[16] Figures provided by Torkild Birkmose of Danish Agricultural Advisory Service

Figure 12: Whole digestate spread on stubble and digestate liquor spread below barley canopy

Sources of Compost and Digestate Material for the Study

The compost used in the trials was supplied, each year by the Waddock Composting Facility Ltd, County Carlow. This facility is licensed by the Environmental Protection Agency (EPA) and has an animal by-product (ABP) licence[17] to process biowaste. The compost product used in the trials was of a grade compliant with Irish Standard 441:2011.

The digestate used was brought from DEFRA licensed[18] digesters in the UK as at the time there were no AD facilities producing digestate from biowaste in Ireland. In 2011 the PAS 110[19] digestate standard and quality protocol had been established and the digestate products used met this standard

Table 5: Details of the digestate and compost used during the trial

	Digestate 2010	Digestate 2011	Compost 2010 and 2011
Contents	5% pig slurry 95% commercial food waste	10% cow slurry 90% commercial food waste	50% municipal food waste 50% wood chip / green waste
Supplier	Biogen/Greenfinch Ltd UK	Lower Reule Biogas Ltd	Waddocks Composting Ltd
Products	Whole digestate	Whole digestate, digestate fibre and digestate liquor	Compost
Quality certification	None available	Pas110:2010	Irish Standard 441:2011

Artificial fertiliser and slurry used

Standard proprietary artificial fertilisers were applied. On the arable farms different artificial compounds such as 18:6:12 (18% nitrogen: 6% phosphorous: 12% potassium) were used to supply the first application of artificial fertiliser to the crop. The compound used was the same as applied by the farmer in the rest of the field. Straight artificial fertilisers calcium ammonium nitrate (CAN)(typically 27% nitrogen), muriate of potash (typically 50% potassium) and superphosphate (typically 16% phosphorous) were used to supply all the artificial fertiliser needs on the grassland, to top up the natural and artificial fertiliser products and for second and third splits, to the amount of nutrient required by the crop.

The slurry used was produced by animals housed on the trial farm.

[17] Licence from Department of Agriculture, Food and the Marine (DAFM)
[18] Licensed by the UK Department of Environment, Farming and Rural Affairs (DEFRA)
[19] PAS110 is a UK publically available standard introduced in 2010 to certify quality digestate products

3.3. NUTRIENT AVAILABILITY

Nutrient availability from fertilisers other than artificial fertiliser is a complex issue, and as a result is inherently variable. Legislation has applied mandated values to some natural fertilisers and not others. The relevant legislation changed during 2010, with SI 610 of 2010 replacing SI 101 of 2009. It resulted in changes to some mandated levels of nutrient availability.

The aim of this trial was to compare the performance of different inputs, therefore it was necessary to apply equivalent amounts of nutrients on each plot. As a result, the application practice employed in the slurry plots was not that permitted by legislation, at farm scale, without the competent authority agreeing to issue a certificate that stated the nutrient content was at a different level.

Table 6: Summary of nutrient availability for the natural fertilisers used in the trials

	2010			2011		
	Nitrogen	**Phosphorous**	**Potassium**	**Nitrogen**	**Phosphorous**	**Potassium**
Compost	10%	75%	80%	10%	75%	80%
Whole digestate	55%	75%	90%	70%	100%	100%
Digestate liquor	-	-	-	80%	100%	100%
Digestate fibre	-	-	-	30%	100%	100%
Slurry	40%	100%	100%	40%	100%	100%

Determining nutrient content and availability in slurry

The nutrient and dry matter content of slurry can vary significantly between loads, even when drawn from the same holding tank. A sample of the slurry was taken from the spreading tanker, after some of the slurry had been discharged onto the field, to ensure that the sample represented the actual slurry applied on the plot.

The spreading of slurry is regulated by SI 610 (2010), which states that the nutrient content per tonne of cattle slurry is 5kg of total nitrogen and 0.8kg total phosphorous and that the nutrient availability is 40% of total nitrogen; 100% of total phosphorous and 100% of total potassium, regardless of dry matter content. This is the nutrient level of slurry that a farmer would have to adhere to, when spreading. This regulatory level of total and available phosphorus controlled the spreading rate of the slurry.

None of the slurries used in the trial had a total phosphorus or total nitrogen content nearing the regulation level. This meant that the slurry plots did not receive as much slurry as could have been applied according to their actual total phosphorous content. Therefore, to enable a reasonable comparison of the growing performance between all the plots, the analysis results were deemed to be the actual total nutrient content of the slurry and artificial fertiliser was used to compensate for the difference in total nitrogen and phosphorous, between the assumed level in the regulations and the actual level. This would not normally be allowed at farm level.

The level of available nitrogen and phosphorus for the trial was taken to be the percentage that is specified by SI 610 (2010). The actual nitrogen availability identified by analysis was found to be different for each sample but was related to the level of dry matter in the slurry, being more available the lower the dry matter, so long as this watery nature was created by the cattle excretions, not from the addition of water. Artificial fertiliser was used in the trials to bring the amount of calculated available phosphorous and nitrogen applied up to an equivalent level to the other plots.

Nutrient content and availability of compost and digestate

A literature review, industry norms, the regulations[20], actual analysis of the products used and the experience gained from the trials, informed the process of determining what level of nutrient availability should be assumed for the compost and digestate products used in the trial.

Planning the Nutrient Supply

A nutrient management plan (NMP) was drawn up for each farm based on the soil phosphorous and nitrogen index, the crop requirement for nutrients (as defined in the regulation) and the calculated available nutrient content of the inputs, as summarised in Table 6.

The amount of natural fertiliser applied in each case was maximised and artificial fertiliser straights were used to balance and top up to the crop nutrient requirement. A table for each farm entitled ‘Planning the nutrient supply’ is provided in Appendix 5 that provides NMP details for each farm in each year.

Research shows that clover nitrogen fixing is inhibited when there is significant available nitrogen application. Therefore allowance was made for the nitrogen that was expected to be provided by the clover in the grass sward at 110kg/ha[21] for the slurry and compost plots as they have higher organically bound nitrogen content and 90kg/ha for the artificial and digestate plots.

The rate of application of the natural fertilisers was determined by

- Available phosphorous content for the compost, digestate fibre and slurry,
- Available nitrogen for the whole digestate and digestate liquor.

As a result, in some cases the advised crop requirement for potassium was exceeded slightly.

Nutrient application was split in accordance with normal farm practice. The phosphorous and potassium required was applied either before sowing or with the balancing application for first split. The exceptions to this were

- Arable: the digestate plots received digestate liquor for the later splits,
- Grass/clover: the slurry and digestate plots were spread after the first cut of silage.

[20] SI 610 states that for products not listed in Table 8 (Amount of nutrients contained in 1 tonne of organic fertilisers other than slurry) the total nitrogen and total phosphorus content per tonne is to be based on certified analysis provided by the supplier. Table 9A states how, for compost the nitrogen availability should be calculated which is in relation to carbon content but SI 610 does not specify level of available phosphorous. Digestate is not specifically mentioned in SI 610 and therefore there is no specified level of availability. However, where digestate feedstock contains manure, the Department of Agriculture currently considers all the digestate to be manure and therefore would require the level of nutrient availability specified in SI 610 for manure to be applied to the digestate

[21] As advised by James Humphreys Teagasc

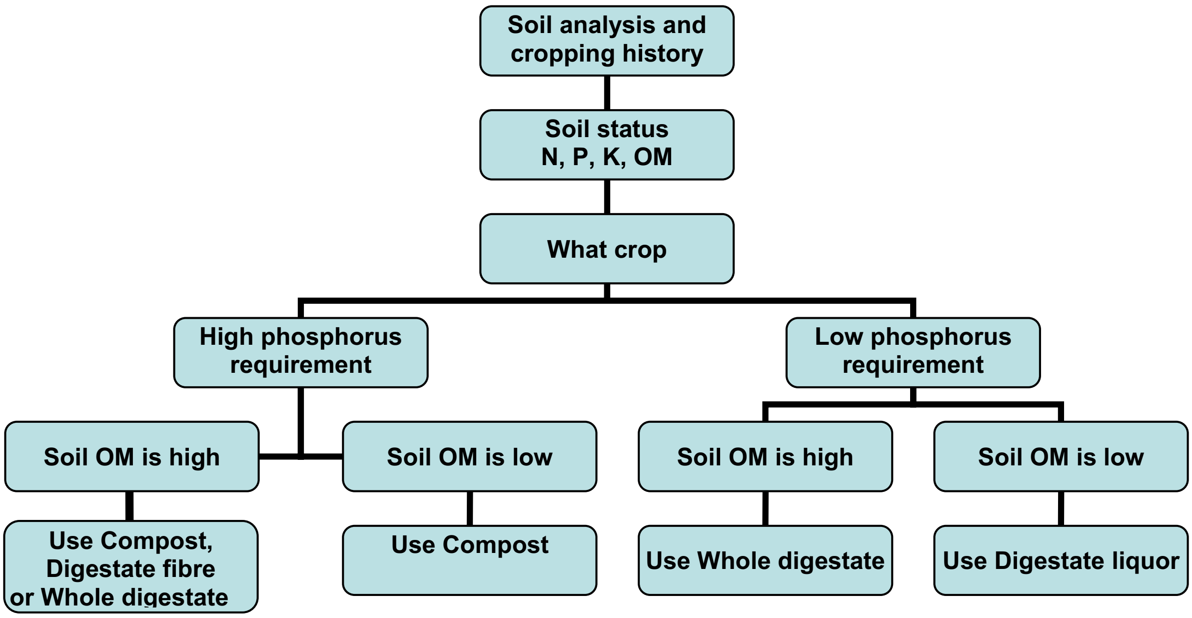
3.4. DECIDING WHICH NATURAL FERTILISER TO USE

Deciding which natural fertiliser to use is dependent on the material available and the attributes sought. The table and decision tree following will facilitate decision making.

Table 7: The attributes that determine which natural fertiliser is the best option

Attribute required	Suitable natural fertiliser
Readily available nitrogen	Digestate liquor, whole digestate
High available phosphorus content	Compost, digestate fibre
Low available phosphorus content	Digestate liquor
Organic matter, when soil phosphorus is low (1 or 2)	Compost, digestate fibre
Organic matter, when soil phosphorus is high (3)	Whole digestate
Application onto growing crop	Digestate liquor
Application after cutting silage	Whole digestate
Surface mulch with slow release of nutrients	Compost, digestate fibre

Figure 13: Decision tree of factors to consider when selecting the type of fertiliser



3.5. SPREADING TECHNIQUES USED IN THE TRIAL

The plot dimensions for each farm were designed to match the cover area of the equipment used on that farm. Care was taken when applying any fertiliser to the plots, and to the rest of the field, to minimise the risk of overlap over plot boundaries. A border strip (1m wide) on each plot was not harvested as part of the trial to ensure that results were not affected by potential overspray or drift of fertiliser from an adjacent plot.

Artificial fertiliser was spread using a dual spinner spreader mounted on a tractor. On Farm A (SB2), B (SW1) and D (SB2) the throw width was 24m in each direction, on Farm C (GC2) the throw width was 12m and on Farm E (WW1) 15m. The width of the plots at each farm were determined by this spread width. Dual spinner spreaders work on the principle of overlapping applications, therefore a different system of spreading had to be used in different situations as outlined below. Figure 14 provides a diagrammatic example where plot A and B require the same type and amount of application but plot C is different.

- Where possible (for example when adjoining arable plots were to receive the same treatment type and rate) the tractor travelled on the tram lines.
- A 12m limiter was used where one adjoining plot received a different application treatment.
- When the plots on both sides received different treatments, then the spreader was set to work on one spinner only at the appropriate rate and travelled around the edge of the plot while spreading. This resulted in the 24m throw covering only the width of the plot.

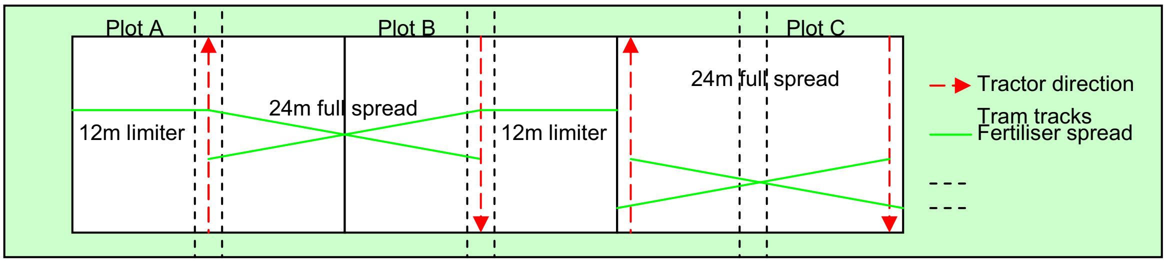


Figure 14: Diagram of how the artificial fertiliser was applied within plots

Several different types of equipment, Ktwo, lime spreader, dung spreader and moving floor trailer, were used to spread the dry natural fertilisers, compost and digestate fibre. The Ktwo worked better than the other equipment to distribute the compost and digestate fibre, which are relatively dry and consisted of short pieces only. A slurry tanker was used to spread the whole digestate, digestate liquor, and slurry.

Figure 15: Ktwo spreading compost on stubble, and photograph showing the spread achieved.

3.6. MONITORING UNDERTAKEN

This crop trial has endeavoured to assess and consider the majority of the factors that are affected by or affect the use of compost and digestate fertiliser products in agriculture, including

- Crop production, quantity, quality and health
- Soil nutrient status, qualities and ability to provide the crop with nutrients and health
- The issues for a farmer to source, store, spread and manage compost or digestate
- The potential longer term effects of use
- The quality and type of the inputs
- Use on different crops and soils in different conditions
- Financial value

The monitoring programme and the type of sampling and tests undertaken were therefore chosen to achieve this aim of integrated assessment. Table 8 provides a summary of the monitoring undertaken. Full details are provided in Appendix 7.

Table 8: Timing of sampling and analysis regime

Parameter	Timing of sampling and analysis
Natural fertiliser	• Sampled on delivery to farm or in slurry tanker
Soil qualities	• Before input application and crop sowing • Mid summer during growth • At the end of the growing season
Crop	• Growing crop - throughout the growing season. • Harvested crop - weighed and analysed for nutrients and qualities

3.7. ADDITIONS DURING THE TRIAL

During 2010 it was found that there was no significant change in some aspects being monitored. Although the knowledge that these factors (e.g. soil qualities in the arable soils) were not changing rapidly was important in itself, it was decided to reduce the frequency of the monitoring of those aspects and monitor other areas more. In 2011 the following additional features were added to the trial.

- An additional plot at each site was added which received no application of fertiliser
- Nitrogen uptake by the crop was monitored throughout the growing season

In 2010, all the digestate plots received one application of whole digestate only, due to logistics reasons. For the 2011 growing season, it was decided to use whole digestate for first applications in the arable crops and digestate liquor for the grassland and the later split applications in the arable. Digestate fibre was applied to the land where the spring wheat was grown where the soil P was index 1 and required a significant application of available phosphorous.

Additional treatment plots were added to the wheat trials (two types of digestate treatments in the spring wheat at Farm B (SW1), and compost with digestate at Farm E (WW1) in the winter wheat). This allowed observation of the effects of different management approaches.

3.8. FARM ACTIVITIES

Weather conditions determine the timing of crop and manure management, therefore the timing of the farming activities on the trial plots was different for the very dry spring in 2011 to those of 2010, which was a wet spring[22]. The timing for the work that was undertaken on the farms is provided in Table 9 and 10.

Table 9: Timing of arable farming activities for the crop trials

Arable management	Spring barley	Spring wheat	Winter wheat
Plough	Early March	Late January	September
Soil sample	After plough	Before plough	Before plough
Apply natural fertiliser	Early March	February	Early February
Apply compound and digestate	Late March	Late February	Late February
Cultivate and sow	Late March	Late February	October
Apply artificial fertiliser top up	Early April	Early March	Late February
Second split fertiliser	Early May	Early April	Early April
Apply herbicide and insecticide	Early May	Early May	Late April
Third split fertiliser	-	Early May	Early May
Apply first fungicide	Mid May	Mid May	Early May
Apply second fungicide	Mid June	Mid June	Mid June
Harvest	August	August	August

Figure 16: Crop trial plots at Farm E (WW1)

Table 10: Timing of grassland activities for the crop trials

Grassland management	Timing
Soil sample	Late February
Apply natural fertiliser for first cut	Early March
Apply artificial fertiliser top up	Late March
Harvest first cut silage	End of May
Apply natural fertiliser for second cut	Early June
Apply artificial fertiliser top up	Mid June
Harvest second cut silage	End July
Harvest third cut silage	Mid September

[22] Weather data can be found in Appendix 12

3.9. PROMOTIONAL ACTIVITIES

Figure 17: Arable trial open day events

A number of methods were used, during this project, to publicise the results of the crop trials and to encourage farmers and other people to visit the crop trial sites to view the results of using compost and digestate as fertilisers, (see appendix 13 for full details). The purpose was to provide information and to receive feedback. The following promotional activities were undertaken

- Presentations at five significant conferences each with over 100 attendees representing waste suppliers and processors and people from the agricultural sector
- Press articles and reports
- Open days on each of the arable trial sites and three events on the grassland farm
- Posters which were displayed at several additional conferences
- Information leaflets were prepared to provide information on natural fertilisers and on the trial results and were distributed at open days and at conferences

Figure 18: Open day on Farm C (GC2)

4. CROP TRIAL REPORTS

This chapter details the definitive results from the trials, with regard to farming sector, arable and grassland. The reporting focuses on the results from 2011, as two years use of the inputs provides more definitive data on the sites. Detailed results of all the monitoring that was undertaken at each of the sites can be found in Appendix 8. Chapter 7 provides discussion of data and issues where further research would help to define the rationale for their occurrence.

The trial has demonstrated that available nutrients in compost and digestate fertiliser products can replace nutrients otherwise supplied by artificial fertiliser.

4.1. GRASS / CLOVER

This section reports on the results of the trials undertaken on grassland at farm scale on Farm C (GC2) in Castlemahon, West Limerick and the factorial trial plots at Lyons farm, UCD[23].

Table 11: Planning the nutrient supply in 2011 (kg/ha) – Grass / Clover at Farm C (GC2)

Per ha basis	Artificial fertiliser			Slurry			Compost			Digestate		
	N	P	K	N	P	K	N	P	K	N	P	K
Crop requirement	226	30	145	226	30	145	226	30	145	226	30	145
Natural fertilizer total	0	0	0	34	10	62	18	30	48	136	7	61
Artificial fertilizer total	226	30	145	82	21	83	98	0	98	0	23	84
1st cut applications	55%			25t/ha			9.2t/ha			27.6t/ha		
Natural fertiliser	0	0	0	23	7	48	18	30	48	95	5	44
clover	30	0	0	37	0	0	37	0	0	30	0	0
kg of artificial fertiliser	95	20	95	65	13	48	71	0	48	0	15	51
2nd cut applications	45%			12.5t/ha			0t/ha			11.9t/ha		
Natural fertiliser	0	0	0	11	3	14	0	0	0	41	2	17
clover	60	0	0	73	0	0	73	0	0	60	0	0
kg of artificial fertiliser	41	10	50	17	7	36	28	0	50	0	8	33

At Farm C (GC2), during the growing season, the silage crop was given the following amount of available nutrients - 226kg of nitrogen, 30kg of phosphorous (soil P index 3) and 175kg of potassium[24]. The nutrient application was split between first and second cuts. However, all whole digestate[25] and compost was applied before first cut in 2010. All the compost required was applied before first cut in 2011.

Available phosphorous content limits application rate for compost and slurry. The available nitrogen content determined the rate applied for digestate, both whole and digestate liquor.

An allowance was made for the nitrogen considered to be provided by the clover over the year. As the nitrogen in digestate and artificial fertiliser is more available, this was expected to reduce the amount of nitrogen produced by the clover, so a smaller allowance[26] was made (90kg/ha) for the digestate and artificial fertiliser plots than the allowance (110kg/ha) for the compost and slurry plots.

[23] More detailed report of this trial held at UCD is in Appendix 12
[24] in 2010 as soil potassium levels were low and 145kg in 2011 as soil K level had increased
[25] The whole digestate for logistical reasons and the compost was all applied early in the growing season to allow it to wash down to the soil surface and the rain and soil activity to bring the nutrients to the plant roots
[26] This allowance was calculated based on the advice received from clover researchers

4.1.1. Results Yield from Farm C (GC2)

- All three natural fertiliser treatments performed well in 2010 and 2011 as can be seen in the wet and dry yield graphs in Figure 19.
- It is very clear from the results that grass/clover sward responded better to all three natural fertilisers than to the artificial fertiliser. (see figures below)
- In 2010 the highest dry matter yield was from the compost plots and the highest wet yield was from the digestate plots
- In 2011, the wet yield was higher than in 2010 from both the compost and digestate plots, and the highest dry and wet yield was from the digestate plots
- In 2011 the dry matter yield for the year for both the digestate and the compost plots was higher (24% and 3% respectively) than the artificial fertiliser plot.
- The yield response and nitrogen uptake in the trials at both Farm C (GC2) and UCD indicate that the available nitrogen release from the compost is around 20%
- The yield from both the grass only and the grass/clover plots at UCD increased with the rate of application of the compost. But there was no difference in yield with changes in application rate in the clover only sward
- There is an incremental yield increase from using compost on a grass/clover sward compared to a grass only sward (Figure 21)

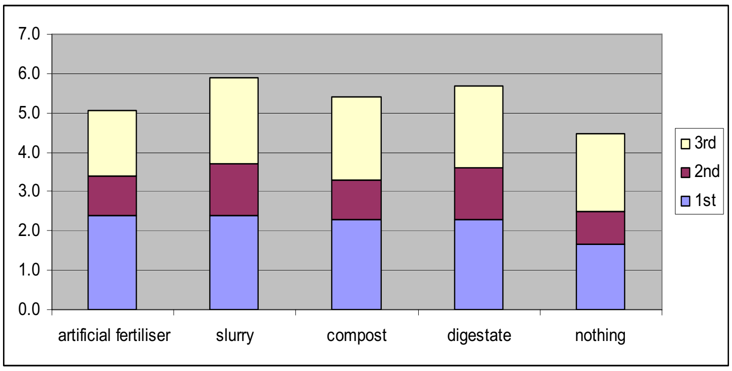


Figure 19: 2011Yield (in t/ha) of grass DM at Farm C

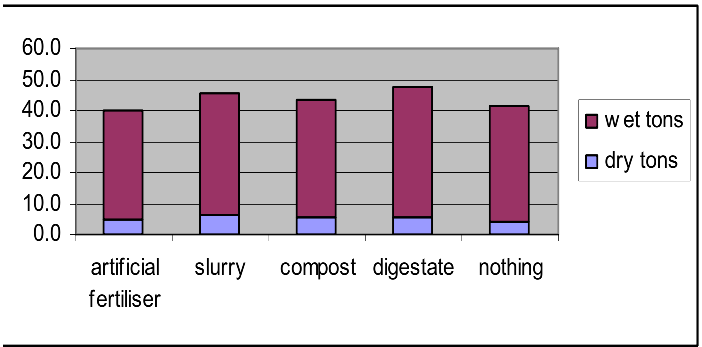


Figure 20: Dry yield (in t/ha) as part of wet yield

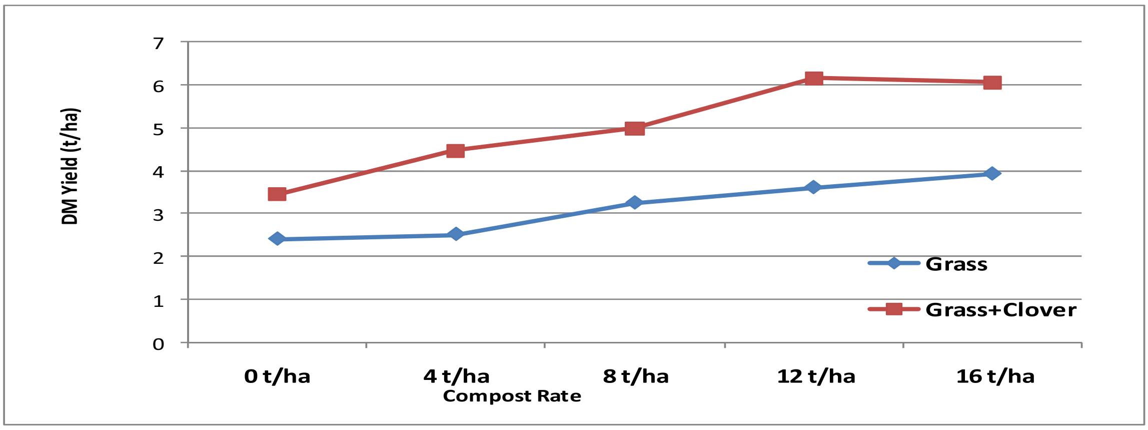


Figure 21: The cumulative yield by sward type and compost rate at UCD.

The trial plots at UCD were established plots of grass, grass/clover and clover only. There were three replicates of each treatment and each plot size was 10m^2. In this trial different rates of application (0, 4, 8, 12, 16t/ha) of compost only were applied to the different types of sward. Figure 19 shows the results of the trial carried out at UCD for the yield from the grass only and the grass/clover swards[27]

4.1.2. Results - Mineral uptake by the crop

A grass/clover sample was taken for analysis of mineral content each time the sward was cut. The total nitrogen uptake by the grass/clover crop was significantly higher in the digestate plots (Figure 20) compared to both the artificial fertiliser and slurry plots, mostly due to the higher amount of DM yield.

Protein levels in the grass did not follow the same pattern as nitrogen uptake. The protein level in the grass from the digestate plots was highest for the first two cuts but reduced considerably by the third cut. In comparison, the protein content levels in the artificial fertiliser plot continued to rise, being highest in the third cut.

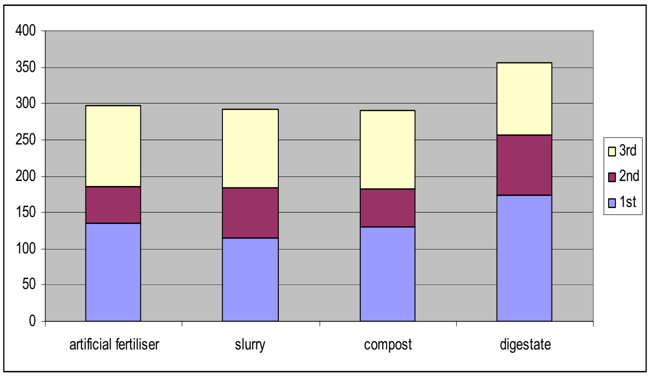


Figure 22: 2011 Nitrogen offtake (kg/ha) Farm C

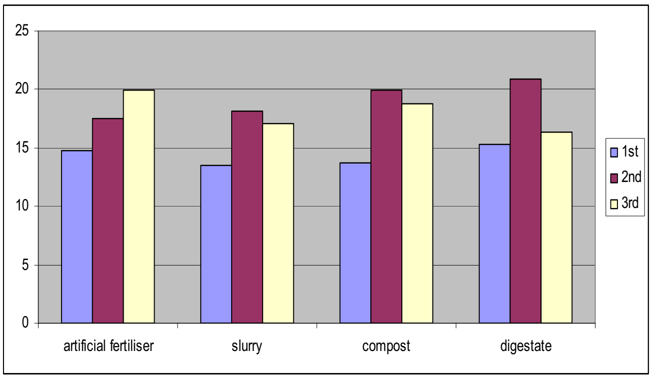


Figure 23: 2011 protein content (%) at Farm Compost

The grass/clover, at UCD, had a higher nitrogen content and higher crop nitrogen uptake than the grass only swards (Figure 24). This is the same pattern of response to higher rates of compost application to that of the dry matter yields. Increasing rates of compost application to the grass/clover sward appears to give additional incremental benefits in CNU further increasing productivity relative to the grass.

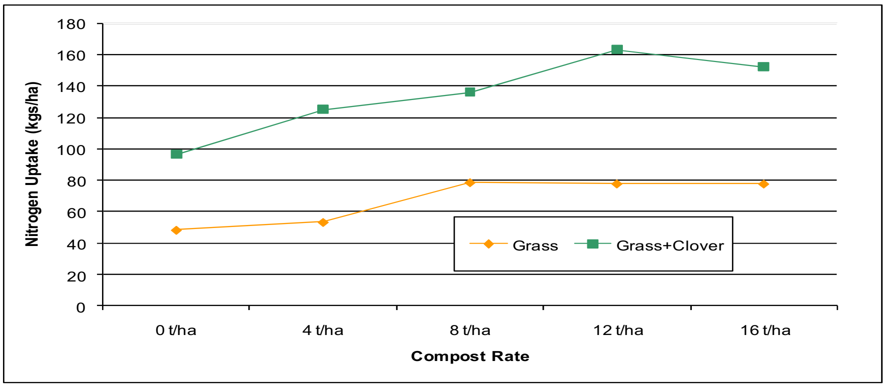


Figure 24: The nitrogen uptake by sward type and compost rate in UCD trial.

[27] The clover only sward results are not shown here as there was no significant response to changes in the application rate of compost

Figure 25: Silage making on the trial plots at Farm C (GC2)

The total crop mineral off take, for both minor and major minerals, over the year (2011) is given in the figures below. The highest off take of all major minerals and most of the minor minerals is in the digestate plots. The mineral off take is higher for most minerals in the compost plots than the artificial fertiliser plots. The total off take is obviously related to the amount of yield, however, even when the greater yield from the natural fertiliser plots is allowed for, and the mineral off take is still higher per tonne of grass dry matter. The artificial fertiliser plots have the highest off take for all the heavy metals, despite being the lowest DM yielding plot.

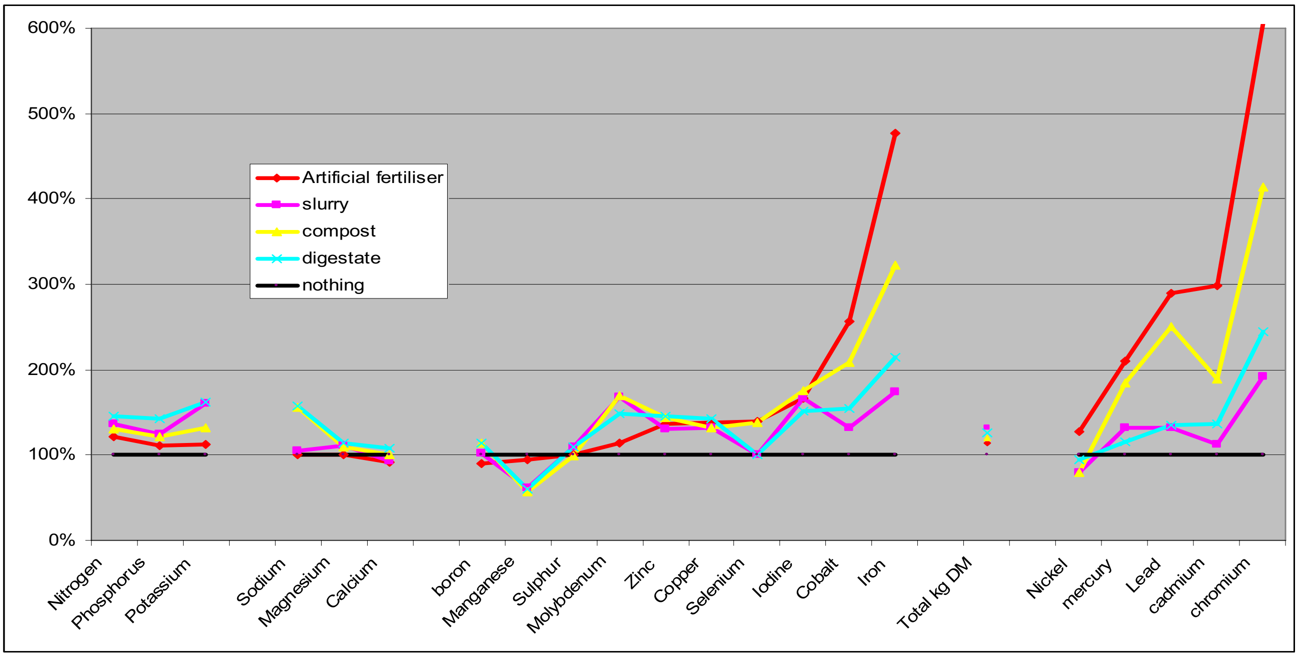


Figure 26: Mineral offtake, relative to the do nothing plot for 2011 at Farm C (GC2)
(Using fresh grass DM% to calculate DM harvest weight per plot)

4.1.3. Results - Soil qualities

In 2010, natural fertilisers caused an increase in the levels of major nutrients and trace elements in the soil but little change in the soil pH or organic matter levels.

However, by the autumn of 2011 there were some quite noticeable differences between the different types of grassland plots, which could indicate that these differences are due to the type of fertiliser applied. Table 12 shows the values found in the soil samples taken in autumn 2011, full details can be found in Appendix 8.

Table 12: Autumn 2011 soil qualities in the different plots at Farm C (GC2)

	pH	Morgans P	OM	Total N	Nitrate
		mg/l	%w/w	% w/w	mg/kg
Artificial	6.2	4.0	6.7	0.29	16.1
Slurry	6.1	3.3	6.8	0.31	20.2
Compost	6.5	5.7	7.1	0.34	19.6
Digestate	6.4	5.7	7.2	0.38	21.2

The main points are summarised below

- The pH in the artificial fertiliser and slurry plots is similar to that found at the start of the trials, but the pH in the digestate and compost plots has increased a little.
- The Morgan's P level in the digestate and compost plots is very slightly higher to the level at the start of the trial, however the level in the artificial and slurry plots has dropped significantly
- The OM content has risen in all plots although only slightly in the slurry and artificial fertiliser plots but more significantly in the compost and digestate plots
- The total soil nitrogen has gone down slightly in the artificial fertiliser plot, stayed the same in the slurry plot, increased slightly in the compost plot and increased more in the digestate plot.
- The soil nitrate had increased in all of the natural fertiliser plots, but stayed at the same level as that found at the start of the trial, in the artificial fertiliser plot
- There appears to be no noticeable change in other mineral or heavy metal content in the soils of any of the plots
- The trial results indicate that the use of either compost or digestate stimulates a healthy well functioning soil, although further research is required to identify why this occurs and how best to encourage this for crop production and soil health.

4.1.4. Results - Cost benefit

This cost/benefit analysis identifies the value of the avoided artificial fertiliser cost relative to the crop yield for that method of nutrient management, when as much as possible of the crop requirement for nutrients is met by using a natural fertiliser.

This cost/benefit analysis does not try to place a financial value on the other benefits that this trial indicates may arise when using natural fertilisers in agriculture, nor does it allow for costs that may be incurred for purchase, transport, storage or spreading as these will vary considerably from farm to farm. (More details in Appendix 10).

