Title: Incorporation of nitrogen from crop residues into light fraction organic matter in soils with contrasting management histories

Authors: Gary D. Bending* and Mary K. Turner

Address: Warwick HRI, University of Warwick, Wellesbourne, Warwick CV35 9EF, UK

Corresponding author:

GD Bending
Telephone: +44 (0) 24 76575057
Fax: +44 (0) 24 7657 4500
Email: gary.bending@warwick.ac.uk

Incorporation of nitrogen from crop residues into light fraction organic matter in soils with contrasting management histories

Gary D. Bending* and Mary K. Turner

Warwick HRI, University of Warwick, Wellesbourne, Warwick CV35 9EF, UK

Abstract The proportion of N from crop residues entering the light fraction organic matter (LFOM) pool was investigated in soils with contrasting soil organic matter and microbial characteristics arising from different management histories. A laboratory experiment was conducted in which ^{15}N-labelled sugarbeet, Brussels sprout or ryegrass shoots, which possessed a range of C/N contents, and hence different biochemical qualities, were incorporated into a sandy-loam soil collected from within a field (FC), or from the field margin (FM). Amounts of C and N incorporated into LFOM were determined after 112 d. The FC and FM soils had organic C contents of 0.9 and 2.5 % respectively. Addition of crop residues increased total LFOM N content and reduced its C/N in FC soil, but had no effect on total LFOM N or its C/N in FM soil. Ryegrass incorporation into FC was the only treatment in which there was a net increase in LFOM C. Isotopic analysis indicated that more crop residue derived N became incorporated into the LFOM N pool in FM relative to FC soil, with % crop residue N incorporated ranging from 25.9 to 35.3 % in FC, and between 38.9 and 68.5 in FM. Incorporation of crop residues had a positive priming effect on pre-existing LFOM N in FM but not FC soil. We conclude that the characteristics of plant

Deleted: immobilisation

Deleted: i

Deleted: nto

Deleted: , and a

Deleted: Initial amounts of C and N in LFOM were 5 and 14 times higher in FM relative to FC soil respectively.

Deleted: all

Deleted: However, i

Deleted: -

material, together with differences in soil organic matter and microbiology resulting from contrasting management, determined the amount of crop residue C and N incorporated into both HFOM and LFOM.

Deleted: incorporated into soil

Deleted: differences

Deleted: in

Keywords: soil organic matter; Light fraction organic matter; crop residue quality; decomposition; priming

Introduction

Understanding the factors controlling the interplay between mineralisation and stabilisation of soil organic matter (SOM) is a prerequisite for managing both nutrient dynamics and C sequestration, and thereby optimising the ecosystem service provided by a given soil (Janzen 2006). SOM is a heterogeneous substrate comprising materials with a range of origins and characteristics, and SOM pools have been separated and characterised using both physical and chemical methods (von Lutzow et al. 2006). Physical fractionation of SOM attempts to separate SOM according to the degree to which it is protected against microbial degradation, and pools are quantified by determining the organic material protected through chemical interactions, association with clay and silt particles, physically protected within aggregates, or that remaining unprotected (Six et al. 2002).

Deleted: controlling

Deleted: ,

Deleted: ,

Deleted: 2007

Deleted: ,

One of the key pools defined within physical fractionation schemes is light fraction organic matter (LFOM). The LFOM pool largely represents partially degraded plant materials together with microbial tissues and products which are not associated with mineral soil particles (Six et al. 2002). LFOM represents an unprotected pool of SOM and is readily degradable relative to protected pools. It is therefore considered to be

Deleted: ,

one of the most labile pools of SOM. As a result, the size of the LFOM pool responds much more quickly to agricultural management than the total SOM pool, and LFOM is considered to represent an early indicator to determine long term impacts of management on soil quality and C sequestration (Janzen et al, 1992; Bending et al, 2004; Leifeld and Kogel-Knaber 2005). Soil C, N and P mineralisation have all been correlated with LFOM, confirming that it represents an active pool of SOM with importance to plant nutrient supply (Hassink 1995; Sierra 1996; O'Hara et al, 2006). Much is known about the influence of soil, environmental and management variables on the dynamics of LFOM, with the size of the LFOM pool influenced by crop rotation (Bending et al, 2000, 2004; Marriott and Wander 2006), N fertilisation (Malhi et al, 2003), and tillage (Beare et al, 1994). However, mechanisms controlling the formation and turnover of LFOM are poorly understood. The biochemical quality of inputs clearly has a role in directing amounts of C and N incorporated into LFOM. Bending et al. (1998) indicated that net amounts of crop residue C and N incorporated into the LFOM pool depended on crop residue quality, with N content and cellulose in particular being important predictors of the amount of C and N immobilised. However, the amount of LFOM can vary widely in different soil types (Hassink 1995), and the role of specific major soil factors such as texture, clay and existing SOM content in controlling retention of crop residue inputs as LFOM remains to be determined.

