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ORIGINAL ARTICLE

Spent mushroom compost as a nitrogen source for spring barley

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Abstract Spent mushroom compost (SMC) contains a range of plant nutrients, including nitrogen (N), a large proportion of which originate from arable crops. Using SMC as an organic fertilizer for crops recycles these nutrients. Effective use of SMC in fertilizer regimes requires knowledge of the nitrogen fertilizer value (NFV) of the SMC, which is the amount of mineral fertilizer N required to give the same N yield, or marketable yield, as an application of SMC. The objectives of these experiments were to evaluate the effect of SMC on spring barley grain yield and quality and to determine its NFV. Experiments were carried out on two soils, light- and medium-textured, over 3 years (2008–2010). The experiments compared the yield response and N uptake of spring barley to fertilizer N with and without SMC. SMC application gave similar or higher grain yield and N uptake compared to fertilizer only treatments at corresponding fertilizer N rates. SMC had no significant ($P > 0.05$) effect on the economic optimum fertilizer N rate but the maximum yield was significantly ($P < 0.05$) higher where SMC was applied in two of the six experiments. Effects of SMC on grain quality were small. Results indicated that the NFV, expressed as a proportion of the total N applied in SMC, ranged from 0.05 to 0.29 kg kg^{-1} N applied in SMC, with a mean of 0.15 kg kg^{-1}. It is concluded that SMC can contribute to the nitrogen nutrition of small grain cereal crops in high yield potential environments.

Keywords Spent mushroom compost · Fertilizer value · Nitrogen · Barley

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Introduction

Mushroom compost is initially formulated with a mixture of wheat straw, poultry manure and/or horse manure, gypsum and nitrogen supplements (Maher et al. 1993; Jordan et al. 2008). After it has been used for producing the mushroom crop it becomes a waste product to the mushroom industry and is known as spent mushroom compost (SMC) or spent mushroom substrate. SMC has many potential uses including bioremediation of contaminated lands, energy production, animal bedding and disease control (Lau et al. 2003; Finney et al. 2009; Phan and Sabaratnam 2012; Yohalem et al. 1994). In field crop production the principal uses of SMC are as an organic fertilizer (Gerrits 1994; Mullen and McMahon 2001; Maher 1994) and as a soil conditioner for enhancing physical and/or chemical properties of soil (Mullen and McMahon 2001; Courtney and Mullen 2008).

SMC contains a range of plant nutrients but many of these are in forms not readily available to plants and are only slowly mineralised (Stewart et al. 2000). This is particularly the case for nitrogen. Maher et al.

(2000) reported that only 10.8 % of the total N in SMC was present in the plant available forms of nitrate and ammonium, the remainder being in organic forms. Similarly, Becher and Pakula (2014) and Stewart et al. (1998b) both reported that mineral N comprised less than 10 % of total N in SMC. Studies have also shown that a large proportion of the organic N in SMC is present in forms that are not readily mineralised and therefore not likely to contribute significantly to the nitrogen requirements of a crop fertilized with SMC (Stewart et al. 1998a). This suggests that when SMC is used as a source of N for crops, its contribution to the N nutrition of that crop will be small.

Typically SMC will be used to supply only part of a crops fertilizer N requirement, with the remainder applied as mineral fertilizer, particularly in high yielding environments. Failure to properly account for the supply of N from SMC can lead to incorrect decisions regarding a crops requirement for fertilizer N which, in turn, can lead to reduced profitability for the farmer or loss of N to the environment. The ability of an organic manure to supply N to a crop can be expressed as the nitrogen fertilizer replacement value (NFV), which can be defined as the amount of mineral fertilizer N required to give the same N yield, or marketable yield, as an application of an organic manure such as SMC (Schroder 2005). This requires that the contribution of the organic manure to a crops N uptake or yield is compared to the response of the crop to a range of fertilizer N rates in the absence of the organic manure. When the NFV is expressed as a proportion of N applied in the organic manure it can be referred to as relative NFV (rNFV).

A number of authors have evaluated effects of SMC on yield and N uptake of cereal crops compared to a control not receiving SMC but did not include a fertilizer N response that would allow calculation of NFV as defined here (Wuest et al. 1995; Courtney and Mullen 2008). There are relatively few field studies determining the NFV of SMC for small grain cereals, particularly under high yielding European conditions. Duggan (2004) achieved rNFV values, calculated using N yield, of 0.22 and 0.20 kg N kg^{-1} N applied in SMC for application rates of 16 and 32 t ha^{-1} respectively when SMC was used as a fertilizer source for spring wheat under Irish conditions.

The objectives of this work were to determine the effect of SMC, from *Agaricus bisporus* production, on grain yield and grain quality of field grown spring barley under high yielding north-west European conditions and to determine the NFV of SMC when used as a source of nitrogen.

