Field experiments for quality digestate and compost in agriculture

February 2016

DC-Agri **research summary**

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Introduction

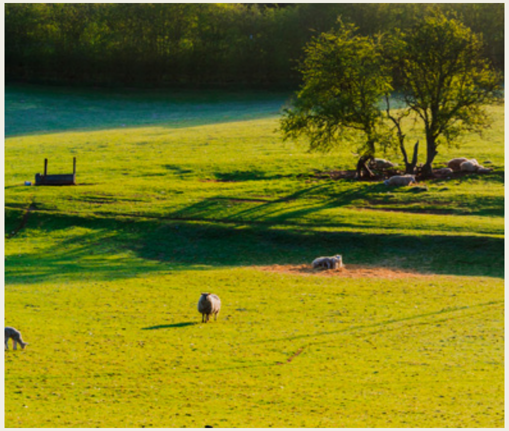
The Digestate and Compost in Agriculture (*DC-Agri*) field experiments provide a robust evidence base to support the confident use of digestates and composts by farmers and growers as renewable fertilisers.

The research demonstrates that digestates and composts can increase yields with no negative impacts on crop quality or safety, and that compost can increase soil organic matter more quickly than other organic materials.

Importantly, the results show how farmers can make the most of the nitrogen fertiliser value in food-based digestate, but underline the high economic and environmental cost of applying it when crops do not require nitrogen.

The *DC-Agri* project was commissioned in 2010 and the core experiments ran across three growing seasons, with supplementary research completed in 2015. The experiments were underpinned by robust scientific methodologies.

There were 22 experimental sites throughout Wales, Scotland and England across the various work packages, with cross-site protocols and standard operating procedures providing quality control and consistency between sites. All treatments were in triplicate, increasing the strength of the data generated.



In 2010, food-based digestate was a little understood, little used, 'novel' material. Now farmers have a range of fertiliser planning tools and guidance at their fingertips. Built on *DC-Agri* data, these resources enable them to maximise the fertiliser value of more than 1.5 million tonnes of food waste that is processed by the UK's anaerobic digesters every year.

Whilst compost is not new, we now have the scientific evidence base required to enable the materials to be used reliably and with an understanding of the contribution that both green/food and green compost (compost made from feedstocks containing green waste only or a mixture of green and food waste) can make to improving key soil properties; one of our most precious natural resources.

The full project reports are available at **www.wrap.org.uk/dc-agri-reports**. This summary covers the key research findings.

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1 Materials used

The *DC-Agri* field experiments were undertaken using the following organic materials:

	Whole food-based digestate[1]	Livestock slurry	Green compost	Green/food compost	Farmyard manure
pH	8.50	7.37	8.26	8.50	8.16
Dry matter (%)	2.16	4.60	70	66	27

1. Digestate made from livestock manures was used at two sites in Scotland. The relevant results are reported in the full report available at **www.wrap.org.uk/dc-agri-reports**

2 Fertiliser value

Many organic materials contain nitrogen that can be used to grow healthy crops, but how this becomes available to plants is generally less well understood in comparison with bagged fertilisers. Digestate contains more available nitrogen than most organic materials, and this section describes one of the principal focusses of the *DC-Agri* project, which was to quantify how much of this will become available for crops so that farmers can use it reliably.

This section also describes the results showing how organic materials, including digestate and compost, can increase crop yields as a result of the range of nutrients that they provide.

a) Digestate as a nitrogen fertiliser

Food-based digestate is an effective renewable fertiliser supplying readily available nitrogen. Nitrogen is the single most important nutrient influencing crop yields. It is important to provide farmers with the information necessary to quantify how much crop available nitrogen will be provided by digestate.

Indicative nutrient contents for food-based digestate

Dry matter content	4%
Nitrogen (N)	5 kg/t
Readily available N	4 kg/t
Phosphate (as P_2O_5)	0.5 kg/t
Potash (as K_2O)	2.0 kg/t
Magnesium (as MgO)	0.1 kg/t
Sulphur (as SO_3)	0.4 kg/t

Just like livestock slurries and manures, when digestate is applied to a field not all of the nitrogen will be taken up by the crop. Some of it may be lost, for example as ammonia gas or as water soluble nitrate.

