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Accepted Version

Short running title: Digestate application to grasslands

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Abstract

Anaerobic digestate applied to land is a source of readily available nutrients, yet there is a paucity of knowledge regarding effects on grassland. To address this, we investigated the viability of using digestate as an alternative to mineral fertilizer for *Lolium perenne* L. (ryegrass) grassland maintenance. We present findings of two independent field-trials, where food-waste digestate was applied over two growing seasons at two rates (100 and 200 kg N ha^{-1} y^{-1}) and compared to mineral fertilizer (N:P:K-12:4:6 @ 100 kg N ha^{-1} y^{-1}) and control (no additions) plots. *L. perenne* nutrition (N, P and K), chlorophyll and sward composition were assessed in the summer and autumn to observe treatment and seasonal effects. The sward benefited from digestate application in the summer with reduced occurrence of dead *L. perenne*. Both the digestate and mineral fertilizer shifted the sward composition similarly and in favor of *Poa annua* L. in summer and *L. perenne* in autumn, with reduced broad-leaved weeds and bare soil coverage regardless of season. Quantities of foliar N and K uptake were similar between the digestate and mineral fertilizer, however the highest rate of digestate application was required to supply similar quantities of P to the grass compared to the mineral fertilizer. Grass chlorophyll was not adversely affected by the high ammonium-N in the digestate. These broadly positive results for digestate present opportunities for the development of digestate use as a fertilizer on amenity grassland such as outfields in sports facilities, parks, and road verges as well as showing potential for supplementing the fertility of pasture systems.

Keywords

Anaerobic digestate; *Lolium perenne*; plant nutrients; sward composition.

Introduction

The global interest in the production of biogas has led to the installation of more than 4,000 farm-scale anaerobic bioreactors in Europe (Weiland 2010). Biogas digestate, the residual slurry by-product of the anaerobic digestion (AD) process, is a rich source of plant available nutrients often recycled to soil as a fertilizer. With economic and regulatory drivers, ecological advantages of using digestate as a replacement to conventional mineral fertilizers are also becoming apparent (Vaneeckhaute *et al*. 2013). Information regarding the nutrient content of digestates is well documented (Möller and Müller 2012; Nkoa 2014), however research on the use of digestates as a fertilizer remains in its infancy (Teglia *et al*. 2011; Nkoa 2014). Specifically, more long-term field-scale research of digestate application is required on grasslands (Andruschkewitsch *et al*. 2013). It is recognized that digestate application increases crop (Garg *et al*. 2005; Möller *et al*. 2008; Terhoeven-Urselmans *et al*. 2009) and *Lolium perenne* (ryegrass) production (de Boer 2008; Gunnarsson *et al*. 2010), but also has inhibitory effects on *Vigna radiate* L. Wikzek (Mung bean) germination (Kataki *et al*. 2017). Also, mineral fertilizers are known to affect species composition in pasture (Santamaria *et al*. 2014) and grasslands (Lanta *et al*. 2009). With the exception of Dahlin *et al*. (2015), who reported increased *L. perenne* and reduced *Trifolium pratense*

L. (red clover) after digestate amendment in a pot-based study, there remains a paucity of information on the effects of digestate on nutrient uptake and sward composition in field-based grassland studies.

We aimed to identify the effectiveness of using digestate from food waste as a fertilizer for *L. perenne* by comparing its effects on nutrient (NPK) uptake and sward composition to mineral fertilizer application. Two field-trials were designed that differed in respect to soil texture and rainfall. We hypothesized that digestate would alter sward community composition and improve foliar nutrition content compared to mineral fertilizer inputs. We were also interested to investigate how these responses might vary with season.