Materials and methods

Two field experiments, one on a light textured sandy loam soil and one on a medium textured clay loam soil, were established in each of three seasons, 2008–2010, at the Teagasc, Crops Research Centre, Carlow, Ireland (52.86° N, 6.92° W, 54 m a.m.s.l.). The light textured soil was of the Athy Complex, shallow component, which are Eutric Cambisols with stony or gravelly coarse sandy loam texture and low moisture-holding capacity. The medium soil type was of the Mortarstown series, which is an Alfisol Orthic Typudalf, with a medium clay loam texture and a high moisture-holding capacity (Conry and Ryan 1967). A new area was used for each soil type in each season either in the same or an adjacent field and both sites were located within 500 m of each other within a season. In each case the site had been in tillage for at least 20 years and the previous crop was a cereal.

A split-plot design with four replications was used for each experiment. SMC application rate was the main plot factor and fertilizer N application rate was the split-plot factor. Details of SMC treatments and fertilizer N application rates for each experiment are presented in Table 1. Two SMC application rates were included in all experiments; 0 t ha^{-1}, subsequently denoted as SMC_0, and 15 t ha^{-1} freshweight (14 t ha^{-1} on the medium soil in 2008), subsequently denoted as SMC_L. In addition, on the light soil only, a third, higher, SMC application rate (30 t ha^{-1} freshweight) was included at two fertilizer N rates, 0 kg N ha^{-1} and the highest rate of fertilizer N in the respective experiment. This higher rate of SMC is subsequently denoted as 'SMC_H'. Fresh SMC was obtained from a local producer operating a Dutch shelving system 1–2 weeks before use. SMC was applied by hand and incorporated by mouldboard ploughing within 48 h. Samples of the SMC were taken at the time of application and analysed for % DM, total N, and NH_4–N. PK fertilizer was applied to plots not receiving SMC at the time of SMC application to balance the phosphorus and potassium applied in the SMC.

Fertilizer N rates varied between experiments (Table 1). Fertilizer N rates were 0, 15, 30, 50, 85,

Table 1 SMC treatments and fertilizer N rate used at each SMC rate

SMC treatment		SMC_0	SMC_L	SMC_H
SMC rate (t ha^{-1})		0	15[a]	30
Soil	Year	Fertilizer N rates (kg N ha^{-1})		
Light	2008	0, 15, 30, 50, 85, 120, 155, 174		0, 174
	2009	0, 15, 30, 50, 85, 120, 155, 190		0, 190
	2010	0, 15, 30, 50, 85, 120, 155, 190		0, 190
Medium	2008	0, 27, 50, 85, 118, 155, 185		–[b]
	2009	0, 15, 30, 50, 85, 120, 155, 190		–
	2010	0, 15, 30, 50, 85, 120, 155, 190		–

[a] SMC application rate on the medium soil in 2008 was 14 t ha^{-1}

[b] SMC_H was not included in the experiments on the medium soil in any year

Table 2 Dates of SMC application and incorporation and spring barley sowing and harvest dates

Soil	Year	SMC		Spring barley	
		Application	Ploughing	Sowing	Harvest
Light	2008	Apr 03	Apr 04	Apr 04	Aug 15
	2009	Mar 12	Mar 13	Mar 13	Aug 12
	2010	Mar 02	Mar 04	Mar 14	Aug 05
Medium	2008	Mar 05	Mar 07	Mar 19	Aug 23
	2009	Feb 26	Feb 26	Mar 2	Aug 13
	2010	Mar 03	Mar 03	Mar 11	Aug 06

120, 155 and 190 kg N ha^{-1} in 2009 and 2010. In 2008 fertilizer N rates were 0, 27, 50, 85, 118, 155, and 185 kg N ha^{-1} on the medium soil and 0, 12, 27, 49, 76, 102, 124, 155 and 174 kg N ha^{-1} on the light soil. Split-plot length was 12–15 m and width was 2.3 m.

Spring barley (*cv*. Wicket) was sown following cultivation of the ploughed soil. Dates of SMC application and incorporation and crop planting and harvest are given in Table 2. Fertilizer N was applied as calcium ammonium nitrate. For application rates up to and including 50 kg N ha^{-1} all N was applied at GS11-13 (Zadoks et al. 1974). For higher rates 50 kg N ha^{-1} was applied at GS11-13 and the remainder at GS 21-23.

Nutrients other than nitrogen were applied uniformly over the experimental area at rates equal or higher than those recommended for spring barley production (Coulter and Lalor 2008); nutrients applied in SMC or to balance nutrients in the SMC were disregarded in calculating required nutrient amounts. Pest, disease and weed control was according to standard farm practice.