For farmers to be able to use digestate reliably, it is therefore necessary to calculate the nitrogen use efficiency (NUE), i.e. the efficiency with which the nitrogen applied is taken up by the crop after losses are taken into account. It is also necessary to understand how higher NUEs can be achieved.

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Digestate as a nitrogen fertiliser (continued)

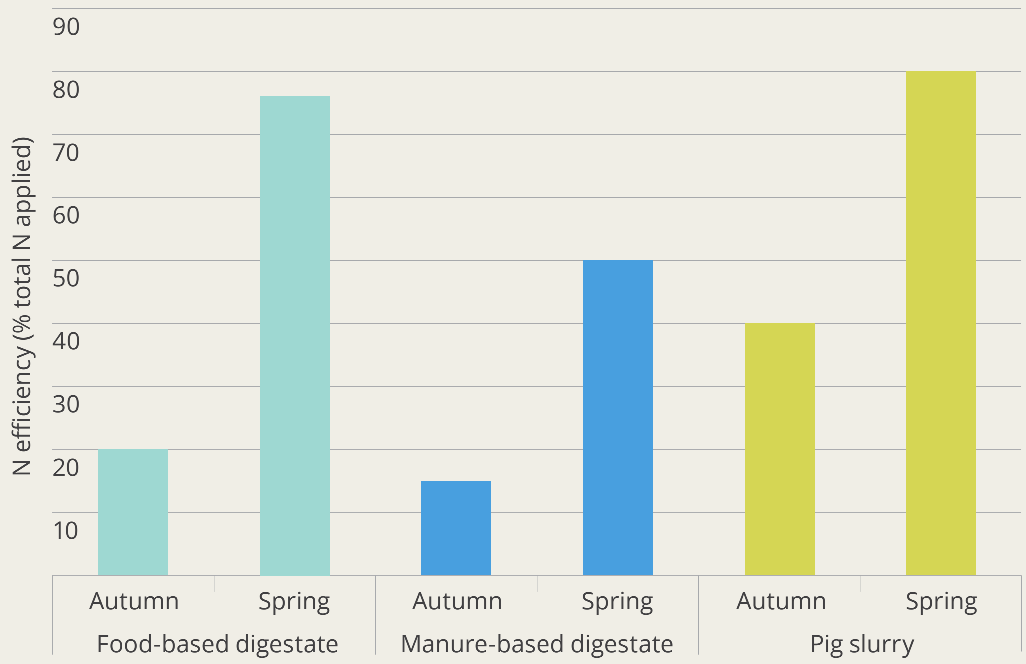
The average NUE of food-based digestate, applied in spring using a bandspreader, was c. 55% of total nitrogen applied, as measured in replicated field experiments. This was reduced to c. 15% of total nitrogen applied when food-based digestate was bandspread in the autumn, highlighting the effect of nitrogen losses via overwinter nitrate leaching.

Livestock slurry-based digestate applied in spring had a mean NUE of c. 50% which decreased to c. 15% of total nitrogen applied for autumn applications.

For both materials, there was considerable variation between the NUE results obtained from the individual experimental sites; this was understandable given the complexity and interactions of the processes involved and is also the case for other organic material applications (e.g. livestock slurries).

There was good agreement between NUE estimates made using MANNER-*NPK*, the freely available fertiliser planning tool, and the field measurements. This indicates that MANNER-*NPK* can provide good estimates for farmers and advisors who want to account for the nitrogen content of digestates when developing fertiliser strategies. However, there is scope for the MANNER-*NPK* estimates to be further improved by incorporating information on environmental nitrogen losses from digestate into the MANNER-*NPK* algorithms.

The experiments also showed that repeat compost applications significantly increased the levels of soil nitrogen that can be supplied to crops.