Materials and methods

Experimental design

The field experiments, previously described in Pawlett and Tibbett (2015), comprised of 12 plots (5m x 5m with a 0.5m boundary between plots) arranged in a randomised block design (four treatments and three replicates) at two locations: (i) Silsoe (E England; 52° 00' N and 0°26' W; 67 m.a.s.l.), and (ii) Myerscough College (NW England; 53° 44' N and 2° 88' W; 12 m.a.s.l.). Locations differ in annual rainfall (584mm at Silsoe compared to 998mm at Myerscough), soil texture (sandy loam at Silsoe, and a silty clay loam at Myerscough) and available P and K concentrations, which were 69 and 13 mg P kg^{-1} and 236 and 131 mg K kg^{-1} for Silsoe and Myerscough respectively. The dominant species was *L. perenne* L (perennial ryegrass) which was maintained at 20mm (clippings collected) using a cylindrical mower. *L. perenne* was selected as it is commonly sown on amenity and agricultural grasslands. The experimental design comprised of fresh PAS110 (Publically Available Specification: the UK industry quality specification) digestate (Table 1) of food origin (multiple sources) in slurry form applied based on the quantity of total N (as total Kjeldahl Nitrogen to BS EN 13654-2:2001) at two rates (100 and 200 kg N ha^{-1}, equivalent to 22 and 44 t/ha respectively at 0.45% N), a mineral fertilizer applied at 100 kg N ha^{-1}; and a control (no additions). Application rates (based on N) equated to 21 and 42 kg ha^{-1} for total K, and 7.1 and 14.2 kg ha^{-1} for total P (*aqua regia* extractable P and K to BS 7755: Section 3.13:1998). The mineral fertilizer was a liquid (Greenmaster Liquid Spring and Summer: Product ID 342GREEL0250, PC PitchCare) which consisted of 12% total N (as ammoniacal-N), 4% P, and 6% K. Application at 100 kg N ha^{-1} equated to 33 and 50 kg ha^{-1} for P and K respectively. Mineral fertilizer and digestates were both applied using a watering can at the same time, which was seven times throughout the trial (September 2012 through to October 2013).

Sward sampling and analysis

Sampling occurred on 15/07/13 (summer assessment) and 06/11/13 (autumn assessment) two weeks following a digestate application. Sward samples (approximately 100g fresh weight/plot) were sampled using gardening sheers for nutrient analysis. Total N, P and K were determined on dried (40°C) grass material. Total nitrogen was determined by Kjeldahl extraction (Rowell 1994), and total potassium and phosphorus were determined as acid (hydrochloric) extractable nutrients (US EPA Method 3051). Chlorophyll was analyzed as described by (Witham *et al.* 1971) in summer only for the Myerscough trial, but in both seasons at Silsoe. The sward composition was assessed at the same time as sampling using Laycock and Canaway's (1980) 10 point system, commonly used for turfgrass studies (Wheeler *et al.* 2000; Dunn *et al*. 2002). The quadrat was randomly placed within each plot 10 times and the percentage composition of grasses (*L. perenne* at both locations and *Poa annua*-Annual Meadow Grass at Myerscough), broad-leaved weeds, bare soil and dead plants was estimated.

Statistics

Data was analyzed using a factorial ANOVA (Tukey): two field locations (Myerscough/Silsoe) x four treatment variables (control, mineral fertilizer, and digestate applied at 100 and 200 kg N ha^{-1} y^{-1}) using a Repeated Measures design (summer and autumn). Statistics were performed using Statsoft, Inc. (2012) STATISTICA version 11 (data analysis software system), with an alpha value of 0.05.

Results and discussion

Sward Composition

Both the digestate and mineral fertilizer shifted the sward composition in favour ($p<0.05$) of *P. annua* (at Myerscough in summer but not autumn) or *L. perenne* (both locations: autumn and not summer) with reduced ($p<0.05$) broad-leaved weeds and bare soil coverage (Myerscough and not Silsoe: both seasons). The top digestate application rate (200 kgN ha^{-1}) further reduced ($p<0.05$) the proportion of broad leaved weeds but did not affect the rest of the sward composition (Figure 1).

There was little further difference in living sward composition due to digestate or mineral fertilizer amendment, even where treatment effects occurred ($p<0.05$). However, there was a notable reduction in the proportion of dead grass under digestate application at both application rates ($p<0.05$). This only occurred in the summer season at the Myerscough site and suggests that digestate application to turfgrass during the summer may be favourable compared to mineral fertilizer. The reduction of dead grass may be through synergistic effects of nutrients within the digestate, which collectively improved grass health (Figure 1).