At crop maturity, just prior to combine harvest, samples of whole barley plants were taken from each plot. Samples were threshed to separate grain and straw and both fractions were dried at 70 °C for 48 h. Harvest index (HI) was determined as the ratio of grain DM to total DM of the threshed sample. Nitrogen concentration of the straw component, after milling through a 2 mm sieve, was determined using Dumas combustion (Leco FP428, Leco Corp., St. Joseph, MI). Grain yield (adjusted to 85 % DM) was determined using a small plot combine harvester. Grain protein concentration and specific weights were determined using a whole grain analyser (Infratec 1241 grain analyzer; Foss Tecator AB, Hoganas, Sweden). Thousand grain weight (TGW) was determined using an electronic grain counter (Contador, Pfeuffer, Kitzingen Germany). Grain N uptake was determined as the product of grain yield and grain N concentration (calculated from grain protein concentration using a conversion factor of 6.25). Crop N uptake (N_{upt}) was calculated as the sum of grain N uptake and straw N uptake. Straw N uptake was calculated as the product of straw N concentration and straw DM yield [calculated as grain yield × (1 − HI)].

Statistical analysis

Data were initially subjected to ANOVA using PROC MIXED and means of SMC_0, SMC_L, and for the light soil, SMC_H without fertilizer N were compared using Fishers Protected LSD. Subsequently grain yield (Y) and N_{upt} response to fertilizer N for the SMC_0 and the SMC_L treatments within each site/year was modelled using PROC NLMIXED taking into account the split-plot nature of the experiments (Knezevic et al. 2002). Analyses were performed with SAS 9.3. (SAS Institute Inc., Cary, NC, USA) The yield and N uptake response to fertilizer N for SMC_H was not modelled since only two levels of fertilizer N were applied to SMC_H. The grain yield (t ha^{-1}) and N uptake (kg ha^{-1}) response to increasing fertilizer N rate for both SMC_0 and SMC_L was modelled using the following models

$$Y = aN^2 + bN + c \quad (1)$$

$$N_{upt} = bN + c \quad (2)$$

where N is applied fertilizer N rate; a (quadratic), b (linear) and c (intercept) are constants obtained by model fitting for the SMC_L and SMC_0 treatments.

ESTIMATE statements were constructed to compare characteristics of the response curves and determine NFV of the SMC. N_{max}, the fertiliser N rate giving the maximum yield, was estimated for SMC_L and SMC_0 for each experiment by letting the first order derivative of Eq. 1 equal zero. The yield corresponding to N_{max} was calculated by inserting N_{max} into Eq. 1. Economic optimum N rates (N_{opt}) for yield were calculated by setting the first derivative of Eq. 1 equal to the ratio of the price per kilogram of fertilizer N and the price per kilogram of grain. A price ratio of 7:1 was used which is typical for spring barley production in Ireland (Wall et al. 2015; Central Statistics Office 2015). Yield at N_{opt} (Y_{Nopt}) was calculated by inserting N_{opt} into Eq. 1.

NFV based on yield (NFV_{yield}; kg ha^{-1}) was estimated by setting the function describing yield response to fertilizer N for SMC_0 equal to the grain yield obtained with SMC_L or SMC_H without fertilizer N (i.e. at 0 kg N ha^{-1}). For this calculation the mean value calculated during ANOVA was used as the estimate of yield for SMC_L or SMC_H at 0 kg N ha^{-1}. Relative NFV ($rNFV_{yield}$; kg kg^{-1} N applied in SMC) was calculated as

$$rNFV_{yield} = NFV_{yield}/N_{SMC} \quad (3)$$

where N_{SMC} was the total N applied in the SMC. NFV determined using N uptake (NFV_{Nupt}) was estimated by setting the function describing N uptake response to fertilizer N for SMC_0 equal to N uptake where SMC_L or SMC_H, but no fertilizer N, was applied. Relative NFV ($rNFV_{Nupt}$; kg kg^{-1} N applied in SMC) was calculated as

$$rNFV_{Nupt} = NFV_{Nupt}/N_{SMC} \quad (4)$$

The net benefit, expressed in terms of yield, of using SMC as part of the N fertilization of spring barley, taking into account the NFV value of the SMC and using a price ratio of 7:1 was calculated as

$$Net\ benefit = \left[Y_{(Nopt\,(SMCL)-NFVyield)} - Y_{Nopt\,(SMC0)}\right] + \left[NFV_{yield} * 0.007\right] \quad (5)$$

where $Y_{(Nopt(SMCL)\,-\,NFVyield)}$ is the yield, calculated using Eq. 1, where N rate is equal to N_{opt} for SMC_L less NFV_{yield} and $Y_{Nopt(SMC0)}$ is the yield at N_{opt} for SMC_0. The net benefit was only calculated for SMC_L. For the purposes of the calculations no cost was attributed to the SMC or its application as reliable values were not available. For all statistical analysis effects were deemed significant where $P < 0.05$.