Nitrogen use efficiency at the Wensum site growing winter wheat. This is an example of the low nitrogen use efficiency of autumn bandspread applications in comparison with spring applications. This result was seen consistently across the other sites.

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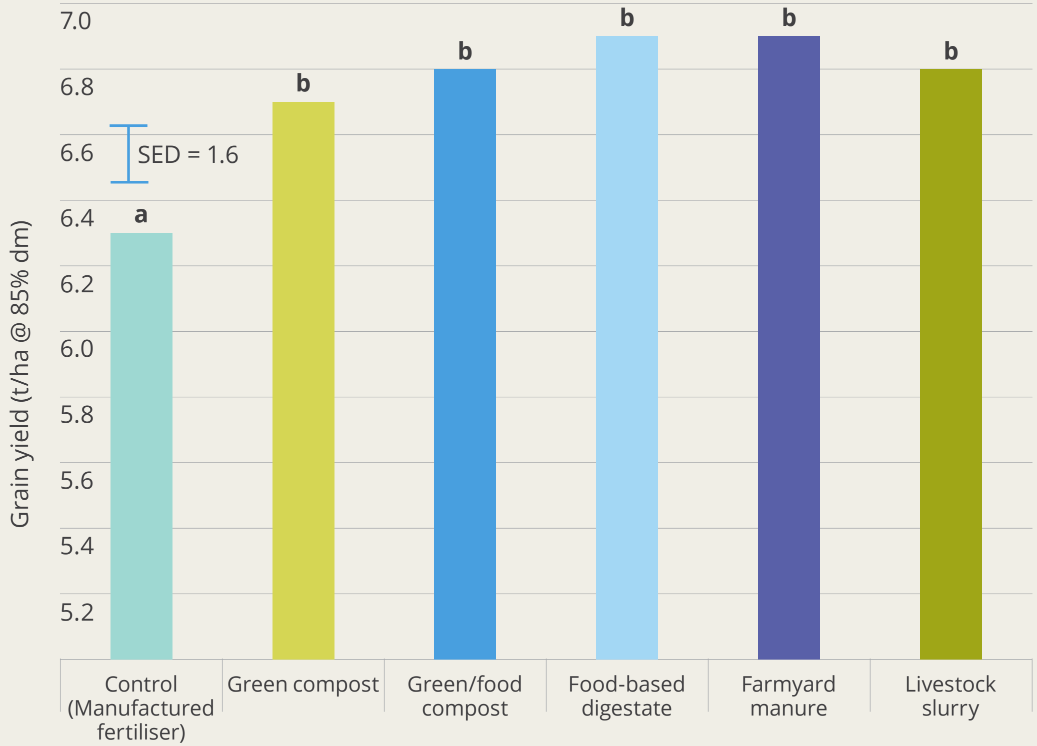
b) Nutrient boost from organic materials

Composts and digestates provided an additional source of phosphate, potash and sulphur, providing a 'nutrient boost' early in the season which resulted in higher crop yields in comparison with crops grown only with bagged fertilisers. This is particularly important on shallow soils over chalk and limestone where it can be difficult to reach and maintain target phosphorus levels, soils with a low nutrient status or soils susceptible to sulphur deficiency.

This benefit was valued at £55-£160/ha, taking into account the value of bagged fertiliser saved and the cost of spreading (but not sourcing) the organic materials. It also demonstrated the value of an integrated nutrient management plan, using compost or digestate and manufactured fertiliser together. Benefits were also measured for crops grown using other organic materials.



Average winter cereal yields from 2011-2013 at the soil quality experimental sites (results are an average across eight site/seasons), comparing organic materials applied in combination with manufactured fertilisers, against the fertiliser-only control. The standard error of the difference between mean values (SED) was 0.16. Bars labelled with different letters indicate significant differences between treatments (P<0.05).

