The usability of digestate in organic farming
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ABSTRACT
As organic farming prohibits the use of synthetic fertilisers, animal slurries and manures must be used. Digestate offers an alternative to these and this study reports on three experiments conducted to determine its usability in terms of: (1) the effect on earthworm populations, (2) its fertilising effects on Italian Ryegrass and wild Creeping Thistle, and (3) the suppression effects digestate has on weed emergence. The results for digestate application to field plots were intermediate between slurry and no treatment for earthworm attraction and wild thistle suppression. In glasshouse trials it led to increased ryegrass growth compared with undigested slurry. Analysis showed that the digestate had improved nitrogen availability, leading to increased plant growth, but a reduced organic matter content compared with the slurry, leading to a positive though less beneficial impact on the earthworms. Digestate therefore provides a suitable fertiliser for organic farming. This suitability could be improved by drying or separation to increase the OM content making its properties closer to those of slurry whilst still retaining the higher content of plant available nitrogen.

Key words | digestate, earthworm, organic farming, slurry

INTRODUCTION
In 2009, the European Commission agreed to binding legislative targets to reduce Greenhouse Gas (GHG) emissions, increase renewable energy use, and improve energy efficiency all by 20% of the baseline value set in 1990 by 2020 (EC 2008). Promoting the use of anaerobic digestion (AD) to process food and farm waste is one method by which countries can achieve these targets. AD provides farmers with an opportunity to adopt a technology that will reduce their emissions and increase their profits. However, convincing farmers to adopt government schemes is often only successful when the scheme appeals to the farmer’s personal motivation (Beedell & Rehman 2000). It is therefore likely to be easier to persuade farmers to adopt environmentally friendly enterprises if the farmer already displays concerns for environmental issues. As organic farmers often convert to organic farming because of their personal desire to operate in an environmentally friendly manner (Fairweather 1999), they may be ideal candidates to target when promoting AD within the agriculture sector.

The husbandry methods used on organic farms prohibit the use of synthetic fertilisers. As a consequence, to improve soil fertility organic farmers must practice good nutrient management through crop rotation and the recycling of organic material such as manures (Lampkin et al. 2008). Although less environmentally harmful than the production of synthetic fertilisers (Deike et al. 2008), the storage and use of animal manure is a major source of methane emissions from agriculture (EEA 2010). AD can offer farmers a method of reducing emissions from their stored manures (Amon et al. 2006).

The residual organic material produced in an AD unit is known as digestate. Organic farmers who use organic material as a feedstock for an AD unit, instead of applying it directly as a fertiliser, will therefore need to be able to use the digestate produced as a fertiliser. Because of the restriction on organic farmers with regard to the sources of nutrients applied, a thorough assessment of the effect digestate has on the environment is required to reassure organic farmers that use of digestate is safe. If application causes harmful effects on the environment, production on the farm may be negatively affected and the digestate deemed unsuitable for organic farmers.

Anaerobic digestion reduces the organic matter (OM) content of animal slurries and manures and although the digestate has equal amounts of total nitrogen, it has a higher ammoniacal content, and therefore provides nitrogen to plants in a more readily available form, similar to that of inorganic fertilisers (Moeller & Stinner 2009). Organic
farming relies on fertilisers with high OM and high organic nitrogen, so using a material lower in OM and organic nitrogen may compromise crop yield (Lampkin et al. 2008). Soil dwelling species are important in many ecosystem functions and rely on organic material as a food source (UN 2005). By reducing OM availability, there will be a loss of their beneficial functions, which will have a detrimental effect on the ecosystem service they belong to. Equally, high levels of nitrogen applied to the soil may have toxic effects on soil species (Cotton & Curry 1980b). Earthworms, for example, are a major ecosystem service provider and are essential for maintaining fertile soil. Their absence will therefore result in lower fertility (Mader et al. 2002).

Identified here are three potential agricultural issues with regard to the use of digestate as a suitable organic fertiliser. The first involves assessing whether digestate has a detrimental effect on earthworm populations. The second involves the benefits of digestate in plant growth with regard to both crops and weeds. The final issue involves the use of digestate as a method of both weed transmission and weed suppression, in particular, Creeping Thistles (Cirsium arvense) due to its persistence in agricultural fields (Bond et al. 2007).

METHODS

Replicated experiments using organic dairy cattle slurry stored in an open topped lagoon, and digestate produced from the same slurry, were carried out under field and glasshouse conditions. The slurry and digestate were collected from an AD unit at Lodge Farm, Wrexham, UK (SJ 538354). For the field trials the slurry and digestate were stored at the field site in closed containers to reduce chemical changes through emission losses (Amon et al. 2006) and kept at ambient temperature. Spreading occurred once weather conditions were suitable in accordance to DEFRA guidelines (DEFRA 2009). Analysis was performed for each sample 3 weeks before spreading. Slurry and digestate for glasshouse studies were stored at −20 °C until needed, in order to minimise changes to chemical composition, and then at +4 °C thereafter.