Results

The composition of the spent mushroom compost used is shown in Table 3. The DM content ranged from 25.6 to 30 %. Total N content of the SMC varied from 5.19 to 7.21 g kg^{-1}. This variation in N content gave rise to differences in the amount of N applied in the SMC in the different experiments. The N amounts applied in the first season were lowest with the highest amounts applied in the second season. There was

Table 3 Nitrogen concentrations and nitrogen loadings of SMC applications for each experiment in each year

Soil	Year	DM (%)	N conc.		N application rate			
					Total N		NH_4-N	
			N (g kg^{-1} fresh)	NH_4–N (g kg^{-1} fresh)	SMC_L (kg N ha^{-1})	SMC_H (kg N ha^{-1})	SMC_L (kg N ha^{-1})	SMC_H (kg N ha^{-1})
Light	2008	27.3	5.19	0.87	77.8	155.6	13.3	26.5
	2009	27.0	6.81	0.63	102.2	204.3	9.6	19.1
	2010	26.4	6.20	1.69	93.0	186.0	25.4	50.7
Medium	2008	30.0	5.37	0.65	75.2	–	9.2	–
	2009	27.0	7.21	0.66	108.2	–	9.9	–
	2010	25.6	6.10	0.85	91.5	–	12.7	–

considerable variation in the proportion of total N present as NH_4-N with values ranging from 9.2 to 27.3 % which gave rise to large differences in the amount N applied as NH_4-N.

Grain yield

Yield where no fertilizer N or SMC were applied ranged from 2.25 to 4.22 t ha^{-1} (Fig. 1). Comparison of the effects of SMC on yield in the absence of fertilizer N indicated that SMC_L significantly increased yield in 2008 but not in 2009 or 2010 on the medium textured soil. On the light soil SMC_L significantly increased yield in 2008 but not in the other years, where no fertilizer N was applied. SMC_H significantly increased yield compared to the lower rate in 2008, but not in other years. SMC_H increased yield compared to SMC_0 in 2008 and 2010, but not in 2009.

In general the effects of SMC_L on yield response to fertilizer N were small (Table 4; Fig. 1). SMC_L addition significantly reduced the slope of the response curve in 2008 on the light soil but had no significant effect in 2009 or 2010 or in any season on the medium soil. SMC_L had no significant effect on yield at N_{max} on the light soil in any season. On the medium soil SMC_L significantly increased yield at N_{max} in 2009 and 2010 but not in 2008. However, calculated N_{max} was greater than the highest rate applied in some experiments and comparisons involving these values must be treated with caution.

While SMC_L gave lower N_{opt} on the light soil and increased N_{opt} on the medium soil compared to the fertilizer N only treatment the differences were not statistically significant (Table 4). However standard errors associated with N_{opt} were relatively large making detection of significant differences difficult. SMC_L addition did not have a significant effect on yield at N_{opt} on the light soil in any season. On the medium soil yield at N_{opt} with SMC_L addition was significantly higher in 2010 compared to where no SMC was applied; there was no significant difference in either 2008 or 2009.

NFV_{yield} ranged from 5.87 to 22.31 kg N ha^{-1} for SMC_L (Table 5). For SMC_H NFV_{yield} ranged from 14.14 to 33.12 kg N ha^{-1}. When these values were expressed as a proportion of the amounts of N applied in the SMC, $rNFV_{yield}$ ranged from 0.054 to

