ARE WE UNDERESTIMATING BIOSOLIDS CROP AVAILABLE NITROGEN SUPPLY?

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Abstract

Biosolids are a valuable source of plant available nutrients, particularly nitrogen (N) and phosphorus. Many research studies that have quantified the N supply properties of biosolids have only measured release to the next crop grown, and have not quantified N supply to following crops. At ADAS Gleadthorpe, the N supply properties of two contrasting biosolids products were measured over four winter wheat cropping years (2006 to 2009). Mean N supply in the first cropping year was c.13% of total N applied and c.10%, c.4% and c.4% in cropping years two, three and four, respectively. Over the four cropping years, N supply was equivalent to 31% of the total N applied. Based on a single application of 250 kg/ha total N, biosolids crop available N supply over the four years was equivalent to c.77 kg/ha N or £77/ha (based on a manufactured fertiliser N price of 100 p/kg N)

Key words

Biosolids, crop available nitrogen, fertiliser, nitrogen, plant nutrient, sewage sludge.

Introduction

The application of biosolids (i.e. treated sewage sludge) to agricultural land is regarded as the *Best Practicable Environmental Option* in most circumstances (Defra, 2007). Biosolids provide a valuable source of plant available nutrients and organic matter that can be of benefit to soil quality and fertility. In 2008, *c.*77% of UK sludge production was recycled to farmland as biosolids (Water UK, 2010). Digested cake is the most common biosolids product applied to farmland. However, the development of new technologies, such as thermal drying, has produced new enhanced treated biosolids products that are likely to have different nutrient supply properties compared with conventional digested sludge cake products. Thermally dried biosolids have a number of advantages compared with conventionally treated products, viz.: the volume of material to be transported is reduced, the material can be pelletised and is therefore relatively easy to spread, and the product is low in odour, however, they are energy intensive to produce. Typical nitrogen (N) content data for contrasting biosolids products are summarised in Table 1 below (Defra, 2010). However, the nutrient characteristics of these products will vary depending on the individual source and treatment processes undergone.

Table 1: Typical total and readily available nitrogen content of biosolids (fresh weight basis)

Biosolids	Dry Matter (%)	Total N (kg N/t)	Readily available N (kg N/t)
Digested cake	25	11	1.6
Thermally dried	95	40	2.0
Lime stabilised	40	8.5	0.9
Composted	60	11	0.6

Source: Defra (2010)

The percentage of the total nitrogen content that will be available to the next crop grown varies in relation to biosolids type, application timing and method (surface applied or incorporated), soil type and rainfall. Nitrogen will also be supplied to crops in the seasons following application, according to "The Fertiliser Manual (RB209)" (Defra, 2010) "in the second year, digested cake has been shown to supply around 10% of the total N applied, and around 5% in the third year". However, there have been relatively few studies on the residual fertiliser N value of biosolids products, with most studies focusing on N supply to the next crop grown following application.

Severn Trent Water established pilot plants at the Worksop and Coventry Sewage Treatment Works to manufacture thermally dried biosolids and plate-pressed vacuum dried biosolids, respectively. Although similar biosolids types (thermally dried - TD and plate-pressed vacuum dried - PPVD) had been produced and used in other parts of the country, the products were new to Severn Trent Water and hence it was important to quantify and demonstrate the N supply benefits of these new biosolids products. The objective of this study was to quantify the N supply properties of a single (2006 cropping year) application of Severn Trent Water TD and PPVD biosolids to winter wheat over four cropping years (2006-9).

Methodology

Experimental plots were established at ADAS Gleadthorpe (near Mansfield in Nottinghamshire) in September 2005 to evaluate the fertiliser N replacement value and residual N supply properties of TD and PPVD biosolids applied at 125 and 250 kg N/ha, using winter wheat as the test crop. In the first cropping year, the biosolids treatments were applied in either September 2005 (autumn applications - TD biosolids only) or top dressed in spring 2006 (spring applications - TD and PPVD biosolids). The biosolids and manufactured fertiliser N treatments are summarised in Table 2. The manufactured fertiliser N response treatments were applied as top dressings in spring of each cropping year (i.e. 2006, 2007, 2008 and 2009) at the rates specified in Table 2.