3 Crop quality

The impact of using green/food compost, green compost and food-based digestate on crop quality and safety was measured. The quality of crops grown with compost and digestate was measured against specific grain weight, grain protein content and the oil content of rape seed and found to be just as good as crops grown using bagged fertilisers.

Similarly, crops grown using compost and digestate were found to be safe following assessments of crop metal concentrations, mycotoxins in cereal grains and organic material contamination of cut grass.

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❹ Soil quality

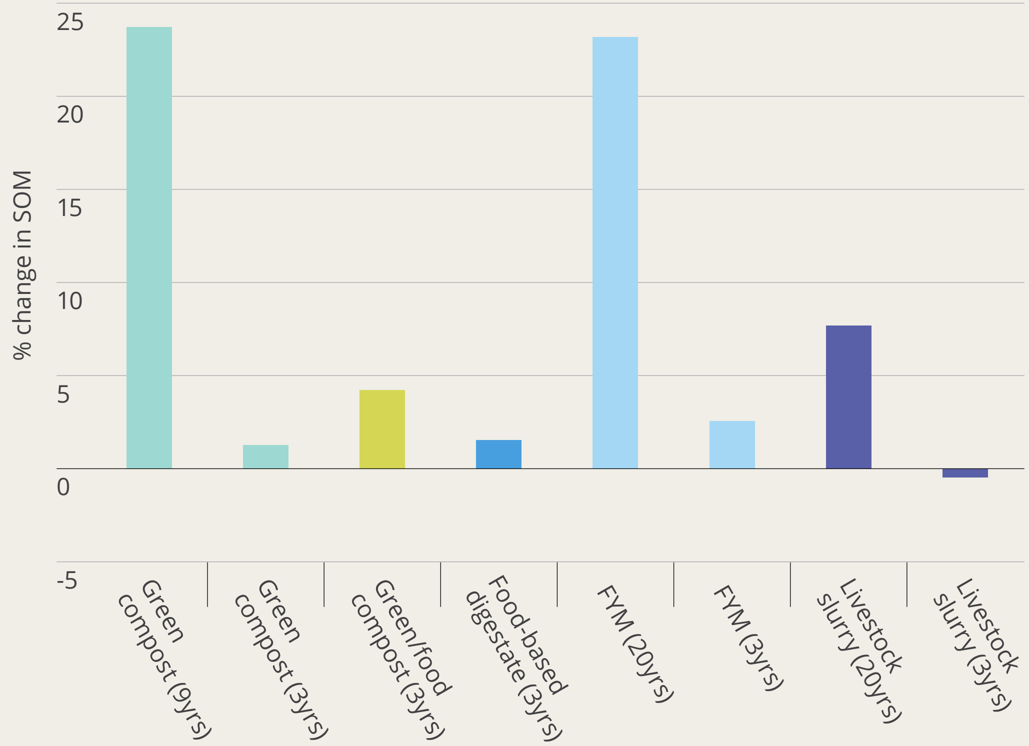
a) Soil organic matter

Two of the experimental sites were used in previous experiments and had a known history of organic material applications prior to *DC-Agri*. Here there was clear evidence that repeat applications of bulky organic materials for nine years or more increased topsoil organic matter contents, with both green compost and farmyard manure resulting in a c. 20-25% increase in soil organic matter relative to the control treatment, which only received bagged fertilisers. At the other sites, where materials were applied for only three years, there were small, non-significant increases in soil organic matter.

None of the whole food-based digestates used had a significant impact on soil organic matter levels. This was consistent with the results for the livestock slurries used and understandable given the low dry matter content of these materials.

Although the nine years of green compost applications supplied only half the organic matter that had been supplied by the almost 20 years of farmyard manure applications, it resulted in a comparable increase in total soil organic matter levels and shows that compost can build soil organic matter levels more quickly than other materials. Retention of the organic matter supplied by the green compost was almost double that of farmyard manure, which suggested that green compost was more resistant to decomposition.