Sward nutrients and chlorophyll content

Foliar nutrient concentrations (Table 2) fell within ranges that suggest no deficiencies (Jones 1980). Effects of both the digestate and mineral fertilizer on foliar nutrients (N and K) and sward nitrogen content (Table 2) content were consistent within each season and field-trial locations as there were no interaction effects. However, effects on foliar P concentrations were specific to the location and season. Chlorophyll concentration was greater ($p<0.05$) where either the digestate (200 kgN ha^{-1}) or mineral fertilizer (both@100 kgN ha^{-1}) had been applied compared to the control plots, but increasing digestate application rate (200 kgN ha^{-1}), had no further effect ($p>0.05$). *L. perenne* is often prone to chlorophyll loss or leaf-tip necrosis (scorching) where exposed to ammonium (Watson and Miller 1996). There was no evidence that the high ammonium-N (86% of total N) applied in this study caused any chlorophyll loss at either of the dose application rates.

Application of either digestate or mineral fertilizer at 100 kg N ha^{-1} increased ($p<0.05$) the foliar N and K content compared to the control plots, but with no difference of foliar N or K between the mineral fertilizer and digestate applied plots where applied at the same rate. Increasing the digestate application rate to 200 kg N ha^{-1} further increased ($p<0.05$) foliar N and K. The increase of foliar N is consistent with Andruschkewitsch *et al*. (2013) who also found increased N contents of *L. perenne* with increasing digestate N application rate.

Foliar P concentration did not increase (compared to the control) where digestate was applied at 100 kg N ha^{-1} (Silsoe both seasons), however application of the mineral fertilizer at the same N rate increased foliar P ($p<0.05$). Application of digestate at 200 kgN ha^{-1} was required to increase foliar P to a level that was greater than the control ($p<0.05$) and similar ($p>0.05$) to that of the mineral fertilizer. The increased application rate for effects to become apparent is likely due to the quantity of P within the digestate being lower than N and K (Table 1). Where applied at 100 kgN ha^{-1}, only 7.1 kg P ha^{-1} is applied. At Myerscough in summer, digestate (100 or 200 kgN ha^{-1}) did not affect foliar P compared to the control in either summer or autumn. Raising soil pH is commonly known to cause P to precipitate as calcium (or magnesium) phosphate. The pH of the digestate was a mean of 8.38, thereby it is feasible that the P within the digestate at Silsoe may be unavailable through precipitation. However, the pH of the soil was 7.15 (SE 0.07) at Silsoe and 6.06 (SE 0.06) at Myerscough and so precipitation is not likely to occur. An alternative hypothesis might be that P was not available to *L. perenne* as it was immobilized by the microbial biomass. Microbial immobilization of P has also been reported after sewage sludge application under a *L. perenne* sward (Smith *et al.* 2006).

Season and location effects of sward composition and foliar nutrients may be due to differences of nutrient leaching (Burkitt 2014) and volatilization. The quantity of N and K within the grass was significantly greater during autumn at both locations. It is likely that soil available N was reduced in the summer through NH_4^+-N volatilization. Thereby, although increases of N occurred in the foliar tissue, it may be necessary to keep applying to maintain grass health or alternatively apply before a rainfall event to prevent volatilization (Bouwmeester 1985). Ryan *et al*. (2011) have modelled other factors that might affect NH4+-N volatilization (including method of application).

Conclusions

Application of digestate at 100 kg N ha^{-1} performed similarly to the mineral fertilizer in respect of shift in sward composition, foliar N and foliar K. This indicates the potential for food-sourced digestate as a fertilizer for *L. perenne* for grassland management. However, 200 kg N ha^{-1} y^{-1} was required to increase foliar P to levels similar to the mineral fertilizer (Silsoe). This study suggests that digestate has the potential for use as an alternative fertilizer for turf-grass, but that the land manager should consider as to whether digestate would deliver adequate available phosphorus. This study suggests there may be opportunities for the development of digestate uses as a fertilizer on amenity grassland, such as outfields in sports facilities, but may also be beneficial for parks, and road verges, as well as pasture systems (where grass yield would also be an important consideration). However, it may be important to consider any variability between digestates, which could occur through different feedstocks and digester designs.