Table 2: Biosolids treatment details

Number	Treatment
1	Untreated control
	Thermally dried biosolids treatments
2	TD autumn applied (2005) at 125 kg total N/ha (TD 125 Aut)
3	TD autumn applied (2005) at 250 kg total N/ha (TD 125 Aut)
4	TD spring applied (2006) at 125 kg total N/ha (TD 125 Spr)
5	TD spring applied (2006) at 250 kg total N/ha (TD 125 Spr)
	Plate-pressed vacuum dried
6	PPVD spring applied (2006) at 125 kg total N/ha (PPVD 125 Spr)
7	PPVD spring applied (2006) at 250 kg total N/ha (PPVD 250 Spr)
	Manufactured fertiliser treatments (annually applied)
8	50 kg N/ha
9	100 kg N/ha
10	150 kg N/ha
11	200 kg N/ha
12	250 kg N/ha

The target biosolids total N application rates of 125 and 250 kg N/ha were based on the analyses summarised in Table 3.

Table 3: Thermally dried and plate-pressed vacuum dried biosolids properties

Property*	Thermally dried		Plate-pressed vacuum dried
	Autumn 2005	Spring 2006	Spring 2006
Dry matter (%)	90.6	93.6	78.4
pH	6.3	6.7	7.3
Total N (kg/t dm)	37.0	30.8	41.7
Readily available N (% of total N)	<1	<1	4
Total P_2O_5 (kg/t dm)	58.9	46.0	83.4
Total K_2O (kg/t dm)	0.96	1.33	1.45
Total MgO (kg/t dm)	2.98	3.32	4.64
Total SO_3 (kg/t dm)	19.8	16.5	21.3
Total Zn (mg/kg dm)	1173	1004	553
Total Cu (mg/kg dm)	229	277	328
Total Cd (mg/kg dm)	3.4	2.62	1.4
Total Cr (mg/kg dm)	23.8	26.3	62.3
Total Ni (mg/kg dm)	14.0	16.5	114
Total Pb (mg/kg dm)	42.9	52.0	87.2
Total Hg (mg/kg dm)	0.56	0.61	1.62

*units: kg/t dm = kilograms/tonne dry matter; mg/kg dm = milligrams/kilogram dry matter

Results

Grain yields and N offtakes (August 2006); crop year one

The application of TD and PPVD biosolids increased grain yields by *c*.1.3 t/ha above the untreated control (P<0.001) in 2006, with no clear difference between the two biosolids types (P>0.05; Figure 1). Yields were slightly greater from the higher rate (250 kg N/ha) biosolids applications (0.2-0.7 t/ha) and from the spring compared with the autumn applications of TD biosolids (0.2-0.6 t/ha), although these differences could not be confirmed statistically (P>0.05). Grain N offtakes showed a similar trend to grain yields, with increases of *c.*26 kg/ha measured on the biosolids treatments (P<0.001) above the untreated control, and no clear differences between the two biosolids types.

The yield response to manufactured fertiliser N (Figure 1) was described by a linear plus exponential function (yield=a+br^N+cN) (George, 1984). The economic optimum fertiliser N rate (Nopt) was calculated to be 122 kg/ha (at a break-even ratio of 5 kg grain per 1 kg fertiliser N applied), with an optimum yield of 7.54 t/ha. Using this relationship, it was possible to calculate the fertiliser N replacement value and N utilisation efficiency of the biosolids treatments, using the internationally accepted method (Chambers *et al.,* 1999; Schroder and Stevens, 2004; Schroder, 2005) (Table 4). The mean fertiliser N replacement value was 21 kg N/ha across the six treatments (range 15-35 kg N/ha), with a mean N use efficiency of 13% (mean for TD = 12%; mean for PPVD = 15%) and no difference (*P*>0.05) between the two biosolids types.