Therefore, there will be a net financial benefit for the farmer, from using compost or digestate, if the saving in artificial fertiliser cost achieved is greater than the associated costs of use (purchase, transport, storage or spreading).

Table 13: Cost benefit analysis for nutrients applied at Farm C (GC2) in 2011

	Grass DM yield	Artificial fertiliser cost	Cost saved	Artificial fertiliser cost of grass	Value natural fertiliser applied	Natural fertiliser applied
Units	t/ha	€/ha	€/ha	€/t	€/t	t/ha
Artificial	5.1	343.88	0.00	32.02	n/a	n/a
Slurry	5.9	165.31	178.57	14.23	4.76	37.5
Compost	5.4	209.92	133.97	18.91	14.56	9.2
Digestate	5.7	140.53	203.35	10.52	5.15	39.5
Nothing	4.5	0.00	343.88	0		

DM values used for harvest were those of fresh cut grass for all cuts and yield weights were wilted grass

There is a significant reduction in artificial fertiliser used in grass/clover production when any of the natural fertilisers are used. The reduction in cost of artificial fertiliser to produce one dry matter tonne of grass/clover amounts to €13.11 for compost used and €21.50 for digestate compared to using only artificial fertiliser.

Although there are greater reductions in the cost of artificial fertiliser for slurry and digestate than for compost, greater volumes of digestate or slurry need to be spread, therefore the value per tonne of slurry (€4.76) and digestate (€5.15) is less than for compost (€14.56).

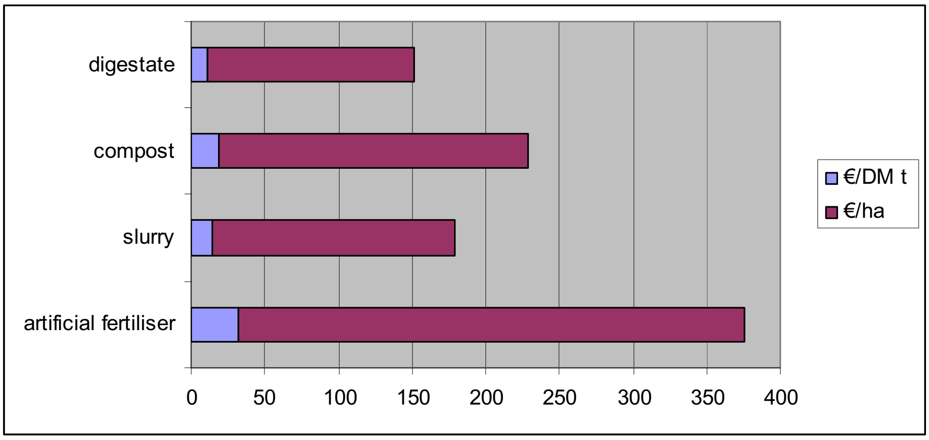


Figure 27: Cost of artificial fertiliser per ha and the artificial fertiliser cost of producing grass (/tDM) for each type of treatment in 2011

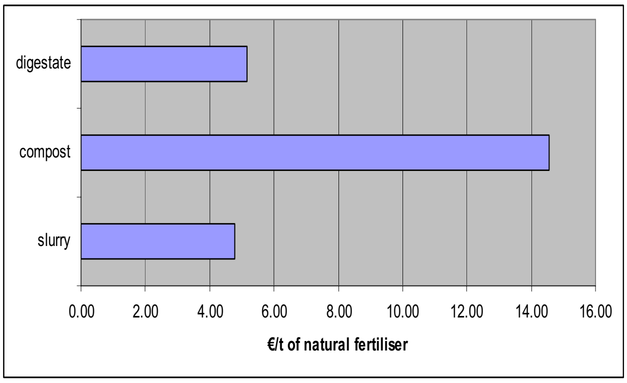


Figure 28: Value in €/t of the natural fertiliser based on artificial fertiliser cost avoided, the amount of natural fertiliser applied and the crop yield

4.2. ARABLE TRIALS

Conditions differ at the four arable sites, and different crops were grown. Site variability was deliberately introduced to allow assessment of how the fertiliser products perform in different conditions. However, the wide variety of farming conditions in the trials means caution must be used when comparing the results of the trials from each farm.

The differing conditions for the trials have provided some clear general and some specific observations about the use of compost and digestate on arable crops. This section provides details of those observations arising from the trials and the trial management. Individual site reports can be found in Appendix 8

4.2.1. Nutrient management

The nutrients applied at each site were those specified by SI 610 (2010) relative to the soil status and the crop requirement for the specific crop grown. Table 14 shows the amount of nutrients applied for each crop and the timing and amount of nitrogen applied.

Table 14: The nutrient requirement for each site

	Crop nutrient need kg/ha			N application split		
	N	P	K	1st	2nd	3rd
Spring barley - Farm A	135	35	75	50% pre-sow	50% surface	-
Spring barley - Farm D	135	35	65	50% pre-sow	50% surface	-
Spring wheat - Farm B	110	45	90	41% pre-sow	45% surface	14% surface
Winter wheat - Farm E	140	25	50	20% surface	50% surface	30% surface

The nitrogen was applied as per normal practice in two or three splits, depending on the crop grown. The total requirement for available phosphorous and potassium was applied with the first split of nitrogen for all plots, except in the digestate plots where an allowance was made for these nutrients that would be included within any subsequent application of digestate. Table 15 provides an example of the NMP for Farm D (SB2) in 2011.

Table 15: Planning the nutrient supply for 2011 at Farm D (SB2) (kg/ha)

	Nitrogen		Phosphorous		Potassium (K)		t/ha
from	natural	artificial	natural	artificial	natural	artificial	rate
1st split	68		35		65		
artificial	0	68	0	35	0	65	-
slurry	23	45	7	28	48	17	44
compost	21	47	35	0	56	9	10.7
digestate	68	0	9	22	33	0	26
2nd split	67		0		0		
artificial	0	67	0	0	0	0	-
slurry	0	67	0	0	0	0	0
compost	0	67	0	0	0	0	0
digestate	67	0	4	0	35	0	22

The first split of nutrients was met by using natural fertilisers or compound (for the artificial fertiliser plot) applied after ploughing and before sowing, except in the winter wheat where they were applied in late winter (once spreading was permitted) on the emerged crop. Straight artificial fertilisers were used to; balance the natural fertilisers and to top up the compound artificial fertilisers applied to the artificial fertiliser plot, to the nutrient requirement and were applied after emergence.

Calcium ammonium nitrate (for the artificial, slurry and compost plots) or digestate liquor (on the digestate plots in 2011) were used to meet second and third split nitrogen requirement. Table 16 provides an example (from Farm D (SB2)) of how the nutrient requirement at each split was supplied by artificial and natural fertilisers for each plot.

Table 16: Example of application timing (Farm B SW1)

Application	2011
1st split part A Before cultivation	Compound in artificial fertiliser All slurry, compost & digestate fibre Whole digestate to first split nitrogen crop requirement
1st split part B After emergence	Balancing artificial straights
2nd split	Second split artificial nitrogen to artificial fertiliser, slurry & compost plots Digestate liquor on both digestate plots for second & third split nitrogen need
3rd split	Third split artificial nitrogen to artificial fertiliser, slurry & compost plots

In 2010, only whole digestate was used in the digestate plots and all of this was applied before sowing and all the arable plots received a dressing of calcium ammonium nitrate at second split application. In 2011 whole digestate was applied for the first application. Digestate liquor was used to supply the requirement for nitrogen at subsequent splits[28] in the digestate plots.

[28] The amount of digestate liquor requirement for the second and third splits was applied in one application at second split as the very small quantity required for third split would have made application very difficult.

At Farm B (SW1) there was the opportunity to have two types of digestate plots. In one pair of replicates (plots named 'digestate' (B1)) the nitrogen availability from the whole digestate and liquor was assumed to be higher[29]. This approach allowed the observation of crop performance when a higher availability was assumed. In the second pair of replicates (named 'fibre/digestate' (B2)) digestate fibre and whole digestate were used as the initial application due to the low soil phosphorous status, and digestate liquor was used for the later crop need for nitrogen

Figure 29: Spring wheat after emergence at Farm B (SW1)

4.2.2. Summary of the arable results

- The trials showed clearly that the available nutrients in the compost and digestate applied, can directly replace nutrients normally supplied by artificial fertiliser, for barley and wheat production. Tables 17 and 18 summarise the performance results which can be found in detail in appendix 8

- The nitrogen release rate from digestate liquor and artificial fertiliser appeared to be similar, although in some circumstances the nitrogen supply was not sustained for as long with the digestate liquor.

- More research and experience is needed to determine the optimum application timing and method to achieve the best results in differing conditions

Table 17: Summary of arable performance - compost V artificial fertiliser

Farm	establish	growth	yield	CNU	Protein %	1000 grain[30]
A (SB2)	C	C	H	L	L	C
D (SB2)	C	C	C	C	H	H
B (SW1)	C	L	H	H	L	-
E (WW1)	n/a	C	H	MH	H	H

C = comparable L = lower ML = much lower H = higher MH = much higher

Table 18: Summary of arable performance - digestate compared to artificial fertiliser

Farm	establish	growth	yield	CNU	Protein %	1000 grain
A (SB2)	C	C	n/a	L	C	H
D (SB2)	C	C	H	L	L	H
B1 (SW1)	L	L	H	C	L	-
B2 (SW1)	L	L	H	H	L	-
E (WW1)	n/a	L	ML	ML	C	L

29 Ten per cent higher compared to that assumed for all other trials.
30 1000 grain weight is the means of measuring the bushel weight (weight per volume of grain)

B1 = digestate at Farm B (SW1) B2 = fibre/digestate at Farm B (SW1) N/A = not applicable

4.2.3. Results - Barley trials over two growing seasons

Nitrogen utilisation and Yield

In 2010 at Farm A (SB2) and Farm D (SB2) the nitrogen utilisation was significantly higher in the digestate plots than other plots and the 1000 grain weight was also highest, indicating a high level of nitrogen use efficiency.

In 2011 in the digestate plots at Farm D (SB2) the growth was similar to the artificial fertiliser plots although the crop appeared to ripen slightly earlier. The grain yield and 1000 grain weight was high compared to the artificial fertiliser but the protein level was lower. These results indicate that with digestate there was high early-season nitrogen availability and crop uptake but low nitrogen utilisation later in the season.

At Farm A (SB2) in 2011, the plant growth in the digestate plots was similar to the artificial fertiliser plots. The protein level in the grain was higher than the slurry plots and only slightly lower than the artificial fertiliser plots, indicating the nitrogen supply was maintained through the summer period. The 1000 grain weight was higher than all other plots, but unfortunately, the true yield could not be calculated due to infestation by wild oats in both digestate plots.

In 2011, the compost programme at Farm D (SB2) had a yield comparable to artificial fertiliser, but less than the slurry plots. The grain protein content was higher than the artificial fertiliser plots, and the 1000 grain weight higher than both slurry and artificial fertiliser plots. These results indicate that, in the compost plots, there continued to be nitrogen release and hence availability in the summer period which was utilised by the crop and resulted in higher grain protein content. The compost plots had a similar plant establishment and nitrogen uptake profile to the artificial and slurry plots during growth monitoring throughout the summer, indicating sufficient supply of nitrogen at this stage of growth.

In 2011 at Farm A (SB2) the yield from the compost plot was higher than the other plots and the 1000 grain weight was comparable as was the establishment and growth indicators. The crop nitrogen uptake (CNU) and the protein content of the grain were similar to the slurry but lower than the artificial fertiliser plots, indicating that in this trial there was good early supply of nitrogen but less available as the summer progressed.

Figure 30: Bringing in the harvest from plots

4.2.4. Results - Wheat over one growing season

At Farm B (SW1) all of the natural and the artificial fertiliser nutrient programmes were observed to provide a good crop nutrient supply to the wheat crop. The favourable agronomic and crop nutrition effects observed at the canopy complete stage in June, continued throughout the ear emergence and grain-filling period to the end of the crop cycle. The compost and both types of digestate plots performed well over the season, with good nitrogen uptake measurements recorded during the grain-filling period combined with high grain yield and favourable grain and straw nitrogen uptake data also being recorded

The digestate plots performance was equivalent or only slightly less than the fibre/digestate plots throughout the early growing period, but began to fall behind in growth scores towards the late summer and the final yield was lower, indicating that less nitrogen was available in the digestate plots, later in the year. However, the CNU measured at harvest was comparable with the fibre/digestate plots and CNU was higher for both types of digestate plots than the other treatment plots.

The monitoring of the compost plots showed that establishment and growth was ahead of the slurry plots, but slightly lower than the artificial fertiliser plots, although the nitrogen level recorded in the crop before ripening was lower than both these treatments. However, the crop yield and CNU was higher than both the slurry and artificial fertiliser plots.

At Farm E (WW1) the compost plots had the highest yield of all the plots at 11t/ha. They also had the highest 1000 grain weight and CNU of all the plots and had protein content better than slurry, and comparable to artificial fertiliser.

The compost/digestate plot performed better than the digestate only plot, but not as well as the compost plot for yield, 1000 grain and N uptake in the grain, and not as well as the digestate only plot with regard to protein content.

The digestate plots throughout growth and in yield performed in line with a 40 per cent application of the required nitrogen had been applied. Notably though, the mean grain protein content in the digestate only plots was higher than the slurry plot and compost/ digestate plot, and only slightly lower than the compost and artificial fertiliser plots.

Figure 31: Collecting and weighing the grain at harvest

4.2.5. Results - Soil Qualities

At Farm A spring barley (SB2)

- The addition of natural fertilisers increased soil moisture retention.
- There were increases in, Morgan's P and also pH in the compost plots over the two years.
- Soil organic matter (SOM) content was maintained better in the compost plots than the other types of plots, but was still lower than at the start of the trial.
- The bulk density results in 2011 indicate that the addition of organic matter that contains structural carbon (compost and slurry) can create a more open soil structure over two years, even when the amounts added are relatively small
- The trial indicates that continual use of digestate liquor on arable crops, without an application of additional structural carbon, may actually reduce SOM faster than other treatments.
- The only other noticeable changes would be that the pH dropped slightly in the artificial plots and the Morgan's P level dropped in both the slurry and artificial plots.

At Farm D spring barley (SB2)

- The pH increased in all plots over the course of the trial from 6.4 at the start in 2010 to over 7 in all plots. There was no apparent reason for this significant rise in pH.
- The Morgan's P levels increased in all plots but most in the artificial fertiliser plots.
- The organic matter levels decreased over the two years in all the plots but most in the digestate and zero application plots.
- Total nitrogen levels were highest in the artificial fertiliser plot and Nitrate levels highest in the slurry plot. The lowest levels of both total nitrogen and nitrate found in the plots that received treatments were in the digestate plots.
- There were no significant changes in the other minerals tested for in the soil samples.

For wheat at Farm B (SW1) and Farm E (WW1)
There was very little difference in any of the soil qualities between the different trial plots. This is similar to the results of soil analysis at farms A (SB2) and D (SB2) after one year of the trial.

4.2.6. Results - Arable cost benefit

The trials showed that the available nutrients in both compost and digestate can be used to directly replace nutrients otherwise supplied by artificial fertiliser.

There may also be other benefits to the soil and crop, other than nutrients. However, this cost benefit analysis assesses only the value of the nutrients supplied relative to the crop yield. The resultant value of the artificial fertiliser cost saved by using the natural fertiliser would need to be sufficient to pay for the cost of purchase, transport, storage and spreading for there to an overall cost saving from the use of these natural fertilisers.

The savings in artificial fertiliser purchase per hectare (Figure 32 and Table 20) are greatest for the digestate. However, because the amount of digestate or slurry spread per hectare is about four times more than the compost the value per tonne of compost is highest (see Table 19).

Table 19: Values in €/t natural fertiliser applied at the different farms in 2010 and 2011

	Slurry	Compost	Digestate	Whole/ liquor	Compost/ digestate
Farm A 2010 - Spring barley	0.56	2.20	1.56	-	-
Farm D 2010 - Spring barley	1.55	4.40	2.52	-	-
Farm D 2011 - Spring barley	0.06	8.14	3.49	-	-
Farm B 2011 - Spring wheat	5.10	9.10	6.86	4.95	-
Farm E 2011 - Winter wheat	2.34	8.47	4.79	-	5.96

For example for the spring barley at Farm D (SB2) in 2011, the artificial fertiliser cost saving was €41.81/tonne of barley harvested for the digestate, but because 48t/ha of digestate were applied that produced 6.5t/ha of barley, the nutrient value calculates to be € 3.49 per tonne of digestate applied. Whereas, with the compost the artificial fertiliser cost saving was €27.14/tonne of barley harvested, but because just 10.7t/ha of compost were applied that produced 5.9t/ha of barley, the nutrient value calculates as € 8.14 per tonne of compost.

Figure 32: Comparison of artificial fertiliser cost €/tonne of grain produced (by treatment and farm)

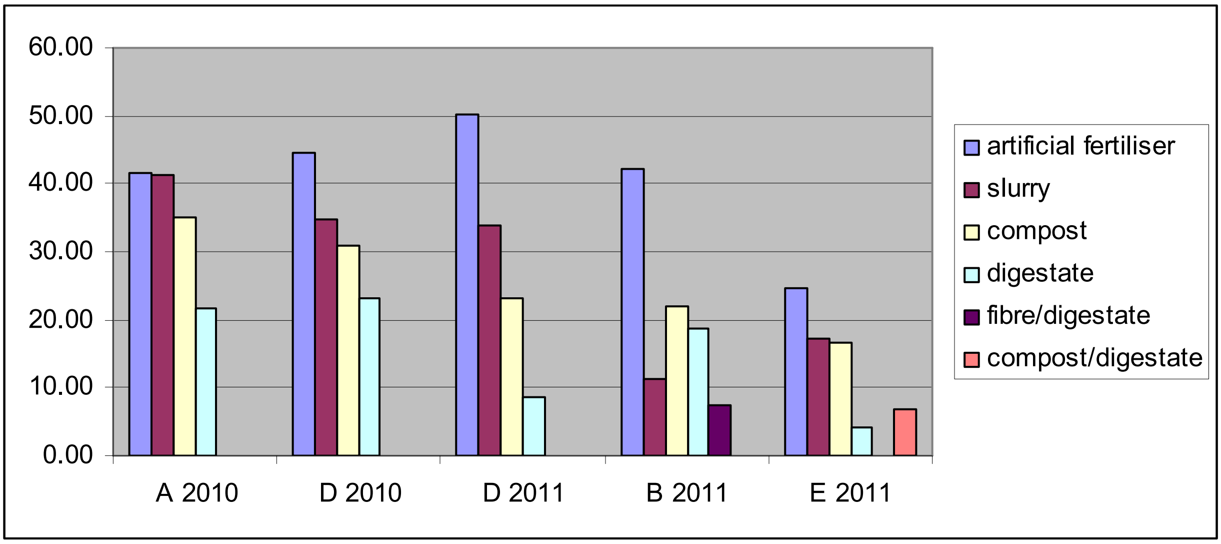


Table 20: Savings in artificial fertiliser cost in €/t of grain produced at the arable trial farms for the different treatments in 2010 and 2011 (worked examples in Appendix 10)

	artificial fertiliser	slurry	compost	digestate	whole/ liquor	compost/ digestate
Farm A 2010 - Spring barley	41.60	41.39	35.18	21.81	n/a	n/a
Farm D 2010 - Spring barley	44.50	34.77	30.79	23.22	n/a	n/a
Farm D 2011 - Spring barley	50.28	33.84	23.14	8.47	n/a	n/a
Farm B 2011 - Spring wheat	42.16	11.16	21.94	18.60	7.51	n/a
Farm E 2011 - Winter wheat	24.69	17.14	16.68	4.03	n/a	6.72

4.3. FEEDBACK FROM THE OPEN DAYS

- Most of the farmers would be interested in using natural fertilisers to replace some if not all of their farm nutrient needs.

- There was general agreement from those attending open days that natural fertilisers would provide organic matter to fields where organic matter was low and needed to be brought up to meet cross compliance requirements.

- There was interest in the possible non-nutrient benefits of using natural fertilisers, and the farmers who were already using such fertilisers all stated that there seemed to be more benefits from using natural fertilisers than just nutrients, but that they were unsure how those benefits came about or exactly what they were.

- Concern about the availability of the compost or digestate at a price that does not exceed normal fertiliser costs. The cost of transport makes up a major part of the cost of using natural fertilisers, therefore farmers felt that treatment facilities should be located near to the land where the natural fertiliser will be utilised.

- Concern that there might not be sufficient quantities available, delivered and spread when they are ready to get on with planting and managing their crops

- Concern about the local availability of suitable spreading equipment

- Concern about the additional paperwork requirements and of attracting additional farm inspections from DAFM by being a registered user of natural fertilisers made from biowaste. Farmers feel that paperwork already takes too much of their time away from the real activities of farming, and they fear the potential risk that if everything is not perfectly in order they will be punished by a reduction in support payments

- Concern by arable farmers about using fertilisers that are inherently variable in nutrient content and the additional cost that would be incurred if they have to pay for sampling or on-farm storage prior to use. Artificial fertilisers are widely available, can be delivered to the farm well in advance of use and can be stored easily and without cost, and although they do vary in nutrient content the perception is that the amount of nutrient spread using artificial fertilisers is known and reliable and will produce a guaranteed effect.

- More education is required to reassure livestock farmers about the perceived disease risk of using natural fertilisers made from biowaste,

- Concerns from livestock farmers about keeping under the 170kg/ha limit for manure nitrogen, as a natural fertiliser that contain even a small amount of manure is currently considered to be 100 per cent manure under the Irish interpretation of the EU Nitrates Regulations

4.4. COMPOST AND DIGESTATE MANAGEMENT CHALLENGES

The challenges that had to be met during the course of these crop trials are identified below. Some affected the outcome of the trial, despite measures to minimise or avoid effects. Effects considered to alter the results of the trial have been allowed for when interpreting the results of the trial. Some challenges presented the opportunity to improve the project or gain knowledge. This knowledge was included when forming the recommendations arising from the trial.

- The use of standard farm machinery on limited land areas, using materials unfamiliar to the operator, made it difficult to ensure that the fertiliser was spread evenly and accurately. However, the level of accuracy of spreading in the trial was within an acceptable deviation, due to the care taken and the spreading experience of the operators involved.
- The very dry spring in 2011 created different challenges than the wet spring of 2010. It was apparent that the timing of natural fertilisers applications might need to differ from the norm for artificial fertiliser application and that weather conditions might have a greater impact than with other types of fertiliser.

Figure 33: Delivery of the digestate liquor and temporary storage of compost and digestate liquor

- The logistics required to supply and store the right amount of digestate products to all five farms, were complex, because the farms had different schedules for crop management, and a sample had to be analysed before the products were required for spreading. Temporary storage facilities were provided on the farms.
- Weather conditions determine the timing of crop management and the benefit that arises from the application of any fertiliser. Six types of fertiliser used in this trial, so compromises had to be made to enable similar timing of application of each of the fertilisers at a trial site. This resulted in applications during less than optimum conditions for some of the fertiliser treatments to be utilised by the crops.
- The trials were conducted on commercial farms, and the farmer undertook most of the agricultural production work. This presented challenges for the farmer to be able to provide equipment and manpower when the trial required their input. However, the experience and knowledge provided by the feedback from the farmers involved, has been crucial in the provision of advice on how to use the fertiliser products.

5. DISCUSSION

This chapter presents information where the results and observations from the trials varied between trial sites, or do not correlate with existing knowledge, or raise questions. These matters are discussed below; however, further focused research would help to provide more clarity in most cases.

5.1. NUTRIENT MATTERS

There were a number of indications from the analysis results that the use of digestate or compost may increase the amount of available nutrients in the soil and plants beyond the amount of available nutrients which are applied. These indications include

- The amount of the major and minor minerals applied in the digestate is significantly lower than the off take. This would indicate that there is a significant release of soil bound minerals, as a result of applying the digestate.
- The analysis results showed that all the natural fertiliser products had a lower water soluble phosphorous and potassium content (less than 10% of the total) than availability assumed for the trial. Therefore, it would be reasonable to assume that the amount of available phosphorous in the natural fertiliser products applied was lower than the crop requirement, but the crop offtake of phosphorous was normal to high. Also, in a number of the trials the level of measurable soil phosphorous (Morgan's) increased, with continued use, over time.

The reason why these effects are occurring is not clear from these trials and requires further research. Research at Bangor University, and University College Cork (UCC), and in Europe indicate that there may be an increase in plant root development and also in the level of bacterial and fungal activity in the soil as a result of applying digestate or compost, which could facilitate the release of soil bound minerals. However, it does not explain why this occurs only in relation to positive minerals but not with heavy metals

Nitrogen availability

- Analysis of the compost in 2011 showed and the results from the UCD trial indicated that the available nitrogen in the compost was closer to 20% than the 10% that had been assumed for the trial based on the literature review.

  At Farm E (WW1) the application of the compost on the surface, at the beginning of spring growth, was observed to show excellent crop benefits with good growth, crop nitrogen status and crop colour in the wheat crop throughout the spring and summer period. This clearly indicated that there was early availability of key nutrients to the growing crop which produced high grain yield exceeding 11 t/ha. This observation of the effects of surface applied compost use on the winter wheat trial site would correlate with the consistent good agronomic performance from the surface applied compost on grassland sites in 2010 and 2011.

  However, when compost is incorporated in the soil there are indications that the nitrogen availability is inhibited initially and may even lock up available nitrogen from other sources, but the nitrogen comes available later in the season with a steady release. It is also known from other research projects that the nitrogen availability of compost varies with the kind of compost and its maturity. Further research would help to identify the optimum methods for utilising compost.

- The ability of clover to fix nitrogen from the air is normally inhibited by significant levels of available nitrogen being applied in artificial fertiliser. However, when digestate, which has high nitrogen availability, is applied on the grass/clover sward the nitrogen off take in the crop was higher than all other treatments and soil nitrogen levels did not appear to diminish. Therefore it appears that the digestate stimulates the clover performance.

Fertiliser management factors that affected the nitrogen availability

It appeared from both the winter wheat trial and the grass/clover trial that there was higher nitrogen availability in surface applied compost than from the compost that was incorporated in the soil.

In 2011 the whole digestate and the digestate liquor were stored in a slurry tanker at Farm A (SB2) and Farm B (SW1). At Farm D (SB2) and Farm E (WW1) the whole digestate and the digestate liquor were stored in containers for 10-14 days in hot sunlight.

The trial results indicate that there was less nitrogen available to the crop later in the growing season at Farm D (SB2) as growth was strong but it appeared that there was less nitrogen available at grain fill in 2011. At Farm E (WW1) it appeared from the monitoring and the crop performance that 40% less nitrogen was available to the crop than in the other plots. Given the difference in storage methods (slurry tanker/containers) it is reasonable to assume that there was a significant loss of available nitrogen during storage in the containers exposed to sun and that at Farm E (WW1) as the digestate was applied in dry weather, there were additional losses.

Figure 34: Winter wheat plots, with arrow showing colour change (nitrogen uptake) differences between treatments

The results from the two sets of digestate plots at Farm B (SW1) concur with this conclusion as they show that the nitrogen uptake and the protein levels are slightly lower in the digestate plots where the nitrogen availability from the whole digestate and digestate liquor was assumed to be higher, compared to the digestate fibre/digestate plots.

Sunlight causes nitrogen loss through volatilisation. These trials show that that volatilisation loss can be significant even in a short period of time. Therefore liquid digestate products should be stored out of sunlight, and applied in suitable weather conditions.

5.2. GRASS/CLOVER MATTERS

Three crops of silage were taken to allow an assessment of how much grass each plot produces over the year and the qualities of that grass. However, grassland and particularly grass/clover swards perform better if they are grazed rather than cut. Clover generally performs better, if the sward is kept short. Therefore, the total yield of the sward from the plots may have been less, during the trial, and the clover may respond differently, when a sward is grazed.

- There is an incremental yield increase from using compost on a grass/clover sward compared to a grass only sward, but this benefit does not occur when applied to a clover only sward. This suggests that there is an interaction between compost and clover that stimulates the clover to fix nitrogen, but only increases the yield when it is utilised for grass production.
- It would appear that the incremental benefit of applying compost in a grass/clover sward is maximised at an application rate of 8-12t/ha. This correlates well with the application rate that was used in the farm trials which was the permitted level, due to the phosphorous content, according to SI 610 (2010).
- In the compost plot a significant amount of artificial fertiliser was added to make the amount of available nitrogen applied comparable with other treatments. The results indicate that this addition of artificial nitrogen fertiliser may have inhibited the clover performance in the compost plots, and thereby reduced the crop output in 2011.
- In both 2010 and 2011 there was scorching of the sward when the digestate was applied before first cut, due to the grass already being quite long, the dry sunny weather and the application rate being over 10t/ha. Although this may have delayed initial growth the sward recovered well and gave a high performance. It would be preferable to apply digestate earlier or in cloudy damp conditions if it is to be applied in one application, or to apply the digestate in more applications of around 10t/ha per application or to dilute the digestate with water before application. Research at UCC indicates that plant root development is stimulated by digestate applications of around 10t/ha, but may be inhibited by higher rate applications.

5.3. ARABLE MATTERS

Nitrogen is a key nutrient which is critically important in arable crops for high grain yield and grain quality. It is well known that with artificial fertiliser use, high early-season nitrogen uptake promotes high yield, while higher mid to late-season nitrogen availability promotes high grain nitrogen and protein.

- It would appear that the compost which is incorporated before cultivation provides a release of nitrogen later in the growing season, which encourages good grain quality. However, early growth may need more encouragement. Surface application rather than incorporation of the compost may facilitate the early take up of nitrogen, and continued supply throughout growth.
- It would appear that the high nitrogen availability in the digestate encourages high yield and grain weight, however, losses of nitrogen during storage and application must be avoided if nitrogen availability is to be sustained to encourage good protein content in the grain.
- The results of these trials from compost or digestate use at the different sites show a different pattern of nitrogen availability in different circumstances. Some of this variance can be attributed to different management and the cropping history of the field. However, there were indications that the timing and method of application may be crucial too and may not be the same as the normal timing for applications of artificial fertiliser

5.4. SOIL MATTERS

Changes in soil qualities occur relatively slowly, because the amount of input applied is small relative to soil mass. The variation in results could relate to the soil type and initial organic matter content of the soil. However, some tentative conclusions can be drawn from the two years of the trials.

- The drought conditions in the spring of 2011 affected all crop growth. Soils with higher levels of organic matter retain moisture and could support the crop growth better in drought conditions. This may be the explanation why the plots that received slurry or compost for two years performed better in 2011 than other plots.
- The addition of organic matter in the natural fertilisers appears to help reduce the bulk density of the soil which will help drainage, soil health and plant development.
- The digestate liquids, whole digestate and digestate liquor, appear to stimulate soil activity so that in arable soils the organic matter and soil nitrogen levels reduce. This is the opposite of what occurred in the grassland.
- The increase in soil nitrogen and nitrate in some of the compost plots could be attributed to the unavailable portion of total nitrogen in the compost which was applied over two years. However, the increase of soil nitrogen in the digestate plots is surprising given that the total nitrogen off-take was the highest in the grass from the digestate plot for both years, and greater than the amount of nitrogen applied.
- The assessment of the worm populations at the end of year two of the trial found there to be no clear differences between treatment types at any of the farms. This is somewhat surprising as normally worm populations increase when there is more SOM.

Further research is required to determine how use of compost and digestate affects soil activity.

5.5. REGULATION MATTERS

DAFM considers that digestate that contains any manure must be treated as manure. This may inhibit the production of digestate made from biowaste for use in agriculture. This is because

- The anaerobic digestion process is more stable and therefore produces a digestate more suited to agricultural use when manure is co-digested with food waste compared to digestion of only food waste.
- Digestate is not mentioned in SI 610, however digestate containing any manure is considered as manure so it will be assumed to have the nutrient availability of slurry and this is not suitable or applicable.
- The rate of application of manure is limited to 170kg/ha. Whereas for any material not containing manure any amount can be spread, so long as the available nitrogen or phosphorus content does exceed the crop requirement.

6. CONCLUSIONS

Advantages of using compost or digestate

1) The crop trials have demonstrated that the application of compost or digestate, as quality fertiliser products to grow crops, can replace nutrients usually supplied by artificial fertiliser, bring other agronomic and environmental benefits and be managed within a farming regime.
2) The nitrogen availability in digestate liquor is similar to that of artificial fertiliser. However, further research is required to determine the best times to apply it to achieve the yield and crop qualities required in different cereal crops and soils.
3) There is an indication, particularly in the grass/clover, that the addition of digestate and compost increases soil pH, total phosphorous and total nitrogen levels as well as SOM, even when the off-take in the crop is more than that which is applied.

For grassland

4) The silage production was higher from the compost plots than the artificial fertiliser plots. However, there are indications that the amount of available nitrogen applied to the crop as artificial fertiliser should be reduced, from the normal crop requirement, when compost is used and then the grass/clover sward may perform even better
5) The trials show clearly that clover responds well to natural fertilisers. The yield and quality of grass/clover silage is increased when using digestate and compost.
6) There is an indication that the use of digestate may cause an increase in the release of minerals, both major and minor, from the soil to the plants compared to artificial fertiliser and other natural fertilisers, although further research is required to identify why and how this interaction occurs.

For arable crops

7) Crops respond well to natural fertilisers, however benefits are limited and slow to build up, due to the amounts that can be spread each year, limited by nutrient content
8) The slow release of nitrogen from compost use can compliment the readily available nitrogen from artificial sources over the season. However, when compost is incorporated in the soil, it would appear that there may be a depletion of available nitrogen to the crop initially, but a steady availability of nitrogen later in the season. When the compost is surface applied this inhibition effect does not seem to occur.
9) Digestate products are an excellent source of available nitrogen at the key late-spring / early-summer application timing.
10) Product consistency and even application are very important for arable crop, therefore care must be taken when applying natural fertilisers to achieve an even spread

Regarding soil and nutrient management

11) There are indications from the 2-year field trial studies that the addition of compost, digestate fibre or whole digestate may increase soil organic matter (SOM), worm populations and other beneficial soil qualities. However, there is indication that continual use of digestate liquor on arable crops, without an application of additional structural carbon, may actually reduce SOM.

12) There were improvements in the bulk density of the soil in the plots that received fertilisers containing high levels of lignin, which would indicate that the addition of compost and digestate fibre could reduce the effects of soil compaction

13) The rate of any change in soil qualities will be slow, due to the amounts that can be spread in one year relative to the soil mass

14) There would appear to be no negative effects on the soil and the quality of the crop from using compost or digestate as fertilisers.

Regarding logistics and cost

15) If compost and digestate fertiliser products are used to provide the nutrient requirements of the crop, there could be financial savings, but the products would have to be available locally to where they will be utilised, to minimise transport costs.

16) Care must be taken when storing and spreading whole digestate and digestate liquor to avoid nitrogen loss, by ensuring the material is not left exposed to sunlight or drying winds. Depending on the viscosity of the liquid, it may be beneficial to add water to aid dispersal and reduce the risk of scorching if applied to growing crops/grass.