This was supported by the lignin composition of the applied materials, with the organic matter content of the green compost containing c. 70% lignin compared to c. 55% in the farmyard manure. Soil organic matter content is a key indicator of soil health, and increasing soil organic matter is generally associated with stronger, more resilient crops. This is as a result of the combined improvement in soil physical and biological properties, which are described in the following sections.



Change in soil organic matter following the repeated addition of organic materials for three and over nine years. Results are expressed as a percentage difference from the control treatment (bagged fertiliser only). Annual applications of organic materials were made for longer at some sites than others: on two sites green compost was applied for nine years and FYM and livestock slurry applications were made for 20 years; on at least five sites, all other materials were applied for three years.

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b) Soil biology

Measurements of the size of the soil microbial pool, as determined by its carbon and nitrogen content, indicates a soil's ability to store and recycle nutrients, and is also important in the development of soil structure, with higher content linked to better soil quality.

Statistically significant increases in soil microbial biomass were found where green compost had been applied for nine years. The increases were greater where farmyard manure had been applied for 20 years, despite similar increases in soil organic matter on the green compost treatment. This is most likely because the farmyard manure applications comprised a more readily decomposable source of organic matter that was able to support a bigger microbial population than that produced by the green compost additions.

Earthworms have a major influence on soil quality, and higher additions of fresh organic matter to soil are usually associated with greater earthworm populations. Earthworm populations were greater following the application of farmyard manure and to a lesser extent green and green/food compost to both arable and grassland soils, most likely due to the additional food supply provided by the organic materials.

However, earthworm populations were sometimes lower following the application of higher levels of ammonium in the food-based digestate, compared to the other treatments. At one grassland site, there was also a statistically significant difference between the food-based digestate and the fertiliser only control, and the effects at this site were still apparent approximately two years after the final digestate application (largely due to a reduction in the population of juvenile earthworms).

It is known that livestock slurries that contain a high proportion of ammonium may sometimes have a negative impact on earthworms, and additional laboratory research confirmed that this effect may also be seen sometimes following applications of food-based digestate.

Based on this research, **WRAP's guides to good practice** include recommendations that ammonium-N loading rates are controlled by following normal good practice (as described in the guides), and that users adjust application rates using up-to-date digestate nutrient analysis data in order to reduce the possibility of any negative impacts. Rapid on-farm nitrogen meters (e.g. Agros and Quantofix) can be used to provide on-site measurements of digestate ammonium-N contents.

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c) Soil physical properties

Soil density, particularly topsoil bulk density, has a direct impact on a number of essential soil physical and biological processes. These include root penetration, water infiltration rates, gas exchange and soil biological activity. Soil density is usually a key measure in the assessment of soil compaction and tends to be inversely related to soil organic matter content.

Published research has shown that decreases in soil density will reduce the amount of force required for ploughing and other tillage operations. This can generate financial savings for farmers as a result of the related reductions in machinery wear and fuel costs.

At the arable sites, improvements in soil organic matter and soil biological functioning on the long-term green compost treatment (and farmyard manure treatment) were associated with a decrease in bulk density. These decreases were greater on the farmyard manure treatment, which had similar soil organic matter contents, although the time-frame over which this was achieved and the total organic matter load required to achieve it was almost double that of the green compost treatment.

At the grassland sites, compost and farmyard manure additions also decreased bulk density. Where digestate and livestock slurry had been applied for three years, there was some evidence of soil compaction (i.e. increased bulk density), although these changes were not statistically significant.

d) Soil heavy metals and organic contaminants

There was no effect of the compost and digestate additions on topsoil total metal contents, and all measurements remained well below maximum permissible limits set in relation to applications of sewage sludge.

Measurements of organic contaminants (PAHs, dioxins, furans and phthalates) were generally low and considered to be acceptable. Whilst there are no specified 'safe' limits for these contaminants in agricultural soils (or soil amendments such as sewage sludge, compost or digestate), a set of preliminary, human health related limits have been suggested for land application of wastewater and sewage sludge. For PCBs, the proposed maximum soil concentration of 0.89 mg/kg was greater than the concentrations measured at the *DC-Agri* experimental sites (at <0.002 mg/kg). These results are in line with research in Finland, where observed annual loadings from digestates of dioxins, furans, phthalates and PCBs were similar to or lower than those from atmospheric deposition in Scandinavia, and were therefore of low-risk to food safety.