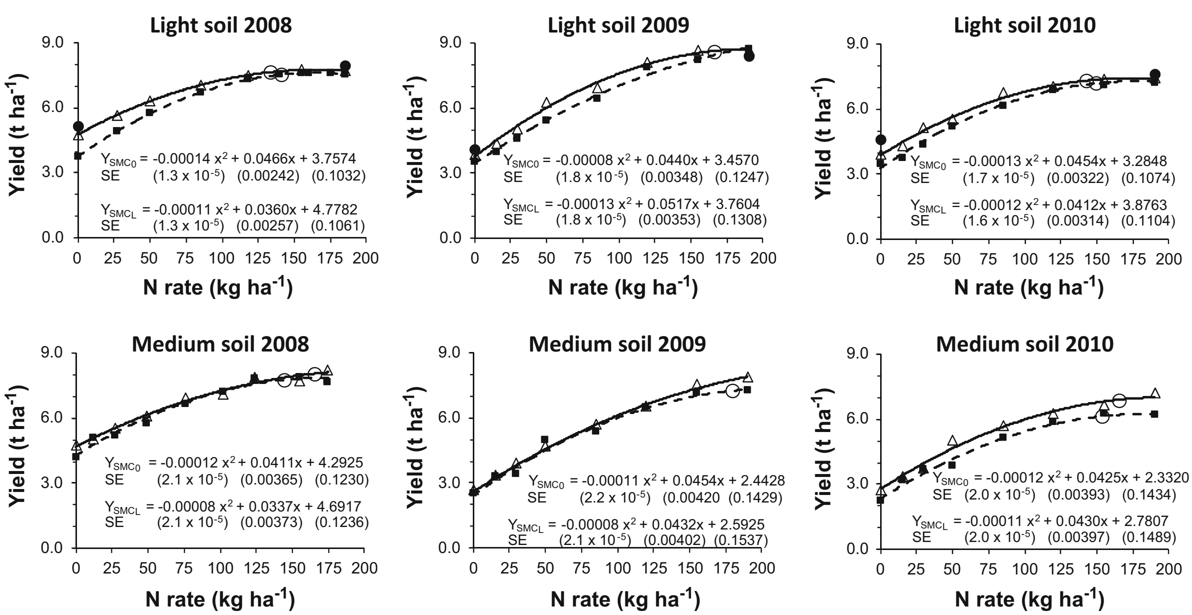

Fig. 1 Effect of SMC addition and fertilizer N level on grain yield of spring barley over three seasons. *Lines* represent quadratic regressions for SMC_L (*continuous lines*) and SMC_0 (*dashed lines*). *Symbols* represent means of SMC_0 (*filled square*), SMC_L (*triangle*) and SMC_H (*filled circle*). N_{opt} (*empty circle*) for the respective response curve is also presented. N_{opt} which were higher than the highest N rate used are not presented. Coefficients of the quadratic functions and their respective standard errors (SE) are also presented. SMC application rates were 0, 15 and 30 t ha^{-1} for SMC_0, SMC_L and SMC_H respectively

Table 4 Effect of SMC addition on rate of fertilizer N required to give economic optimum (N_{opt}) and maximum (N_{max}) yields on two soils in 2008, 2009 and 2010

Soil	Year	ΔSlope ($\times 10^{-2}$)	N_{opt}		N_{max}		ΔYield	
			SMC_L (kg N ha^{-1})	SMC_0 (kg N ha^{-1})	SMC_L (kg N ha^{-1})	SMC_0 (kg N ha^{-1})	N_{opt}	N_{max}
Light	2008	1.05*	133.2a	140.9a	165.3a	165.8a	ns	ns
	2009	−0.76ns	165.7a	219.9a	191.7a	261.4b	ns	ns
	2010	0.41ns	142.5a	149.1a	171.6a	176.3a	ns	ns
Medium	2008	0.73ns	165.1a	144.4a	208.4a	174.1a	ns	ns
	2009	0.33ns	224.7a	179.5a	268.2a	211.3a	ns	*
	2010	−0.05ns	164.8a	153.7a	196.9a	184.0a	**	**

ΔSlope is the difference in the slope of the yield response functions with and without SMC. ΔYield indicates if the difference in yields with and without SMC addition at N_{opt} and N_{max} are statistically significant ($P < 0.05$). N_{opt} or N_{max} values within a row followed by the same letter are not significantly different

* Significantly different from 0 ($P < 0.05$), ns not significant ($P > 0.05$)

Table 5 Nitrogen fertilizer value of SMC on two soils in 2008, 2009 and 2010 calculated using grain yield

Soil	Year	NFV_{yield}		$rNFV_{yield}$		Net benefit	d.f.
		SMC_L (kg N ha^{-1})	SMC_H (kg N ha^{-1})	SMC_L (kg kg^{-1})	SMC_H (kg kg^{-1})	SMC_L (t ha^{-1})	
Light	2008	22.31 ± 1.853	33.12 ± 1.847	0.287 ± 0.0238	0.213 ± 0.0118	0.14	43
	2009	9.88 ± 2.395	14.14 ± 2.247	0.097 ± 0.0234	0.069 ± 0.0110	−0.32	50
	2010	15.07 ± 1.849	31.47 ± 1.710	0.162 ± 0.0199	0.169 ± 0.0092	0.15	52
Medium	2008	12.05 ± 2.474	–	0.160 ± 0.0329	–	0.08	48
	2009	5.87 ± 2.781)	–	0.054 ± 0.0257	–	0.42	51
	2010	10.24 ± 2.896	–	0.112 ± 0.0317	–	0.63	48

Data are mean ± s.e.m. The net benefit of using SMC as part of a fertilizer N programme compared to fertilizer alone is also presented

0.287 kg kg^{-1} where the lower rate of SMC was applied. Where the higher rate of SMC was applied $rNFV_{yield}$ ranged from 0.069 to 0.213 kg kg^{-1}.

N uptake

N uptake by the spring barley at harvest is presented in Fig. 2. Comparison of the effects of SMC on N uptake in the absence of fertilizer N indicated that while SMC_L increased N uptake on the medium soil by between 5 and 10 kg N ha^{-1} when compared to SMC_0, these increases were not statistically significant. On the light soil SMC_L significantly increased N uptake where no fertilizer N was applied in 2008 by 13.8 kg N ha^{-1} but not in the other two seasons. On the light soil SMC_H significantly increased N uptake compared to SMC_0 in 2008, by 21.2 kg N ha^{-1}, and in 2010 by 14.2 kg N ha^{-1}, but not in 2009. There was no significant difference in terms of N uptake between SMC_L and SMC_H.