17) Farmers would be willing to use these natural fertiliser products if they were more widely available, and information was provided on how to use them to best effect.

18) It would be helpful if suitable farm machinery for spreading compost and digestate was widely available.

19) The existing good reputation of agricultural quality compost and digestate must be maintained and the public informed about the beneficial and safe nature of these fertiliser products, if they are to become widely accepted as suitable fertilisers for food production.

Figure 35: Farm machinery in use on trial plots

7. RECOMMENDATIONS

7.1. GENERAL RECOMMENDATIONS FOR USING DIGESTATE OR COMPOST

- Compost and digestate should be used as part of a nutrient management plan for the farm and use must comply with SI 610 (2010), Good Agriculture Practice guidelines and the ABP requirements regarding use as a fertiliser.
- The compost or digestate product should be sampled and analysed before delivery and delivered directly to the field where it is to be used, to minimise transport, storage and application costs
- A recent analysis of the compost or digestate products should be used to calculate the NMP for a particular crop and farm[31].
- Compost should be ideally protected from the rain.
- Compost should be surface applied as early in the year as possible for best results.
- Digestate products should be stored undercover and spread in cloudy weather, or late in the evening, or below the crop canopy, or incorporated directly after application, to minimise nitrogen loss or the risk of leaf scorch.
- Care and planning are required when applying liquid fertiliser products, because the earth becomes wet and time is required for drying between spreading and cultivation, and nitrogen loss can occur in bright sunshine or drying winds. Therefore, ideally the liquid products should be applied on the evening before the morning the land is cultivated, when there is good drying conditions.

7.2. SPREADING RECOMMENDATIONS FOR GRASSLAND

- Compost applied by a Ktwo or similar spreader, early in the spring spreading season and at a rate to supply the whole year's requirement for available phosphorus
- Digestate fibre applied by a Ktwo or similar spreader, while grass is short, anytime during the spreading season, but early spring-time is preferable
- Whole digestate applied by a slurry spreader (low trajectory, dribble bar or trailing shoe), when grass is short, and in suitable weather conditions
- Digestate liquor applied by a slurry spreader (low trajectory, dribble bar or trailing shoe) or with a spreading boom behind a tractor supplied by a small bore (30mm) irrigation (umbilical) hose, or by a low trajectory moving irrigator. Should be spread at low volumes (e.g. 10t/ha) during the spreading season at regular intervals throughout the growing season[32].

[31] This approach is possible within SI 610 (2010) where Table 8, states: "Dairy processing residues and other products not listed above - total nitrogen and total phosphorus content per tonne based on certified analysis shall be provided by the supplier."

[32] There is a high level of available nitrogen in the whole digestate and digestate liquor, which is easily volatilised. Therefore digestate should be kept out of strong sunlight and drying winds in storage or when being applied. If applied in dry weather it may cause short term scorching on the leaves of growing grass or crops.

7.3. SPREADING RECOMMENDATIONS FOR ARABLE CROPS

- Compost or digestate fibre applied by Ktwo or similar spreader, after ploughing and before or after cultivation
- Whole digestate applied by slurry spreader (low trajectory, dribble bar or trailing shoe) after ploughing and before cultivation. Should be incorporated as soon as possible after spreading and without having been left in strong sunlight, to avoid nitrogen volatilisation.
- Digestate liquor applied by slurry spreader if applied before cultivation. If applied after the crop has emerged it can be spread by a spreading boom (with dribble pipes or trailing shoes) from the tram lines. Ideally a boom carried behind a tractor supplied by a lightweight (30mm) irrigation (umbilical) hose to a holding tank or tanker should be used, rather than a tanker travelling the field[33].

7.4. THE FACTORS DETERMINING WHICH NATURAL FERTILISER PRODUCT TO USE

Soil and Crop	
Soil	**Soil type and condition**: determines whether organic matter is important **Soil phosphorus index**: used in conjunction with the crop requirements to determine the quantity, if any, of phosphorus that may be applied. If only small amounts or no phosphorus can be applied then compost or digestate fibre may have too much phosphorous content, but other digestate products might suit
Crop	**Crop to be grown**: determines when the fertiliser can be applied, the nutrients required and what other fertiliser properties are beneficial **Timing of nutrient application**: digestate fibre, compost and whole digestate can be applied before a crop starts to grow. Only digestate liquor should be used once the crop/grass is growing and it should be applied below the canopy

Cost and Logistics
Cost of the natural fertiliser product, its transport and spreading: for comparison with the cost of alternative fertilisers, and other methods of improving soil quality and crop performance
Cost of analysis of natural fertiliser unless supplier has a recent typical analysis **The type of spreading equipment available**
Ensuring enough material is available at the spreading time : Plan how the natural fertiliser is to be transferred from the delivery vehicle to the spreading equipment and whether storage is required between delivery and spreading

[33] see Appendix 2 for schematic of this method

7.5. FURTHER RESEARCH

Further research is required to identify;

- The benefits to and effects on soil and plant health and performance from the continual use of natural fertilisers[34].
- The pattern of nutrient release from the inputs and from the soil in the years following application and to establish whether this is mostly related to cropping history, soil type or weather conditions
- The reason why compost and digestate stimulate crop growth, soil activity and the plants interaction with the soil.
- Whether there are differences in growth response, soil or plant activity when different grades (dependant on materials processed and processing method and time) of a category (compost, whole digestate, digestate fibre, or digestate liquor) of natural fertiliser is used
- The optimum timing of application of compost or digestate in different crops.
- The optimum management methods for use of the natural fertilisers in different crops, on different soils and in different weather

7.6. RECOMMENDATIONS FOR SUPPORTING INFORMATION PROVISION

- Provision of advice to farmers concerning where they can obtain compost or digestate products and the amount of available nutrients provided over time, in relation to total nutrients and other qualities, for these natural fertilisers.
- A test method for assessing nutrient availability in liquids should be available in Irish laboratories, at the current time this seems to be available only in UK or Europe
- Advice leaflets for farmers are made available on how to develop a nutrient management programme using compost or digestate, which product is most suited to their situation and crop, and when to spread for optimum performance
- Advice leaflets are made available to farmers about how to use machinery accurately when spreading compost and digestate

Figure 36: Ears of wheat in the trial plots

[34] 10 years of research trials is normal practice to observe the medium term effects of soil changes

7.7. PRODUCTION OF COMPOST AND DIGESTATE FOR AGRICULTURAL USE

It is clear from these crop trials that if compost or digestate are to be financially attractive for commercial agricultural production, they will have to be utilised close to where they are produced, otherwise the transport costs will make them financially unattractive. Therefore, the size of the composting or AD facility and its location should be related to the size of available land bank locally to utilise the fertiliser outputs.

7.7.1. Good Management at the processing facility

The most important requirement to producing high quality natural fertiliser products is that the processing facility is managed well and the process used is operating well. Good management will ensure that there are adequate controls to ensure only feedstock which is of suitable quality is used in the process, and that waste suppliers understand what quality of waste is required.

7.7.2. Collection of biowaste

It is important that feedstock is free of contaminants before it is processed by composting or anaerobic digestion to produce a fertiliser product for agriculture. Therefore, biowaste must be collected separately to other waste. Green waste can be collected with food waste for composting. However, it may be technically and financially preferable to collect green waste and food waste separately for either processing option.

The way food waste is collected is important. Kitchen waste should be collected separately, using small bins, with inspections for contamination. Significant on-going education of the waste producers is required.

7.7.3. Product standards and quality assurance schemes

An Irish compost standard I.S. 441 has been developed and an Irish digestate standard is being developed in 2012. A Quality Assurance scheme (QA) for compost is in pilot operation in 2012. A QA is awarded to a compost product where the product reaches the compost standard and the management system has been certified as ensuring the standard can be maintained.

During the trials there was significant interest from the organic farming in compost and digestate. Currently the organic farming sector cannot use these products, when made from municipal or commercial food waste in practice. This is due to there being a requirement for source separation of waste, but no definition from DAFM of what is acceptable as source separation.

7.7.4. Animal By-Products Regulation

The objective of the Animal By-products legislation is to ensure that there is no risk of disease transfer to animals and that compost and digestate meet the treatment standards.

A compost or anaerobic digestion facility that processes animal by-products (this includes food waste and catering waste; manure; fish and milk products) must be licensed by Department of Agriculture, Fisheries and Marine (DAFM). Generally, if these materials are reduced to 12mm particle size and pasteurised at 70°C for one hour, and the management at the treatment facility reaches certain management standards, the resultant product is considered to be safe to apply to farmland as a fertiliser.

Farmers must register with DAFM as users of the fertiliser products. A specified period is currently required between application and grazing or harvest.

APPENDICES

APPENDIX 1: ABOUT COMPOSTING & COMPOST

The processes which take place in a composting plant can generally be described as falling into three categories:

- delivery of waste and mechanical pre-treatment
- First stage : intensive aerobic decomposition
- Second stage: extensive maturation (humification)

During the aerobic composting process, heat is produced. Temperatures of 70°C can be reached in the first stage, whereas temperatures < 55-60°C are best for the second stage of humification.

There are many different composting technologies,

- open or closed composting
- with or without forced aeration
- different process techniques like windrow, container- box, tunnel or hall composting
-

Research

Some research[35] shows that the bacteria that develop during the composting process can, when fresh compost is incorporated into the soil, stimulate beneficial soil bacteria to develop in greater numbers, thereby improving activity in the soil and improving the health of soil and plants. The potential beneficial aspects of composts are higher aggregate stability and increased pore volume. Higher aggregate stability reduces loss of soil structure and increases as well as the percolation of rainfall through the upper soil layers. Greater pore volume improves gas exchanges in the deeper soil layers and facilitates the percolation of surface water through these layers.

If the composting process is well managed, these compounds will contribute to increase the humus content of the soil. With the exception of peat soils, increasing the humus content is considered generally desirable as it greatly increases both the nutrient storage capacity of the soil and the bioavailability of the nutrients for plants.

Soil improvement

- The primary benefit from adding organic matter to soil is that it feeds the soil biomass. If the soil organic matter content (OM) increases it will sustain larger populations of earthworms and other organisms.
- A more stable organic (humic) fraction improves the cation exchange capacity of the soil and buffers it against possible physico-chemical imbalances (improved structure, water retention capacity and permeability, protection against erosion**)**

Inhibition of plant diseases

- Compost will affect plant health indirectly, by providing micro- and macronutrient and by improving the soil structure and water balance.
- Antagonistic microorganisms, which develop during the maturation phase of quality compost, help to protect plants effectively against diseases. This disease suppressivity can be of practical importance, if the compost is used correctly.
- To be of maximum benefit to plant health, composts must be produced from carefully chosen feedstock and undergo optimal degradation and storage. Only then will the risks of unpleasant surprises from weed germination and contamination with diseases be reduced to negligible levels. Producing this kind of composts requires effort, proper infrastructures and an impermeable work surface.

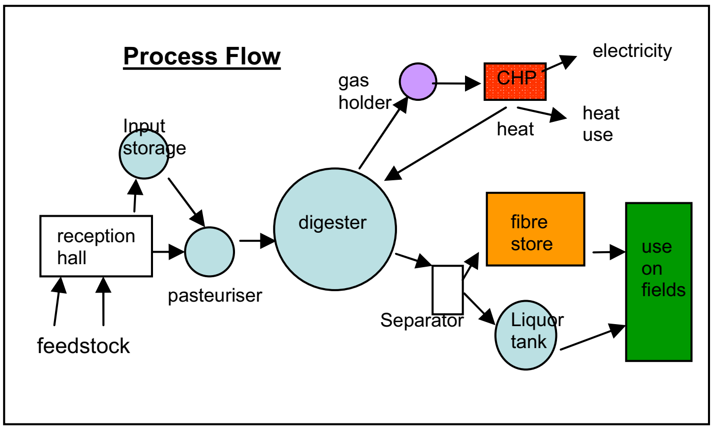
[35] Wider benefits of composting: A survey of the beneficial effects of the application of compost and digestate *K. Schleiss, C. M. Fischer, J. Fuchs and U. Galli*

APPENDIX 2: ABOUT AD AND DIGESTATE

There are broadly three types of Anaerobic Digestion (AD) process namely

a) high solids dry, (batch and continuous)
b) high solids wet (single or multi-stage)
c) low solids liquid (e.g. process water)

Generally only the high solids wet process is used to process biowaste into agricultural fertiliser products.



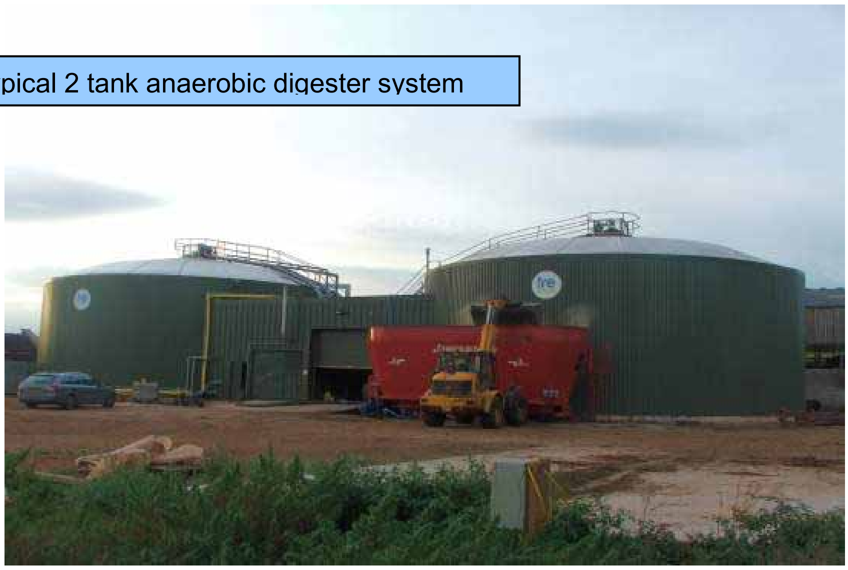
Commercial anaerobic digestion facilities are operated either at mesophillic (30-45°C) or at thermophillic (48-60°C) temperatures. To process biowaste, maceration (to reduce particle size) and pasteurisation (70°C) are required as additional steps. The digestion process produces biogas, which can be used for producing heat, electricity or vehicle fuel.

During digestion the material becomes more watery, as carbon (typically 50-80% of the solids) is converted into biogas. The removal of solids instigates the conversion of Organic-N into Ammonium-N, which is the form of nitrogen readily available to plants.

The co-digestion of manure with food waste improves the stability of the AD process, without manure there needs to be careful monitoring and mineral supplements added to the food feedstock

A good digestion process destroys weed seeds and 99% of pathogens and produces a stable digestate with low odour and a nitrogen content that is highly plant available. An additional process step of pasteurisation at 70°C for one hour is used to ensure full pathogen destruction in food waste.

Typical 2 tank anaerobic digester system



Spreading digestate

- Whole digestate can be spread using a slurry tanker with trailing shoe or splashplate. Ideally it should be spread before the crop starts to grow or just before cultivation on a dull or damp day. If spread on growing grass a spread rate of less than 10t/ha should be employed
- Digestate fibre is a friable material with short fibres, so the spreading equipment should be suitable for this sort of material. If spread correctly it will wash easily through the grass onto the soil. However, if spread in dry weather it will tend to lodge in the grass and grow up with it.
- Digestate liquor can be used as a top dressing for growing crops or on growing grass however it should ideally be spread below the canopy to prevent leaf scorch and nitrogen loss through volatilisation. A slurry tanker with a trailing shoe can be used or by using an adapted crop spraying boom mounted on a tractor and fed by a 30mm umbilical pipe from a feed tanker parked at the edge of the field. This method is shown in the schematic Figure 38. In the crop trials an adapted form of this method was used shown in the photo in Figure 37

Figure 37 Top dressing digestate liquor between rows of growing barley

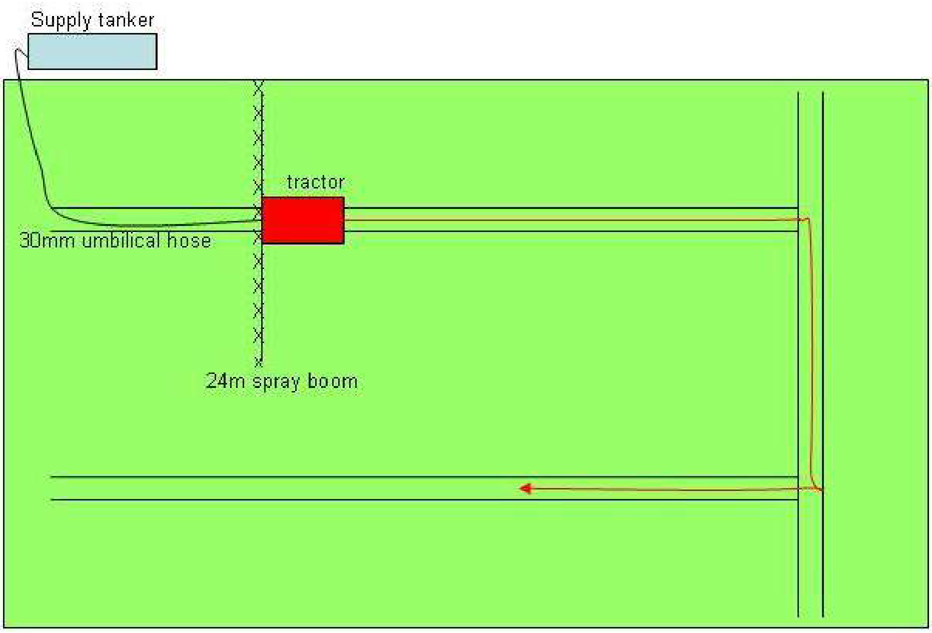


Figure 38 Schematic of digestate liquor spreading using an umbilical cord feed

APPENDIX 3: INPUTS USED 2010

Table 21: Nutrient status[36] of the inputs used in 2010 (kg/wet tonne)

Input	DM %	pH	Total N	Avail N	total P	Avail P	total K	Avail K	total N:P ratio	avail N:P ratio
compost	78.8	5.9	19.7	1.97	5.0	3.71	6.9	5.53	3.94	0.53
whole digestate	3.3	8.3	4.9	2.92	0.2	0.14	1.8	1.58	24.50	20.86
Slurry A	8.5	7.2	1.5	0.62	0.5	0.50	2.2	2.21	3.00	1.24
Slurry D	7.0	7.1	1.5	0.58	0.6	0.56	2.9	2.91	2.50	1.04
Slurry C	1.1	7.3	0.5	0.21	0.1	0.07	0.6	0.64	5.00	3.00

Table 22: Availability of nutrients assumed for 2010

	N	P	K
compost	10%	75%	80%
whole digestate	55%	75%	90%
slurry	40%	100%	100%

Table 23: Contamination indicators and trace nutrients in the 2010 natural fertilisers (mg kg^{-1} DM)

	Compost	Whole Digestate	Slurry A	Slurry C	Slurry D	PAS *
Arsenic	0.70	<1.5	<0.5	<4.7	<0.5	
Cadmium	0.23	<0.1	0.38	<0.2	0.16	1.5
Chromium	8.4	6.6	3.8	5.7	4.4	100
Lead	13.1	2.4	6.4	5.7	2.2	200
Mercury	<0.05	<0.1	0.02	<0.02	<0.02	1.0
Nickel	10.7	6.0	7.7	5.7	3.9	50
Copper	28.9	84	52	57	62	200
Zinc	56.9	14.2	190	137	182	400
Iron	1773	4819	7100	33962	5300	
Boron	6.1	27	16	28	24	
Calcium	7467	15361	13200	18868	23200	
Magnesium	793	867	3780	76604	4300	
Manganese	58.3	123	364	481	272	
Molybdenum	0.65	10.2	9.5	10.4	5.2	
Selenium	0.12	1.33	0.62	0.47	0.34	
Sulphur	980	8434	4200	14151	5600	

[36] Figures provided for available N & P content are as assumed for the trial, not that recorded by analysis

Dry matter	**78.6%**	**3.3%**	**8.6%**	**7.0%**	**1.1%**	

Table 24: Contamination indicators in the 2010 natural fertilisers (mg kg^{-1}) by fresh weight

PTEs	compost	digestate	slurry A	Slurry D	Slurry C
Cadmium	0.18	<0.002	0.03	0.01	<0.002
Chromium	6.60	0.22	0.32	0.31	0.06
Lead	10.30	0.08	0.55	0.15	0.06
Mercury	<0.04	<0.002	<0.002	<0.002	<0.002
Nickel	8.41	0.20	0.66	0.27	0.06
Copper	22.72	2.80	4.45	4.31	0.60
Zinc	46.30	14.20	16.25	12.65	1.45

Table 25: Physical qualities of 2010 inputs

	units	compost	digestate	slurry A	Slurry D	Slurry C
Bulk density	g/cu cm	0.3				
Dry matter	%	78.6	3.35	8.55	6.95	1.06
Organic matter	%	65.1				
pH	units	5.9	8.3	7.2	7.1	7.3

APPENDIX 4: INPUTS USED IN 2011

Table 26: Nutrient status[37] of the inputs used in 2011 (kg/wet tonne)

Input	DM %	pH	Total N	Avail N	total P	Avail P	total K	Avail K	total N:P ratio	avail N:P ratio
compost 1	41.1	6.4	13.1	1.3	3.9	2.9	2.4	2	3.4	0.4
compost 2	62.1	6.5	19.3	1.9	4.4	3.3	6.5	5.2	4.4	0.6
whole digestate	3.4	8.4	3.7	2.6	0.35	0.35	1.2	1.2	10.6	7.4
digestate fibre	19.1	5.8	2.2	0.7	2.10	2.10	6.3	6.3	1.0	0.3
digestate liquor	2.4	8.1	3.8	3.0	0.17	0.17	1.6	1.6	22.4	17.9
Slurry A	11.1	7.5	3.3	1.3	0.31	0.31	2.6	2.6	10.6	4.3
Slurry B	5.8	7.3	1.6	0.6	0.38	0.38	1.4	1.4	4.2	1.7
Slurry D	2.0	7.5	1.4	0.6	0.07	0.07	1.7	1.7	20.0	8.0
Slurry E	6.8	7.3	1.2	0.5	0.39	0.39	1.8	1.8	3.1	1.2
Slurry C1	7.2	7.1	2.3	0.9	0.27	0.27	2.0	2	8.5	3.4
Slurry C2	6.0	6.9	2.2	0.9	0.20	0.20	1.2	1.2	11.0	4.4

Table 27: Availability of nutrients assumed for 2011

	N	P	K
compost	10%	75%	80%
whole digestate	70%	100%	100%
digestate fibre	30%	100%	100%
digestate liquor	80%	100%	100%
slurry	40%	100%	100%

Table 28: Contamination indicators in the 2011 natural fertilisers (mg kg^{-1} DM)

PTEs	Compost 1	Compost 2	Digest fibre	Whole digest	Digest liquor	Slurry A	Slurry B	Slurry D	Slurry E	Slurry C1	Slurry C2
Cadmium	0.4	0.5	0.1	<0.3	<0.37	<0.09	0.6	<0.5	0.2	0.3	0.3
Chromium	25.0	24.3	2.97	3.5	4.5	<0.09	4.0	2.5	4.4	1.8	5.4
Copper	230.0	188.0	43.4	82.6	79.5	9.8	41.3	34.5	62.0	25.1	77.7
Lead	84.0	87.5	9.9	17.9	16.3	1.2	15.0	1.0	2.2	5.8	13.3
Mercury	0.04	0.56	<0.02	<1.5	<1.9	<0.45	<0.17	<0.5	<0.2	<0.7	<0.5
Nickel	17.0	22.5	3.4	11.5	9.5	6.8	9.8	5.0	3.9	2.4	8.2
Zinc	354.0	311.0	194	170.6	803.0	97.3	193.0	8.5	182.0	76.9	64.8
Dry matter	41.1	62.1	19.1	3.4	2.6	11.1	5.8	2.0	6.8	7.2	6.9

[37] Figures provided for available nitrogen & phosphorous content are as assumed for the trial, not that recorded by analysis

Table 29: Contamination indicators in the 2011 natural fertilisers (mg kg^{-1}) by fresh weight

PTEs	Compost 1	Compost 2	Digest fibre	Whole digest	Digest liquor	Slurry A	Slurry B	Slurry D	Slurry E	Slurry C1	Slurry C2
Cadmium	0.18	0.32	0.02	<0.01	<0.01	0.06	0.03	<0.01	0.01	0.02	0.02
Chromium	10.28	15.09	0.57	0.12	0.12	<0..01	0.23	0.05	0.30	0.13	0.32
Copper	94.53	116.75	8.29	2.81	2.1	1.09	2.40	0.69	4.22	1.81	4.63
Lead	34.52	54.34	1.89	0.61	0.43	0.13	0.87	0.02	0.15	0.42	0.79
Mercury	0.02	0.35	<0.01	<0.05	<0.05	<0.05	<0.01	<0.05	<0.01	<0.05	<0.05
Nickel	6.99	13.97	0.65	0.39	0.25	0.75	0.57	0.10	0.27	0.17	0.49
Zinc	145.5	193.1	37.1	5.8	21.2	10.8	11.2	0.2	12.4	5.5	3.9

Table 30: Physical qualities of 2011 inputs

	Compost 1	Compost 2	digest fibre	whole digest	digest liquor	Slurry A	Slurry B	Slurry D	Slurry E	Slurry C1	Slurry C2
Dry matter %	41.1	62.1	19.1	3.4	2.6	11.1	5.8	2.0	6.8	7.2	6.0
pH	5.9	6.5	5.8	8.4	8.1	7.5	7.1	7.5	7.2	7.1	6.9
stability mgCO2/gV/d		3.4									
VFA g COD/g VS				0.16							

APPENDIX 5: NUTRIENT MANAGEMENT PLANNING (NMP)

A nutrient management plan (NMP) is developed to allow the maximum amount of nutrients to be supplied by the natural fertiliser. The first step is to identify what the soil nutrient status is and the crop requirement. Then an assessment should be made as to which type of natural fertiliser product to use for that particular situation. The typical main attributes of each type of product are summarised in the following table. The availability and transport cost of the product will also affect the decision of which product to use.

Once it is decided which type of product is to be used, a typical recent nutrient analysis should be obtained from the supplier. Once the typical nutrient content of the product is known it is possible to calculate what the maximum spreading rate can be. This may be controlled by Nitrogen or Phosphorous content depending on the product, soil status and crop requirement. It is then possible to calculate how much other fertiliser is required to balance the supply to the crop need. A financial assessment can then be made of the cost of such an approach.

Table 31: how to make calculations using natural fertilisers in a NMP for grass/clover silage

Steps in developing a NMP for grass/clover	Method
total nutrients in 1t of the natural fertiliser (NF)	From analysis
Availability of nutrients	Defined by SI 610 or analysis
Required nutrients for 1st cut	Defined by soil analysis and crop grown
Allowance for nutrients from clover in sward	Depends on clover % in sward
Spread rate	Nutrient need divided by either available N or P
Total nutrients applied with spread rate	Total nutrients in NF x spread rate
Available nutrients supplied in NF	Total nutrients applied in NF x availability %
Top up of artificial fertiliser needed 1st cut	Nutrient need - total nutrients applied in NF
Nutrients required for 2nd cut	Defined by soil analysis and crop grown
Allowance for nutrients from clover in sward	Depends on clover % in sward
Spread rate	Nutrient need divided by either available N or P
Total nutrients applied with spread rate	Total nutrients in NF x spread rate
Available nutrients supplied by NF	Total nutrients applied in NF x availability %
Top up of artificial fertiliser needed 2nd cut	Nutrient need - total nutrients applied in NF
Total artificial fertiliser used for both cuts	Total of artificial fertiliser applied for 1st & 2nd cut

Table 32: the attributes that determine which natural fertiliser product is best to use

Attribute required	Suitable natural fertiliser
Readily available Nitrogen	Digestate liquor, whole digestate
High Phosphorus content	Compost, digestate fibre
Low Phosphorus content	Digestate liquor
Organic matter when low soil P (1 or 2)	Compost, digestate fibre
Organic matter but high soil P (3)	Whole digestate
Application onto growing crop	digestate liquor
Application after cutting silage	Whole digestate

Surface mulch with slow release of nutrients	Compost, digestate fibre

Deciding which natural fertiliser to use
The choice of which natural fertiliser product to use depends on many factors and should take into account the following aspects

Soil	Soil type and condition - determines whether organic matter is required
	What is the soil N & P index - if only small amounts of P or no P can be applied then not suited to compost or digestate fibre
Crop	Crop to be grown - determines when the fertiliser is can be applied, the nutrients required and what qualities would be beneficial
	Timing of nutrient application - digestate fibre, compost and whole digestate can be applied before a crop starts to grow. Only digestate liquor should be used once the crop/grass is growing and it should be applied below the canopy
Costs & Logistics	The costs of the natural fertiliser product, the transport from processing facility and spreading - allows comparison with the cost of alternative fertilisers, and other methods of improving soil quality and crop performance
	What spreading equipment is available
	How the natural fertiliser is to be transferred from the delivery vehicle to the spreading equipment and whether storage is required in between delivery and spreading, to ensure enough material is available at the spreading time
Fertiliser	What attributes are required

Comparative examples of using either digestate or compost in different agricultural situations

The examples provided below show how to calculate a nutrient management plan using compost or digestate fertiliser products. A number of examples are provided to show how the nutrient content of the different types of inputs and the soil nutrient status must be considered, if it is desired to maximise the reduction in artificial fertiliser input.

In a particular farming situation the use of one type of input may have the greatest reduction in artificial fertiliser, whereas in another farming situation, a different input might be better. Whether the reduction in artificial fertiliser use by using compost or digestate products achieves an overall production cost reduction depends on the costs related to the cost of supply and spreading the compost or digestate. Appendix 10 provides cost data.

Examples 1 (Z and Y) and 2 (W and X) compare the use of the same whole digestate and compost products on grass/clover swards where the soil phosphorous status varies. This comparison shows that there are greater artificial fertiliser savings for compost use when the soil P index is 2 rather than 3, but less artificial fertiliser savings for whole digestate use when the soil P index is 2 rather than 3.

Examples 1 (Z and Y) and 3 (V and U) compare the use of whole digestate and compost products on grass/clover swards where the nutrient value of the input varies but the soil phosphorous status is the same. This comparison shows that there are greater artificial fertiliser savings for both the whole digestate and compost use when the compost has a higher phosphorous content. It also shows that in example 1 the spreading rate of the whole digestate is controlled by the nitrogen content and in example 3 the spreading rate of whole digestate is controlled by the phosphorous content.

Example 4 (R,S and T) compare the use of compost, digestate fibre only and digestate fibre and digestate liquor to grow spring barley where the soil has a status of phosphorous Index 2 and nitrogen Index 1. This comparison shows that the greatest artificial fertiliser savings can be achieved in this situation when the digestate fibre and digestate liquor are used, but the artificial fertiliser savings are lowest when only digestate fibre is used.

Example 1 - Soil P index 3 grassland comparison using compost or whole digestate

Z - NMP for clover rich grassland with 2 cuts of silage (no grazing) applying compost

When compost is used the amount of compost spread is controlled by the available phosphorous content and the amount spread is 9.2t/ha.

Roughly 45% of the crop need for nitrogen is supplied by the clover in the sward, 16% by the compost and a 40% by artificial fertiliser. No artificial phosphorous is required and about 35% of the potassium needs are provided by the compost the rest would be supplied by artificial fertiliser.

- The compost is applied in early spring to maximise the benefit and is applied at a rate that provides all the phosphorous required for both first and second cut silage.
- It is assumed that the nutrients are released from the compost over the growing season

Example 1 - Z	**Nitrogen**	**Phosphorous**	**Potassium**
Compost total nutrients in 1t	19.3	4.4	6.5
Availability of nutrients	20%	75%	80%
Required nutrients for 1st cut	125	20	95
Total nutrients applied with spread rate of 9.2t/ha	**177**	**40**	**59**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in compost	18	20	24
Top up of artificial fertiliser needed 1st cut	67	0	71
Nutrients required for 2nd cut	101	10	50
Allowance for nutrients from clover in sward	60	0	0
Allowance for nutrients released from the compost	18	10	24
Top up of artificial fertiliser needed 2nd cut	23	0	26
Total artificial fertiliser used for both cuts	**91**	**0**	**97**
Cost of artificial fertiliser €/ha	108	0	90

When using compost in this situation the total artificial fertiliser cost amounts to €198/ha

Y - Example for clover rich grassland with 2 cuts of silage (no grazing) applying whole digestate

When whole digestate is used the amount spread is controlled by the available nitrogen content. An application of whole digestate is made before each cut but should be made when the grass is short due to the digestate fibre content in the whole digestate.

The total amount of whole digestate spread over both cuts is 41t/ha. About 45% of the crop need for nitrogen is supplied by the clover in the sward, and the rest by the whole digestate, and no artificial nitrogen is required. About 35% of the crop need for phosphorous and potassium is required from artificial fertiliser

- The whole digestate is applied in early spring and directly after first cut is harvested to maximise the benefit.
- The rate of application is controlled by the available nitrogen content

- To reduce cost of applications it would be advised that the requirement of artificial phosphorous and potassium for second cut be applied when the artificial top up is applied for first cut.

Example 1 - Y	Nitrogen	Phosphorous	Potassium
total nutrients in 1t whole digestate	4.4	0.5	2.5
Availability of nutrients	70%	100%	100%
Required nutrients for 1st cut	125	20	95
Total nutrients applied with spread rate of 28t/ha	**121**	**14**	**69**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in whole digestate	85	14	69
Top up of artificial fertiliser needed 1st cut	0	6	26
Nutrients required for 2nd cut	101	10	50
Total nutrients applied with spread rate of 13t/ha	**59**	**7**	**33**
Allowance for nutrients from clover in sward	60	0	0
Available nutrients supplied in whole digestate	41	7	33
Top up of artificial fertiliser needed 2nd cut	0	3	17
Total artificial fertiliser used for both cuts	**0**	**10**	**43**
Cost of artificial fertiliser €/ha	0	26	39

When using whole digestate in this situation the total artificial fertiliser cost amounts to €65/ha

Example 2 Soil P index 2 grassland comparison using same compost or whole digestate as in Example 1

X - grassland with 2 cuts of silage and no grazing applying compost (NPK as example 1A)
The amount of compost spread is controlled by the phosphorous content once again but the amount spread increases to 12t/ha.

Roughly a 45% of the crop need for nitrogen is supplied by the clover in the sward, the compost supply increases to 20% and artificial fertiliser required reduces to 35%. No artificial phosphorous is required and about two thirds of the potassium needs to be supplied by artificial fertiliser.