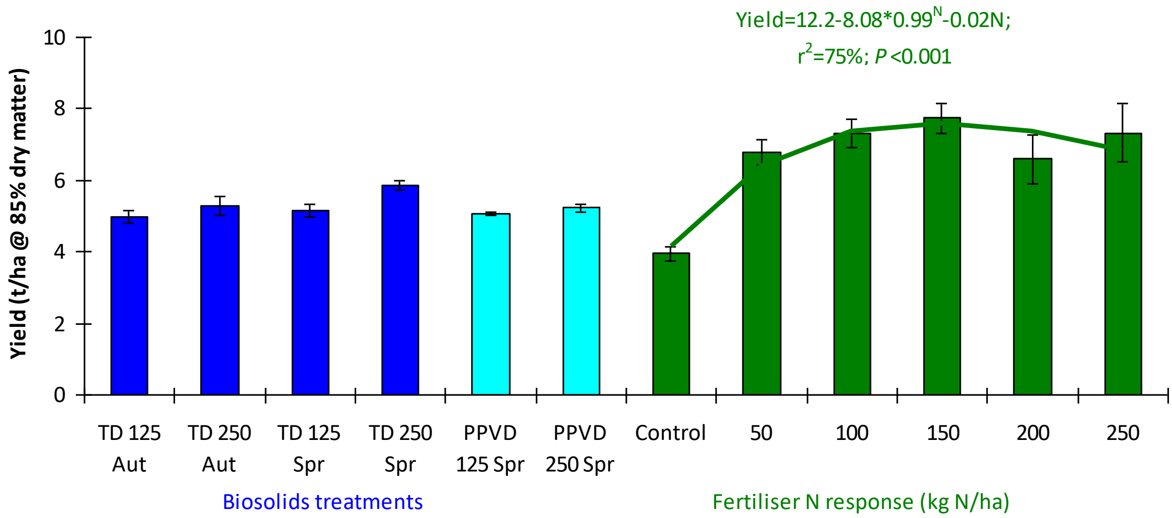

Figure 1: Effect of biosolids and manufactured fertiliser N additions on grain yields (August 2006)

Table 4: Fertiliser N replacement values (kg/ha) and N utilisation efficiencies (%) of TD and PPVD biosolids applications at harvest in 2006 (crop year one), 2007 (crop year two), 2008 (crop year three) and 2009 (crop year four).

Treatment	**Total N applied (kg/ha)**	**Fertiliser N replacement value (kg/ha)**				**Utilisation efficiency (%)**			
		2006	2007	2008	2009	2006	2007	2008	2009
TD 125 Aut	113	15	15	3	7	14	13	3	6
TD 250 Aut	227	21	18	4	6	10	8	2	3
TD 125 Spr	156	18	16	4	1	12	10	3	1
TD 250 Spr	312	35	20	15	2	11	7	5	1
PPVD 125 Spr	94	17	10	7	7	18	11	7	7
PPVD 250 Spr	188	20	16	2	4	11	9	1	2

Grain yields and N offtakes (August 2007); crop year two

There was a *residual* effect in crop year two from the year one TD biosolids applications, with grain yields increased by *c*.1 t/ha above the untreated control (*P*<0.001; Figure 2). Similarly, the *residual* effect of the year one 125PPVD (*P*>0.05) and 250PPVD (*P*<0.05) biosolids applications increased yields in crop year two by *c*.0.5 t/ha and *c*.0.9 t/ha above the untreated control, Figure 2. Grain N offtakes showed a similar trend to grain yields with the TD and PPVD biosolids applications in crop year one increasing grain N offtakes by *c.*10 kg/ha (range 5-17 kg/ha), although these increases could not be confirmed statistically (P>0.05).