This is an important finding for the sustainable use of compost and digestate on agricultural land, providing confidence that they can be used safely on agricultural soils.

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5 Emissions to the environment

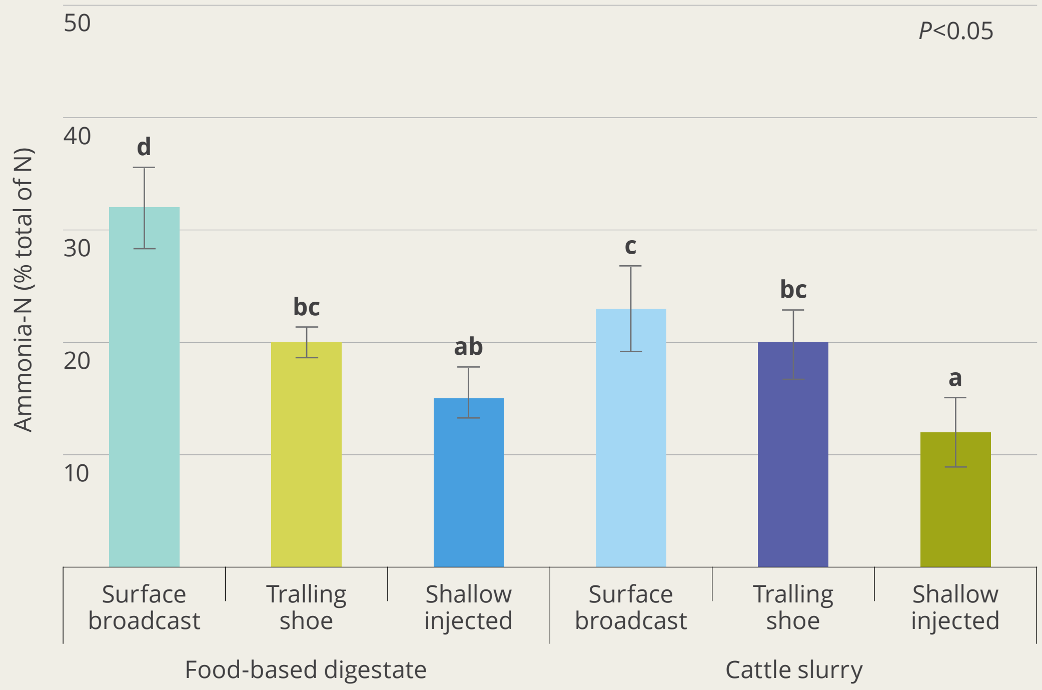
As noted above, digestate is an effective renewable fertiliser supplying readily available nitrogen, mostly in the form of ammonium. This is a significant benefit, but the unstable nature of ammonium emphasises the need to follow good practice in order to avoid environmental harm.

Based on the *DC-Agri* research data, WRAP has published several guides for digestate and compost use in agriculture, available at **www.wrap.org.uk/using-renewable-fertilisers** In summary, it is recommended that digestate is only applied when there is a crop nitrogen requirement and using precision application methods such as bandspreading or shallow injection.

a) Ammonia

Greater ammonia emissions were found from applications of food-based digestates (c. 40% of total nitrogen applied) compared to livestock slurry (c. 30% of total nitrogen applied). This was partly due to the greater ammonium content of the food-based digestate and partly to its elevated pH (mean pH 8.3).

Ammonia emissions were reduced on grassland where the food-based digestate (and cattle slurry) was applied via trailing hose and particularly when it was applied via shallow injection. However, appropriate soil conditions are required for shallow injection to operate to its full potential (i.e. soils should not be too wet or stoney).