Example 2 - X	Nitrogen	Phosphorous	Potassium
Compost total nutrients in 1t	19.3	4.4	6.5
Availability of nutrients	20%	75%	80%
Required nutrients for 1st cut	125	30	95
Total nutrients applied with spread rate of 12t/ha	**234**	**53**	**79**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in compost	23	30	32
Top up of artificial fertiliser needed 1st cut	62	0	63
Nutrients required for 2nd cut	101	10	50
Allowance for nutrients from clover in sward	60	0	0
Allowance for nutrients released from the compost	23	10	32
Top up of artificial fertiliser needed 2nd cut	18	0	18
Total artificial fertiliser used for both cuts	**79**	**0**	**82**
Cost of artificial fertiliser €/ha	95	0	75

When using compost in this situation the total artificial fertiliser cost amounts to €170/ha

W- Where soil P is index 2 grassland with no grazing using whole digestate (NPK as example 1B)

The amount of whole digestate spread is controlled by the available nitrogen content, therefore although the phosphorous requirement increases because of the lower soil P index the rate of application does not change to that in example 1B. The total amount of whole digestate spread over both cuts is 41t/ha. About 45% of the crop need for nitrogen is supplied by the clover in the sward, and the rest by the whole digestate, and no artificial nitrogen is required. The proportion of phosphorous provided by the whole digestate reduces to 60% (from 65%). About 65% of the crop need potassium is from the whole digestate

Example 2 - W	**Nitrogen**	**Phosphorous**	**Potassium**
total nutrients in 1t whole digestate	4.4	0.5	2.5
Availability of nutrients	70%	100%	100%
Required nutrients for 1st cut	125	30	95
Total nutrients applied with spread rate of 28t/ha	**121**	**14**	**69**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in whole digestate	85	14	69
Top up of artificial fertiliser needed 1st cut	0	16	26
Nutrients required for 2nd cut	101	10	50
Total nutrients applied with spread rate of 13t/ha	**59**	**7**	**33**
Allowance for nutrients from clover in sward	60	0	0
Available nutrients supplied in whole digestate	41	7	33
Top up of artificial fertiliser needed 2nd cut	0	3	17
Total artificial fertiliser used for both cuts	**0**	**20**	**43**
Cost of artificial fertiliser €/ha	0	54	39

When using whole digestate in this situation the total artificial fertiliser cost amounts to €93/ha

Example 3 - Soil P index 3 grassland as in Example 1 - comparison using compost or whole digestate each with a different nutrient analysis

V - grassland with 2 cuts of silage and no grazing applying compost (different NPK to 1A)

Example 3 - V	**Nitrogen**	**Phosphorous**	**Potassium**
Compost total nutrients in 1t	13.1	3.9	2.4
Availability of nutrients	20%	75%	80%
Required nutrients for 1st cut	125	20	95
Total nutrients applied with spread rate of 10.3t/ha	**134**	**40**	**25**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in compost	13	20	10
Top up of artificial fertiliser needed 1st cut	72	0	85
Nutrients required for 2nd cut	101	10	50
Allowance for nutrients from clover in sward	60	0	0
Allowance for nutrients released from the compost	13	10	10
Top up of artificial fertiliser needed 2nd cut	28	0	40
Total artificial fertiliser used for both cuts	**99**	**0**	**125**
Cost of artificial fertiliser €/ha	119	0	115

When using compost in this situation the total artificial fertiliser cost amounts to €234/ha
The amount of compost spread is controlled by the phosphorous content once again but the amount spread is 10.3t/ha.

Roughly a 45% of the crop need for nitrogen is supplied by the clover in the sward, the compost supply is 10% and artificial fertiliser required is 45%. No artificial phosphorous is required and about 15% of the potassium needs are provided by the compost.

U - Where soil P is index 3 grassland with no grazing using whole digestate (NPK differs to 1B)

The amount spread of whole digestate is controlled by the phosphorous content, for both cuts of silage The total amount of whole digestate spread over both cuts is less at 37.5t/ha. About 45% of the crop need for nitrogen is supplied by the clover in the sward, 52% by the whole digestate, and artificial nitrogen is required to meet 3% of the crop need. The proportion of phosphorous provided by the whole digestate is now 100%, therefore about 80% of the crop need potassium is now provided from the whole digestate

Because of the small amounts of top up artificial fertiliser required for second cut, the total amount of artificial fertiliser required for both cuts should be applied for the first cut

Example 3 - U	Nitrogen	Phosphorous	Potassium
total nutrients in 1t whole digestate	4.4	0.8	3.5
Availability of nutrients	70%	100%	100%
Required nutrients for 1st cut	125	20	95
Total nutrients applied with spread rate of 25t/ha	**110**	**20**	**88**
Allowance for nutrients from clover in sward	40	0	0
Available nutrients supplied in whole digestate	77	20	88
Top up of artificial fertiliser needed 1st cut	8	0	7
Nutrients required for 2nd cut	101	10	50
Total nutrients applied with spread rate of 12.5t/ha	**55**	**10**	**29**
Allowance for nutrients from clover in sward	60	0	0
Available nutrients supplied in whole digestate	39	10	29
Top up of artificial fertiliser needed 2nd cut	3	0	21
Total artificial fertiliser used for both cuts	**11**	**0**	**28**
Cost of artificial fertiliser €/ha	13	0	26

When using whole digestate in this situation the total artificial fertiliser cost amounts to €39/ha

Example 4 - spring barley grown on soil with P index 2 and N index 1

T - using digestate fibre and digestate liquor to meet all the nutrient needs of the spring barley

The digestate fibre and first digestate liquor application is spread after ploughing and before cultivation. The second digestate liquor application is applied at a similar time in the crop development as CAN fertiliser would be applied normally.

The spread rates are controlled by the available phosphorous content in the digestate fibre and the available nitrogen content in the digestate liquor. This makes it possible to meet all the crop nutrient needs for phosphorous and nitrogen. It is likely that the amount of potassium applied in the natural fertilisers will differ from that stated as required by the crop. In the case of this example 10kg/ha too much is applied. However, this is currently considered unlikely to create a problem for the crop or the environment

When calculating the spread rates for the digestate fibre and digestate liquor applications for the first split, allowance is made for the phosphorous and potassium supplied in the digestate liquor for second split

Example 4 - T	**Nitrogen**	**Phosphorous**	**Potassium**
total nutrients in 1t of digestate fibre	6.4	4.4	2
Availability of nutrients in digestate fibre	30%	100%	100%
total nutrients in 1t of digestate liquor	4.4	0.3	1.8
availability of nutrients in digestate liquor	80%	100%	100%
Required nutrients for crop 1st split	68	35	65
Available nutrients supplied from digestate fibre spread rate of 5.5t/ha	10	24	11
Available nutrients supplied from digestate liquor spread rate of 16.3t/ha	58	5	29
Nutrient requirement for 1st split not supplied	0	6	25
Nutrients required for 2nd split	67	0	0
Available nutrients applied digestate liquor spread rate of 19t/ha	67	6	34
Total artificial fertiliser used for both cuts	**0**	**0**	**0**
Cost of artificial fertiliser €/ha	0	0	0

S - using only digestate fibre and artificial fertiliser to meet the nutrient needs of the spring barley

Example 4 - S	**Nitrogen**	**Phosphate**	**Potash**
total nutrients in 1t of fibre	6.4	4.4	2
Availability of nutrients in fibre	30%	100%	100%
Required nutrients for crop 1st split	68	35	65
Available nutrients supplied from fibre spread rate of 8t/ha	15	35	16
balance of nutrients required for 1st split	53	0	49
Nutrients required for 2nd split	67	0	0
Total artificial fertiliser used for both cuts	**120**	**0**	**49**
Cost of artificial fertiliser €/ha	144	0	45

R - *using compost and artificial fertiliser to meet all the nutrient needs of the spring barley*

The compost can be spread after ploughing and before cultivation or after cultivation and sowing of the seed. The balance of nitrogen and potassium required are met by using straight forms of artificial fertiliser and are spread when the compound would normally be spread. CAN fertiliser is applied for second split.

The spread rate for the compost is controlled by the available phosphorous content in the compost

Example 4 - R	**Nitrogen**	**Phosphorous**	**Potassium**
total nutrients in 1t of compost	19.3	4.4	6.5
Availability of nutrients in compost	20%	75%	80%
Required nutrients for crop 1st split	68	35	65
Available nutrients supplied from digestate fibre spread rate of 10.6t/ha	41	35	55
balance of nutrients required for 1st split	27	0	10
Nutrients required for 2nd split	67	0	0
Total artificial fertiliser used for both cuts	**94**	**0**	**10**
Cost of artificial fertiliser €/ha	113	0	9

APPENDIX 6: DETAILS ON THE SAMPLE ANALYSIS METHODS USED

In 2010 and up to end of January 2011, IAS ltd (Independent Analytical Services) was the accredited lab used for analysing samples. For 2011 it was decided to use NRM Ltd a UK accredited lab, for several reasons, including reduced costs, capability to undertake stability tests and available nitrogen and phosphorous tests on the inputs, and reliable turnaround times, even though there would be additional time required for postage.

Where possible, NRM were asked to use similar test methodologies in 2011 to those used by IAS in 2010. However, in some tests the methods are different and/or the results reported in a different manner.

Tests undertaken on Soils

Samples analysed by IAS, used standard techniques, as detailed below, otherwise the techniques were the same as NRM

- Organic N - colourimetry LPM 6.5.3.1
- Nitrate & Calcium - Colourimetry
- Phosphorous (Morgans) - Colourimetry SOP 2008
- Potassium - AA SOP 2009
- pH - Electrometry SOP 2001

Samples analysed by NRM, used standard techniques, as detailed below.

- Organic matter % (loss in ignition),
- Phosphorus and potassium using Morgan's reagent
- Available nutrients by water extraction and EUF analysis,
- Total metals by aqua regia digest and ICP-MS analysis
- Organic matter by dry ashing at 500°C
- Dry matter by drying at 105°C
- pH in water and in SMS
- Kjeldahl nitrogen
- Sulphate according the BS 1377-3: 1990
- Particle size analysis

Tests undertaken on natural fertiliser inputs

- Total nutrients and metals by ICP-MS analysis after sample digestion
- Dry matter by drying at 105°C
- pH in water
- Kjeldahl nitrogen

Sample methodology used

- Soil sampling - at the commencement of the trial a single sample of the entire trial area on a farm was taken by using standard soil sampling methods as specified in SI 101.
- Soil samples at all other stages were taken for each individual plot, by taking at least 13 core samples randomly in a 'w' pattern within the plot. Core samples were not taken from within the margins or within the tramlines of the plots.
- Soil samples for the mid and end of season in the grassland - were taken at the same time and within the same quadrat as the grass samples for first and third cut silage. Three soil cores were taken within each quadrat location (amounting to 15 samples per plot)
- Bulk density - A cone penetrome of a specific capacity is hammered into the soil at five random locations within each plot.

- Grass herbage samples were taken immediately after the sward was cut. Samples were taken from within the area of a quadrat at 5 random locations within each plot
- The cut sward was allowed to wilt for 24hrs and was raked to aid drying and collection, before baling a measured area. The bale was then weighed.
- Fresh Yield arable per hectare – a measured area was harvested from within the plot and weighed, either by using onboard weighing in the research combine (when available) or by unloading the combine into a tonne bag and weighing the bag. A margin of at least 1 metre each side of the division between plots was not included in the harvest to minimise the risk of cross contamination between applications affecting results.
- A representative sample was taken from the harvested grain, to analyse for grain quality
- 100 stems were cut at ground level, before harvest commenced, from 6 points within each plot, to assess ears/ha and to analyse straw quality
- Dry Matter Yield– Dry matter percentage is identified by analysis and wet yield per hectare is then multiplied by DM%
- Emergence (at 1st node) and tiller counts in 2010, by placing a quadrat at 5 random locations, and counting the number within the quadrat. The plot means were tested for equality before combining the five counts from treatment reps to produce treatment counts for statistical analysis.
- Ear and stem counts were taken in 2011 by placing a metre stick randomly in the plots, counting the number of tillers along this metre line and then counting the number of tillers that would produce heads along this metre line. This was carried out six times in each plot.
- Plant counts in 2011 - a metre stick was thrown randomly in the plot 6 times. Each time the number of plants along this metre were counted and then calculated to give a square metre reading.
- Crop Nitrogen Uptake – Samples of the crop are tested for nitrogen percentage. From knowing the amount of nitrogen applied to the crop the crop nitrogen uptake (CNU) can be calculated
- Six clover scores were taken randomly in each plot. In 2010 clover leaves inside a quadrat were counted at 5 random locations within each plot. In 2011 a meter squared area was examined for the percentage clover in the crop at 6 random points in each plot.
- Nitrogen Sensor (NIR and NDVI readings) - The nitrogen sensor is held approximately 1 metre over the crop and the person holding the nitrogen sensor walks at a calibrated pace for the length of the plots. This was carried out at three stages of growth. The readings are then analysed to determine greenness and amount of biomass within the growing crop
- Samples from dry inputs (compost and digestate fibre) were taken by collecting material from at least 13 places within the heap of material. This collected material was then well mixed together and a sample taken from this to be sent for analysis
- Samples from whole digestate and digestate liquor were taken from the delivery tanker during delivery to one of the farms
- Samples of slurry were taken from the slurry tanker, at the time the slurry was being spread on the slurry trial plots on the farm.
- Earthworm assessment in 2010 - Earthworm populations were assessed in October by hand counting the number of worm casts in a quadrat (50cm x 50cm) in 5 random locations in each plot
- Earthworm assessment in 2011 - Earthworm sampling took place on October 27th (Site C & D) and November 2nd (Site A & B), 2011. Earthworm populations were assessed by hand sorting of soil-blocks (25 x 25 x 25 cm deep). Two soil-blocks were taken in each treatment plot.

APPENDIX 7: DETAILS ON WHAT TESTS WERE UNDERTAKEN IN 2010 AND 2011

Table 33: Tests undertaken in 2010

type of test	to identify	how assessed
Crops	plant establishment	Count: No. plants per unit area (5 50x50cm quadrats/plot)
	plant growth & development	5 plants in each of three rows on a plot
	Clover count	No. clover leaves in quadrat at 5 locations
	herbage yield (grass)	weighing
	seed yield (cereals)	weighing
	grain quality	Standard quality analysis
	grass quality	Standard quality analysis (plus molybdenum on grass)
	plant disease	visual assessment of roots and plant pre-harvest in lab
		visual checks in field during growth
Soil	Bioindicators – worms	Visual assessment of worm casts/unit area (5 50x50cm quadrats/plot)
	Workability	bulk density & field soil water content; cone penetration resistance
	Erodibility	Aggregate stability
	SOM	lab analysis
	nutrient content	lab analysis of soils (total and available macro- & micro-nutrients)
Nutrition	Fertilizer replacement value	lab analysis of inputs (total and available macro- & micro-nutrients)
Contraindicators	Metals soil	lab analysis of soils
	metals inputs	lab analysis of applied materials

Table 34: Tests undertaken in 2011

type of test	to identify	how assessed
Crops	plant establishment	Count: No. plants per m^2 5 locations in plots
	monitoring of crop biomass	at GS 31 (mid-spring) , GS 39/55 (mid-summer) using a crop N sensor
	assess nitrogen uptake	Sampling x3 dates in May / June GS 32, 39 and 69 for arable
	Clover count	Start of season no./m^2
	herbage yield (grass)	Weighing bales
	grass quality	Nutrient analysis
	wellbeing	visual checks in field
Soil	SOM	lab analysis
	nutrient content	lab analysis (total and available macro- & micro-nutrients) at start
		N,P and qualities mid season
Nutrition	Fertilizer replacement value	lab analysis of inputs (total and available macro- & micro-nutrients)
Contraindicators	Metals soil	lab analysis of soils
	metals inputs	lab analysis of applied materials
	Stability inputs	lab analysis of applied materials

Table 35: Analysis tests

Soil	
Spring	Morgan's P&K, pH, Nitrate, Org N
	OM
	EUF available minerals set, Ca, Mg, Na, Mn, Cu, Zn, Bo, Mo, Su
mid-season	Nitrate, Organic Nitrogen
	pH
post harvest	Morgan's P&K, Kjeldahl N, Org N, Nitrate, pH
	LOI
	EUF available minerals set, Ca, Mg, Na, Mn, Cu, Zn, Bo, Mo, Su
	Total Ca, Cd, Cr, Cu, Hg, Mg, Mo, Ni, Pb, Su
	Worm count, bulk density,
grass	Keljdahl N,P,K,Crude protein, DM
	Fibre, Sugars, Energy, Nitrate
	EUF available minerals set, Ca, Mg, Na, Mn, Cu, Zn, Bo, Mo, Su
	Total Ca, Cd, Cr, Cu, Hg, Mg, Mo, Ni, Pb, Su
	Weighing wet yield
inputs	Total Ca, Cd, Cr, Cu, Fe, Hg, Mg, Mo, Ni, Pb, Se, Su
	Keljdahl N,P,K,pH,DM
	Available N&P
arable	NIVI & NRV (in 2011)
	Plant emergence & tillering (in 2010); plant m2 (in 2011)
	Ears/m2
Grain harvest	weighing wet weight
	DM, 1000 grain,
	CNU, SNU, GNU

APPENDIX 8: RESULTS FROM FARMS

Farm A (SB2) - Spring Barley 2010 and 2011

The trial site on Farm A, near Mullingar in County Westmeath, grew spring barley for two years (2010 and 2011). The field was in tillage for more than 10 years before the trial. The bedrock geology is Westmeath Limestone overlain by deep deposits of glacial drift. The soil loam/clay loam texture with moderate-high organic matter (4.5%) and slightly acidic pH (6.1 pH units). Soil phosphorus was index 2. It is free draining, with a weak structure and high silt content. The field slopes away to the south east. The plots were situated at least one tram line width out from the headland.

Plot layout at farm A

The crop nutrient requirement in both years was 135kg of N, 35kg of phosphorus and 75kg of K. Nutrients were applied in 3 applications: natural fertilisers or compound (for the artificial plot) prior to sowing; straight artificial fertilisers to balance first split nutrient need after sowing; compound ammonium nitrate or digestate liquor to meet second split nutrient need. The fertiliser programme maximised the amount of natural fertilisers applied. Phosphorus controlled the rate of application for compost and slurry. Available nitrogen determined the rate applied for digestate. Nitrogen application was 50% in first split and 50% in second split.

Cultivation method at Farm A is to use minimum-tillage of the ground before seeding. The natural fertilisers were applied on to the stubbles before cultivation. Spraying for weeds and disease prevention was as for the rest of the field.

Table 36: application timing at Farm A

application	2010	2011
Prior to cultivation	Compound in artificial fertiliser All slurry, compost and digestate	Compound in artificial fertiliser All slurry, compost Whole digestate to initial nitrogen crop requirement
After emergence	artificial straights to 1st split need	artificial straights to 1st split need
2nd split	2nd split artificial nitrogen	2nd split artificial nitrogen to artificial fertiliser, slurry and compost plots Digestate liquor on digestate plots for 2nd split nitrogen need

Table 37: Fertiliser applications 2010 at Farm A

	Natural fertiliser kg				Top up artificial kg		
	t/ha	Av N	P	K	Av N	P	K
compost	14.2	28	53	78	131	0.0	0.0
digestate	46.4	124	6	73	50	21	0.0
slurry	31.3	19	16	69	95	21	0.0
artificial	n/a	-	-	-	105	17	38

Table 38: Fertiliser applications in 2011 at Farm A

	Natural fertiliser kg/ha				Top up artificial kg/ha		
	t/ha	**Av N**	**P**	**K**	**Av N**	**P**	**K**
compost	12	16	35	24	119	0	51
digestate	26+22	135	13	68	0	22	7
slurry	44	58	14	114	77	21	0
artificial	n/a				135	35	70

Table 39: Schedule of the nutrient supply for the 2011 trial at Farm A

	N		P		K		rate
from	Natural fertiliser	Artificial fertiliser	Natural fertiliser	Artificial fertiliser	Natural fertiliser	Artificial fertiliser	t/ha
1st split	68		35		75		
from	0	68	0	20	0	65	-
slurry	58	10	14	21	114	0	44
compost	16	52	35	0	24	51	12
digestate	68	0	9	22	33	0	26
2nd split	67		0		0		
artificial	0	67	0	0	0	0	-
slurry	0	67	0	0	0	0	0
compost	0	67	0	0	0	0	0
digestate	67	0	4	0	35	0	22

Summary of Results from 2010

There were differences in nutrient application levels and timing across the four treatment plots, specifically in total nitrogen levels applied, so caution has been applied in reaching firm conclusions from the results of this first year of field data. Each of the trial applications gave good levels of grain output in the 2010 trial. The nitrogen utilisation (relative to that applied) was significantly higher in the digestate plots indicating a higher level of nitrogen use efficiency. It was found that adding natural fertilisers appeared to increase the levels of moisture retention in the soil.

Summary of harvest results from 2011

The unusual spring and summer weather pattern in 2011 created unique soil nutrient effects and had major effects on the agronomic performance of spring barley and other spring cereal crops in the Midlands region. The prolonged low rainfall period between crop drilling and the end of crop tillering (mid-March to mid-May) led to a significant soil moisture deficit which reduced crop growth and crop nutrient utilisation.

As this spring barley crop was established by minimum-tillage, there was an interaction effect with cultivation practices and crop root development during the prolonged ‘drought’ type conditions which endured until late-May. In contrast the spring barley crop at Site D had significant rainfall from early-May onwards which facilitated better crop growth promoted by higher levels of nutrient utilisation.

There was a high level of problem grass-weeds in a number of the trial plots due to difficult weather conditions for herbicide use and to the build-up of problem grass-weeds typically observed in minimum-tillage cultivation systems. Hence, the 2011 agronomic data from this trial site requires caution in reaching conclusions based on the trial data presented. However, the results of the monitoring during the crop growth show clearly that the compost and digestate fertiliser products are able to stimulate the crop to perform at least as well as slurry and in some aspects slightly better than artificial fertiliser even in a difficult growing year in the Midlands area.

Summary of soil changes over the two years of the trial

There were increases in the compost plots over the two years in Morgan's phosphorus and also slightly higher pH. Organic matter was maintained better in the compost plots than the other types of plots, but was still lower than at the start of the trial. pH dropped slightly in the artificial plots and the Morgan's phosphorus dropped in both the slurry and artificial plots.

2011 bulk density results indicate that the addition of structural carbon from compost and slurry can create a more open soil structure over two years, even when the amounts added are relatively small.

Table 40: Soil pH levels throughout trial at Farm A

plot		2010			2011		
no.	**name**	**Composite**	**Mid**	**autumn**	**spring**	**Mid**	**end**
A1	**artificial**	6.1	5.7	7.7	6.2	5.8	6.3
B2	**artificial**		5.8	7.7	6	5.9	5.5
B1	**slurry**		5.8	7.8	6.2	6.1	6.6
D2	**slurry**		5.7	7.6	6.1	6.5	5.7
C1	**compost**		5.8	7.9	6.3	6.3	6.4
A2	**compost**		5.7	7.6	6.3	6.3	6.3
D1	**digestate**		5.9	7.8	6.1	5.9	5.9
C2	**digestate**		5.8	7.5	5.9	5.9	6.4
e1	**nothing**				4.2	5.9	6.2

Table 41: Soil Morgan's P levels throughout trial at Farm A

plot		2010		2011	
no.	**name**	**Composite**	**autumn**	**spring**	**autumn**
		mg/l	mg/l	mg/l	mg/l
A1	**artificial**	5.1	5.7	6.9	6.5
B2	**artificial**		3.8	4.3	4.9
B1	**slurry**		6.9	5.7	5.3
D2	**slurry**		5.2	4.8	5.4
C1	**compost**		4.5	5.9	6.3
A2	**compost**		6.4	8.9	12.4
D1	**digestate**		6	5.3	5.7
C2	**digestate**		4	4.4	6.6
e1	**nothing**			10.4	8

Table 42: Soil organic matter LOI levels throughout trial at Farm A

plot		2010			2011		
no.	**name**	%	%	%	% w/w	% w/w	% w/w
		composite	**Mid**	**autumn**	**spring**	**mid**	**end**
A1	**artificial**	4.5	4.9	5.0	4.4	4.7	4.4
B2	**artificial**		5.0	5.6	4.2	4.5	4.7
B1	**slurry**		5.0	4.7	3.8	4.9	4.2
D2	**slurry**		5.1	5.3	4.4	6.7	5.0
C1	**compost**		4.8	4.9	4.3	5.0	4.3
A2	**compost**		5.0	5.4	4.5	5.2	5.2
D1	**digestate**		4.7	4.8	4.0	5.0	4.7
C2	**digestate**		5.0	5.1	4.3	4.9	4.5
e1	**nothing**				4.6	4.9	4.8

Table 43: Soil total N levels throughout trial at Farm A

plot		%	%	% w/w	%w/w	% w/w
no.	**name**	**composite**	**autumn**	**spring**	**mid**	**end**
A1	**artificial**	0.25	1.40	0.24	0.19	0.20
B2	**artificial**		1.20	0.17	0.20	0.20
B1	**slurry**		1.60	0.21	0.19	0.20
D2	**slurry**		1.40	0.23	0.22	0.23
C1	**compost**		4.60	0.20	0.22	0.21
A2	**compost**		1.30	0.18	0.23	0.24
D1	**digestate**		1.70	0.20	0.22	0.23
C2	**digestate**		2.90	0.18	0.22	0.21
e1	**nothing**			0.16	0.21	0.21

Table 44: Soil Nitrate N levels throughout trial at Farm A

plot		mg/l	mg/l	mg/l	mg/kg	mg/kg	mg/kg
no.	**name**	**composite**	**mid**	**autumn**	**spring**	**mid**	**autumn**
A1	**artificial**	15.0	21.0	4.7	2.0	7.9	11.8
B2	**artificial**		27.0	2.9	1.5	9.9	12.4
B1	**slurry**		22.0	8.3	2.4	7.0	11.3
D2	**slurry**		16.0	24.5	<0.05	7.9	18.7
C1	**compost**		14.0	28.4	1.1	8.5	11.2
A2	**compost**		18.0	5.8	1.2	6.8	19.2
D1	**digestate**		17.0	2.9	<0.05	23.7	18.1
C2	**digestate**		22.0	6.1	1.3	6.7	12.3
e1	**nothing**				1.8	3.9	9.0

Table 45: Other mineral levels soil throughout trial at Farm A

	start 2010	**end 2011**				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	composite	**artificial fertiliser**	**slurry**	**compost**	**digestate**	**nothing**
Calcium	1,796.50	1,694.50	1,793.50	2,001.50	1,531.00	1,885.00
Cadmium	0.91	0.88	0.86	0.88	0.85	0.80
Chromium	21.70	80.75	82.65	89.85	76.25	73.60
Copper	17.00	19.70	17.20	19.70	16.80	14.50
Mercury	0.07	0.11	0.09	0.09	0.08	0.07
Magnesium	756.00	418.00	482.00	397.00	455.50	456.00
Molybdenum	3.18	3.20	3.55	3.80	3.15	3.20
Nickel	38.50	45.00	40.40	45.00	36.85	31.30
Lead	16.55	14.70	13.75	15.00	13.95	13.20
Sulphur	396.50	294.50	297.00	340.00	313.00	322.00
Potassium	109.00	110.65	144.55	159.20	137.10	110.60

Plant growth

In 2010 relative plant growth between the plots was measured by counting the number of plants per row on emergence and the number of tillers per row two weeks later. Spring barley plant emergence and tillering at the first node stage were assessed on 19/5/10 and 4/6/10 respectively

Table 46: Emergence and tillering in 2010 at farm A

(Mean values ± S.E., n = 10). Values followed by the same letter are significantly different ($p < 0.05$).

	Emergence plants/row-metre	Tillering tillers/row-metre
Artificial	21.45 ±1.02ab	58.10 ±5.04c
Slurry	25.30 ±1.69a	66.05 ±3.95
Compost	27.30 ±1.49	72.90 ±5.02
Digestate	29.50 ±2.12b	80.00 ±6.31c

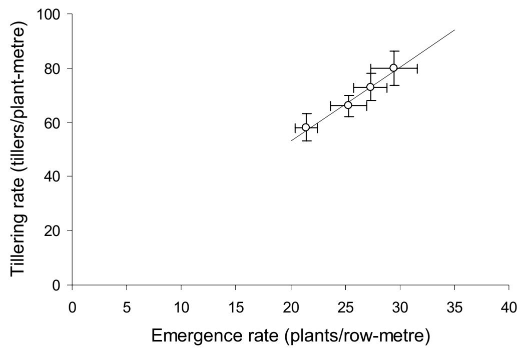


Table 47: Crop yield 2010 and quality at Farm A

(Mean values ± S.E., n = 2)

Treatment:		Artificial	Slurry	Compost	Digestate
Fresh yield	t/ha	4.60±0.06	4.20±0.11	4.55±0.23	5.45±0.00
Dry yield	t/ha	3.59±0.03	3.33±0.13	3.57±0.17	4.31±0.02
Specific Wt	kg/hl	56.6±0.0	55.1±2.1	56.6±2.0	55.6±1.0
Moisture	%	22.0±0.3	20.9±0.8	21.4±0.3	21.0±0.3
Screening	%	1.75±0.25	1.75±1.25	1.75±1.25	3.50±0.00
1000 Grain Wt	g	52.34±1.65	51.70±3.34	54.08±2.23	55.46±01.15
Aluminium	mg/kg	1.4±0.1	2.9	1.6±0.2	2.7±0.2
Boron	mg/kg	0.50±0.1	0.35±0.15	0.50±0.1	0.80±0.3
Calcium	mg/kg	341.0±9	344.0±0.13	390.5±0.5	411±10
Copper	mg/kg	2.1±0.1	2.25±0.05	2.4±0.0	2.5±0.0
Iron	mg/kg	11.8±0.3	16.1±2.8	12.3±0.2	12.1±0.3
Magnesium	mg/kg	948±8	954±11	987±44	968±8
Kjeldahl N	%	1.29±0.08	1.50±0.13	2.93±1.67	2.30±0.56
Phosphorus	mg/kg	2520±20	2600±30	2635±165	2570±100
Potassium	mg/kg	3625±25	3720±90	3920±20	4000±180
Sodium	mg/kg	43±3	42±5	85±2	87±4
Sulphur	mg/kg	1450±50	1575±75	1350±50	1605±95
Zinc	mg/kg	12.8±0.4	14.0±1.9	13.5±0.6	18.3±0.4

Table 48: Crop yield in 2011 at Farm A (t/ha at 15% moisture content),

	Grain Yield (t/ha)	Bulk Density soil
Zero Nutrient	5.6	
Artificial	7	1.92
Slurry	6.9	1.86
Compost	8.3	1.86
Digestate	-	1.93

Yield results from one plot only as all other plots were affected by wild oats

Table 49: Growth on 24-5-11 at Farm A

Code	Treatment	Stem Count/m^2	Average
A1	Artificial	633	
B2	Artificial	617	625
B1	Slurry	484	
D2	Slurry	393	439
C1	Compost	592	
A2	Compost	650	621
D1	digestate	812	
C2	digestate	584	698
E1	Nothing	477	477

Table 50: Plants/m^2, Ears/m2 Grains/ear and bulk density data for the 2011 trial Farm A

	Plants/m^2	Ears/m^2	Grains per ear	Green Leaf % July early	Green Leaf % July late	Grain Protein (%)	Hectolitre Wt (kg/hl)
Zero Nutrient	174.6	472.0	16.9	51.5	39.5	8.4	54.3
Zero Nutrient	170.0	465.0	16.8	50.0	38.0	8.4	54.0
Mean	172.3	468.5	16.9	50.8	38.8	8.4	54.1
Artificial fertiliser	201.4	360.0	0.0	70.0	56.0	9.2	54.5
Artificial fertiliser	198.6	760.0	18.0	85.0	69.5	10.4	54.9
Mean	200.0	560.0	9.0	77.5	62.8	9.8	54.7
Slurry	176.0	904.0	20.3	58.5	46.5	8.4	54.7
Slurry	158.6	640.0	22.0	78.0	52.5	9.1	54.1
Mean	167.3	772.0	21.1	68.3	49.5	8.8	54.4
Compost	194.6	740.0	17.0	82.5	70.0	8.6	52.7
Compost	204.0	724.0	19.8	68.0	56.0	8.6	56.5
Mean	199.3	732.0	18.4	75.3	63.0	8.6	54.6
Digestate	228.0	428.0	22.8	77.0	61.5	8.6	51.2
Digestate	193.4	892.0	18.3	77.0	61.0	9.6	57.0
Mean	210.7	660.0	20.6	77.0	61.3	9.1	54.1

Table 51: Growth comparison of means of compost and digestate over slurry, artificial fertiliser & zero nutrient Farm A

	Plants/m^2		Ears/m^2		Grains/ear		Grain protein %	
	digestate	compost	digestate	digestate	compost	compost	digestate	compost
slurry	126%	119%	85%	95%	97%	87%	104%	99%
artificial	105%	100%	118%	131%	108%	97%	93%	88%
nothing	122%	116%	141%	156%	122%	109%	108%	102%

Table 52: Nitrogen uptake monitoring results from Farm A in 2011

	NDVI1 3.6.11	NDVI 6.7.11	NVDI 30-7-1		NIR 13.6.11	NIR 6.7.11	NIR 30-7-11
Zero Nutrient	0.67	0.55	0.54		5.23	3.44	3.39
Zero Nutrient	0.63	0.53	0.53		5.20	3.45	3.40
mean	0.65	0.54	0.54		5.22	3.44	3.40
Artificial fertiliser	0.70	0.66	0.57		5.93	4.93	3.62
Artificial fertiliser	0.72	0.61	0.57		6.25	4.12	3.64
mean	0.71	0.63	0.57		6.09	4.53	3.63
Slurry	0.72	0.62	0.50		6.19	4.37	3.03
Slurry	0.73	0.59	0.55		6.55	3.87	3.49
mean	0.73	0.61	0.53		6.37	4.12	3.26
Compost	0.70	0.60	0.53		5.87	4.02	3.26
Compost	0.74	0.69	0.55		6.68	5.50	3.47
mean	0.72	0.64	0.54		6.27	4.76	3.37
Digestate	0.72	0.62	0.58		6.37	4.36	3.83
Digestate	0.56	0.64	0.58		3.58	4.59	3.84
mean	0.64	0.63	0.58		4.97	4.47	3.84

Table 53: Farm A mean Grain, Straw and Crop N uptake data for the 2011 trial.

	Grain N Uptake (t/ha)	Straw N Uptake (kg/ha)	Crop N Uptake (kg/ha)
Artificial	94.3	34.1	128.5
Slurry	74.4	28.9	103.3
Compost	88.1	35.1	123.3
Digestate	--	--	--

No uptake results from digestate plots as both were affected by wild oats

Farm D (SB2) - Spring Barley 2010 and 2011

Farm D is near Horse and Jockey, County Tipperary and grew spring barley for two years (2010 and 2011). The trial site is typical arable land in the South East region. The ground is ploughed and tilled before planting the spring barley crops.