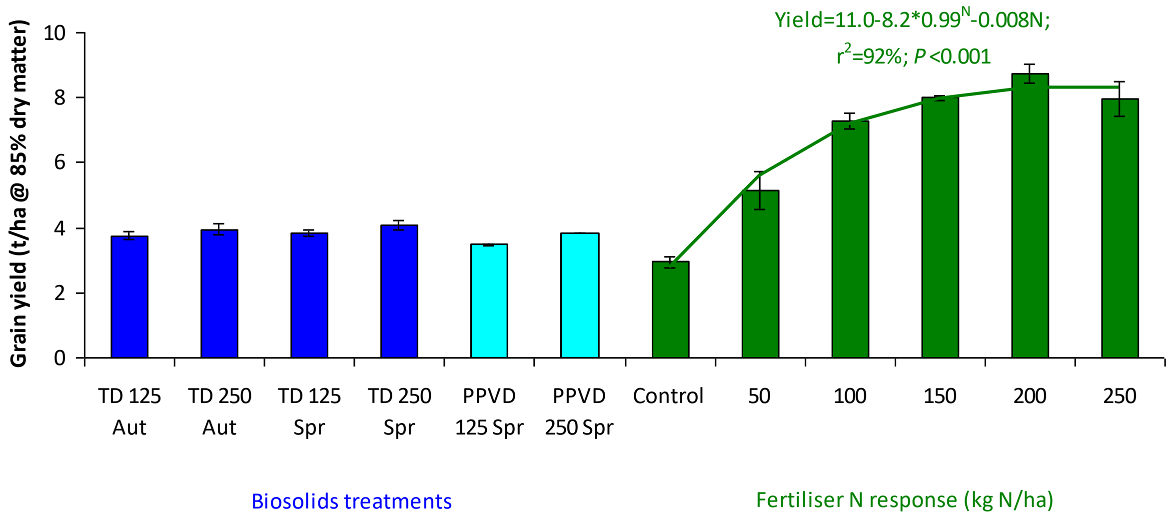

Figure 2: Effect of biosolids and manufactured fertiliser N additions on grain yields (August 2007)

The economic optimum fertiliser N rate (Nopt) was calculated to be 184 kg/ha (at a break-even ratio of 5 kg grain per 1 kg fertiliser N applied), with an optimum yield of 8.21 t/ha. Calculated fertiliser N replacement values were in the range 15-20 kg N/ha for TD and 10-16 kg N/ha for the PPVD biosolids; mean N efficiencies were 10% (range 7-13%) for both biosolids types, Table 4.

Grain yields and N offtakes (August 2008); crop year three

The TD biosolids applications in crop year one had a small *residual* effect on grain yields (*c*.0.2 t/ha increase) in crop year three (P>0.05), Figure 3. There was little *residual* effect of the 125PPVD and 250PPVD year one biosolids applications. Similar to the trends in grain yields, there was little *residual* effect of the year one TD or PPVD biosolids applications on N offtakes in crop year three (P>0.05).