When the N uptake responses to fertilizer N for both SMC_L and SMC_0 were examined, there was a linear increase in N uptake in all experiments in response to fertilizer N application over the range of N levels tested (Fig. 2). There was no significant difference between the intercepts and slopes of the linear regressions of the SMC_L and SMC_0 treatments in 2008 on the medium soil (Table 6). In 2009 SMC_L significantly increased the slope of the response to fertilizer N on the medium soil but had no significant effect on the intercept while in 2010 SMC_L gave a significantly greater intercept but had no effect on the slope of the response. On the light soil SMC_L significantly increased the intercept in all three

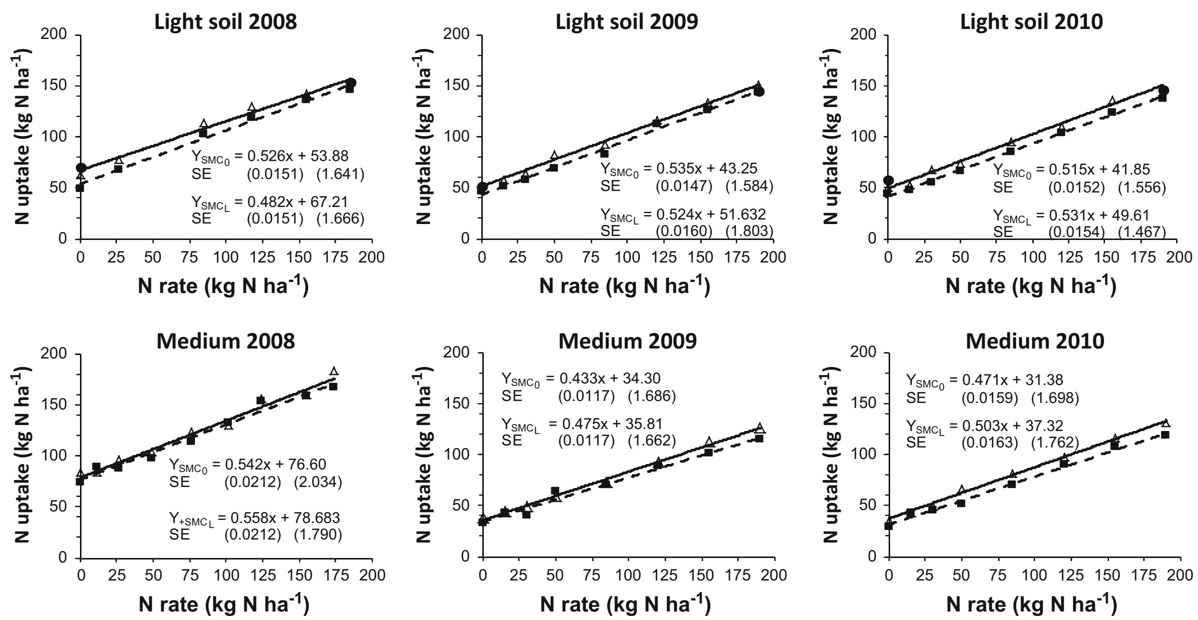

Fig. 2 Effect of SMC addition and fertilizer N level on crop N accumulation of spring barley over three seasons. *Lines* represent linear regressions for SMC_L (*continuous lines*) and SMC_0 (*dashed lines*). Symbols represent means of SMC_0 (*filled square*), SMC_L (*triangle*) and SMC_H (*filled circle*). Coefficients of the linear functions and their respective standard errors (SE) are also presented. SMC application rates were 0, 15 and 30 t ha^{-1} for SMC_0, SMC_L and SMC_H respectively

seasons compared to the intercept for SMC_0. The slope of the response was significantly decreased in 2008 and significantly increased in 2010 by SMC_L; there was no effect of SMC_L on the slope in 2009 on the light soil.

Where no fertilizer N was applied, SMC_L gave N uptakes equivalent to N uptakes obtained by applying between 9.3 and 13.2 kg N ha^{-1} as fertilizer N on the medium soil and between 16.8 and 19.2 kg N ha^{-1} fertilizer N on the light soil (Table 6). The corresponding range for SMC_H on the light soil was 15.0–32.0 kg N ha^{-1}. Expressing these values as a proportion of the N applied in the SMC, the $rNFV_{nupt}$ ranged from 0.086 to 0.22 kg kg^{-1} for SMC_L and from 0.074 kg kg^{-1} to 0.200 on the light soil for SMC_H. When calculated based on the NH_4-N content of the SMC $rNFV_{nupt}$ ranged from 0.662 to 2.011 kg kg^{-1} for SMC_L, and from 0.631 to 1.176 kg kg^{-1} for SMC_H.