The trial field, which slopes gently to the north-east, has been used for arable crops for more than five years, before the trial commenced. The plots nearest the north-eastern part of the field are close to an area prone to water logging after heavy rain. During the trial, in 2010, it became clear that the Replicate 1 plots (i.e. those nearest to this wetter area) did perform differently to the Replicate 2 plots.

Farm D, trial site.

The bedrock geology is Visean limestone and calcareous shale. The soil is typically well-drained, well structured and shows a friable brown to dark brown gravely loam surface. Analysis of the soil has shown it to be loam texture (47% sand, 31% silt, 22% clay) with high organic matter status (5.3 - 7.2%) and neutral pH (6.7 pH units).

Nutrient Management

Crop nutrient requirements were 135kg of Nitrogen, 35kg of phosphorus and 65kg of potassium in both years of the trial. Nutrients were supplied in 3 applications: natural fertilisers or compound (for the artificial plot) prior to sowing with straight artificial fertilisers used to balance 1st split nutrient need after sowing; compound ammonium nitrate or digestate liquor were used to meet 2nd split nutrient need.

The fertiliser programme maximises the amount of natural fertilisers applied. The phosphorus content controlled the rate of application for compost and slurry. The available nitrogen content determined the rate applied for digestate. The nitrogen application was 50% in first split and 50% in second split. The cultivation method was plough and till before sowing. The natural fertilisers were applied after ploughing and before sowing.

Table 54: Application timing at Farm D (SB2)

application	2010	2011
Prior to cultivation	Compound in artificial fertiliser All slurry, compost and digestate	Compound in artificial fertiliser All slurry, compost Whole digestate to initial nitrogen crop requirement
After emergence	Balancing artificial straights	Balancing artificial straights
1st split	1st split artificial nitrogen	1st split artificial nitrogen to artificial fertiliser, slurry and compost plots Digestate liquor on digestate plots for 1st split nitrogen need

Table 55: Fertiliser applications 2010 at Farm D (SB2)

	Natural fertiliser kg				Top up artificial kg		
	t/ha	Av N	P	K	Av N	P	K
Compost	14	28	53	78	131	0	0
Digestate	42	112	6	66	50	20	0
Slurry	31	18	17	91	95	21	0
Artificial	n/a				117	22	45

Table 56: Fertiliser applications 2011 at Farm D (SB2)

	Natural fertiliser kg				Top up artificial kg		
	t/ha	Av N	P	K	Av N	P	K
compost	10.7	21	35	56	104	0	9
digestate	26w+22l	135	14	67	0	20	0
slurry	43.8	25	3	73	108	32	0
artificial	n/a				135	35	65

Table 57: 2011 application details at Farm D (SB2)

Per ha basis	Artificial fertiliser			Compost			Slurry			Digestate		
	N	P	K	N	P	K	N	P	K	N	P	K
Crop requirement	135	35	65	135	35	65	135	35	75	135	35	65
Natural fertiliser total	0	0	0	21	35	56	25	3	73	135	15	67
Additional needed	135	35	65	114	0	9	108	32	0	0	20	0
	applications			applications			applications			applications		
1st split	50%			11t/ha			4t/ha			whole 26.1t/ha		
Natural fertiliser	0	0	0	21	35	56	25	3	73	68	9	33
kg of artificial nutrient	68	35	65	47	0	9	43	32	0	0	20	0
2nd split	50%									digestate liquor 22.2t/ha		
Natural fertiliser	0	0	0	0	0	0	0	0	0	67	6	35
kg of artificial nutrient	67	-	-	67	-	-	67	-	-	0	-	-

Table 58: Planning the nutrient supply for 2011 at Farm D (SB2)

from	N Natural fertiliser	N Artificial fertiliser	P Natural fertiliser	P Artificial fertiliser	K Natural fertiliser	K Artificial fertiliser	t/ha rate
1st split	68		35		65		
artificial	0	68	0	35	0	65	-
slurry	23	45	7	28	48	17	44
compost	21	47	35	0	56	9	10.7
digestate	68	0	9	22	33	0	26
2nd split	67		0		0		
artificial	0	67	0	0	0	0	-
slurry	0	67	0	0	0	0	0
compost	0	67	0	0	0	0	0
digestate	67	0	4	0	35	0	22

Summary of results at Farm D (SB2) in 2011

In 2010 there were differences in nutrient application levels and timing across the four treatment plots, specifically in available nitrogen levels applied, so caution has been applied in reaching firm conclusions from the results of this first year of field data. Each of the trial treatments gave good levels of grain output in 2010 and there was little difference in the yields from different plots. It was clear from the trial where in 2010 the whole digestate was applied in one application, that due to the high rate of availability of N in liquid digestate fertiliser products, the application should be split, similar to artificial fertiliser.

Each of the trial treatments showed good establishment and growth over the season, this is a positive outcome, and of practical importance for the natural fertilisers, slurry, compost and digestate. Adding natural fertilisers increased the levels of moisture retention in the soil.

Summary of results at Farm D (SB2) in 2011

The spring barley crop was sown in excellent conditions in good, dry spring weather in 2011 with good crop establishment levels and growth across each of the trial applications, despite prolonged dry weather. When the various treatments were applied, during the early crop growth periods, the soil conditions were very dry with little rainfall, so this affected the availability to the crop of the nutrients applied. Higher rainfall periods in May increased soil moisture levels and facilitated better nutrient uptake and utilisation.

Excellent crop performance benefits, from the trial applications, were recorded in higher nitrogen monitoring (NDVI and NIR) scores in June and July and also in high green leaf area (GLA) scores during the grain filling period. The strong visual effects of the compost and slurry programmes was also noted in the Farmers Journal article in summer 2011 written after Andy Doyle visited the trial site during July.

Summary of soil changes over the two years of the trial

Soil qualities of the two replicate plots are noticeably different, however, the mean values can still be useful for comparison. The pH increased in all plots over the course of the trial from 6.4 at the start in 2010. The Morgan's P levels increased (from 4.6mg/l) in all the plots that received treatments, and most in the artificial fertiliser plots. The organic matter levels decreased over the two years in all the plots but most in the digestate and zero application plots. Total Nitrogen levels were highest in the artificial fertiliser plot and Nitrate levels highest in the slurry plot. The lowest levels of both total nitrogen and nitrate found in the plots that received treatments were in the digestate plots. There were no significant changes in the other minerals tested for in the soil samples.

Table 59: Soil pH levels throughout trial at Farm D (SB2)

plot		2010			2011		
no.	name	composite	Mid	autumn	spring	Mid	end
A1	artificial	6.4	7.0	6.9	7.0	6.8	7.2
B2	artificial		6.9	6.8	7.4	7.0	7.3
B1	slurry		6.7	7.1	6.8	6.3	6.6
D2	slurry		7.1	6.9	6.8	6.7	7.4
C1	compost		6.9	7.1	7.0	6.9	7.1
A2	compost		6.6	7.2	7.4	6.8	7.3
D1	digestate		6.7	7.0	6.9	6.7	7.0
C2	digestate		6.6	7.0	6.8	6.8	6.8
e1	nothing					7.0	7.4

Table 60: Soil Morgan's P levels throughout trial at Farm D (SB2)

plot		2010		2011	
no.	**name**	**composite**	**autumn**	**spring**	**autumn**
		mg/l	mg/l	mg/l	mg/l
A1	**artificial**	4.6	5.6	5.9	7.1
B2	**artificial**		4.8	6.1	5.8
B1	**slurry**		4.4	4.6	4.0
D2	**slurry**		7.2	4.3	6.8
C1	**compost**		7.0	4.9	6.2
A2	**compost**		4.1	7.3	5.6
D1	**digestate**		3.7	4.5	4.8
C2	**digestate**		3.7	4.3	5.1
e1	**nothing**			4.6	4.4

Table 61: Soil organic matter LOI levels throughout trial at Farm D (SB2)

plot		2010			2011		
no.	**name**	**%**	**%**	%	% w/w	% w/w	% w/w
		composite	**Mid**	**autumn**	**spring**	**mid**	**end**
A1	**artificial**	6.3	6.0	6.9	5.8	6.2	5.9
B2	**artificial**		5.2	5.5	4.3	4.7	3.7
B1	**slurry**		6.2	6.1	5.4	5.4	4.6
D2	**slurry**		5.2	5.1	4.5	4.9	4.2
C1	**compost**		6.0	5.9	5.2	5.6	5.2
A2	**compost**		4.9	5.0	7.6	4.8	4.0
D1	**digestate**		5.6	6.9	6.3	5.3	4.3
C2	**digestate**		4.9	5.2	4.3	4.7	3.8
e1	**nothing**					4.8	4.0

Table 62: Comparison of bulk density, moisture and OM content in 2010 for Farm D (SB2)
(Values are means ± S.E., n = 6)

	Bulk density ($g\ cm^{-3}$)	**Moisture %**	**Loss on Ignition %**
Artificial	1.21 ±0.03	23.88 ±1.04	5.48 ±0.56
Slurry	1.22 ±0.03	27.53 ±1.78	5.28 ±0.39
Compost	1.20 ±0.04	26.58 ±0.64	5.18 ±0.18
Digestate	1.23 ±0.03	26.06 ±0.67	5.03 ±0.17

Table 63: Soil OM and bulk density mean data for October 2011 Farm D (SB2)

	Bulk Density	Soil OM %
Artificial	1.80	5.11
Slurry	1.77	5.08
Compost	1.81	4.63
Digestate	1.94	5.12
LSD (5%)	0.34	--
CV (%)	5.9 %	--

Table 64: Soil total N levels throughout trial at Farm D (SB2)

		2010		2011		
plot		%	%	% w/w	%w/w	% w/w
no.	name	composite	autumn	spring	mid	end
A1	artificial	0.27	0.36	0.31	0.32	0.27
B2	artificial		0.30	0.23	0.20	0.18
B1	slurry		0.22	0.29	0.27	0.22
D2	slurry		0.28	0.18	0.24	0.18
C1	compost		0.25	0.29	0.25	0.24
A2	compost		0.20	0.24	0.22	0.17
D1	digestate		0.22	0.26	0.25	0.22
C2	digestate		0.34	0.22	0.21	0.16
e1	nothing				0.21	0.19

Table 65: Soil Nitrate N levels throughout trial at Farm D (SB2)

		2010			2011		
plot		mg/l	mg/l	mg/l	mg/kg	mg/kg	mg/kg
no.	name	composite	mid	autumn	spring	mid	autumn
A1	artificial	14.0	21.0	15.5	1.9	36.0	36.7
B2	artificial		34.0	18.4	2.2	20.9	20.7
B1	slurry		16.0	9.0	1.4	20.3	33.8
D2	slurry		25.0	13.3	<0.05	11.6	30.6
C1	compost		19.0	16.6	1.8	16.4	31.6
A2	compost		23.0	16.6	2.3	17.0	26.3
D1	digestate		37.0	14.4	2.2	9.1	24.7
C2	digestate		28.0	13.3	1.8	19.9	20.7
e1	nothing					4.5	21.2

Table 66: Other mineral levels soil throughout trial at Farm D (SB2)

	start 2010	end 2011				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	composite	artificial fertiliser	slurry	compost	digestate	nothing
Calcium	3,266	5,675	4,511	4,082	3,070	3,984
Cadmium	0.40	0.38	0.33	0.31	0.30	0.35
Chromium	22.0	56.8	54.4	66.9	48.8	58.6
Copper	8.2	6.9	7.1	7.1	7.4	8.1
Mercury	0.07	0.06	0.06	0.05	0.06	0.06
Magnesium	1,307	1,345	1,392	1,132	1,241	1,334
Molybdenum	1.4	1.9	1.8	1.8	1.3	1.9
Nickel	19.8	21.6	21.8	20.6	17.9	20.2
Lead	18.6	14.7	14.0	13.7	14.1	15.5
Sulphur	467	287	286	298	290	300
Potassium	78.5	58.5	80.7	63.3	64.2	52.7

Table 67: Crop yield and quality at Farm D (SB2) in 2010

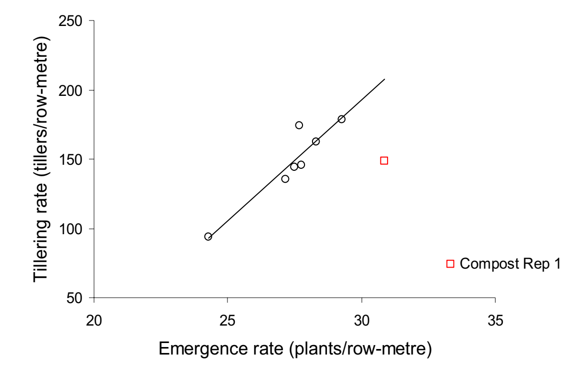
(Mean values ± S.E., n = 2)

Treatment:		Artificial	Slurry	Compost	Digestate
Fresh yield	t/ha	4.95±0.44	4.98±0.02	5.22±0.26	5.01±0.19
Dry yield	t/ha	4.21±0.39	4.18±0.02	4.42±0.23	4.18±0.24
Specific Wt	kg/hl	56.4±1.7	56.4±0.0	55.8±0.8	56.6±0.3
Moisture	%	15.0±0.3	15.8±0.4	16.9±2.0	15.4±0.8
Screening	%	6.3±1.1	2.8±1.8	3.3±1.1	3.3±1.8
1000 Grain Wt	g	41.93±0.83	42.88±2.40	41.04±0.66	42.18±0.47
Aluminium	mg/kg	6.3±2.5	6.0±2.1	5.5±0.7	5.5±1.4
Boron	mg/kg	2.3±0.4	1.8±0.4	1.3±0.4	1.3±0.4
Calcium	mg/kg	600±141	515±0	533±39	573±117
Copper	mg/kg	3.5±0.7	3.0±0.0	3.0±0.0	3.5±0.0
Iron	mg/kg	47.3±8.0	34.0±5.7	33.3±1.1	56.5±37.5
Magnesium	mg/kg	833±74	780±7	760±78	803±60
Kjeldahl N	%	0.34±0.23	0.14±0.04	0.10±0.06	0.21±0.01
Phosphorus	mg/kg	2275±35	2225±35	2200±141	2175±35
Potassium	mg/kg	4125±389	4100±283	4150±0	4075±35
Sodium	mg/kg	106±65	71±13	78±0	84±2
Sulphur	mg/kg	1450±0	1425±35	1400±0	1425±35
Zinc	mg/kg	18.1±0.8	16.6±4.0	17.1±1.3	20.4±4.7

Table 68: Emergence and tillering rates in 2010 at Farm D (SB2)

(Assessed on 20/5/10 and 5/6/10 respectively

	Emergence plants/row-metre	**Tillering** tillers/row-metre
Artificial	28.78±1.39	170.52±11.29
Slurry	27.33±1.87	139.92±7.41
Compost	29.32±0.83	147.10±7.01
Digestate	26.00±0.71	133.87±16.75



Mean values, error bars are S.E., n = 10

Table 69: Spring Barley stem count 8/6/11 at Farm D (SB2)

Plot		Stem Count/m^2	
No.	Treatment	reading	average
A1	Artificial	689	
A2	Artificial	784	737
B1	Slurry	410	
B2	Slurry	588	499
C1	Compost	518	
C2	Compost	473	495
D1	Digestate	333	
D2	Digestate	552	443
E1	Nothing	400	400

Table 70: Growth monitoring for Farm D (SB2) in 2011

	NDVI 8-6-11	NDVI 27-6-11	NDVI 21-7-11	NIR 8-6-11	NIR 27-6-11	NIR 21-7-11
artificial	0.76	0.75	0.64	3.49	6.92	4.59
artificial	0.76	0.75	0.64	3.78	7.11	4.63
slurry	0.76	0.75	0.64	3.55	6.99	4.65
slurry	0.78	0.75	0.66	3.76	6.95	4.94
compost	0.79	0.75	0.66	3.89	7.17	4.86
compost	0.77	0.77	0.60	3.56	7.56	4.10
digestate	0.77	0.73	0.65	3.79	6.40	4.66
digestate	0.76	0.74	0.54	3.38	6.85	3.36
nothing	0.61	0.50	0.47	2.05	3.04	2.80
nothing	0.64	0.54	0.51	2.27	3.38	3.14

Table 71: Plants, ears and green leaf area for Farm D (SB2) 2011

	Plants/m2	Ears/m2	GLA L1 14-8-11	GLA L2 14-8-11
artificial	210	951	84.5	77.2
artificial	224	964	81.5	69.8
slurry	162	1,119	86.0	63.2
slurry	194	912	82.7	69.7
compost	182	855	83.0	73.5
compost	174	1,125	85.0	73.5
digestate	146	815	67.3	37.2
digestate	188	1,076	56.5	41.0
nothing	160	608	45.2	26.8
nothing	160	547	35.2	19.2

Table 72: Crop yield and quality at Farm D (SB2) in 2011

	Grain Yield (t/ha)	Straw yield (t/ha)	Biomass Yield (t/ha)	Grain N Uptake	Crop N Uptake	Protein %
artificial	5.7	6.0	11.7	77	135	10.2
artificial	6.2	6.6	12.8	108	162	13.2
slurry	6.1	5.6	11.7	99	140	12.2
slurry	6.9	6.4	13.3	116	165	12.6
compost	5.8	6.3	12.1	105	160	13.5
compost	5.9	6.3	12.1	88	132	11.3
digestate	6.6	6.6	13.2	81	128	9.3
digestate	6.4	6.4	12.8	68	108	8.0
nothing	4.6	3.6	8.2	44	68	7.3
nothing	4.3	3.4	7.7	42	61	7.3

Table 73: Comparison at Farm D (SB2) of yield and qualities of compost and digestate plots over slurry, artificial fertiliser and no application plots

	grain yield			**1000 grain wt**			**grain protein**	
	digestate	compost		digestate	compost		digestate	compost
slurry	99.8%	90.0%		110.9%	102.6%		69.5%	100.1%
artificial fertiliser	109.3%	98.5%		115.1%	106.5%		74.0%	106.5%
no application	145.8%	131.5%		113.2%	104.8%		118.1%	170.0%

Farm B (SW1) - spring wheat 2011

The field used for this Spring Wheat crop trial is outside Mullingar and is farmed by the same farmer as the Farm A (SB2) site. The field has been in tillage for more than 5 years. The previous crop was spring rapeseed so the Soil nitrogen index is 2. The Soil phosphorus is index 1. This crop trial was held over one growing season only. The soil is a clay loam, with good organic matter (5.8%). Cultivation method is to plough and till the ground before planting crops. The slurry was applied before ploughing. The natural fertilisers were applied after ploughing and before tilling. Spraying programme is as normal.

Field and plot layout at Farm B (SW1)

Nutrient management at Farm B

The need for available nutrients by the crop was 110kg of N, 45kg of phosphorus and 90kg of potassium. Based on the experience of 2010 arable crops it was decided that nutrients should be supplied in 4 applications:

The fertiliser programme maximised the amount of natural fertilisers applied. The phosphorus content controlled the rate of application for compost, digestate fibre and slurry. The available nitrogen content determined the rate applied for digestate liquor and whole digestate. Nitrogen application was 41% pre-sowing; 45% in first split and 14% in second split. The requirement for phosphorus was high as the soil was phosphorus index 1.

The plan in the digestate plots was to not have to use any artificial phosphorus or nitrogen fertiliser by using digestate fibre to supply most of the phosphorus and digestate liquor as the nitrogen supply in subsequent splits. However, when the digestate fibre arrived and was analysed it was found that the phosphorus content was about 50% of the typical analysis provided in advance by the supplier, and there was then not enough digestate fibre supplied. So whole digestate was used as well as digested digestate fibre in the first split and some artificial phosphorus had to also be applied. Allowance was made for the phosphorus and potassium nutrients that would be supplied by applications in subsequent when determining the rate of application of initial and first split applications on the digestate plots.

Table 74: Application timing at Farm B (SW1)

application	2011
Prior to cultivation	Compound in artificial fertiliser All slurry, compost and digestate fibre Whole digestate to initial nitrogen crop requirement
After emergence	Balancing artificial straights
2nd split	2nd split artificial nitrogen to artificial fertiliser, slurry and compost plots Digestate liquor on both digestate plots for 2nd and 3rd split nitrogen need
3rd split	3rd split artificial nitrogen to artificial fertiliser, slurry and compost plots

During the application of the natural fertilisers it was decided that two additional plots would be added, on which whole digestate and digestate liquor would be applied and the availability of the nitrogen content would be assumed to be higher than usual. It was assumed that the availability of nitrogen in the whole digestate would be 80% instead of 70% and in the digestate liquor would be 90% instead of 80%. This assumption of higher availability of nitrogen was done to see what the effects on the crop would be. Also because such small quantities of digestate liquor needed to be applied for the third split and the spreader had to drive over the crop as 24m spreading equipment was not available in Ireland, all the digestate liquor was applied in both types of digestate plots at the time of 1st split applications.

Table 75: Planning the nutrient supply in 2011 at Farm B (SW1) (kg/ha)

Per ha basis	Artificial fertiliser			Compost			Slurry			Fibre/digestate			digestate		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Crop requirement	110	45	90	110	45	90	110	45	90	110	45	90	110	45	90
Natural fertiliser total	0	0	0	20	45	30	52	31	117	110	25	87	83*	8	49
Artificial fertiliser used	110	45	90	90	0	60	58	14	0	0	20	3	0	37	41
applications **1st split** 41%				16t/ha			44t/ha			*Digestate fibre 6t/ha* *whole 14t/ha*			whole 14t/ha		
Natural fertiliser	0	0	0	20	45	30	52	31	117	45	17	38	43	5	18
Artificial fertiliser	45	45	90	25	0	60	0	4	0	0	20	3	8	37	48
2nd split 45%										digestate liquor 16t/ha			digestate liquor 20t/ha		
Natural fertiliser	0	0	0	0	0	0	0	0	0	65	8	49	67	3	31
Artificial fertiliser	49	-	-	49	-	-	42	-	-	0	-	-	0	0	0
3rd split 15%															
Artificial fertiliser	16	-	-	16	-	-	16	-	-	-	-	-	-	-	-

*amount of available nitrogen applied if normal availability assumed although the actual nitrogen availability was taken to be higher, as shown in the values for nitrogen assumed to supplied by the natural fertiliser in 1st (at 80% instead of 70% available) and 2nd split (90% instead of 80% available) application calculations

Table 76: Fertiliser applications in 2011

	Natural fertiliser kg				Top up artificial kg		
	t/ha	Av N	P	K	Av N	P	K
Artificial fertiliser	n/a	0	0	0	110	45	90
Slurry	43.7	52	31	117	58	4	0
Compost	15.5	20	45	30	90	0	60
Digestate *	14+19.6	110	8	49	0	37	41
Fibre/digestate	6+14+16	110	25	87	0	20	3

* assuming 80% (instead of 70%) availability in the whole digestate and 90% (instead of 80%) availability in the digestate liquor

The spring wheat crop performed well after the previous spring oilseed rape at this site in 2011. A positive residual benefit following from the deep rooting oilseed crop was an excellent entry crop for the wheat crop. Therefore a good fertile soil at this site and well managed tillage practices created an excellent high yield potential for the spring wheat crop. This was a favourable situation for a good agronomic performance from each of the five nutrient programmes tested.

At the open evening early-June there was a good visual performance noted for each of the compost and digestate based programmes similar to the artificial and slurry-based programmes. This is in itself a very important observation – which all of the nutrient programmes performed to a similar high level to optimise crop production and these favourable agronomic and crop nutrition effects observed at the canopy complete stage in June continued throughout the ear emergence and grain-filling period to the end of the crop cycle.

Both the compost-based programme and the digestate-based nutrient programmes performed well over the season with good nitrogen uptake measurements recorded during the grain-filling period combined with high grain yield and favourable grain and straw nitrogen uptake data

The whole digestate and the digestate liquor were stored in a slurry tanker at Farm B (SW1). Therefore it is unlikely that there was much loss of nitrogen during storage. This could be the reason that the nitrogen uptake appears to be maintained and that the harvest results do not show a lower protein level in the digestate plots compared to the other plots, or it might be a result of other factors. However, because the nitrogen uptake and the protein levels are slightly lower in the plots where a higher nitrogen availability from the whole digestate and digestate liquor was assumed, this would support the conclusion that when there is little loss of nitrogen during storage and spreading that the digestate can maintain the supply of nitrogen to the crop.

Due to the small quantities of natural fertiliser applied relative to the mass of soil, it would be unlikely that there would be any noticeable change in the soil qualities due to the addition of the fertiliser.

Table 77: Soil pH levels throughout trial at Farm B (SW1)

no.	plot	spring	Mid	end
A1	artificial		6.4	7.1
B2	artificial		7.0	7.1
B1	slurry		6.7	7.4
D2	slurry		7.3	6.4
C1	compost		7.2	7.7
A2	compost		6.7	7.2
D1	digestate		6.5	7.5
C2	digestate		5.8	7
F1	fibre/digestate		6.6	7.7
F2	fibre/digestate		7.3	7.6
E1	nothing	6.8	7.1	7.1

Table 78: Soil Morgan's P levels throughout trial at Farm B (SW1)

<table>
<tr><th>plot</th><th></th><th>autumn composite</th><th>spring</th><th>mid</th><th>autumn</th></tr>
<tr><th>no.</th><th>name</th><th>mg/l</th><th>mg/l</th><th>mg/l</th><th>mg/l</th></tr>
<tr><td>A1</td><td>artificial</td><td rowspan="10">2.4</td><td></td><td>4</td><td>3.1</td></tr>
<tr><td>B2</td><td>artificial</td><td></td><td>5.3</td><td>3.8</td></tr>
<tr><td>B1</td><td>slurry</td><td></td><td>4.1</td><td>3</td></tr>
<tr><td>D2</td><td>slurry</td><td></td><td>4.3</td><td>2.2</td></tr>
<tr><td>C1</td><td>compost</td><td></td><td>4.2</td><td>3.3</td></tr>
<tr><td>A2</td><td>compost</td><td></td><td>3.6</td><td>4.3</td></tr>
<tr><td>D1</td><td>digestate</td><td></td><td>4.2</td><td>4.2</td></tr>
<tr><td>C2</td><td>digestate</td><td></td><td>3.1</td><td>3.1</td></tr>
<tr><td>F1</td><td>fibre/digestate</td><td></td><td>3.8</td><td>2.8</td></tr>
<tr><td>F2</td><td>fibre/digestate</td><td></td><td>4.7</td><td>5.4</td></tr>
<tr><td>E1</td><td>nothing</td><td></td><td>3.3</td><td>7.3</td><td>2.4</td></tr>
</table>

Table 79: Soil organic matter LOI levels throughout trial at Farm B

plot		spring	mid	end
no.	**name**	% w/w	% w/w	% w/w
A1	artificial		5.9	5.8
B2	artificial		6.7	6.8
B1	slurry		6.1	6.6
D2	slurry		6.7	5.6
C1	compost		6.3	6.7
A2	compost		5.8	6.9
D1	digestate		5.8	7.1
C2	digestate		5.4	5.8
F1	fibre/digestate		5.9	6.1
F2	fibre/digestate		6.8	7.2
e1	nothing	5.8	6.7	5.9

Table 80: Soil total N levels throughout trial at Farm B (SW1)

plot		spring	mid	end
no.	**name**	% w/w	%w/w	% w/w
A1	artificial		0.24	0.26
B2	artificial		0.26	0.31
B1	slurry		0.24	0.30
D2	slurry		0.28	0.24
C1	compost		0.27	0.30
A2	compost		0.23	0.31
D1	digestate		0.24	0.39
C2	digestate		0.22	0.25
F1	fibre/digestate		0.24	0.32
F2	fibre/digestate		0.29	0.30
e1	nothing	0.24	0.28	0.23

Table 81: Soil Nitrate N levels throughout trial at Farm B (SW1)

plot		spring	mid	autumn
no.	**name**	mg/kg	mg/kg	mg/kg
A1	artificial		26.3	15.9
B2	artificial		17.7	19.3
B1	slurry		26.0	16.3
D2	slurry		16.5	10.3
C1	compost		11.3	19.3
A2	compost		30.3	22.4
D1	digestate		17.5	19.7
C2	digestate		50.2	13.0
F1	fibre/digestate		27.5	19.2
F2	fibre/digestate		24.6	20.4
E1	nothing	1.7	14.2	13.3

Table 82: Other mineral levels soil throughout trial at Farm B (SW1)

	start	end 2011					
	composite	artificial fertiliser	slurry	compost	digestate	fibre/ digestate	nothing
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Calcium	7,093	5,622	4,475	10,770	2,349	19,758	15,311
Cadmium	1.21	0.98	1.01	1.10	0.51	1.15	0.97
Chromium	31.5	45.0	40.8	62.2	49.6	40.2	58.8
Copper	21.7	17.5	17.8	19.6	19.7	19.7	15.7
Mercury	0.14	0.08	0.08	0.10	0.09	0.10	0.09
Magnesium	1,423	1,964	1,740	1,816	1,917	2,119	1,885
Molybdenum	2.05	1.90	1.85	2.20	2.20	2.05	2.60
Nickel	43.9	43.7	42.9	48.6	48.9	49.3	43.7
Lead	17.4	13.3	13.3	13.2	13.0	11.8	12.7
Sulphur	980	468	471	410	461	282	284
Potassium	106.8	56.8	33.0	48.1	14.5	43.8	46.5
Zinc	103.0	96.0	93.5	88.1	94.3	84.1	76.5

Table 83: Spring Wheat plant count 24/5/11

	Plot	Plant count/m^2	
No.	**Treatment**	**reading**	**average**
A1	artificial	513	
B2	artificial	413	463
B1	slurry	511	
D2	slurry	401	456
C1	compost	655	
A2	compost	548	601
D1	digestate	448	
C2	digestate	425	436
F1	fibre/digestate	220	
F2	fibre/digestate	615	417
E1	none	756	756

Table 84: Growth and soil qualities at Farm B (SW1)

	Plants/m2	Ears/m2	GLA L1	GLA L2	Bulk	SOM
		7/20/11	7/30/11	7/30/11	Density	10/15/11
artificial	193	509	91.5	70.3	1.71	6.31
artificial	174	442	97.8	89.7	1.58	6.21
slurry	158	419	79.7	59.7	1.68	7.10
slurry	142	434	95.0	83.0	1.66	5.87
compost	179	456	91.5	78.2	1.51	5.53
compost	144	403	89.5	74.3	1.94	6.50
digestate	104	345	78.3	64.2	1.54	5.76
digestate	164	407	80.5	64.8	1.60	5.77
fibre/digestate	148	482	96.5	82.8	1.64	
fibre/digestate	140	475	82.7	67.8	1.60	

Table 85: Results of N uptake monitoring at Farm B

	NDVI 13.6.11	NDVI 6.7.11	NDVI 30-7-1	NIR 13.6.11	NIR 6.7.11	NIR 30-7-11
artificial	0.74	0.77	0.65	6.76	7.94	4.86
artificial	0.72	0.73	0.61	6.28	6.40	4.25
slurry	0.68	0.73	0.61	5.39	6.57	4.12
slurry	0.59	0.70	0.62	4.08	5.73	4.24
compost	0.72	0.72	0.60	6.38	6.19	4.06
compost	0.68	0.74	0.62	5.36	6.63	4.23
digestate	0.66	0.71	0.59	5.36	5.96	3.88
digestate	0.71	0.72	0.60	5.90	6.27	4.08
fibre/digestate	0.69	0.72	0.60	5.60	6.18	4.05
fibre/digestate	0.74	0.72	0.60	6.63	6.18	4.06

Table 86: Harvest results for the trial at Farm B (SW1)

	GNU	SNU	CNU	Grain N	Protein	grain yield
	kg/ha	kg/ha	kg/ha	%	%	t/ha
artificial	112.8	52.8	165.7	1.90	10.9	7.0
artificial	116.0	52.2	168.2	1.83	10.5	7.5
slurry	110.1	38.1	148.2	1.72	9.9	7.4
slurry	108.8	47.4	156.2	1.76	10.1	7.4
compost	96.1	44.9	141.0	1.58	9.1	7.1
compost	120.3	60.5	180.8	1.78	10.3	7.9
digestate	132.1	53.9	186.0	1.88	10.8	8.3
digestate	95.7	43.5	139.2	1.69	9.7	6.7
fibre/digestate	124.6	68.3	192.9	1.73	10.0	8.5
fibre/digestate	105.1	47.4	152.6	1.73	10.0	7.1

Farm E (WW1) - Winter wheat 2011

The field used for this Winter Wheat crop trial is on Farm E at Kilsheelan, Clonmel County Tipperary and the crop was grown for one year (planted in 2010 and harvested in 2011). At the commencement of the trial, the field had been in tillage for more than 5 years, under a rotation of crops. Last year, peas were grown so the soil nitrogen is index 2, for the winter wheat. The Soil phosphorus is index 3. The soil is a medium loam, with high organic matter (5.8%). The field has a very gradual slope away to the east.

Crop trial plots at Farm E (WW1)

Cultivation method is to plough and till the ground before planting the farm crops. The natural fertilisers are applied after ploughing and tilling. Spraying programme is as normal.

Nutrient Management at Farm E

The need for available nutrients by the crop is 140kg of nitrogen, 25kg of phosphorus and 50kg of potassium. Nitrogen application was 20% in first split; 50% in second split and 30% in third split. The applications of fertiliser were supplied in 4 applications. All fertilisers were applied in 2011.The fertiliser programme maximised the amount of natural fertilisers applied. The phosphorus content controlled the rate of application for compost and slurry. The available nitrogen content determined the rate applied for digestate.

Table 87: Application timing at Farm E (WW1)

application	2011
1st split Late winter	Compound in artificial fertiliser Slurry, and compost to phosphorus requirement
Later winter	Balancing artificial straights Whole digestate to initial nitrogen crop requirement Compost to additional plot
2nd split Early spring	2nd split artificial nitrogen to artificial fertiliser, slurry and compost plots
3rd split Late spring	3rd split artificial nitrogen to artificial fertiliser, slurry and compost plots Digestate liquor on digestate plots for 2nd and 3rd split nitrogen

Winter wheat does not receive a nitrogen application until late winter. The compost and slurry was spread on the surface of the ground after the crop had emerged, in late winter, as soon as possible after 15th January. As the digestate has a high level of available nitrogen it was planned to spread the digestate at the same time as the artificial fertiliser. However, weather conditions prevented this and the application was delayed. Partly due to this delay and partly for logistics reasons, the subsequent two applications of digestate liquor were also slightly later than the equivalent artificial nitrogen applications. An extra plot combining digestate and compost was included; this allowed the monitoring of the effects of combining these two natural fertilisers.