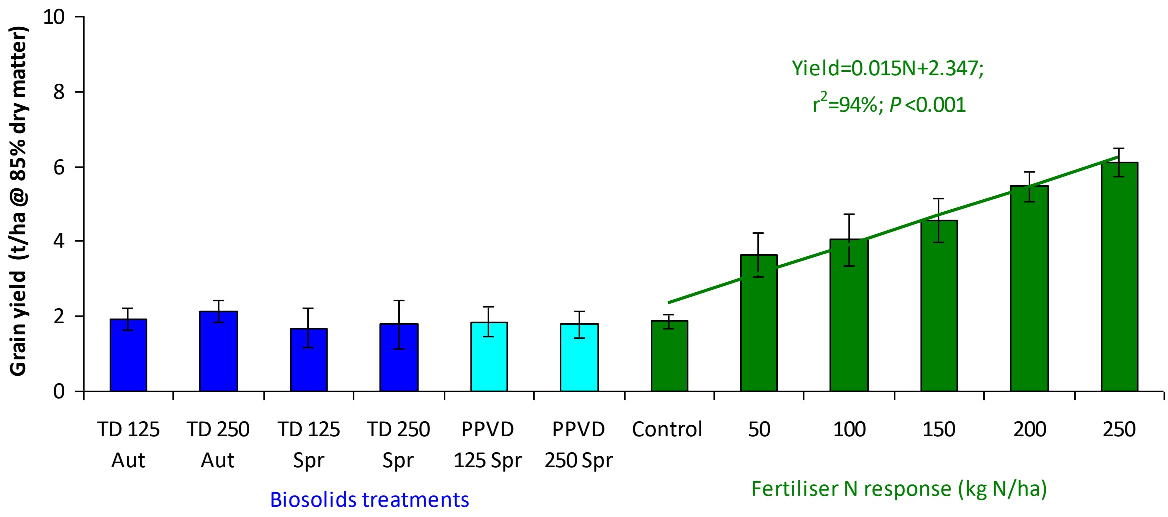

Figure 3: Effect of biosolids and manufactured fertiliser N additions on grain yields (August 2008)

The TD and PPVD biosolids applications in crop year one had *residual* fertiliser N replacement values in cropping year three (2008) in the range 3-15 kg N/ha (mean = 3% N efficiency) and 2-7 kg N/ha (mean = 4% N efficiency), respectively, Table 4.

Grain yields and N offtakes (August 2009); crop year four

The TD biosolids applications in crop year one had a small *residual* effect on grain yields (*c*.0.1 t/ha increase above the untreated control) in crop year four (P>0.05), Figure 4. Similarly, the PPVD biosolids applications in crop year one had a small *residual* effect (P>0.05) on grain yields (0.1-0.3 t/ha increase above the untreated control). There was a small (P>0.05) increase in N offtakes above the untreated control, from both the year one TD (0-7 kg N/ha) and PPVD (2-4 kg N/ha) biosolids applications.

The TD and PPVD biosolids applications in crop year one (2006) had *residual* fertiliser N replacement values in crop year four (2009) in the range 1-7 kg N/ha (mean = 3% N efficiency) and 4-7 kg N/ha (mean = 5% N efficiency), respectively, Table 4.

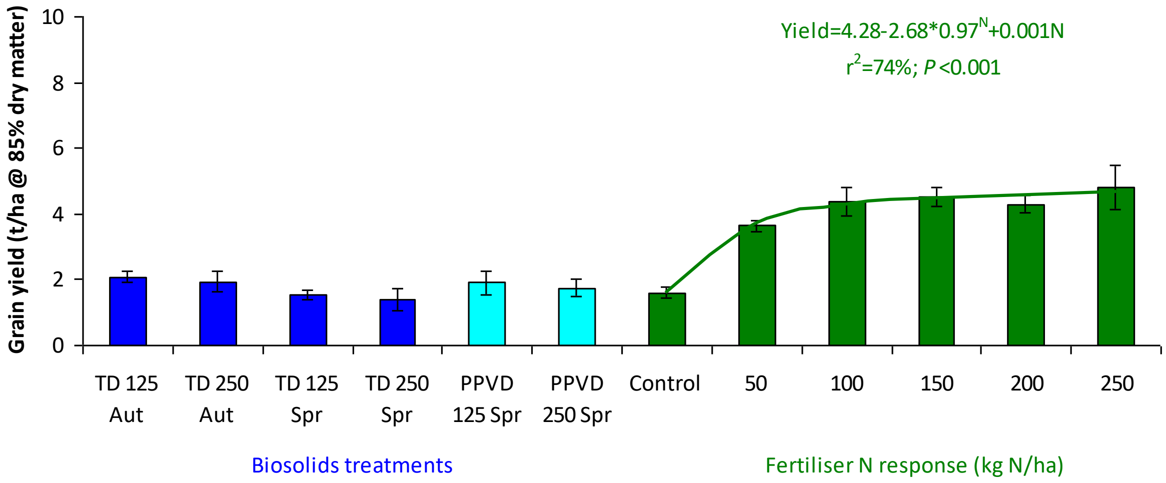

Figure 4: Effect of biosolids and manufactured fertiliser N additions on grain yields (August 2009)