Acknowledgments

The data within this paper are derived from the WRAP (Waste and Resources Action Programme) funded project 'Application of Anaerobic Digestate to Sports and Landscaping Turf' (OMK004-026). Thanks are due to Bob Walker (Cranfield

University) for managing the Silsoe field site, Dr Lynda Deeks for help with fieldwork and to the Cranfield University and Myerscough College technical staff for their assistance.

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Figure Legends

Figures 1a-c Sward composition (mean with SE) for the (a) Silsoe-autumn, (b) Myerscough-summer and (c) Myerscough-autumn field-trials. Composition means of individual components within each time and location with the same superscripts (a, b, c) are not significantly different (*P* >0.05). Black bars Control, white bars Fertilizer, spotted Digestate at 100 kg N ha^{-1}, striped bars Digestate at 200 kg N ha^{-1}.

Table 1 Digestate Characteristics (n=7)

Analysis	mean	SE
Total solids (%)	3.31	0.16
pH	8.38	0.02
Conductivity 1:6 (µS/cm)	5614	263
Total N (% w/w)	0.45	0.03
Ammonium-N (mg kg^{-1})	3960	245
Total P (mg kg^{-1})	327	6
Total K (mg kg^{-1})	938	82

Table 2 Foliar nutrient and chlorophyll concentration

		Myerscough		Silsoe	
Nutrient	**Treatment**	**Summer**	**Autumn**	**Summer**	**Autumn**
N (% w/w)	Control	3.12^{a}	4.56^{a}	1.36^{a}	2.66^{a}
	Fertilizer	3.16^{b}	4.76^{b}	1.79^{b}	3.56^{b}
	Digestate: 100 kg N ha^{-1}	3.16^{b}	4.85^{b}	1.71^{b}	3.47^{b}
	Digestate: 200 kg N ha^{-1}	3.55^{c}	5.18^{c}	2.07^{c}	4.12^{c}
	Pooled SE	0.10	0.18	0.10	0.18
	Significance	***	***	***	***
P (% w/w)	Control	0.44^{a}	0.37^{a}	0.32^{a}	0.45^{a}
	Fertilizer	0.48^{a}	0.41^{a}	0.38^{bc}	0.57^{b}
	Digestate: 100 kg N ha^{-1}	0.46^{a}	0.41^{a}	0.35^{ab}	0.48^{a}
	Digestate: 200 kg N ha^{-1}	0.42^{a}	0.40^{a}	0.40^{c}	0.55^{b}
	Pooled SE	0.01	0.01	0.01	0.01
	Significance	***	***	***	***
K (% w/w)	Control	2.82^{a}	3.41^{a}	1.58^{a}	2.20^{a}
	Fertilizer	2.98^{b}	3.44^{b}	1.93^{b}	2.72^{b}
	Digestate: 100 kg N ha^{-1}	2.90^{bc}	3.68^{bc}	1.85^{bc}	2.71^{bc}
	Digestate: 200 kg N ha^{-1}	3.06^{c}	4.12^{c}	2.00^{c}	2.94^{c}
	Pooled SE	0.08	0.19	0.08	0.19
	Significance	**	**	**	**
Chlorophyll (mg g^{-1})	Control	1.94^{a}	-	1.18^{a}	1.17^{a}
	Fertilizer	2.28^{b}	-	1.67^{b}	1.31^{b}
	Digestate: 100 kg N ha^{-1}	2.27^{ab}	-	1.65^{b}	1.62^{b}
	Digestate: 200 kg N ha^{-1}	2.74^{b}	-	1.66^{b}	1.54^{b}
	Pooled SE	0.14		0.13	0.13
	Significance	**		*	*

** $P<0.01$, *** $P<0.001$. Means with the same superscripts (a, b, c) within each location and season within the column are not significantly different ($P > 0.05$). – not determined