Table 88: Fertiliser applications in 2011 at Farm E (WW1)

	Natural fertiliser kg				Top up artificial kg		
	t/ha	**Av N**	**P**	**K**	**Av N**	**P**	**K**
Artificial fertiliser	n/a	0	0	0	140	25	50
Slurry	31	15	12	55	125	13	0
Compost	8.6	11	25	17	129	0	33
Digestate	9.6+23+15	140	13	72	0	12	0
Compost/digestate	8.6+23	81	31	53	59	0	0

Table 89: Farm E (WW1) 2011 application details (kg/ha)

Per ha basis	**Artificial fertiliser**			**Compost**			**Slurry**			**Digestate**			**Compost/digestate**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Crop requirement	140	25	50	140	25	50	140	25	50	140	25	50	140	25	50
Natural fertiliser total	0	0	0	11	25	17	15	12	55	140	13	72	81	31	53
Artificial fertiliser	140	25	50	129	0	33	125	13	0	0	12	0	59	0	0
1st split 18%	**applications**			8.6t/ha			31.3t/ha			Whole digestate 9.6t/ha			8.6t/ha		
Natural fertiliser	0	0	0	11	25	17	15	12	55	25	3	12	11	25	17
Artificial fertiliser	25	25	50	14	0	33	10	13	0	0	12	0	14	0	0
2nd split 50%	50%									digestate liquor 23t/h			digestate liquor 23t/h		
Natural fertiliser	0	0	0	0	0	0	0	0	0	70	6	36	70	6	36
Artificial fertiliser	70	-	-	70	-	-	70	-	-	0	-	-	0	-	-
3rd split 32%	32%									digestate liquor 14.8t/ha					
Natural fertiliser	0	0	0	0	0	0	0	0	0	45	4	23	0	0	0
Artificial fertiliser	45	-	-	45	-	-	45	-	-	0	-	-	45	-	-

Summary of results at Farm E (WW1) in 2011

This was an interesting trial with many useful observations of nutrient management and agronomic effects being recorded. This was a high yield winter wheat crop grown on an excellent soil by a farmer who is highly regarded for intensive crop production. Applying the compost on the surface at the beginning of spring growth was observed to show excellent crop benefits with good growth and excellent crop nitrogen status and crop colour observed on the wheat crop throughout the spring and summer period with high NIR and NDVI readings recorded for this compost programme.

This apparent benefit from surface compost applied just before the key crop growth phase in spring, indicated that there was useful availability of key nutrients to the growing crop from the surface applied material which produced high grain yield exceeding 11 t/ha. This observation of the effects of surface applied compost use on the winter wheat trial site would correlate with the consistent good agronomic performance from the surface applied compost on grassland sites in 2010 and 2011. Therefore, it indicates that it might be preferable to utilise compost by applying it on the surface after sowing, rather than by spreading before cultivation.

In contrast the digestate material performed poorly in this trial relative to all other nutrient programmes. This is in part attributed to the later dates used for product application but while these dates were relatively ‘late’ to the other applications, this delay should have shown only a low-moderate adverse effect (if-any) on nutrient treatment performance. The initial visual effect of the digestate application to the crop 7-10 days after application was excellent but the effect was not sustained with pale colouring being observed on the crop 2-3 weeks after each application timing indicating that there was significant nitrogen loss from the product during the storage period before application, or after application as there was hot dry weather. The digestate product performed at this site with an apparent nitrogen value which was <40% of the expected nitrogen value.

The compost plots had the highest yield, 1000 grain weight and grain nitrogen uptake of all the plots and had better protein content than slurry, and protein comparable to artificial fertiliser. The compost and digestate plot performed better than the digestate only plot, but not as well as the compost plot for yield, 1000 grain and nitrogen uptake in the grain, but not as well as the digestate only plot with regard to protein content. Interestingly though, although the digestate plot had a lower yield, 1000 grain weight and nitrogen uptake in the grain than all other plots where fertiliser was added, the grain protein content was higher than the slurry plot and compost and digestate plot, and close to the compost and artificial fertiliser plots. This would indicate that although there was a deficiency of available nitrogen at the time of growth in the crop there was nitrogen available to the plant while the grain was filling and ripening.

Only small quantities of natural fertiliser were applied relative to the mass of soil, so it would be unlikely that there would be any noticeable change in the soil qualities due to the addition of the fertiliser. The crop grown prior to the trial commencing was peas, which is an excellent and typical crop to grow prior to winter or spring wheat, however, as a result there may be effects in the soil, over the subsequent year.

Table 90: Soil pH levels throughout trial at Farm E (WW1)

plot		2010	2011		
no.	**name**	**composite**	**spring**	**Mid**	**end**
A1	artificial	7.5		6.9	7.2
B2	artificial			6.8	6.7
B1	slurry			6.9	6.5
C1	compost			6.8	7.2
A2	compost			6.2	7.2
X1	compost/digestate			6.7	6.9
D1	digestate			6.4	7.0
C2	digestate			7.1	7.3
E1	little		7.1	7.1	6.9

Table 91: Soil Morgan’s P levels throughout trial at Farm E (WW1)

plot		composite	spring	autumn
no.	**name**	mg/l	mg/l	mg/l
A1	artificial	7.9		12.6
B2	artificial			6.4
B1	slurry			5.8
C1	compost			8.8
A2	compost			7.3
X1	compost/digestate			5.2
D1	digestate			5.2

C2	digestate			5.9
e1	little		8.9	6.7

Table 92: Soil organic matter LOI levels throughout trial at Farm E (WW1)

		2010	2011		
plot		composite	spring	mid	end
no.	name	% w/w	% w/w	% w/w	% w/w
A1	artificial			4.7	5.0
B2	artificial			4.4	6.6
B1	slurry			4.7	4.8
C1	compost			5.0	5.2
A2	compost			4.0	4.5
X1	compost/digestate	5.8		4.3	4.7
D1	digestate			4.1	4.6
C2	digestate			4.3	4.4
E1	little		5.4	4.6	4.8

Table 93: Soil total N levels throughout trial at Farm E (WW1)

plot		composite	spring	mid	end
no.	name	%	% w/w	%w/w	% w/w
A1	artificial			0.20	0.16
B2	artificial			0.15	0.17
B1	slurry			0.16	0.16
C1	compost			0.19	0.20
A2	compost			0.17	0.17
X1	compost/digestate	0.36		0.18	0.16
D1	digestate			0.19	0.18
C2	digestate			0.15	0.15
E1	little		0.20	0.18	0.18

Table 94: Soil Nitrate N levels throughout trial at Farm E (WW1)

plot		composite	spring	mid	autumn
no.	name	mg/l	mg/kg	mg/kg	mg/kg
A1	artificial			3.9	14.1
B2	artificial			3.1	11.9
B1	slurry			3.0	22.9
C1	compost			3.6	20.1
A2	compost			4.2	12.5
X1	compost/digestate	16.6		2.8	12.7
D1	digestate			2.6	13.9
C2	digestate			2.6	17.0
E1	little		15.0	4.8	19.1

Table 95: Other mineral levels soil at Farm E (WW1) at end 2011

	artificial fertiliser	slurry	compost	digestate	compost/ digestate	nothing
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Calcium	2,251	1,705	2,179	2,185	2,062	1,946
Cadmium	0.84	0.82	0.91	0.79	0.74	0.78
Chromium	55.2	65.2	63.5	55.5	60.3	57.7
Copper	20.1	19.4	21.9	21.3	17.7	20.7
Mercury	0.04	0.03	0.05	0.04	0.09	0.04
Magnesium	1,155	1,034	1,233	1,354	1,188	1,195
Molybdenum	3.6	4.4	3.8	3.4	3.6	3.5
Nickel	38.2	43.9	41.4	38.5	35.8	36.6
Lead	19.3	18.2	19.9	18.9	16.4	18.4
Sulphur	464	713	476	315	323	375
Potassium	103	113	104	99	107	85

Table 96: Grain yield and quality data for the 2011 trial at Farm E (WW1) (t/ha at 15% m.c.)

	Grain Yield (t/ha)	Yield Response (t/ha)	Biomass Yield (t/ha)	1000 Grain Wt (grams)
Zero Nutrient	*6.70*	--	13.53	45.2
Artificial	10.55	+ 3.85	19.80	50.2
Slurry	*10.97*	+ 4.27	22.39	49.4
Compost	11.25	+ 4.55	24.36	51.8
Digestate	8.05	+ 1.35	16.74	46.3
Compost/Digestate	*10.73*	+ 4.03	19.87	46.8
LSD (5%)	0.70	--	--	10.4
CV (%)	1.64 %	--	--	4.9 %

Table 97: Comparison Farm E (WW1) of grain yield and 1000grain weight of compost, digestate and compost with digestate liquor plots over slurry and artificial fertiliser

	grain yield				**1000 grain**		
	digestate	compost	comp/digest		digestate	compost	comp/digest
slurry	73.4%	102.6%	97.8%		93.7%	104.9%	94.7%
artificial fertiliser	76.3%	106.6%	101.7%		92.2%	103.2%	93.2%
zero	120.1%	167.9%	160.1%		102.4%	114.6%	103.5%

Table 98: Grain protein (%), Grain, Straw and Crop N uptake data for the 2011 trial Farm E (WW1)

	Grain Protein (%)	Grain N Uptake (t/ha)	Straw N Uptake (kg/ha)	Crop N Uptake (kg/ha)
Zero Nutrient	9.91	98.0	47.6	145.5
Artificial	9.31	144.8	47.7	192.6
Slurry	9.83	159.4	48.7	208.2
Compost	9.65	160.2	71.5	231.7
Digestate	9.35	111.1	44.0	155.0
Compost/Digestate	8.63	136.8	36.7	173.5
LSD (5%)	2.03	60.4	36.7	
CV (%)	5 %	10.1 %	15.7	

Table 99: Comparison at Farm E (WW1) of grain protein and grain nitrogen uptake of compost, digestate and compost with digestate liquor plots over slurry and artificial fertiliser

	grain protein				grain nitrogen uptake		
	digestate	compost	comp/digest		digestate	compost	comp/digest
slurry	103.7%	105.6%	100.4%		69.7%	100.5%	85.8%
artificial fertiliser	97.4%	99.2%	94.3%		76.7%	110.6%	94.5%
zero	111.8%	113.9%	108.3%		113.4%	163.5%	139.6%

Table 100: Yield response and N uptake efficiency at Farm E (WW1)

	yield response	grain N efficiency	Crop N efficiency
Artificial	3.85	33.4%	33.6%
Slurry	4.27	43.9%	44.8%
Compost	4.55	44.4%	61.6%
Digestate	1.35	9.4%	6.8%
Compost/digestate	4.03	27.7%	20.0%

Table 101: Soil Organic Matter and bulk density data for the 2011 trial at Farm E (WW1)

	Bulk Density	Soil OM %
Artificial	1.80	5.11
Slurry	1.77	5.08
Compost	1.81	4.63
Digestate	1.94	5.12

Farm C (GC2) - Grass Clover 2010 and 2011

The trial site on Farm C is on a dairy farm with 100 milking cows. The field had been in permanent pasture for more than 5 years at the commencement of the trial. A mix of early and summer white clover varieties was "stitched" into all the fields on the farm in 2007, to reduce the need for artificial nitrogen. This clover is has well established. The land is heavy, it rarely dries out fully and it has a naturally high molybdenum and low potassium content. Twenty years ago it was boggy and frequently waterlogged but now has land drains, was regularly aerated before the trial commenced and performs well.

Three crops of silage were taken for the trial to allow an assessment of how much grass each plot produces over the year and the qualities of that grass. This was the best means of identifying how much grass was produced during the trial. However, grass/clover swards perform better if they are grazed rather than cut and clover generally performs better if the sward is kept short. Therefore, the total yield of the sward from the plots may have been less, during the trial, than could be expected from a similar sward being grazed.

Farm C (GC2) trial field

Nutrient Management at Farm C

The need for available nutrients by the silage crop, over each year, is taken to be 226kg of N, 30kg of phosphorus (soil phosphorus index 3) and 175kg of potassium in 2010 (as soil potassium levels were low) and 95kg in 2011. The nutrient application is split between first and second cuts where possible.

The fertiliser programme maximised the amount of natural fertilisers applied. The phosphorus content controlled the rate of application for compost and slurry. The available nitrogen content determined the rate applied for digestate. An allowance was made for the nitrogen considered to be provided by the clover over the year. As the nitrogen in digestate and artificial fertiliser is more available, this was expected to reduce the amount of nitrogen produced by the clover. However, the results of the trial show that in fact the high availability of the nitrogen in the digestate appeared to not adversely affect the performance of the clover.

Table 102: Fertiliser applications 2010 at Farm C (GC2)

	Natural fertiliser	N			P		K	
	spread	clover	natural	artificial	artificial	artificial	artificial	artificial
	t/ha	1st cut						
Artificial		30	0	95	0	20	0	175
Slurry	22.9	37	5	38	2	0	15	88
Compost	12.5	37	25	85	46	0	69	123
Digestate	47.9	30	140	0	7	7	75	123
2nd cut								
Artificial		60	0	41	0	10	0	71
Slurry	35.5	73	43	31	14	14	129	14
Compost	0	73	0	31	0	0	0	52
Digestate	0	60	0	0	0	16	0	47
Annual Total								
Artificial		90	0	136	0	30	0	246
Slurry	58.4	110	48	69	16	14	144	102
Compost	12.5	110	25	116	46	0	69	175
Digestate	47.9	90	140	0	7	23	75	170

Table 103: Fertiliser applications summary in 2011 at Farm C (GC2)

	Clover	Natural fertiliser kg				Top up artificial kg		
	allowance	**t/ha**	**Av N**	**P**	**K**	**Av N**	**P**	**K**
Artificial	90	n/a	0	0	0	136	30	145
Slurry	110	37.5	34	10	62	82	21	8
Compost	110	9.2	18	30	48	98	0	98
Digestate	90	39.5	136	7	61	0	23	84

Table 104: 2011 fertiliser application details at Farm C (GC2) (Kg/ha)

Per ha basis	Artificial fertiliser			Slurry			Compost			Digestate		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Crop requirement	226	30	145	226	30	145	226	30	145	226	30	145
Natural fertiliser total	0	0	0	34	10	62	18	30	48	136	7	61
Artificial fertiliser	226	30	145	82	21	83	98	0	98	0	23	84
1st cut applications	55%			25t/ha			9.2t/ha			27.6t/ha		
Natural fertiliser	0	0	0	23	7	48	18	30	48	95	5	44
clover	30	0	0	37	0	0	37	0	0	30	0	0
Artificial fertiliser	95	20	95	65	13	48	71	0	48	0	15	51
2nd cut applications	45%			12.5t/ha						11.9t/ha		
Natural fertiliser	0	0	0	11	3	14	0	0	0	41	2	17
clover	60	0	0	73	0	0	73	0	0	60	0	0
Artificial fertiliser	41	10	50	17	7	36	28	0	50	0	8	33

Summary of results at Farm C (GC2) in 2010

- Adding natural fertilisers increased the levels of major nutrients and trace elements in the soil but did not significantly change the pH or organic matter levels in year 1 of the trial.
- Each of the trial applications gave good levels of grass output in 2010
- Over the growing season all the plots received equivalent levels of nutrients. However, applications before 1st cut had to be made before the analysis results were known and the whole digestate and the compost were applied all in one application. Therefore the amount of nutrients applied to the different treatment plots was unequal for 1st and 2nd cuts.
- The slower nitrogen release profile of the compost material and of slurry appears to be a positive characteristic in grass with clover, because it contributes to the consistent delivery of high output across the three harvest dates. The highest total dry yield was from the compost plots.
- The highest total nitrogen off-take was in the digestate plots.
-

Table 105: Mean dry matter and fresh weights of the silage cuts in 2010 at Farm C (GC2)

	artificial fertiliser	slurry	compost	digestate
First Cut				
Cut fresh wt (kg)	1,160	805	1,144	1,274
Cut dry weight	308	220	308	265
Second Cut				
Cut fresh wt (kg)	253	234	313	315
Cut dry weight	61	71	75	89
Third Cut				
Cut fresh wt (kg)	266	246	240	292
Cut dry weight	72	67	65	79
Total harvest				
Cut fresh wt (kg)	1,679	1,285	1,697	1,881
Cut dry weight	442	357	448	432

Summary of results at Farm C (GC2) for 2011

It is very clear from the results that grass/clover sward responded better to all three natural fertilisers than to the artificial fertiliser. All three natural fertiliser plots performed well in 2011. In the compost plot a significant amount of artificial fertiliser was added to make the amount of available N applied comparable across the plots. The results indicate that this addition of artificial N fertiliser may have inhibited the clover performance in the compost plots, and thereby reduced the crop output. It was expected that the high level of available N in the digestate would inhibit the clover performance, but this seems to not be the case. When a clover count was made in the spring both the compost and digestate plots had more clover compared to artificial fertiliser plot but significantly less than in the slurry plots. However, it is not clear whether this affected later output.

In 2011 the dry matter yield for the year for both the digestate and the compost plots was higher (24% and 3% respectively) than the artificial fertiliser plot and the digestate was higher (15%) than the output from the slurry plot.

The total N uptake by the crop was significantly higher in the digestate plots compared to both the artificial fertiliser and slurry plots, probably mostly due to the higher amount of DM yield. However, protein levels in the grass did not follow the same pattern as N uptake. The protein level in the grass from the digestate plots was highest for the first two cuts but fell away by quite a margin by the third cut. Whereas the protein levels in the artificial fertiliser plot continued to rise and were the highest in third cut.

The grass at each cut was analysed for mineral content. The highest offtake of all major minerals and many of the minor minerals is in the digestate plots. The mineral offtake in most minerals is higher in the compost plots than the artificial fertiliser plots

The artificial fertiliser plots have the highest offtake of all the heavy metals, despite being the lowest DM yielding plot. The reason for why these effects are occurring is not clear from these trials and requires further research. Other research projects[38] currently underway indicate that there may be an increase in the root development and the level of bacterial activity as a result of applying digestate, which could facilitate the release of soil-bound minerals. The amount of the minor minerals applied in the digestate is significantly lower than the offtake.

Table 106: Soil pH levels throughout trial at Farm C (GC2)

plot		2010			2011		
no.	**name**	**composite**	**Mid**	**autumn**	**spring**	**Mid**	**end**
A1	artificial	6.1	6.4	6.3	6.4	6.3	6.2
B2	artificial		6.2	6.2	6.1	6.7	6.1
B1	slurry		6.2	6.4	6.0	6.2	6.1
D2	slurry		5.9	6.3	5.8	6.4	6.0
C1	compost		6.0	6.4	6.2	6.3	6.3
A2	compost		6.0	6.4	6.1	6.8	6.6
D1	digestate		6.3	6.1	6.1	6.2	6.4
C2	digestate		6.3	5.9	6.5	6.7	6.4
e1	nothing				6.0	5.9	6.1

Table 107: Soil Morgan's P levels throughout trial at Farm C (GC2)

plot		composite	autumn	spring	autumn
no.	**name**	mg/l	mg/l	mg/l	mg/l
A1	artificial	5.5	5.8	6.9	3.5
B2	artificial		5.4	4.3	4.4
B1	slurry		3.5	5.7	3.3
D2	slurry		4.3	4.8	3.2
C1	compost		6.2	5.9	4.9
A2	compost		5.5	8.9	6.5
D1	digestate		6.3	5.3	5.6
C2	digestate		7.5	4.4	5.7
E1	nothing			10.4	3.0

[38] In Bangor University, Wales and UCC, Ireland

Table 108: Soil organic matter LOI levels throughout trial at Farm C (GC2)

		2010			2011		
plot		**composite**	**mid**	**autumn**	**spring**	**mid**	**end**
no.	**name**	**%**	**%**	%	% w/w	% w/w	% w/w
A1	artificial	6.4	7.42	6.2	7.1	6.4	6.6
B2	artificial		7.97	7.1	6.9	7.4	6.8
B1	slurry		7.36	6.9	7.1	6.6	6.5
D2	slurry		8.79	6.9	6.8	7.8	7.1
C1	compost		8.74	6.1	6.3	7	6.7
A2	compost		7.76	6.7	7.9	7.6	7.4
D1	digestate		8.73	6.5	10.2	7.2	7.4
C2	digestate		7.15	7.7	7.4	7.6	6.9
E1	nothing				6.7	7.4	45.9

Table 109: Soil total N levels throughout trial at Farm C (GC2)

plot		**composite**	**autumn**	**spring**	**mid**	**end**
no.	**name**	%	%	% w/w	%w/w	% w/w
A1	artificial	0.33	0.33	0.24	0.19	0.28
B2	artificial		0.37	0.17	0.20	0.30
B1	slurry		0.37	0.21	0.19	0.30
D2	slurry		0.47	0.23	0.22	0.31
C1	compost		0.50	0.20	0.22	0.38
A2	compost		0.28	0.18	0.23	0.29
D1	digestate		0.40	0.20	0.22	0.40
C2	digestate		0.37	0.18	0.22	0.36
e1	nothing			0.16	0.21	0.32

Table 110: Soil Nitrate N levels throughout trial at Farm C (GC2)

plot		**composite**	**mid**	**autumn**	**spring**	**mid**	**autumn**
no.	**name**	mg/l	mg/l	mg/l	mg/kg	mg/kg	mg/kg
A1	artificial	16.0	12.0	6.8	2.0	7.9	12.9
B2	artificial		1.0	13.0	1.5	9.9	19.2
B1	slurry		11.0	7.6	2.4	7.0	16.9
D2	slurry		1.0	13.3	<0.05	7.9	23.4
C1	compost		5.0	7.9	1.1	8.5	19.6
A2	compost		13.0	12.6	1.2	6.8	19.6
D1	digestate		20.0	10.1	<0.05	23.7	22.5
C2	digestate		20.0	15.5	1.3	6.7	19.8
e1	nothing				1.8	3.9	12.9

Table 111: Other mineral levels soil throughout trial at Farm C (GC2)

	start 2010	end 2011				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	composite	**artificial**	**slurry**	**compost**	**digestate**	**nothing**
Calcium	2,614	2,493	2,240	2,466	2,435	2,119
Cadmium	0.40	0.44	0.40	0.42	0.43	0.47
Chromium	20.3	31.4	28.5	30.8	30.5	28.0
Copper	15.4	14.8	13.7	16.5	15.8	24.6
Zinc	78.3	79.6	71.05	78.05	80.8	85.4
Mercury	0.10	0.09	0.09	0.10	0.09	0.09
Magnesium	980	953	950	998	1,023	1,014
Molybdenum	1.4	1.2	1.0	1.2	1.1	1.0
Nickel	18.7	17.4	16.0	18.7	18.5	19.1
Lead	113	104	100	106	102	112
Sulphur	490	393	371	427	350	429
Potassium	34.8	4.0	3.3	5.7	5.7	3.0

Table 112: Grass yield in 2010 at Farm C (GC2) (kg)

	Artificial			Slurry			Compost			Digestate	
	A1	**B2**		**B1**	**D2**		**C1**	**A2**		**D1**	**C2**
First Cut											
Cut fresh weight	1083	1237		687	923		1029	1258		1282	1266
Cut dry weight	271	345		196	244		272	343		222	307
Second Cut											
Cut fresh weight	303	202		162	306		292	334		339	290
Cut dry weight	78	44		56	85		69	80		110	67
Third Cut											
Cut fresh weight	264	268		264	228		220	260		304	280
Cut dry weight	71	72		71	62		59	70		82	76
Total harvest											
Cut fresh weight	1650	1707		1113	1457		1541	1852		1925	1836
Cut dry weight	421	462		323	391		401	494		414	450

Table 113: Nitrogen offtake in 2010 at Farm C (GC2)
(T/ha; mean values ± S.E., n = 2)

Treatment:	**Artificial**		**Slurry**		**Compost**		**Digestate**
1st Cut	117.8±0.8		60.4±7.8		98.9±13.3		107.6±7.0
2nd Cut	35.6±10.4		42.7±10.5		37.7±7.6		58.2±20.0
3rd Cut*	41.3±2.5		43.0±1.7		41.7±7.6		50.9±2.7
Total	194.7±12.1		146.1±16.6		178.3±28.6		216.8±15.7

* The analytical lab did not provide DM results for 3^{rd} cut so DM is assumed as 27% for all treatments

Table 114: Grass Nitrogen Uptake (kg/ha) and total Nitrogen Uptake for 2011 at Farm C (GC2)

	1st Cut	2nd Cut	3rd Cut	total
Artificial	135	49.6	112	297
Slurry	115	68.9	108	292
Compost	129	53.7	107	290
Digestate	174	82.2	99	356

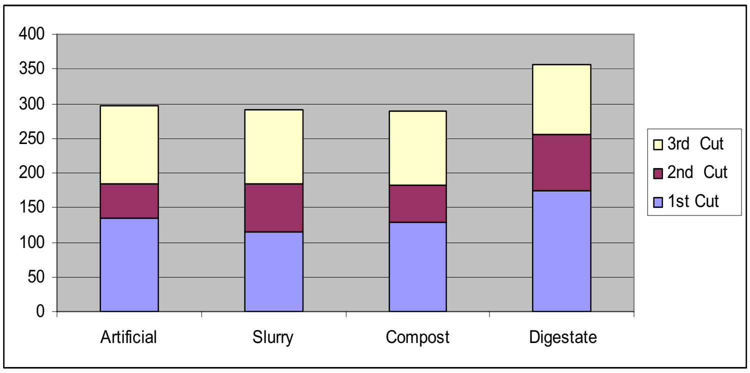
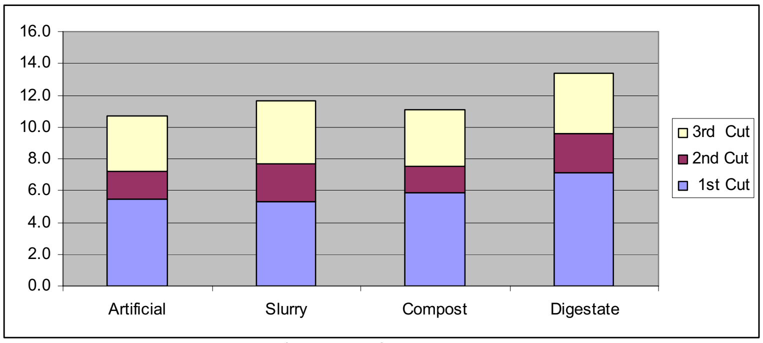


Table 115: Grass DM Yield for 2011 Farm C (GC2)

	1st Cut	2nd Cut	3rd Cut	total
Artificial	5.5	1.8	3.5	10.7
Slurry	5.3	2.4	3.9	11.6
Compost	5.9	1.7	3.6	11.1
Digestate	7.1	2.5	3.8	13.4



1st cut is based on the DM% of the silage analysis, whereas 2nd and 3rd cut DM is that of the fresh grass samples. The weight of all cuts is the weight of the silage bale before wrapping.

Table 116: Grass Crude Protein % on each harvest date, 3/6/11, 4/8/11 and 25/9/11 at Farm C (GC2)

	Grass Protein % 1st Cut	Grass Protein % 2nd Cut	Grass Protein % 3rd Cut	Crop Clover % Cover 25/3
Zero Nutrient				
Artificial	14.8	17.5	19.9	43.3
Slurry	13.5	18.1	17.1	62.3
Compost	13.7	19.9	18.8	53.1
Digestate	15.3	20.9	16.4	48.0
LSD (5%)	10.85	--	2.6	26.5
CV (%)	23.8 %	--	4.5 %	16.1

Table 117: Comparison at Farm C (GC2) of the performance of digestate and compost plots over, slurry, artificial fertiliser and no application plots in 2011

	N uptake in 2011			clover cover			DM yield	
	digestate	compost		digestate	compost		digestate	compost
slurry	121.8%	99.3%		77.0%	85.2%		115.0%	95.5%

artificial fertiliser	120.0%	97.8%		110.9%	122.6%		124.4%	103.4%

Table 118: Dry matter content of fresh cut grass in 2011

	Artificial fertiliser			slurry			compost			digestate			nothing
	A1	B2	mean	B1	D2	mean	C1	A2	mean	D1	C2	mean	E1
dm % 1st	13.0	13.6	13.3	12.7	14.2	13.4	12.5	12.8	12.6	12.7	11.4	12.0	**15.4**
dm % 2nd	14.5	16.2	15.4	14.1	16.2	15.2	13.1	13.6	13.4	14.6	11.4	13.0	**18.7**
dm % 3rd	11.4	10.9	11.2	11.3	12.1	11.7	11.8	11.9	11.9	10.7	11.3	11.0	**12.1**

Table 119: Fresh yield in 2011(t/ha)

	artificial fertiliser	slurry	compost	digestate	nothing
1st	17.8	17.6	18.5	18.9	15.1
2nd	6.7	8.8	7.3	10.0	8.4
3rd	15.5	18.9	17.7	19.0	18.1
total	40.0	45.3	43.5	47.9	41.7

Table 120: Grass Mineral content (mg/kg DM) first cut 2011

1st cut	**artificial fertiliser**			**slurry**			**compost**			**digestate**			**nothing**
mg/kg DM	A1	B2	mean	B1	D2	mean	C1	A2	mean	D1	C2	mean	E1
Nitrogen	16,700	30,700	23,700	20,700	22,400	21,550	22,900	20,900	21,900	25,800	23,200	**24,500**	20,800
Phosphorus	1,914	3,312	2,613	2,559	2,505	2,532	2,593	2,732	2,663	2,952	3,435	**3,194**	2,783
Potassium	14,918	21,395	18,157	22,232	22,356	22,294	20,937	20,422	20,680	20,695	24,487	**22,591**	17,911
Magnesium	1,195	1,995	1,595	1,514	1,413	1,464	1,518	1,776	1,647	1,771	1,740	1,756	**2,066**
Calcium	4,354	7,648	6,001	5,816	4,408	5,112	6,089	7,512	6,801	6,971	8,492	7,732	**11,712**
Manganese	60.9	75.4	68.2	40.5	49.3	44.9	33.1	70.7	51.9	53.7	40.9	47.3	**94.7**
Copper	5.0	8.6	6.8	6.1	6.4	6.3	6.0	6.3	6.2	7.5	7.5	**7.5**	6.3
Sodium	3,918	6,155	5,037	4,019	3,464	3,742	4,654	9,272	6,963	7,659	7,839	**7,749**	6,538
Iron	210	126	**168**	107	58	83	114	189	152	94	95	94	99
Zinc	19.6	31.2	25.4	22.5	22.7	22.6	25.1	24.9	25.0	26.1	28.4	**27.3**	20.7
Molybdenum	1.0	1.3	1.2	1.4	1.2	1.3	1.6	1.6	**1.6**	1.4	1.5	1.4	1.1
Sulphur	1,262	2,443	1,853	1,786	1,721	1,754	1,467	1,869	1,668	2,109	1,729	1,919	**2,115**
Selenium	0.04	0.04	0.04	0.04	0.03	0.04	0.05	0.04	0.05	0.03	0.03	0.03	**0.06**
Iodine	0.18	0.06	**0.12**	0.02	<0.01	0.01	<0.01	0.22	0.11	<0.01	<0.01	<0.01	0.01
Cobalt	0.03	0.06	**0.05**	0.03	0.02	0.03	0.04	0.05	**0.05**	0.03	0.04	0.04	**0.05**
Lead	0.19	0.30	0.25	0.20	0.10	0.15	0.20	0.50	**0.35**	0.15	0.19	0.17	0.29
Boron	4.00	5.30	4.65	5.40	3.50	4.45	4.40	6.60	5.50	5.00	6.00	5.50	**9.80**
Nickel	0.60	1.60	1.10	0.60	0.60	0.60	0.50	0.80	0.65	0.60	0.80	0.70	1.30
Cadmium	0.02	0.03	**0.03**	0.01	0.02	0.02	0.02	0.03	**0.03**	0.01	0.02	0.02	0.02
Mercury	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.10	0.10	0.10	0.10	<0.1	<0.1	0.10	0.20	**0.15**	<0.1	0.20	0.10	0.10
dm %	13.0	13.6		12.7	14.2		12.5	12.8		12.7	11.4		15.4

Table 121: Grass Mineral content (mg/kg DM) second cut 2011

2nd cut	artificial fertiliser			slurry			compost			digestate			nothing
mg/kg	A1	B2	mean	B1	D2	mean	C1	A2	mean	D1	C2	mean	
Nitrogen	29,200	26,800	28,000	30,100	27,800	28,950	32,000	31,600	31,800	33,800	33,000	**33,400**	25,200
Phosphorus	3,799	3,510	3,655	3,610	3,541	3,576	3,378	3,782	3,580	4,214	3,645	**3,930**	3,294
Potassium	25,593	22,773	24,183	38,964	25,615	**32,290**	24,981	30,198	27,590	28,159	35,032	31,596	20,130
Magnesium	2,214	2,426	2,320	2,119	2,056	2,088	2,609	2,268	**2,439**	2,135	2,115	2,125	2,084
Calcium	8,892	9,453	9,173	10,099	7,279	8,689	11,040	8,441	9,741	10,031	9,560	**9,796**	8,214
Manganese	64.0	100.0	82.0	53.0	44.0	48.5	36.0	60.0	48.0	54.0	49.0	51.5	**99.0**
Copper	10.0	8.7	**9.4**	8.5	8.1	8.3	9.5	9.3	**9.4**	9.0	9.7	**9.4**	7.2
Sodium	6,208	5,947	6,078	3,269	6,307	4,788	8,583	8,049	**8,316**	7,590	7,267	7,429	5,652
Iron	991.00	169.00	**580.00**	259.00	132.00	195.50	161.00	272.00	216.50	141.00	148.00	144.50	99.30
Zinc	30.5	23.9	27.2	23.0	23.0	23.0	25.9	35.1	**30.5**	25.4	26.6	26.0	21.2
Molybdenum	1.2	1.2	1.2	2.1	2.3	**2.2**	1.9	2.1	2.0	1.9	1.0	1.5	1.5
Sulphur	2,356	2,506	**2,431**	2,062	2,144	2,103	2,290	2,534	2,412	2,464	2,158	2,311	2,377
Selenium	0.05	0.03	0.04	0.03	0.02	0.03	0.04	0.03	0.04	0.02	0.02	0.02	**0.05**
Iodine	0.75	0.55	**0.65**	0.81	0.45	0.63	0.63	0.59	0.61	0.54	0.50	0.52	0.28
Cobalt	0.19	0.07	**0.13**	0.10	0.04	0.07	0.05	0.07	0.06	0.07	0.06	0.07	0.04
Lead	1.20	0.31	**0.76**	0.52	0.23	0.38	0.25	0.46	0.36	0.37	0.21	0.29	0.27
Boron	6.8	7.3	7.05	9.8	4.9	7.35	7.7	7.1	7.40	7.9	7.2	**7.55**	5.2
Nickel	1.5	1.8	**1.65**	1	1.1	1.05	0.8	1.1	0.95	1	1.3	1.15	1.5
Cadmium	0.08	0.04	0.06	0.04	0.03	0.04	0.03	0.04	0.04	0.03	0.08	0.06	**0.14**
Mercury	0.06	0.02	**0.04**	0.02	0.01	0.02	0.02	0.05	**0.04**	0.01	0.01	0.01	0.01
Chromium	0.7	<0.1	**0.35**	0.2	<0.1	0.10	<0.1	0.2	0.10	<0.1	<0.1	<0.1	<0.1
dm %	14.5	16.2	15.35	14.1	16.2	15.15	13.1	13.6	13.35	14.6	11.4	13.00	**18.7**