Financial value of biosolids application

Over the four cropping years, the mean N utilisation efficiency of TD biosolids was 28% (12%+10%+3%+3%) and PPVD biosolids 34% (15%+10%+4%+5%), Table 5. The mean N supply (for the two biosolids types) was equivalent to *c*.31% of the total N applied over the four cropping years. Based on a single application of 250 kg/ha total N, biosolids crop available N supply over the four years was equivalent to £77/ha (assuming a manufactured fertiliser N price of 100 p/kg N).

Table 5: Fertiliser N replacement values (£/ha) and N utilisation efficiencies (%) of TD and PPVD biosolids applications in 2006 (crop year one), 2007 (crop year two), 2008 (crop year three) and 2009 (crop year four).

Biosolids	**Fertiliser N replacement value (£/ha)**					**Utilisation efficiency (%)**				
	2006	2007	2008	2009	Total	2006	2007	2008	2009	Total
TD	£30	£25	£7.50	£7.50	£70	12	10	3	3	28
PPVD	£37.50	£25	£10	£12.50	£85	15	10	4	5	34
Mean	£34	£25	£8	£10	£77	13.5	10	3.5	4	31

Discussion

In this study, mean N supply in the first cropping year was equivalent to *c*.13% of total N applied, which was consistent with the range of 10 and 20% N availability to the next crop grown reported in "The Fertiliser Manual (RB209)" (Defra, 2010).

Thermally dried biosolids typically contain less readily available nitrogen - RAN (nitrogen that is potentially available for rapid crop uptake) than conventional sludge cake products; thermally dried *c*.5% RAN compared with *c*.15% RAN for digested cake (Defra, 2010). In this study, biosolids RAN concentrations were <1% and *c*.4% of the total N contents of TD and PPVD biosolids, respectively. The low RAN content of thermally dried biosolids is thought to be due to the volatilisation of ammonia during the treatment process (Morris *et al.,* 2003). Therefore, these biosolids types act as a slow-release N source, dependent on biological transformation of the organic N into crop available N forms.

There have been relatively few studies of the residual fertiliser N value of biosolids products, with most studies focusing on N supply to the next crop grown following application. In the UK, Morris *et al.* (2003) showed that residual crop N availability was on average 15% in crop year two, whilst Cogger *et al.* (2004) in studies in the USA measured N availabilities of 5-8% in the second year following application of thermally dried biosolids. Similar to the work of Morris *et al.* (2003) and Cogger *et al.* (2004), this study, clearly demonstrated that TD and PPVD biosolids applications can supply valuable amounts of crop available N to following crops (*c*.10%, *c*.4% and *c*.4% in cropping years two, three and four, respectively). Clearly, it is essential to consider the N supply properties of biosolids over the longer-term, otherwise crop available nitrogen supply and the financial value of biosolids will be underestimated.

Conclusions

This study has shown that a single application of biosolids is a valuable source of crop available N to next and subsequent crops. Mean N supply in the first cropping year was *c*.13% of total N applied and *c*.10%, *c*.4% and *c*.4% in cropping years two, three and four, respectively. Over the four cropping years N supply was equivalent to 31% of the total N applied. Based on a single application of 250 kg/ha total N, biosolids crop available N supply over the four years was equivalent to *c*.77 kg/ha N or

£77/ha (based on a manufactured fertiliser N price of 100 p/kg N), without taking into account the significant amounts of phosphate and valuable organic matter that are also supplied.

Acknowledgements

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