Grain quality

Effects of SMC on the grain quality characteristics determined were generally small and not statistically significant (Table 7). SMC had no significant effect on grain protein, irrespective of the rate applied, nor was there a significant interaction between SMC and N rate in terms of grain protein in any of the experiments. SMC addition had no significant effect on hectolitre weight in five of the six experiments. In 2009 a significant interaction between SMC and N rate was detected on the medium soil. This was largely due to small, inconsistent effects of SMC on hectolitre weight at fertilizer N rates lower than 100 kg N ha^{-1}. SMC application had no significant effect on TGW in five of the six experiments. On the light soil in 2008 a significant interaction between SMC and N rate was detected which was due to a significantly lower TGW for the treatment receiving no fertilizer N where no SMC was applied compared to where SMC_L was applied; this effect did not occur for SMC_H or at either SMC application rate when fertilizer N was applied.

Discussion

Similar rNFV values, calculated using grain yield, to those reported by Maher et al. (2000), who used similar application rates in a similar environment, were observed in this study. However, the mean rNFV

Table 6 Nitrogen fertilizer value of SMC on two soils in 2008, 2009 and 2010 calculated using N uptake at harvest

Soil	Year	ΔSlope	ΔIntercept	NFV_{Nupt}		$rNFV_{Nupt}$		rNFRV NH_4-N		d.f.
				SMC_L (kg ha^{-1})	SMC_H (kg ha^{-1})	SMC_L (kg ha^{-1})	SMC_H (kg ha^{-1})	SMC_L (kg ha^{-1})	SMC_H (kg ha^{-1})	
Light	2008	−0.044*	13.33*	17.11 (2.730)	31.17 (2.434)	0.220 (0.0351)	0.200 (0.0157)	1.290 (0.2059)	1.176 (0.0918)	46
	2009	−0.011ns	8.379*	19.21 (2.579)	15.02 (2.659)	0.188 (0.0253)	0.074 (0.0130)	2.011 (0.2701)	0.787 (0.1392)	58
	2010	0.016ns	7.77*	16.78 (2.656)	31.98 (2.368)	0.181 (0.0286)	0.172 (0.0127)	0.662 (0.1048)	0.631 (0.0467)	54
Medium	2008	0.016ns	2.079ns	13.17 (3.349)	–	0.175 (0.0445)	–	1.429 (0.3632)	–	62
	2009	0.042*	1.503ns	9.27 (3.757)	–	0.086 (0.0347)	–	0.934 (0.3788)	–	54
	2010	0.032ns	5.939*	9.37 (3.359)	–	0.102 (0.0367)	–	0.735 (0.2635)	–	51

ΔSlope and ΔIntercept are the effect of SMC addition on the slope and intercept of the linear functions describing N uptake with and without SMC. rNFV is the NFV value expressed as a proportion of N applied in the SMC. Values in parentheses are s.e.m. for mean values

* Significantly different from 0 ($P < 0.05$) ns not significant ($P > 0.05$)

observed in the current work was greater than that observed in the earlier study. The rNFV values, calculated using N uptake, in this study were higher than those reported by Duggan (2004) but were comparable to the range of N availabilities in other composted materials such as municipal solid waste compost, vegetable, fruit and garden waste compost and composted animal manures (Weber et al. 2014; Wolkowski 2003; Tits et al. 2014; Tontti et al. 2009; Paul and Beauchamp 1993). However they were lower than values reported for manures that have not been composted such as poultry manures, a component of SMC (Chambers et al. 1999).

The low rNFV values, relative to non-composted manures, were most likely as a result of the low amount of plant available N and the recalcitrant nature of a significant proportion of the organic N in SMC (Becher and Pakula 2014; Stewart et al. 1998b). The considerably higher $NFRV_{nupt}$ values obtained when it was calculated using the ammonium N content of the compost rather than the total N content suggest that mineral N present in the applied SMC rather than subsequent mineralisation of organic N was the principal source of N from the SMC for the crop. The C:N ratio of the SMC used in these studies was not determined. However previous studies have indicated that the C:N ratio of SMC is typically 15–17:1 (Stewart et al. 1998a; Paredes et al. 2009) indicating slow mineralisation of N.

In many European countries application of SMC to crops is governed by legislation that sets out rNFV values. In Ireland SMC is assigned a rNFV value, based on total N content of the compost, of 0.2 kg kg^{-1} (Anon 2014a) while in other countries values of 0.25–0.3 kg kg^{-1} are assigned to SMC (Anon 2011, 2014b). In these studies the calculated NFV was lower than this value in five of the six experiments; the mean value of all experiments was 0.15 kg kg^{-1}.

The positive effect of SMC on the economics of producing the crop when account is taken of its N fertilizer value, as evidenced by the positive net benefit recorded in the majority of the experiments suggest that SMC has significant commercial potential for use as a source of N for small grain cereals. This is provided that the cost of obtaining and applying the SMC does not outweigh the net yield benefit.

The residual effects of SMC addition on the nitrogen nutrition of crops grown in the subsequent seasons were not studied in these experiments.