Table 122: Grass Mineral content (mg/kg DM) third cut 2011

3rd cut	artificial fertiliser			slurry			compost			digestate			nothing
mg/kg DM	A1	B2	mean	B1	D2	mean	C1	A2	mean	D1	C2	mean	E1
Nitrogen	31,500	35,200	33,350	33,600	30,400	32,000	33,600	34,700	34,150	35,900	34,400	**35,150**	31,400
Phosphorus	4,187	5,493	4,840	4,995	4,073	4,534	4,687	5,178	4,933	5,329	5,646	**5,488**	4,652
Potassium	18,300	26,363	22,332	33,812	18,604	26,208	24,497	23,336	23,917	30,960	28,711	**29,836**	24,278
Magnesium	2,758	3,113	2,936	2,832	2,770	2,801	2,862	2,987	2,925	2,932	2,915	2,924	**3,044**
Calcium	9,153	8,673	**8,913**	8,161	6,986	7,574	8,103	8,829	8,466	8,441	7,678	8,060	8,358
Manganese	129.0	189.0	**159.0**	69.1	82.8	76.0	64.9	72.4	68.7	75.6	76.3	76.0	**159.0**
Copper	22.9	14.1	**18.5**	13.8	13.1	13.5	13.1	16.9	15.0	15.6	14.1	14.9	12.8
Sodium	6,604	7,234	6,919	5,911	8,521	7,216	9,401	11,819	**10,610**	9,466	9,699	9,583	7,184
Iron	2,877	672	**1,775**	699	262	481	708	1,346	1,027	616	732	674	301
Zinc	53.3	55.8	**54.6**	41.8	39.2	40.5	44.4	54.9	49.7	49.9	45.2	47.6	41.0
Molybdenum	2.0	1.8	1.9	2.8	1.4	2.1	2.3	2.6	**2.4**	2.1	2.2	2.1	1.6
Sulphur	3,395	4,107	3,751	3,363	3,576	3,470	3,133	3,552	3,343	3,786	3,263	3,525	**3,973**
Selenium	0.15	0.05	**0.10**	0.06	0.04	0.05	0.07	0.09	0.08	0.05	0.07	0.06	0.04
Iodine	0.80	0.61	**0.71**	0.69	0.52	0.61	0.61	0.75	0.68	0.62	0.63	0.63	0.53
Cobalt	0.53	0.19	**0.36**	0.18	0.09	0.14	0.21	0.30	0.26	0.16	0.18	0.17	0.11
Lead	6.09	2.16	**4.13**	1.80	1.00	1.40	2.31	3.52	2.92	1.48	1.57	1.53	1.11
Boron	5.10	4.90	5.00	5.20	4.30	4.75	5.70	7.50	**6.60**	6.20	5.70	5.95	4.70
Nickel	2.30	3.00	**2.65**	1.20	1.30	1.25	1.30	1.60	1.45	1.60	1.80	1.70	1.80
Cadmium	0.67	0.11	**0.39**	0.13	0.07	0.10	0.11	0.28	0.20	0.10	0.14	0.12	0.06
Mercury	0.05	0.02	**0.04**	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02
Chromium	2.60	0.70	**1.65**	0.60	0.20	0.40	0.70	1.10	0.90	0.50	0.60	0.55	0.20

dm %	11.4	10.9	11.2	11.3	12.1	11.7	11.8	11.9	11.9	10.7	11.3	11.0	**12.1**

Table 123: Grass mineral total offtake in Mg/kg DM for 2011 at Farm C (GC2)
(Using fresh grass DM% to calculate DM harvest weight)

Total 2011	**artificial fertiliser**	**slurry**	**compost**	**digestate**	**nothing**
mg	mean	mean	mean	mean	E1
Nitrogen	5,707,159	6,401,128	6,140,631	**6,847,841**	4,707,464
Phosphorus	732,826	827,678	801,813	**946,009**	663,226
Potassium	4,255,750	6,071,826	5,011,629	**6,153,087**	3,783,108
Magnesium	449,925	496,675	493,742	**511,188**	448,081
Calcium	1,563,657	1,602,318	1,722,961	**1,864,885**	1,715,381
Manganese	20,845	13,599	12,536	13,249	**22,201**
Sodium	1,205,548	1,259,751	1,868,703	**1,879,114**	1,192,540
Molybdenum	291	425	**429**	377	254
Sulphur	535,661	**585,281**	530,482	583,765	534,793
Selenium	**12.3**	8.9	12.2	8.8	8.8
Iodine	86.3	86.7	**91.3**	78.6	51.9
Cobalt	**34.3**	17.6	28.0	20.7	13.4
Boron	1,076	1,218	1,357	**1,373**	1,198
Copper	2,306	2,221	2,198	**2,393**	1,674
Zinc	7,291	6,936	7,692	**7,751**	5,336
Iron	**160,928**	58,903	108,995	72,664	33,778
Lead	**337.7**	154.5	291.6	157.5	116.5
Nickel	**356.5**	223.8	219.9	265.2	278.9
Cadmium	**31.6**	11.9	20.1	14.5	10.6
Mercury	**4.0**	2.5	3.5	2.2	1.9
Chromium	**136.8**	43.4	93.7	55.2	22.6
Total kg DM	**204**	**236**	**216**	**225**	**179**

Table 124: Comparison of total N, P & K mineral offtake with total amount of fresh grass harvested in 2011 from digestate and compost plots over slurry, artificial fertiliser and no application

	N offtake		**P offtake**		**K offtake**	
	digestate	compost	digestate	compost	digestate	compost
slurry	107.0%	95.9%	114.3%	96.9%	101.3%	82.5%
artificial fertiliser	120.0%	107.6%	129.1%	109.4%	144.6%	117.8%
nothing	145.5%	130.4%	142.6%	120.9%	162.6%	132.5%

Table 125: Comparison of total Ca & Mg mineral offtake with total amount of fresh grass harvested in 2011 from digestate and compost plots over slurry, artificial fertiliser and no application

	calcium offtake		**magnesium offtake**	
	digestate	compost	digestate	compost
slurry	116.4%	107.5%	102.9%	99.4%
artificial fertiliser	119.3%	110.2%	113.6%	109.7%
nothing	108.7%	100.4%	114.1%	110.2%

Table 126: Percentage of N, P & K harvested of available nutrient applied at Farm C

	kg applied	artificial fertiliser	slurry	compost	digestate
N	9.04	63.1%	70.8%	67.9%	75.8%
P	1.2	61.1%	69.0%	66.8%	78.8%
K	5.8	73.4%	104.7%	86.4%	106.1%

Table 127: Percentage of other minerals harvested of available nutrient applied Farm C

	Mag	Sul	Cu	Zn	Moly	Sel	Ca
compost mg/kg DM	4440	3700	188	311	1.89	0.45	42969
mg applied	1,014,664	845,554	42,963	71,072	432	103	9,819,620
harvest/applied	48.7%	62.7%	5.1%	10.8%	99.2%	11.9%	17.5%
digestate mg/kg fresh	77.1	125.0	2.1	21.2	0.131	0.028	636
mg applied	121,818	197,500	3,318	33,496	207	44	1,004,880
harvest/applied	419.6%	295.6%	72.1%	23.1%	181.9%	19.9%	185.6%

Table 128: Silage quality first cut 2011

Plot		Dry Matter	Crude Protein	Sugar	Intake Potential	ME	pH	Ammonia
name	no.	%	%	g/kg	g/kgW 0.75	Mj/kg		% of total N
artificial fertiliser	A1	28.5	140.6	52.9	99.1	10.5	4.1	7.3
artificial fertiliser	B2	25.5	153.4	44.2	98.1	10.6	4.4	7.3
mean		27.0	147.0	48.6	98.6	10.5	4.2	7.3
slurry	B1	35.1	135.8	104.0	104.5	11.6	4.5	13.3
slurry	D2	44.9	118.8	115.3	118.4	11.4	4.6	9.2
mean		**40.0**	127.3	**109.7**	**111.4**	**11.5**	**4.5**	11.3
compost	C1	30.8	133.4	36.5	108.5	10.7	4.2	2.5
compost	A2	23.3	150.7	29.5	99.3	10.1	4.4	6.5
mean		27.1	142.1	33.0	103.9	10.4	4.3	4.5
digestate	D1	29.5	161.1	71.1	101.9	11.2	4.0	9.7
digestate	C2	27.2	171.5	56.6	108.3	11.4	4.1	13.4
mean		28.3	**166.3**	63.8	105.1	11.3	4.1	**11.6**
nothing	E2	32.0	144.8	75.8	107.9	11.0	4.1	9.3

Table 129: Comparison in first cut silage (2011) of digestate and compost qualities over slurry, artificial fertilizer and no application

	ME		intake potential		crude protein	
	digestate	compost	digestate	compost	digestate	compost
slurry	98.1%	90.5%	94.3%	93.2%	130.7%	111.6%
artificial fertiliser	107.1%	98.8%	106.6%	105.4%	113.1%	96.6%
nothing	102.8%	94.8%	97.4%	96.3%	114.8%	98.1%

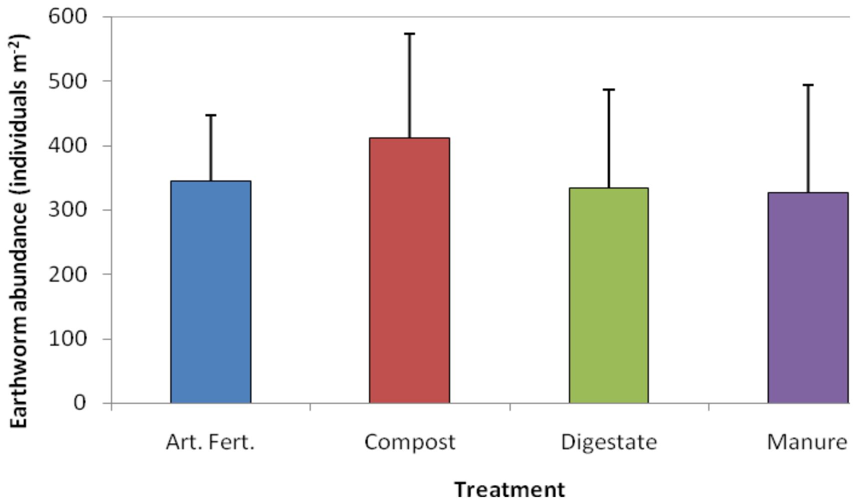
APPENDIX 9: EARTHWORM SAMPLING

Overall Results

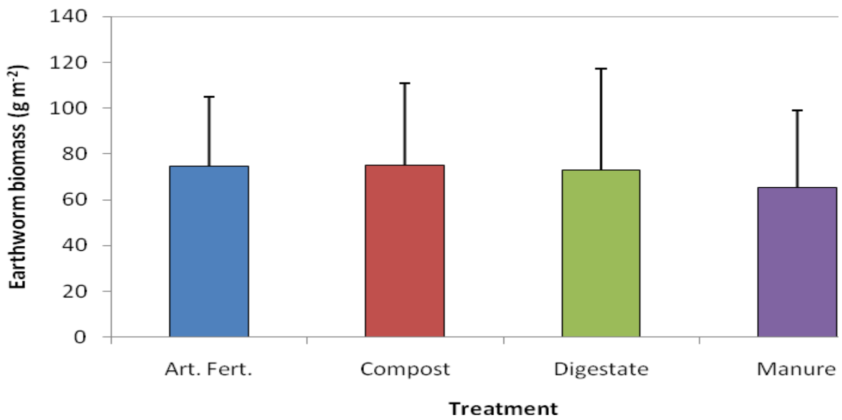
Tillage sites
There was no apparent trend in earthworm populations across the farms (Figures 1.1, 1.2 & 1.4).

Overall mean (± SD) earthworm abundance and biomass for the tillage sites combined was highest for the Compost treatment, 410 ± 162 individuals m^{-2} and 74.9 ± 35.9 g m^{-2}, respectively (Figure 2.). Mean earthworm abundance for the Artificial Fertiliser, Digestate and Manure treatments were largely comparable. Similarly, the earthworm biomass data for all four treatments were comparable.

a).



b).



Overall means of (a) abundance and (b) biomass of earthworm communities for four treatments at three tillage sites,
Sites 1, 2 & 4, autumn 2011 (coloured bars) (means + SD, n = 6). (Art. Fert. = Artificial Fertiliser).

During field sampling at Farm A (SB2), Mullingar, County West Meath, there was a high occurrence of dead worms in three treatment blocks, namely Manure (1 Block) and Digestate (2 Blocks). This may have been due to anaerobic/water-logging conditions of the individual treatment plots due to high rainfall, prior to earthworm sampling.

There was no apparent trend in earthworm species between treatments for the tillage sites. Three endogeic species were dominant in all treatments at all three sites, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.

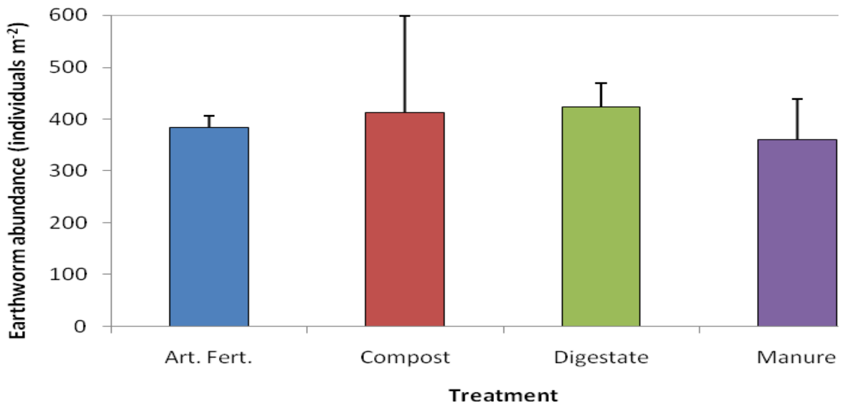
Grass/Clover site
Earthworm populations were highest at the Grass/Clover site when compared to the tillage sites.

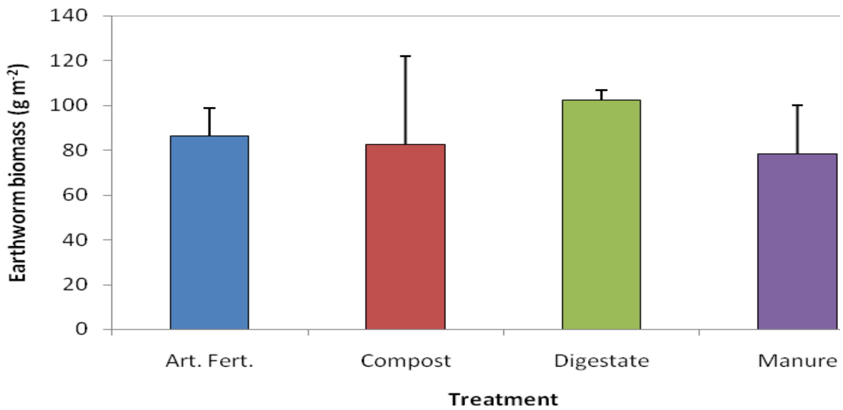
Overall mean (± SD) earthworm abundance and biomass was highest for the Manure treatment, 728 ± 271.5 individuals m^{-2} and 202 ± 17.5 g m^{-2}, respectively (Figure 1.3.). There was no apparent trend in earthworm species between treatments for the Grass/Clover site. Three endogeic species were dominant in all treatments for the Grass/Clover site, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.

Conclusion

- The earthworm data for treatments was sporadic and there was no overall apparent trend in the data (see Figures 1.1. – 1.4.). Earthworm abundance was higher in the Compost treatment for all three tillage sites combined. Whereas, earthworm biomass was similar across all four treatments for the three tillage sites combined.
- The Grass/Clover site showed that the Manure treatment supported highest earthworm population densities. However, it must be noted that the Grass/Clover data represents only one field site.
- Annual earthworm sampling did not occur and therefore the data do not represent the minimum or maximum earthworm population size attainable or show any conclusive pattern in the data.

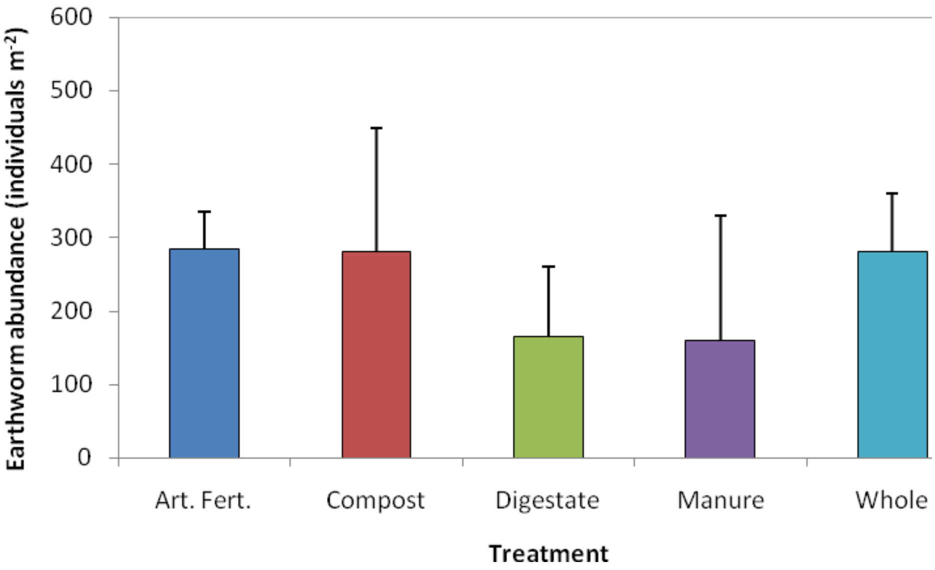
Farm A (SB2) – *Spring Barley – Mullingar, County Westmeath.*
Overall mean (± SD) earthworm abundance and biomass was highest for the digestate plot, 424 ± 45 m^{-2} individuals and 102.4 ± 4.5 g m^{-2}, respectively. Adults of seven species were found in the samples namely *A. chlorotica*, *A. caliginosa*, *A. rosea*, *A. longa*, *L. castaneus*, *L. festivus*, *L. rubellus* and *S. mammalis*. Three endogeic species were dominant in all treatments, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.

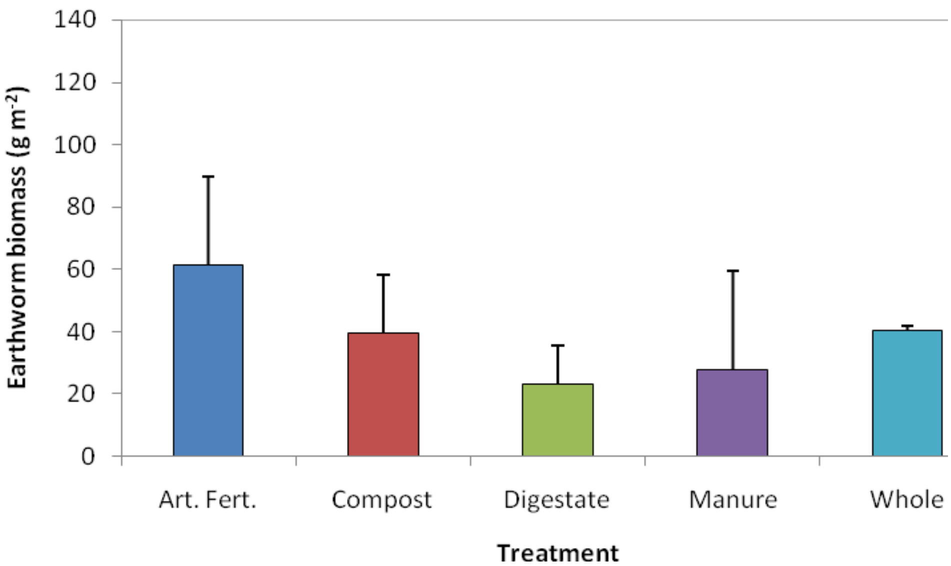




***Overall means of (a) abundance and (b) biomass of earthworm communities in four treatments** (Coloured bars) for one sampling date (November 2nd, 2011) (means + SD, n = 2) at Site A, Mullingar, County West Meath. (Art. Fert. = Artificial Fertiliser).*

Farm B (SW1) – Spring Wheat – Mullingar, County West Meath.
Overall mean (± SD) earthworm abundance and biomass was highest for the Artificial Fertiliser treatment, 284 ± 51 individuals m^{-2} and 61.6 ± 28.3 g m^{-2}, respectively. Adults of seven species were recorded during sampling, namely *A. chlorotica*, *A. caliginosa*, *A. rosea*, *L. castaneus*, *L. terrestris*, *O. cyaneum* and *S. mammalis*. Three endogeic species were dominant in all treatments, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.





Overall means of (a) abundance and (b) biomass of earthworm communities in five treatments *(Coloured bars) for one sampling date (November 2nd, 2011) (means + SD, n = 2) at Site B, Mullingar, County West Meath. (Art. Fert. = Artificial Fertiliser).*

Farm D (SB2) – Spring Barley – Horse & Jockey, County Tipperary.

2010

Worm casts

There was no significant difference ($p = 0.814$) between cast numbers or cast weight on treatment replicate plots. The greatest number of casts was collected from the slurry plots. The smallest number of casts were collected from the artificial and digestate plots, which produced the same number of casts as the artificial plots ($p = 0.868$).

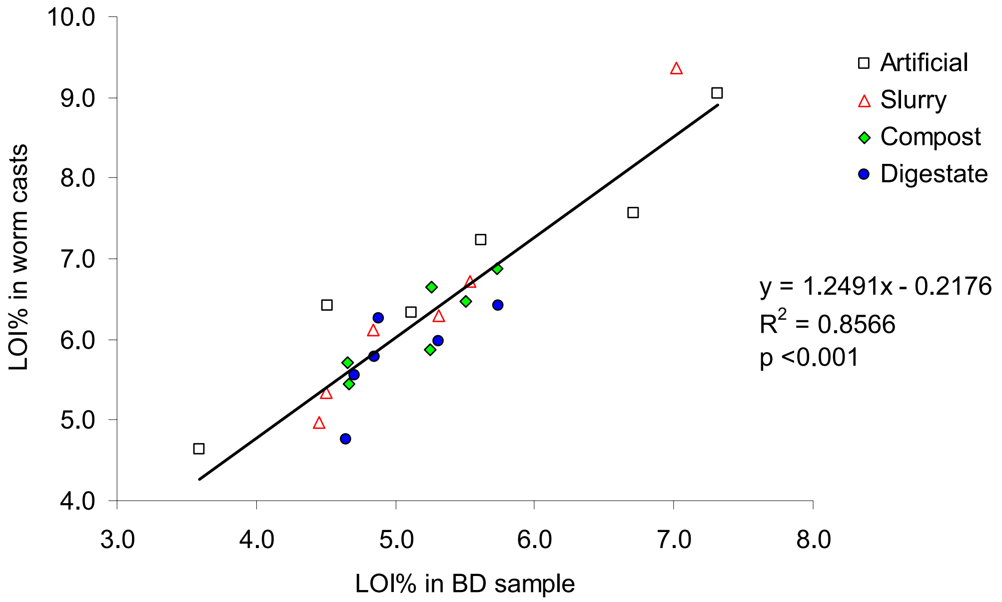


Figure **Comparison of organic matter in worm casts and bulk density (BD) samples**
(Soil depth 0 - 5.1 cm; n = 24)

The cast dry weight varied greatly between samples; consequently differences between three of the treatments were not statistically significant ($p >> 0.05$). However, the mass of casts collected from the digestate plots was significantly lower than for slurry ($p = 0.023$) and compost ($p = 0.040$).

Table 130: Comparison of cast numbers/weights and OM under different fertiliser treatments
(Data are means ± S.E., n = 6)

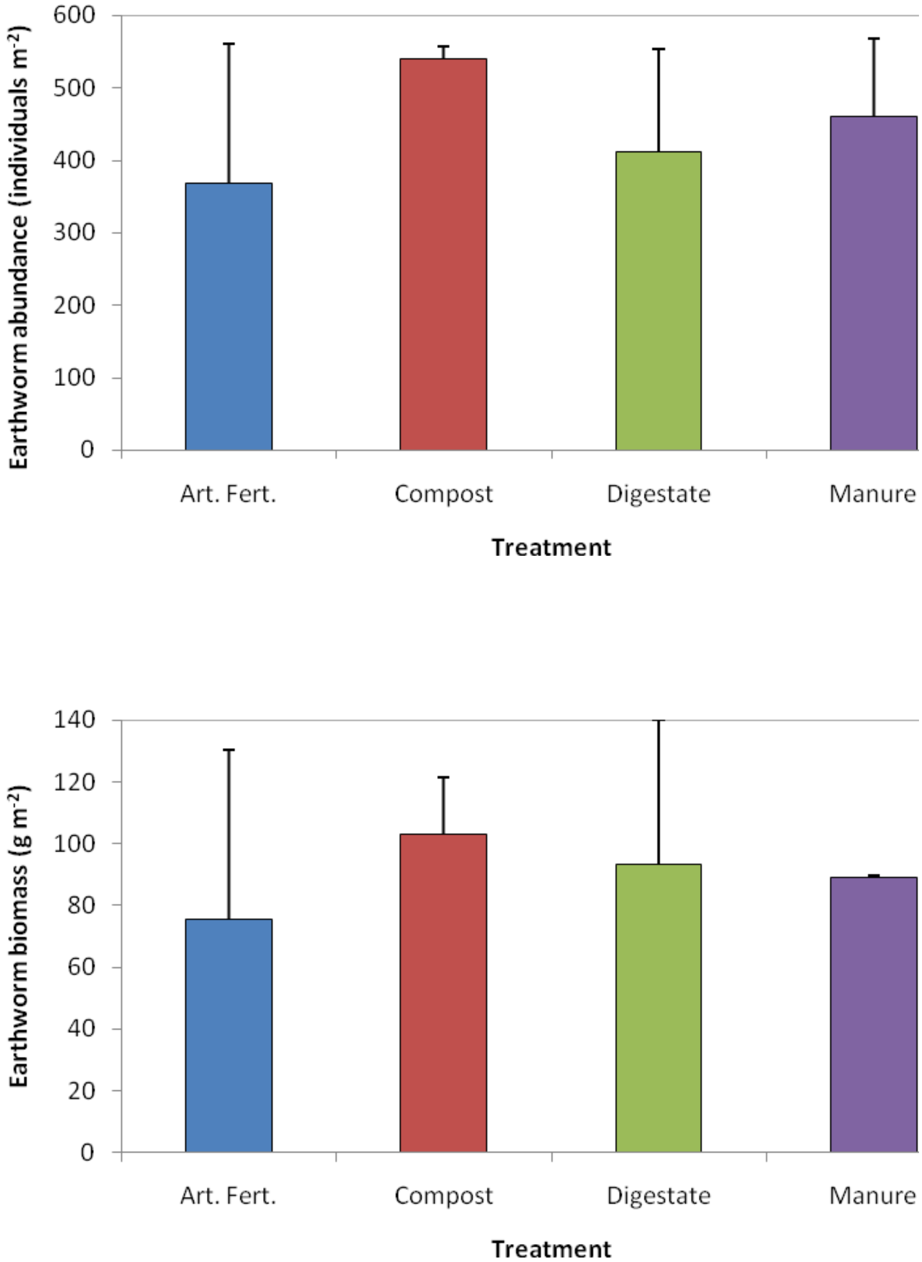
	No. casts (m^{-2})	Casts dry weight (g m^{-2})	Loss on Ignition %
Artificial	143±38	81.1±24.9	6.79±0.59
Slurry	269±77	118.1±20.9	6.39±0.62
Compost	211±42	89.9±10.6	6.10±0.23
Digestate	149±24	57.3±8.9	5.37±0.23

LOI % measured in worm casts varied greatly. Consequently, although the treatment means indicate differences, these are not significant ($p > 0.1$).

There are no statistically significant between-treatment differences, but it is worth noting that mean LOI % in worm casts decreases in the order Artificial > Slurry > Compost > Digestate. This sequence is also seen in LOI % measured in the bulk density samples and in the mid-season and post-harvest soil samples. This sequence is counter to what might be expected since the amounts of OM added to the soil decreases in the order Compost > Slurry > Digestate > Artificial.

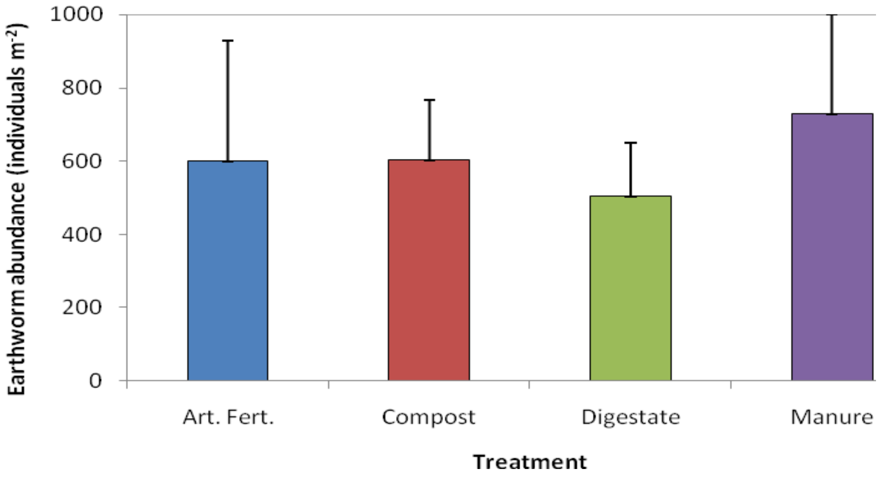
2011

Overall mean (± SD) earthworm abundance and biomass was highest for the Compost treatment, 540 ± 17 individuals m^{-2} and 102.8 ± 18.7 g m^{-2}, respectively. Adults of six species were recorded during sampling, namely *A. chlorotica*, *A. caliginosa*, *A. rosea*, *L. castaneus*, *L. festivus* and *L. terrestris*. Three endogeic species were dominant in all treatments, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.

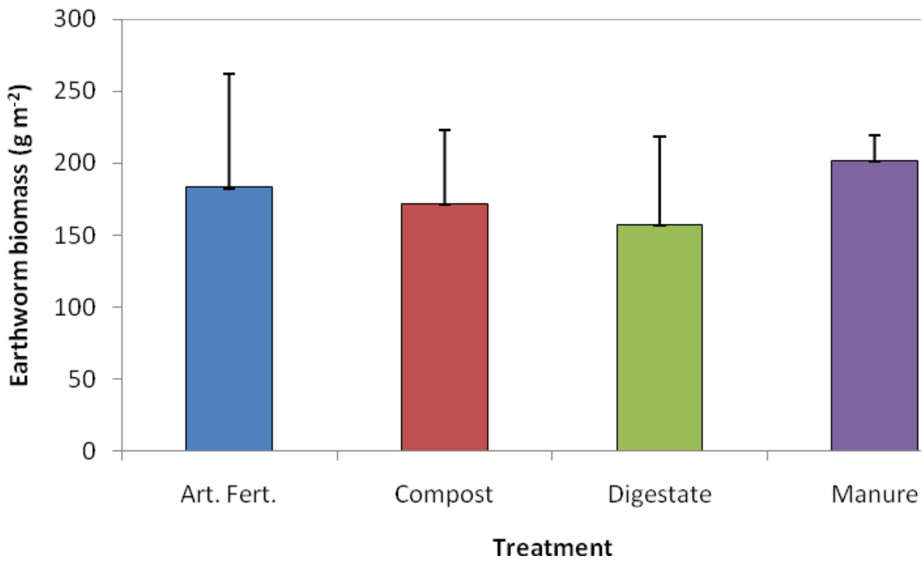


Overall means of (a) abundance and (b) biomass of earthworm communities in four treatments *(Coloured bars) for one sampling date (October 27th, 2011) (means + SD, n = 2) at Site D, Horse & Jockey, County Tipperary. (Art. Fert. = Artificial Fertiliser).*

Farm C (GC2) – Grass/Clover – Newcastle West, County Limerick.
Overall mean (± SD) earthworm abundance and biomass was highest for the Manure treatment, 728 ± 271.5 individuals m^{-2} and 202 ± 17.5 g m^{-2}, respectively. Adults of seven species were recorded during sampling, namely *A. chlorotica*, *A. caliginosa*, *A. rosea*, *A. longa*, *L. castaneus*, *L. festivus* and *L. terrestris*. Three endogeic species were dominant in all treatments, namely *A. chlorotica*, *A. caliginosa* and *A. rosea*.



b).



Overall means of (a) abundance and (b) biomass of earthworm communities in four treatments *(Coloured bars) for one sampling date (October 27th, 2011) (means + SD, n = 2) at Site C, Newcastle West, County Limerick. (Art. Fert. = Artificial Fertiliser).*

APPENDIX 10: COST BENEFIT

The following tables 132-138 show the cost of artificial fertiliser saved at each of the trial sites in each growing season for each of the treatments. The cost reduction achieved by using the natural fertilisers per hectare and per tonne of crop and the value of the nutrient in the natural fertiliser is calculated from the amount of artificial fertiliser cost saving.

However, the natural fertiliser nutrient content, the soil status, the type of crop grown and the costs relating to supply, transport and spreading determine whether there is a financial advantage from using one of the natural fertilisers on a particular farm. At the end of this Appendix a worked example taking into account all these factors is provided.