Cross-site ammonia emissions from both autumn and spring applications to grassland at three sites. Bars labelled with different letters indicate statistically significant differences between treatments (P<0.001) and show that both shallow injection and trailing shoe application methods reduce ammonia emissions by 40-50% in comparison with surface broadcasting.

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b) Greenhouse gases

Nitrous oxide losses from the food-based digestates were low, with measured emission factors all less than the current default value of 1% set by the Intergovernmental Panel on Climate Change. This is consistent with data from on-going research into livestock manures and slurries undertaken as part of the Agricultural GHG Research Platform.

Methane emissions from digestates were lower than from livestock slurry. Small increases in cumulative (12 month) carbon dioxide emissions were observed on the slurry and digestate treatments compared with the untreated control, and to a lesser extent the farmyard manure treatment. The reason for the small increase in carbon dioxide emissions was unclear; one possible explanation is that microbial respiration was stimulated by the supply of both readily available nitrogen and readily decomposable carbon.

c) Leaching losses

Overwinter nitrate leaching losses from food-based digestate were significant and similar in magnitude to those from pig slurry (at c. 15-20% of the total N applied), but much greater than those from farmyard manure or compost (at <5% of the total N applied). Nitrate leaching losses can be reduced and nitrogen use efficiency increased by applying digestate only when there is a crop nitrogen requirement.

Phosphorus leaching losses were low for all organic materials and similar to those measured on the untreated control treatment. No viable *E.coli* were found in the drainage waters even where organic materials were applied.

d) Compost

Atmospheric emissions (i.e. ammonia, nitrous oxide, methane) and leaching losses (nitrate, soluble phosphate and *E.coli*) from both green and green/food compost were found to be low. Due to its valuable total nitrogen content, but low readily available nitrogen content, compost applications should be seen as a means to build up long-term (organic) soil nitrogen reserves rather than as a short-term replacement for bagged nitrogen fertiliser.

6 Tools and training

An integrated dissemination programme has been central to the *DC-Agri* project, translating research results into practical advice for industry. This has focussed on farmers, farmer advisers and agriculture students across GB, and provided them with the training and tools necessary to make informed decisions about the use of digestate and compost.

Further information is available at **www.wrap.org.uk/dc-agri-training**

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7 Conclusions

The *DC-Agri* results have clearly demonstrated that the repeated application of compost is a valuable means by which farmers can improve soil organic matter status, with associated increases in soil biological and physical functioning. This will ultimately lead to increases in crop yields and resilience, as well as reduced fuel costs.

The increased nutrient supply from organic materials, including digestate and compost, can produce higher crop yields of equal quality to crops grown with bagged fertilisers. This, combined with a reduced reliance on manufactured fertiliser inputs, can also lead to improved financial returns.

Digestate is a good source of crop available nitrogen, and the *DC-Agri* results highlight the importance of following good practice to maximise its potential as a renewable fertiliser. The results also highlight the economic and environmental cost of mismanaging the high ammonium content. One of the most valuable outputs of the *DC-Agri* project is the robust scientific evidence that is now available to inform good practice which is encapsulated in **WRAP's guides to good practice**.

8 Other useful resources

The full *DC-Agri* project reports are available at **www.wrap.org.uk/dc-agri-reports**

Whilst this research summary has focussed on composts and food-based digestate, the full reports also include results on the comparator organic materials used in the research, particularly farmyard manure and livestock slurry. There is also information on the livestock slurry based digestate used at the Scottish research sites.

9 Acknowledgements

The *DC-Agri* project has been delivered over the period 2010-15. WRAP is very grateful to Defra, WRAP Cymru and Zero Waste Scotland for their whole-hearted support, without which longer term, strategic research of this nature would not have been possible.

The farming, composting and anaerobic digestion industries have also provided extensive support, and we are very grateful for the guidance and engagement provided.

WRAP is also grateful to the numerous organisations that have excelled in the delivery of the *DC-Agri* project, in particular, ADAS and Earthcare.

WRAP's vision is a world in which resources are used sustainably.

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