Analysis

Total Kjeldahl nitrogen (TKN) and ammoniacal nitrogen (NH₄-N) were determined by the Kjeldahl method (Bremner 1960). Dry weight percentage (DW%) was determined by weighing samples to an accuracy of 0.001 g, before and after oven drying at 104 °C for 24 h. Percentage of organic matter (OM%) was determined by weighing samples to ±0.0005 g, before and after furnace firing at 550 °C for 2 h (Reijs et al. 2003).

Field trials

Field trial site

Field trials were conducted in 2010 at Chilworth Science Park, Southampton, UK (SU 440118). The plot site had been free from agrochemicals for at least 2 years prior to 2010. Nine plots of 9 m² with 2 m margins between plots and arranged in a 3 × 3 formation were cleared by weeding and ploughing. Organic Italian Ryegrass (Lolium multiflorum) (Cotswolds Seeds Ltd, Gloucestershire, UK), was sown on 15 April and 15 July 2010 at 5.5 g m⁻². No artificial irrigation was used in the trials.

Treatment types

Three fertiliser treatments were used: (1) organic slurry, (2) digestate produced from organic slurry, and (3) no treatment (control). Each treatment was assigned to plots in a Latin Square design, allowing three replicates for each treatment. To simulate standard farming methods slurry or digestate was applied to the plots at 71.9 kg N ha⁻¹ in April 2010 and September 2010 to standardise against other field studies (Cotton & Curry 1980a). This involved the application of 31 L of the digestate and 35 L of the slurry to each plot.

Earthworm sampling in field plots

Sampling took place on three occasions between August and November 2010: 1 week prior to the September fertiliser application, 1 week after application, and 6 weeks after application. Sampling was not performed around the April fertiliser application due to the disturbance caused by the plot preparation. Earthworm samples were taken by removing soil from an area of 160 cm² to a depth of 15 cm from each plot and hand sorting for individuals. Sorting time was standardised to 45 min per plot. Additional earthworms located below 15 cm depth were retrieved by pouring 3 L of mustard solution (Spiceworld, UK) diluted in water at a concentration of 15 mg L⁻¹ into the hole created by removal of the soil (Gunn 1992). Any earthworms that emerged within 15 min were then added to the collected soil bag to be sorted. Earthworms collected were stored on wet paper at

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10 °C for 24 h to allow gut emptying. The worms were then weighed using a top-pan balance to ±0.001 g. Data were not normally distributed and unable to be transformed, so were analysed with a Kruskal–Wallis test to compare between treatment types and sampling dates. Earthworm frequency data were analysed with a t-test for slurry and digestate treatments against values for the control plots. All statistics were analysed using Minitab® Statistical Software v16.1.0. (Minitab Inc., State College, PA., USA).

Thistle germination in field plots

Plots were monitored for wild thistles on five occasions between March and June 2010. The total count and percentage cover of thistle seedlings were recorded. Emergence data for thistle counts were analysed using a Generalised Linear Model for repeated measures. Thistle cover data were arcsin transformed and analysed using a t-test.

Glasshouse trials

The glasshouse trials were conducted under conditions of 20 °C ± 2 °C on a 12:12 light to dark regime and with watering added to the top of the pot three times per week.

Seeding growth in glasshouse trials

Organic Italian Ryegrass as used in the field trials and Creeping Thistle seeds harvested from plants near the field plot site were scattered onto autoclaved soil at ∼60 mg cm⁻². Treatments of either slurry or digestate were added at 63 kg N ha⁻¹ (calculated using 250 kg N ha⁻¹ yr⁻¹ as the UK’s maximum N spread rate with an average of 4 applications yr⁻¹), with an equivalent volume of water to that of the digestate water content, added to the controls. After 30 days the total count of thistle seedlings emerging was recorded. Wet surface biomass for both thistle and ryegrass was collected and weighed to ±0.001 g using a top-pan balance. Samples were then dried at 70 °C until no further weight loss occurred, and final biomass recorded to ±0.001 g. Wet and dry weights for grass and thistle seedlings were analysed using analysis of variance (ANOVA) between treatments.

Potential contamination from treatments

To ensure the digestate and slurry used were not vectors for seed contamination, 20 mL of digestate, and slurry, 20 g of field plot soil and no treatment were each added to 20 pots of autoclaved loam soil. After 30 days the frequency of emerged seedlings for each pot was recorded and analysed using the Sign Test.