Table 131: Cost benefit analysis for nutrients applied at Farm C (GC2) in 2010

	Grass DM yield (t/ha)	Artificial fertiliser cost[39] €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	9.2	426.68	0.00	46.39	n/a	n/a
Slurry	7.4	216.66	257.33	29.13	3.60	58.4
Compost	9.3	315.63	158.36	33.86	8.88	12.5
Digestate	9.0	156.40	317.59	17.38	5.64	47.9

DM values used for harvest were those of fresh cut grass and yield weights were wilted grass

Table 132: Cost benefit analysis for nutrients applied at Farm C (GC2) in 2011

	Grass yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	10.74	343.88	0.00	32.02	n/a	n/a
Slurry	11.62	165.31	178.57	14.23	4.76	37.5
Compost	11.1	209.92	133.97	18.91	14.56	9.2
Digestate	13.36	140.53	203.35	10.52	5.15	39.5
Nothing	6.2	0.00	343.88	0		

DM values used for harvest were those of wilted grass for 1st cut and fresh cut grass for 2nd & 3rd cut and yield weights were wilted grass

Table 133: Cost benefit analysis for nutrients applied at Farm A (SB2) in 2010

	Grain DM yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grain €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	4.6	191.37	0.00	41.60		
Slurry	4.2	173.84	17.53	41.39	0.56	31.3
Compost	4.55	160.08	31.29	35.18	2.20	14.2

[39] Artificial fertilisers as straights (CAN, superphosphate and muriate of potash) are assumed to cost €1.20/kg of N, €2.75/kg of P and €0.92/kg of K

Digestate	5.45	118.85	72.52	21.81	1.56	46.4

Table 134: Cost benefit analysis for nutrients applied at Farm D (SB2) in 2010

	Grain yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	5	222.51	0.00	44.50		
Slurry	5	173.84	48.67	34.77	1.55	31.3
Compost	5.2	160.08	62.43	30.79	4.40	14.2
Digestate	5	116.10	106.41	23.22	2.52	42.3

Table 135: Cost benefit analysis for nutrients applied at Farm D (SB2) in 2011

	Grain yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	5.9	298.66	-	50.28		
Slurry	6.5	219.98	78.68	33.84	1.80	43.8
Compost	5.9	135.37	163.29	23.14	15.26	10.7
Digestate	6.5	55.00	243.66	8.47	5.08	48
No application	4.5	0.00	298.66	0.00		

Table 136: Cost benefit analysis for nutrients applied at Farm B (SW1) in 2011

	Grain yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	7.25	305.66	0.00	42.16	n/a	n/a
Slurry	7.4	82.61	223.05	11.16	5.10	43.7
Compost	7.5	164.54	141.12	21.94	9.10	15.5
Digestate	7.5	139.47	166.19	18.60	4.95	33.6
Fibre/digestate	7.8	58.59	247.07	7.51	6.86	36

Table 137: Cost benefit analysis for nutrients applied at Farm E (WW1) in 2011

	Grain yield (t/ha)	Artificial fertiliser cost €/ha	Artificial fertiliser cost saved €/ha	Artificial fertiliser cost of grass €/t	Value €/t natural fertiliser applied	Natural fertiliser t/ha applied
Artificial	10.55	260.53	0.00	24.69	n/a	n/a
Slurry	10.97	188.00	72.53	17.14	2.34	31
Compost	11.25	187.68	72.86	16.68	8.47	8.6
Digestate	8.05	32.45	228.08	4.03	4.79	47.6
Compost/Digestate	10.73	72.10	188.43	6.72	5.96	31.6

little	6.7	120.00	140.53	17.91		

Factors to consider when evaluating compost or digestate fertiliser products

Benefits

- The nutrient value.
- The additional benefits to the soil and plant health. Currently it is not possible to place a value on these additional benefits

Associated costs

- The cost of the natural fertiliser products. Typically this varies from no cost up to €30/tonne
- The transport cost - the compost or digestate fibre must be transported in a tipping bin, the whole digestate or digestate liquor in a tanker. The cost of transport differs for the liquid and solid products, because the solid products have a mass of 2-3m$^{3:}$1t whereas the liquid products are around 1m$^{3:}$1t. Transport costs can vary significantly depending on the size of the load, the distance travelled and the number and frequency of the loads
- Storage, transfer and spreading costs on the farm.

Example accounting for purchase, transport and spreading costs

- It is assumed that the distance between the processing facility and the farm is about 5 miles and that therefore the cost of transporting a full load is €100/load. It is assumed that the tanker carries 25t of digestate and the truck carries 10t of compost or digestate fibre. This would mean that the transport cost for the compost or digestate fibre is €10/t and for the whole digestate or digestate liquor is €4/t[40].
- It is assumed that the spreading cost (€20/ha) is the same for both natural fertilisers and artificial fertiliser and that there is one additional spread trip when using natural fertiliser. Although in some instances there may be two additional spreading trips with the natural fertiliser it is assumed to be one additional trip because the artificial fertiliser use per hectare is reduced when using natural fertilisers, therefore less loads of artificial fertiliser will be required.
- The purchase cost for the compost and digestate fibre is €2/t and for the whole digestate and digestate liquor is €0.50/t

Table 138: Example of total financial cost/benefit calculation for grassland
using the artificial fertiliser cost savings from Farm C (GC2) in 2011 €/ha

	Compost & top up	*Digestate liquor & top up*
Saving in artificial fertiliser	**133.97**	**203.35**
Material cost	18.40	19.75
Transport cost	92.00	158.00
Additional spreading cost	20.00	20.00
Total additional cost/ha	130.40	197.75
Saving in all costs €/ha	**3.57**	**5.60**

[40] Compost is a bulky product, so the amount in tonnes that can be transported in a full truck load is less than the weight of whole digestate that can be transported in a full load.

Table 139: Example of total financial cost/benefit calculation for spring barley using the artificial fertiliser cost savings from Farm D (SB2) in 2011 €/ha

	Compost & top up	*Whole digestate and Digestate liquor & top up*
Saving in artificial fertiliser	**163.29**	**243.66**
Material cost	21.40	24.00
Transport cost	107.00	192.00
Additional spreading cost	20.00	20.00
Total additional cost/ha	148.40	236.00
Saving in all costs €/ha	**14.89**	**7.66**

General comment

It is apparent from the examples provided that the transport and material costs are crucial factors in relation to the financial viability of using compost or digestate fertiliser products. The transport cost is the most important factor to financial viability and the transport cost is related to distance travelled. Therefore it is essential that the processing facility is located close to where the fertiliser product is to be used.

APPENDIX 11: WEATHER DATA[41]

Table 139 Average conditions 1979-2008 in Mullingar - Farm A (SB2) and Farm B (SW1)

TEMPERATURE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean daily max	7.4	7.9	9.8	12.1	14.9	17.3	19.2	18.9	16.7	13.2	9.9	7.9
mean daily min	1.5	1.5	2.8	4.1	6.3	9.2	11.1	10.8	8.9	6.2	3.5	2.2
mean temperature	4.5	4.7	6.3	8.1	10.6	13.2	15.2	14.8	12.8	9.7	6.7	5.0
SUNSHINE (hours)												
mean daily duration	1.8	2.5	3.2	4.9	5.8	5.0	4.6	4.6	3.9	3.2	2.2	1.6
RAINFALL (mm)												
mean monthly total	91.7	72.0	78.3	62.1	68.7	70.5	61.8	80.8	73.8	102.0	82.4	97.1
greatest daily total	30.3	24.7	29.5	27.6	26.1	52.9	26.6	58.2	42.1	48.8	43.7	38.8
WIND (knots)												
mean monthly speed	9.0	9.1	9.1	7.7	7.3	6.7	6.4	6.3	6.7	7.5	7.8	8.3

Table 140 Average conditions 1981-2010 in Shannon Airport - Farm C (GC2)

TEMPERATURE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean daily max	8.8	9.2	11.1	13.3	16.0	18.3	19.8	19.6	17.7	14.3	11.1	9.0
mean daily min	3.2	3.2	4.5	5.7	8.2	10.9	12.9	12.7	10.8	8.2	5.5	3.6
mean temperature	6.0	6.2	7.8	9.5	12.1	14.6	16.4	16.2	14.2	11.2	8.3	6.3
SUNSHINE (hours)												
mean daily duration	1.6	2.3	3.2	5.1	5.8	5.2	4.5	4.5	3.9	2.9	2.0	1.4
RAINFALL (mm)												
mean monthly total	102	76.2	78.7	59.2	64.8	69.8	65.9	82.0	75.6	105	94.1	104
greatest daily total	38.2	29.4	28.1	40.2	25.0	40.6	39.5	51.0	52.3	36.9	26.9	41.2
WIND (knots)												
mean monthly speed	10.3	10.2	10.0	9.0	8.9	8.5	8.5	8.2	8.4	9.2	9.1	9.4

Table 141 Average conditions 1978-2007 near Kilkenny city - Farm D (SB2) and Farm E (WW1)

TEMPERATURE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean daily max	8.2	8.6	10.6	12.9	15.7	18.2	20.3	20.2	17.8	14.1	10.8	8.8
mean daily min	1.6	1.9	3.2	4.2	6.5	9.3	11.3	11.0	9.1	6.5	3.7	2.4
mean temperature	4.9	5.2	6.9	8.5	11.1	13.8	15.8	15.6	13.4	10.3	7.3	5.6
SUNSHINE (hours)												
mean daily duration	1.8	2.3	3.2	4.9	5.6	4.9	4.7	4.7	4.0	3.0	2.2	1.6
RAINFALL (mm)												
mean monthly total	78.3	66.1	67.9	56.4	60.4	61.0	54.6	77.8	69.0	95.3	80.2	90.4
greatest daily total	25.2	24.8	27.9	23.4	31.1	28.2	66.4	58.3	34.7	33.6	34.2	43.8
WIND (knots)												

[41] Data provided by Met Eireann website

mean monthly speed	7.9	8	8.1	7.0	6.6	6.2	5.9	5.7	6.2	6.8	6.9	7.3

Table 142 Monthly conditions for 2011 in Mullingar- means are for period 1981-2010

Total rainfall in millimetres for Mullingar

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	47.1	119.0	36.1	35.0	67.3	65.1	60.3	65.1	122.1	133.0	106.2	87.8	944.1
Mean	92.5	70.3	76.6	65.9	69.2	73.8	71.1	86.1	78.3	104.3	88.1	94.7	970.9

Mean temperature in degrees Celsius for Mullingar

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	2.9	6.3	6.0	10.5	10.6	11.6	14.1	13.2	13.3	11.0	8.9	5.1	9.5
mean	4.5	4.7	6.4	8.2	10.7	13.4	15.2	14.9	12.8	9.7	6.6	4.7	9.3

Mean 10cm soil temperature for Mullingar

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	2.7	6.0	7.1	12.3	13.0	15.5	17.4	16.3	14.4	12.1	9.2	5.1	11.0
mean	3.6	3.9	5.7	8.5	12.0	15.4	16.9	16.0	13.5	10.1	6.1	4.5	9.7

Table 143 Monthly conditions for 2011 in Shannon Airport- means are for period 1981-2010

Total rainfall in millimetres for Shannon Airport

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	74.1	149.0	34.3	42.2	93.3	112.5	31.7	54.1	94.7	99.1	87.2	144.7	1016.9
mean	102.3	76.2	78.7	59.2	64.8	69.8	65.9	82.0	75.6	104.9	94.1	104.0	977.5

Mean temperature in degrees Celsius for Shannon Airport

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	3.6	7.4	7.0	12.0	11.8	12.8	14.7	14.1	14.2	12.2	10.4	7.1	10.6
mean	6.0	6.2	7.8	9.5	12.1	14.6	16.4	16.2	14.2	11.2	8.3	6.3	10.7

Mean 10cm soil temperature for Shannon Airport

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	3.6	6.4	7.4	12.7	13.1	15.1	16.9	16.1	14.2	12.2	9.7	6.4	11.2
mean	4.8	4.8	6.3	8.5	12.1	15.1	16.6	16.1	13.6	10.3	7.4	5.5	10.1

Table 144 Monthly conditions for 2011 in Oak Park - means are for period 1981-2010

Total rainfall in millimetres for Oak Park

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	50.6	121.9	16.0	19.5	51.2	72.7	46.4	25.5	93.9	93.9	89.2	55.5	736.3
mean	80.4	57.3	63.4	55.9	59.8	60.8	58.7	71.9	69.6	mean	80.4	57.3	63.4

Mean temperature in degrees Celsius for Oak Park

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	3.2	7.2	6.7	10.8	11.3	12.3	14.7	13.9	13.9	11.9	9.7	5.9	10.1
mean	5.5	5.6	7.3	8.9	11.5	14.1	16.0	15.8	13.7	10.6	7.6	5.8	mean

Mean 10cm soil temperature for Oak Park

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2011	2.9	6.5	7.3	12.9	13.0	15.4	17.9	16.5	14.1	12.0	9.3	4.9	11.1
mean	3.7	3.7	5.4	8.1	12.0	15.5	16.9	15.9	13.0	9.3	mean	3.7	3.7

APPENDIX 12: COMPOST TRIALS CONDUCTED AT UCD LYONS FARM USING GRASS, CLOVER AND GRASS/CLOVER

Undertaken by S. Walsh, M.B. Lynch and T. McCabe

The small plot replicated trials at UCD Lyons Research farm investigated the effect of compost application on the agronomic performance of grass, grass + clover and clover-only swards, dry matter yield and crop nitrogen uptake. The trials programme was divided into two field experiments : A and B. Experiment A examined the effect of two different sward types, which were grass and grass + clover and investigated the effect of five compost application rates on crop performance. Experiment B examined the effect of three compost application rates on clover sward performance and was designed as a 3 x 5 factorial trial of split plot design. There were two factors, factor A: compost rate (0, 4, and 8 t/ha) and factor B: clover variety (Crusader, Chieftain, Alice, Aran and Barblanca).

It was a good summer in 2011 for grass growth with adequate soil moisture levels during the summer period and mild autumn temperatures, allowing for a long growing season. The lowest rainfall in the spring and summer months was 30mm. In each trial N sensor readings were taken twice before each scheduled harvest date, firstly at three weeks growth and repeated again at seven weeks growth - harvest time. DM yield and crop nitrogen uptake were also recorded for each plot in each trial.

Results -- Experiment A

Experiment A was designed as a 2 x 5 factorial design with four replicates of each treatment. The two factors in the trial are Factor A: Sward type (grass and grass + clover) and Factor B: Compost rate: untreated control (zero rate) and 4 t/ha, 8 t/ha, 12 t/ha and 16 t/ha). Result data is in Tables 145-147.

Table 145 The effect of sward type and compost rate on dry matter (DM) yield, N content and crop nitrogen uptake (CNU) on the first harvest date (June)

Treatment	Parameter		
	DM Yield (t/ha)	N Content (%)	CNU
Factor A – Sward type			
Grass	1.54	2.01	30.72
Grass + Clover	2.78	2.54	70.45
Level of significance	***	***	***
L.S.D (P<0.05)	0.18	0.18	6.01
Factor B – Compost rate			
0 t/ha	1.40	2.20	32.19
4 t/ha	1.80	2.37	44.04
8 t/ha	2.18	2.44	54.09
12 t/ha	2.70	2.30	64.17
16 t/ha	2.73	2.08	58.45
Level of significance	***	n.s	***
L.S.D (P<0.05)	0.29	--	9.50

Sward type had a significant effect on dry matter yield, nitrogen content and crop nitrogen uptake with DM yield, N content and CNU all being significantly increased in the grass + clover swards over the grass-only swards on each harvest date in 2011. The higher-dose compost application rates significantly increased the DM yield and the CNU (P<0.001). As compost dose rate increased the DM yield also increased.

Table 146 The effect of sward type and compost rate on dry matter yield, N content and crop N uptake on the second harvest date (September)

Treatment	Parameter		
	DM Yield (t/ha)	**N Content (%)**	**CNU**
Factor A – Sward type			
Grass	1.13	1.98	23.40
Grass + Clover	1.57	2.57	40.68
Level of significance	***	***	***
L.S.D (P<0.05)	0.20	0.31	7.62
Factor B – Compost rate			
0 t/ha	1.12	2.35	27.02
4 t/ha	1.18	2.21	27.82
8 t/ha	1.30	2.28	31.26
12 t/ha	1.44	2.39	36.93
16 t/ha	1.70	2.14	37.16
Level of significance	**	n.s	n.s
L.S.D (P<0.05)	0.32	--	--

Table 147 The effect of sward type and compost rate on dry matter yield, N content and crop N uptake on the third harvest date.

Treatment	Parameter		
	DM Yield (t/ha)	**N Content (%)**	**CNU**
Factor A – Sward type			
Grass	0.54	3.01	16.06
Grass + Clover	0.58	3.57	20.61
Level of significance	n.s	***	***
L.S.D (P<0.05)	--	0.18	2.43
Factor B – Compost rate			
0 t/ha	0.46	3.32	15.53
4 t/ha	0.51	3.36	17.38
8 t/ha	0.55	3.36	17.81
12 t/ha	0.60	3.04	17.35
16 t/ha	0.67	3.46	23.59
Level of significance	**	n.s	**
L.S.D (P<0.05)	0.10	--	3.83

The data in Figure A shows the total dry matter yield for the 2011 season, including data from all three harvests. The dry matter yield of the grass swards increased as compost rate increased. Swards of grass

+ clover gave a significantly higher yield. This yield increased with compost rate from 0 to 12 t/ha with a 2 t/ha plus yield response observed on the grass + clover sward. The graph in Figure B shows the difference in crop nitrogen uptake between the trial treatment combinations. The CNU level almost doubles with the inclusion of clover in the grass sward. CNU increases with compost rate in the grass + clover swards from 0 to 12 t/ha. The trend is similar in grass swards but the effect is relatively less as CNU increases from 0-8 t/ha where it reaches a plateau for higher compost application levels.

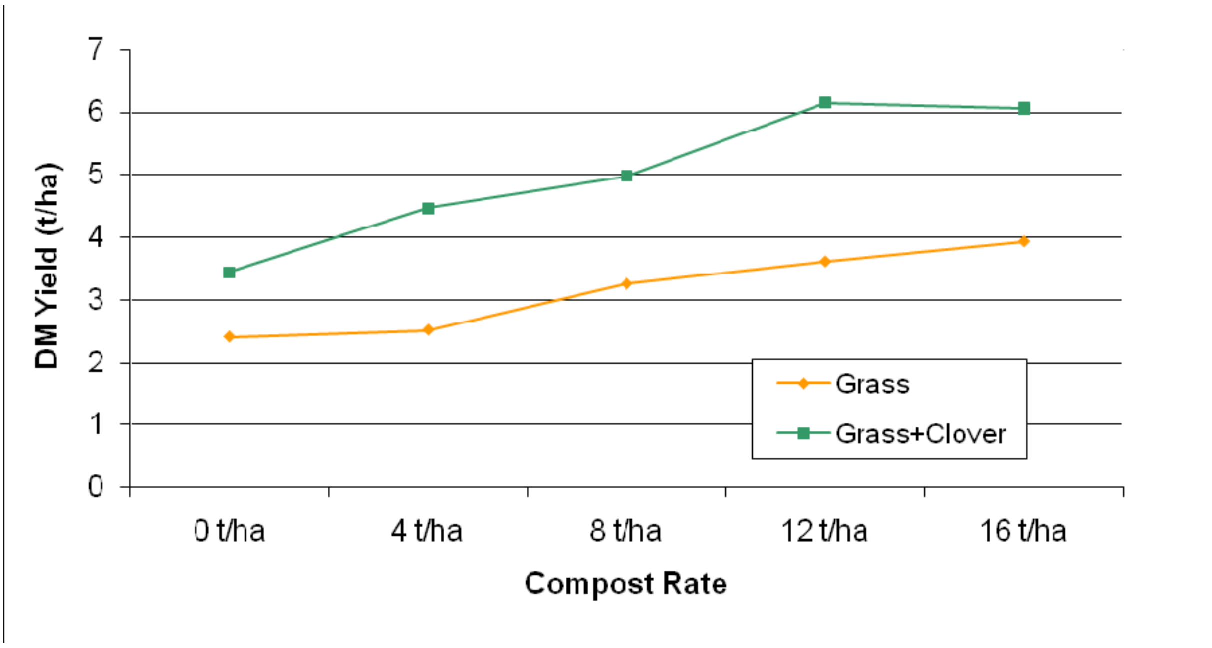


Figure A. The total season yield as effected by sward type and compost rate.

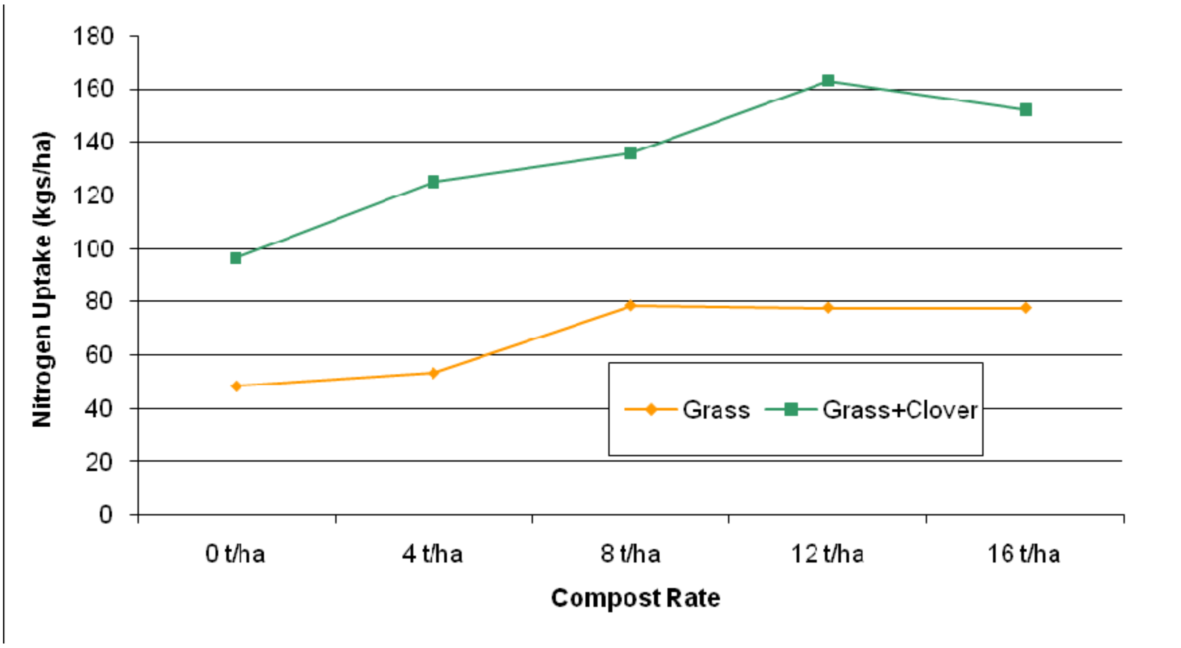


Figure B. The total crop nitrogen uptake as affected by sward type and compost rate.

Results Experiment B

This trial investigated the effect of three compost rates on clover sward performance trial design with a 3 x 5 factorial arrangement. The three compost rates (Factor A) were: untreated control (0 t/ha), 4 t/ha and 8 t/ha

Table 148 The effect of compost rate and clover variety on dry matter yield, N content and CNU on the first harvest date – 28th June.

Treatment	Parameter		
	DM Yield (t/ha)	N Content (%)	CNU (Kgs/ha)
Factor A (Main plot) – Compost rate			
0 t/ha	4.55	3.65	165.6
4 t/ha	4.51	3.65	164.1
8 t/ha	4.83	3.58	172.5
Level of significance	n.s	n.s	n.s
L.S.D. (<0.05)	--	--	--
Factor B (Subplot) – Clover variety			
Crusader	4.63	3.65	166.8
Chieftain	4.47	3.59	160.9
Alice	4.73	3.59	169.8
Aran	4.81	3.57	171.4
Barblanca	4.52	3.72	168.1
Level of significance	n.s	n.s	n.s
L.S.D. (<0.05)	--	--	--

Table 149 The effect of compost rate and clover variety on dry matter yield, N content and CNU on the second harvest date – 17th August.

Treatment	Parameter		
	DM Yield (t/ha)	N Content (%)	CNU (Kgs/ha)
Factor A (Main plot) – Compost rate			
0 t/ha	3.02	3.79	116.17
4 t/ha	3.08	3.70	112.03
8 t/ha	3.02	3.70	111.31
Level of significance	n.s	n.s	n.s
L.S.D. (<0.05)	--	--	--
Factor B (Subplot) – Clover variety			
Crusader	2.84	3.89	112.28
Chieftain	3.22	3.65	119.42
Alice	3.00	3.66	109.72
Aran	3.11	3.63	114.98
Barblanca	2.92	3.82	109.44
Level of significance	*	*	n.s
L.S.D. (<0.05)	0.254	0.18	--

Compost rate did not significantly affect DM yield, nitrogen content or crop nitrogen uptake levels across the five clover varieties on the first two harvest dates.

Table 150 The effect of compost rate and clover variety on dry matter yield, N content and CNU on the third harvest date - 6th October

Treatment	Parameter		
	DM Yield (t/ha)	N Content (%)	CNU (Kgs/ha)
Factor A (Main plot) – Compost rate			
0 t/ha	1.57	4.44	69.39
4 t/ha	1.56	4.47	69.87
8 t/ha	1.58	4.50	70.95
Level of significance	n.s	n.s	n.s
L.S.D. (<0.05)	--	--	--
Factor B (Subplot) – Clover variety			
Crusader	1.60	4.48	71.03
Chieftain	1.42	4.44	62.86
Alice	1.45	4.46	64.66
Aran	1.74	4.39	76.42
Barblanca	1.64	4.58	75.38
Level of significance	*	n.s	*
L.S.D. (<0.05)	0.204	--	10.03

In this trial compost application rate treatments did not significantly increase clover DM yield, N content or crop N uptake levels.

Discussion of trial results

The field trial studies in 2011 at UCD investigated the effect of compost application rate and sward type on dry matter yield and crop nitrogen uptake. A consistent trend observed was that the grass + clover yielded higher than grass-only treatments and also had a higher N content and higher crop N uptake than the grass swards. Compost use showed a consistent positive benefit to crop performance with the crop dry matter yield increasing significantly with increases in compost application rate. The compost rate treatments did not significantly affect the crop N content but did increase CNU levels on the 1st and 3rd harvest dates. With an increase in compost application soil inorganic N generally increases and this is due to N mineralisation. This can result in an increased N uptake in the crop, but, according to Yun *et al.*, 2006, this may not lead to an increase in dry matter or crop quality. However, in this trial carried out in Lyons it was shown that dry matter yield increased proportionally with an increase in compost rate per hectare. As compost is expected to behave similar to a slow releasing fertiliser it provides the plant with nutrients throughout the season and into the following season. As has been shown by many other trial studies compost has a lot of benefits to its use, due to it's nutrient value (Gonzalez *et al.*, 1992; Sikora and Enkiri, 1999; Tejada *et al.*, 2001), its help in preventing soil acidification (Bengtson and Cornette, 1973) and erosion and improving the soil's physical and biological properties. This information shows how the use of compost promotes soil productivity and quality it has also been shown that excess compost application can degrade soil and water quality and may inhibit crop growth (Yun *et al.*, 2009).

Research studies have observed that the source of the compost, the soil texture where applied and moisture conditions in that soil and previous cropping all effect the composts performance in the particular site where it is used (De Leon-Gonzales, 2000; Drozd, 2003). As compost content and quality can show considerable variation it makes comparability of field performance. However in this current study compost application has shown a very good agronomic benefit on both grass and grass + clover swards however there is some indication that a very high dose application of compost (16 t/ha) can have a small detrimental effect on the crop performance. In experiment A the inclusion of clover in the sward had a very significant beneficial effect on the crop's performance, showing a higher increase in the key agronomic performance parameters; crop DM yield and crop N uptake and indicating that there may be a very useful synergistic effect of compost application on the grass + clover sward similar to the effect observed in the large demonstration plot trials on Farm C (GC2) in Limerick.

Nitrogen sensor evaluation data for the Compost rate x Grass/Clover trial at UCD in 2011

Nitrogen sensor readings were taken at three weeks growth and at harvest time for all three harvests.

Table 151 The effect of sward type and compost rate on nitrogen sensor readings on 6 dates

	N-sensor evaluations (NDVI Units and NIR Units)											
Index Date	**NDVI 1 7-7**	**NDVI 2 28-7**	**NDVI 3 25-8**	**NDVI 4 9-9**	**NDVI 5 3-10**	**NDVI 6 28-10**	**NIR 1 7-7**	**NIR 2 28-7**	**NIR 3 25-8**	**NIR 4 9-9**	**NIR 5 3-10**	**NIR 6 28-10**
Factor A – Sward type												
Grass	0.72	0.74	0.74	0.73	0.75	0.72	6.33	6.83	6.60	6.47	7.19	3.96
Grass + Clover	0.75	0.74	0.76	0.76	0.76	0.75	6.94	6.82	6.84	7.41	7.34	4.04
Level of significance	***	n.s	***	***	n.s	n.s	***	n.s	**	***	n.s	n.s
L.S.D (P<0.05)	0.01	--	0.01	0.01	--	--	0.21	--	0.17	0.41	--	--
Factor B – Compost rate												
0 t/ha	0.70	0.74	0.74	0.74	0.75	0.73	5.81	6.65	6.28	6.78	7.01	3.87
4 t/ha	0.72	0.74	0.74	0.74	0.75	0.73	6.19	6.76	6.47	6.71	7.12	3.92
8 t/ha	0.74	0.74	0.75	0.74	0.76	0.73	6.89	6.84	6.79	6.82	7.27	4.00
12 t/ha	0.75	0.75	0.75	0.75	0.76	0.74	7.07	6.98	6.98	7.01	7.44	4.09
16 t/ha	0.76	0.75	0.76	0.76	0.76	0.75	7.23	6.92	7.09	7.39	7.50	4.12
Level of significance	***	n.s	*	n.s	n.s	n.s	***	n.s	***	n.s	n.s	n.s
L.S.D (P<0.05)	0.01	--	0.02	--	--	--	0.33	--	0.27	--	--	--

The table above shows how NDVI and NIR were affected by the trial treatments of sward type and compost rate. The table shows the level of significant difference

Nitrogen Sensor Evaluations for the Compost rate x Clover trial at UCD in 2011.

Nitrogen Sensor Evaluations (NDVI & NIR) were taken at three weeks growth and again four weeks later at harvest for all three cuts.

Table 152 the effect of compost rate and clover variety on NDVI and NIR on six dates.

Treatment	**N-Sensor Evaluations NDVI Units and NIR Units)**											
Index date	**NDVI 1 2-6**	**NDVI 2 28-6**	**NDVI 3 26-7**	**NDVI 4 17-8**	**NDVI 5 9-9**	**NDVI 6 6-10**	**NIR 1 2-6**	**NIR 2 28-6**	**NIR 3 26-7**	**NIR 4 17-8**	**NIR 5 9-9**	**NIR 6 6-10**
Factor A (Main plot) – Compost rate												
0 t/ha	0.80	0.75	0.79	0.80	0.80	0.81	8.99	4.87	8.62	8.87	9.22	9.82
8 t/ha	0.80	0.75	0.79	0.80	0.80	0.82	9.14	4.95	8.54	8.86	9.13	9.98
12 t/ha	0.80	0.76	0.79	0.80	0.80	0.82	9.06	4.91	8.59	9.01	8.87	10.2
Level of significance	n.s	*	n.s	n.s	*	n.s	n.s	n.s	n.s	n.s	*	n.s
L.S.D (P<0.05)	--	0.01	--	--	0.00	--	--	--	--	--	0.20	--
Factor B (Subplot) – Clover variety												
Crusader	0.80	0.74	0.79	0.80	0.80	0.82	8.86	4.80	8.54	8.94	9.03	9.91
Chieftain	0.80	0.75	0.78	0.79	0.79	0.81	9.07	4.91	8.38	8.75	8.74	9.66
Alice	0.80	0.76	0.79	0.80	0.80	0.82	9.06	4.91	8.56	8.83	9.10	10.2
Aran	0.80	0.76	0.79	0.80	0.80	0.82	9.24	5.00	8.69	9.06	9.25	10.1
Barblanca	0.80	0.76	0.79	0.80	0.80	0.82	9.09	4.92	8.74	8.99	9.25	10.2
Level of significance	n.s	**	**	**	n.s	*	n.s	n.s	**	**	n.s	**
L.S.D (P<0.05)	--	0.01	0.01	0.00	0.01	0.01	--	--	0.18	0.17	0.38	0.33

The table above shows the nitrogen sensor readings of NDVI and NIR taken throughout the trial's growing season. It also shows the levels of significant difference from these results.

APPENDIX 13: PROJECT PROMOTION

Presentations

- The Bioregions workshop in Mullingar, on 3rd February - aim to promote the use of Bioenergy, both AD and wood energy, in Midlands region. About 110 people attended the workshop.
- The IrBEA annual National conference on 17th Feb in Portlaoise to which a wide range of delegates (about 140) who have interest in all aspects of the Bioenergy industry, including many farmers, attended.
- The Cré and ECN international conference on AD held in Dublin on 24/25th Feb, to which those involved in composting and AD from around the world attended.
- The CIWM annual conference held at the end of April in Horse & Jockey, to which about 80 people involved in the waste management industry attended. About 45 people attended the crop trial site visit in the afternoon site, an open discussion occurred concerning the use of compost in arable crops
- Siobhan Walsh presented a paper on the use of compost on a grass and grass/clover sward at the Agricultural Research Forum in Tullamore in March 2012. The paper was well received by the audience primarily comprised of researchers from the university sector and Teagasc.

Posters

Posters displaying the results of the trials in 2010 and 2011 were exhibited at

- The 2 day SEAI seminar on biogas held at the AD facility in West Limerick (6/9/11 & 7/9/11).
- the annual organic conference organised by Teagasc held at Limerick Junction (14/9/11) at which there were over 100 people,
- The International Energy Agency biogas task group conference organised by UCC (15/9/11) at which there were 70 people.
- A farmer's meeting in Kinsale

Open days

Open days were held at each of the crop trial sites during May and June 2011. An additional open day was held at the grassland crop trial in September 2011. The events were well publicised

For each event a handout was prepared, specific to the trial at that farm and providing information on rx3 and general information on composting, digestate and the purpose of the trials. Poster presentations were prepared and put up at the event and a verbal explanation of the information was given on the open day. Each plot had a marker board which identified the plot and provided information on what had been applied to that plot. Presentations were made and then people were taken around the plots and a verbal explanation of the information on the plot markers was given. A general discussion ensued after the presentations

- At Farm C (GC2) in West Limerick on 12th May. 22 people attended, mostly local farmers. James Humphreys, the Teagasc expert on clover, was present, and there was much discussion about the performance of the clover in the compost plots
- In Tipperary on 7th June a half day event was organised to include a visit to both arable sites (Farms D & E) and also a visit to Acorn's composting facility in Littleton. 10 people attended, mostly local farmers, despite heavy rain falling all morning. A good discussion ensued.

- In Mullingar on 9th June both sites (Farms A & B) were visited and there was a tour of Johnstown Recycling composting facility. About 20 people, mostly farmers but also a number of key stakeholders. There was a good discussion about the trials and the use of natural fertilisers
- On Farm C (GC2) on 28th June presentations were held and a tour of the crop trial was given as part of a Teagasc farm walk organised for REPS farmers. About 30-40 people were present
- At Farm C (GC2) at end of September, around 100 people attended.

A number of individuals, including crop advisors, industry representatives, a reporter and farmers were taken to the crop sites at their requests as they hadn't been able to attend an Open Day event

Information leaflets

Information leaflets were prepared to provide information on natural fertilisers and on the trial results to those people that attended the open days, have also been distributed at several events where farmers, who might be interested in the results, have gathered.

Press coverage

- Farming Independent published an article written by one of their reporters who attended the IrBEA conference
- Farmers Journal article on use of digestate and compost in arable crops.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agricultural
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Programme
regulatory
Regulation
sustainable
Quantification
Evaluation
Calculation
Council
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Windrow
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questionnaire
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treatment
Intertrade
conditioner
accounts
questions
understanding
certified
address
volumes
mixes
specify
consumed
purchase
Tipperary
Multipurpose
amendments
primarily
Determining
Specification
Association
specialist
household
assumption
follows
contacted
cheaper