Table 7 Effect of SMC addition on grain quality of spring barley on two soil types over three seasons

Parameter	Light soil			Medium soil		
	2008	2009	2010	2008	2009	2010
Protein (g 100 g^{-1})						
None	9.16a	8.32a	9.09a	10.83a	7.63a	7.83a
SMC_L	9.30a	8.43a	9.38a	10.94a	7.84a	7.90a
SMC_H	9.24a	8.45a	9.23a	–	–	–
SMC	ns	ns	ns	ns	ns	ns
N rate	***	***	***	***	***	***
*SMC*Nrate*	ns	ns	ns	ns	ns	ns
Hectolitre weight (kg hl^{-1})						
None	64.4a	65.5a	69.9a	62.5a	64.9a	68.5a
SMC_L	65.2a	64.6a	70.4a	62.5a	65.2a	68.8a
SMC_H	65.1a	64.4a	70.4a	–	–	–
SMC	ns	ns	ns	ns	ns	ns
N rate	**	***	***	***	***	***
*SMC*Nrate*	ns	ns	ns	ns	*	ns
1000 grain weight (g)						
None	51.8a	48.4a	50.2a	51.9a	50.8a	50.4a
SMC_L	53.6b	48.7a	50.1a	52.0a	51.7a	51.2a
SMC_H	52.7ab	48.2a	50.1a	–	–	–
SMC	ns	ns	ns	ns	ns	ns
N rate	***	***	***	***	ns	ns
*SMC*Nrate*	*	ns	ns	ns	ns	ns

For the light soil data are the mean of the highest rate of fertilizer N and the unfertilized treatment, for the medium soil data are the mean of all treatments. Means followed by the same letter are not significantly different

However it is well accepted that organic amendments have a residual effect in subsequent years and this effect is often greater for amendments with low initial availability of N (Schroder 2005). Repeated applications of an organic amendment to the same land can therefore lead to higher NFV values than are obtained following single applications (Nevens and Reheul 2005). However SMC applications are subject to legislative limits based on both N and P content and in many cases repeated applications will be limited by the P content of the compost. This suggests that in reality SMC application to a particular land parcel is more likely to be occasional rather than repeated suggesting that NFV based on single year evaluations may be more appropriate.

Calculation of NFV requires that the effect of the compost is due solely to substitution of fertilizer N with compost N. Such effects would have no effect on the maximum yield achieved, they would only reduce the amount of fertilizer N required to achieve that yield. Non-N effects of the compost would increase, or decrease, yield irrespective of fertilizer N. Differences in maximum yield derived from a fertilizer N response curve can therefore indicate the presence of non-nitrogen effects. The significantly higher calculated maximum yield as a result of SMC application in two of the three seasons on the medium soil indicate that SMC was influencing yield in a manner that was not directly related to N supply. The cause of such non-N effects are unclear. Phosphorus and potassium were applied to the treatments not receiving SMC at rates equal to or greater than that applied in the compost treatments at the time of compost application. Subsequently phosphorus, potassium, sulphur and magnesium were also applied to all treatments in amounts equal to normal recommendations which should have ensured that the crop was not relying on the SMC for these elements. It is possible that as the sulphur and magnesium were applied after crop emergence that the SMC treatments may have benefitted from any sulphur or magnesium in the SMC for the period between emergence and application. However this effect should be more likely to occur on the light soil where sulphur deficiency is more likely. A more likely reason for the non-N benefits of SMC on yield on the medium soil may be beneficial effects of SMC on some physical characteristic of the soil (Curtin and Mullen 2007).

Lory et al. (1995) suggested that where non N effects are expected that an approach that determines the NFV based on the difference in optimum N rates be used. While the design of the experiments allowed this calculation examination of the results suggested that it was not appropriate for two reasons. Firstly for the sites where the non-N effects were suspected N_{opt} with SMC application was higher than without SMC, which would have given a negative NFV, indicating immobilisation of fertilizer N by the SMC. While immobilisation of N where both SMC and fertilizer N are applied has previously been reported (Stewart et al. 1998b) in these experiments there was no significant effect of SMC on the response of N uptake to fertilizer N in one season while in the other season that non N effects were suspected SMC increased N uptake as fertilizer N rate increased which suggests that N immobilisation was not a significant factor. Secondly, since calculated N_{opt} where SMC was applied were greater than the highest fertilizer N rate used for the two of the experiments where the non-N effects were suspected calculation of NFV using N_{opt} would have been based on extrapolated values.

The lack of any consistent effect, positive or negative, of SMC application on grain quality suggests that SMC will have no effect on a growers ability to meet market specifications and that there will be no effect on the price received per tonne of grain.

Conclusions

Spent mushroom compost can contribute to the nitrogen nutrition of small grain cereal crops in high yield potential environments. However, the proportion of total N in the compost that is recovered by the crop is relatively small, 0.15 kg kg^{-1} on average, and variable. SMC has no negative effects on the main quality characteristics of grain when used as a fertilizer source. SMC can have positive effects on grain yield other than those attributable to the nitrogen effect also.

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