RESULTS AND DISCUSSION

The characteristics of the slurry and digestate treatments were DW 3.96 and 1.27%; OM 0.1 and 0.03% of DW; TKN 1853 and 2059 mg L⁻¹; and NH₄-N 864 and 1045 mg L⁻¹.

Field trials

Earthworm sampling in field plots

All plots saw an increase in earthworm numbers 1 week after application (Figure 1(a)). This was expected due to natural seasonal fluctuations (Edwards & Lofty 1972). Increase between treatments differed, with slurry treated plots containing significantly more earthworms than the control plots (T₄ = 5.38, p < 0.05), suggesting earthworm numbers not only naturally increased, but were attracted to the plots. Digestate treated plots saw an increase in average earthworm frequency similar to that seen in slurry treated plots, but was not significantly different from the earthworm numbers found in the control plots (T₄ = 1.78, p = 0.150). By week 6, there was no difference in earthworm numbers between all treatments (H₈ = 7.20, p = 0.515). The lack of differences between treatments after 6 weeks suggests that the attraction caused by the slurry application lasts only for a limited time. Longer term studies have shown a higher frequency of earthworms in fields treated with manure fertilisers rather than inorganic fertilisers (Estvez et al. 1996; Whalen et al. 1998) although this effect was less obvious in grasslands, as in this study, compared with arable lands (Edwards & Lofty 1982).

There were no significant differences in earthworm mass between treatments 1 week before application (H₂ = 0.28, p = 0.870) (Figure 1(b)) or 6 weeks after application (H₂ = 1.28, p = 0.527). Biomass was significantly influenced by treatment 1 week after application (H₂ = 8.28, p < 0.05) with earthworms in slurry-treated plots on average larger than earthworms located in digestate or control plots. Earthworms in plots treated with slurry were also significantly larger 1 week after treatment, compared with 1 week before (T₁₈₈ = p < 0.05). This may be due to individual earthworm biomass increasing. In the 1 week after sample, there was an increase in frequency of earthworms in the larger biomass categories, compared with
the frequencies seen in the control plots for the same biomass categories, suggesting a species composition change, with larger individuals being attracted to the plot, rather than just increasing in average biomass. More *Lumbricus* species were also observed during the second collection (personal observation). Changes in species composition have been seen previously in the literature, with an increase of *Lumbricus* individuals being attracted to fields treated with slurry (Cotton & Curry 1980a). In digestate-treated plots, earthworm number increased but the average biomass decreased between 1 week before and 1 week after treatment. Plots treated with digestate therefore may have seen an increase in small individuals, possibly as juveniles.

Increasing nitrogen and OM content in fertilisers has a positive effect on earthworm populations (Edwards & Lofty 1982). The application of slurry increases earthworm frequency and biomass more than the use of inorganic fertilisers with a similar total N concentration, due to the higher OM content (Cotton & Curry 1980a; Edwards & Lofty 1982). Equally, plots treated with farmyard manure (FYM), which has a higher OM content than slurry, contain more earthworms than slurry-treated plots (Edwards & Lofty 1982). An increase of nitrogen content in fertilisers with the same OM content can also increase earthworm frequency. Cotton & Curry (1980a) applied pig slurry with 4,400 mg N L⁻¹, 3000 mg ammoniacal N L⁻¹ and 9% OM and found a higher frequency and total biomass of earthworms compared with 9% OM cattle slurry with a lower ammoniacal nitrogen content. A second experiment found that application of pig slurry at 345 m³ ha⁻¹ yr⁻¹ in three equal applications within four months had a detrimental effect on earthworm numbers, and reduced species diversity composition (Cotton & Curry 1980b). Although the treatment volume used here was about nine times that used in this study, the decrease in earthworm numbers was attributed to the high copper content of the slurry, rather than the high nitrogen content, which was not reported here. As our treatments contained low concentrations of TKN, ammoniacal nitrogen and OM compared with Cotton & Curry’s study (1980a), it was expected that the results for earthworm frequency and biomass would be less obvious. The significant result for slurry-treated plots at such a low nitrogen and OM content shows that application at levels found in agricultural practice can still have an effect. The trend in earthworm populations in digestate-treated plots potentially indicates OM and/or nitrogen was too low to have a noticeable impact on earthworm frequencies, compared with the slurry. From a practical point of view, this means it may be possible to add digestate in larger amounts than seen here before it starts to affect earthworm numbers.

**Thistle germination in field plots**

Plot trials showed an increase in thistle emergence over all plots with time (Figure 2). Reduced emergence was seen in plots treated with digestate and slurry compared with no treatment (GLM repeated measures $F_{3,19.66} = 4.66, P < 0.01$). Although both digestate and slurry had a lower percentage coverage of thistles compared with no treatment, cover 47 days after application showed no significant difference between the control and digestate-treated plots ($T_3 = -0.36, P = 0.743$) or control and slurry-treated plots ($T_3 = -3.04, P = 0.056$).

The reduction in thistle numbers suggests the application of digestate and slurry both had a negative effect on the emergence of seedlings and/or thistle sprouting roots. This may have been due to the increase in nitrogen, which has been shown to suppress thistles both directly and indirectly. High levels of nitrogen can be toxic to thistles (ISO 2003), although toxicity is unlikely within this study.
It is more probable that spreading of slurry and digestate increased shading over the soil, reducing the thistle’s ability to grow; also the additional nutrients from treatment application would have caused an increase in competition from other plants for light, again causing shading over emerging thistles (Bond et al. 2007).

Percentage coverage of thistle did not differ significantly between the three fertiliser treatments by the end of the trial period, suggesting that once thistles emerged, they were no longer shaded by neighbouring species or by the OM spread in the treatments, and could access the applied nitrogen for growth. Alternatively, cover from the treatments may have washed off or been incorporated into the soil within the trial period.

**Glasshouse trials**

**Seedling growth in glasshouse trials**

Thistle biomass averages were not significantly different between the three fertilising treatments for wet (ANOVA, $F_{2,27} = 2.10, p = 0.143$) or dry biomass (ANOVA, $F_{2,27} = 1.27, p = 0.297$) (Figure 3). There were also no significant differences in the number of seedlings growing per pot (ANOVA, $F_{2,27} = 1.99, p = 0.158$), the average wet biomass per plant (ANOVA, $F_{2,27} = 0.84, p = 0.444$) or the average dry biomass per pot (ANOVA, $F_{2,27} = 0.07, p = 0.937$). This may have been due to the regular watering regime washing off the treatments from the soil surface and reducing any shading effects seen in the field plots.

Italian ryegrass seeds grown in control conditions had a significantly lower wet biomass, and digestate seedlings had a significantly higher wet biomass, compared with seedlings grown in slurry (ANOVA $F_{2,27} = 17.92, p < 0.001$) (Figure 3). Dry biomass values for ryegrass were also significantly higher in seedlings grown in digestate, compared with slurry and no treatment (ANOVA $F_{2,27} = 12.54, p < 0.001$).

Organic fertilisers such as slurry rely on soil biota to aid the gradual breakdown and release of nutrients in a plant-available form (Mader et al. 2002). Digestate offers more nitrogen in an accessible form for the plant to utilise and thus may have led to the higher wet weight values seen in the digestate-treated grass (Moitzi et al. 2007). The OM content in digestate means there is still material for soil biota to feed on, thus retaining a highly valued quality in slurry (Lampkin et al. 2008), but also allowing an increase in crop yield compared with raw manures (Chadwick & Pain 1997). As the soil was autoclaved, soil microbes would have been inactivated and unable to breakdown OM to release nutrients.

**Potential contamination due to applied treatment**

Neither the slurry (Sign test, $p < 0.001$) nor digestate (Sign test, $p < 0.001$) used were contaminated with seeds. Field plot soil contained seeds (Sign test $p < 0.001$), with an average of 3.7 seedlings per pot (S.E. ± 0.417; max = 8, min = 1). Autoclaved soil did not contain seeds (Sign test $p < 0.001$).

**CONCLUSIONS**

The option of using digestate as an organic fertiliser exists for organic farmers due to digestate possessing both beneficial qualities of organic and inorganic fertiliser options. As an organic fertiliser, digestate can increase the OM within the soil, while recycling organic materials readily available on farms. The similar effects that digestate had on earthworm frequencies, compared with slurry, should reassure farmers that application will not decrease
earthworm numbers, although the potential effect digestate had on species diversity needs further exploration. The application of digestate can also aid in weed management both by creating a shading effect to reduce weeds, and acting as an effective fertiliser for increasing crop competition with weeds and increasing overall yield.

As a fertiliser, digestate offers more readily available nutrients in a form plants can use to further improve the usability of digestate, reducing the water content thereby increasing the OM content per litre spread may further attract earthworms to fields and increase shading on thistles by spread cover. In addition to this, more nitrogen per litre of digestate can be added compared with slurry, and added in a more available form for plants to use. This could result in farmers needing to spread less, which in turn may save them money and time, minimise impact to fields, and further reduce GHG emissions from diesel powered machinery. Modelling is currently being undertaken to look into the suitability and practicality of AD for dairy and mixed organic farms.

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