In the current study we used paired soils with identical mineralogical composition but differing organic matter contents to investigate how soil and crop residue characteristics affect amounts of crop residue C and N stabilised into LFOM.

Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: ,
Deleted: immobilised
Deleted: ,
Formatted: Indent: First line: 36 pt

Methods

Soil

Soil was collected from 2 sites with identical mineralogical composition, but different amounts of organic matter, from Bradley's field at Warwick HRI, Wellesbourne, Warwickshire, UK. The soil is an undifferentiated sandy-loam of the Wick series with 74 % sand and 14 % clay (Whitfield 1974). The first site (FM) was located in the field margin near to a hawthorn (*Crataegus monogyna* Jacq.) hedge. The second site (FC) was located within the farmed part of the field, approximately 8 m from the FM site (Bending et al 2002). The field had been ploughed following a crop of winter wheat. At both sites, soil was collected from 0-30 cm depth. Surface litter was removed from the FM site prior to sampling.

Soil from both sites was sieved (<3 mm), air dried overnight, and stored at 4°C for 4 weeks. Total organic C and N were determined using an automated C/N analyser (CB-2000, Leco Corporation, Michigan, USA). The FC and FM soils were shown to possess, respectively, organic C contents of 0.86 and 2.5 %, organic N contents of 0.08 and 0.21 %, and pH values of 5.3 and 5.4. While respiration in the soils prior to the start of the experiment was equivalent, microbial biomass-N was 3.2 and 38.3 µg g^{-1} dw soil in FC and FM respectively (Bending et al 2002). Prior to use, the soils were moistened to a water holding capacity of 60 %, and incubated at 15°C for 7 days.

Plant materials

Sugarbeet (*Beta vulgaris* L.), Brussels sprout (*Brassica oleracea* L. var gemmifera) and rye grass (*Lolium perenne* L.) were grown in sand culture under controlled environment glasshouse conditions (16 h day length, maximum day temperature 25°C,

Deleted: ,

Deleted: ,

Formatted: Indent: First line: 36 pt

Deleted: s

Deleted: ,

minimum night temperature 15°C), and fed weekly with Hewitt's solution (Hewitt and Smith 1975), in which the N source was 10 at % ^{15}N-labelled $^{15}NH_4{}^{15}NO_3$. After 8 weeks growth, mature leaves were removed, and the lamina and petiole cut into approximately 1 cm square pieces, and was incorporated into soil fresh without drying. The biochemical quality of oven dried plant materials was determined by sequential fractionation, to give soluble carbohydrate, phenolic, cellulose, and lignin contents (Rahn et al. 1999). Total C and N were determined by C/N auto-analysis.

Deleted: ,

Deleted: used

Deleted: the

Incubation study

Five g fresh weight (fw) of plant material was mixed into 100 g fw soil, and poured into polystyrene containers. The ryegrass, sugarbeet, and Brussels sprout leaves had moisture contents of 77.5, 86.1 and 80.4 % respectively. The additions provided carbon inputs of 5.2, 3.2 and 4.6 mg C g^{-1} dw soil for the ryegrass, sugarbeet and Brussesl sprout respectively (Table 1). The base of the pot was tapped firmly to allow the contents to settle, providing a water filled pore space of approximately 22 %. Control treatments containing unamended soil were also included. Five replicates of each treatment were set up for each harvest. Containers were incubated using a randomised block design in the dark at 15°C, inside 15 L plastic tubs through which moist air was continuously circulated to maintain an aerobic atmosphere (Bending and Turner 1999).

Deleted: materials contained approximately 90 % moisture, so that t

Deleted: s

Analysis of soil C and N pools

After 28, 56 and 112 days, pots were destructively harvested and the soil mineral-N pools determined as described in Bending et al. (1998). Soil mineral-N was extracted

Deleted: using methods

Deleted: ,

in 0.5 M K_2SO_4, and NH_4^+-N and NO_3^--N quantified using an EnviroFlow 5012 flow injection system (Tecator AB, Sweden).

After 112 days, light fraction organic matter (LFOM) was extracted from 30 g fw soil (equivalent to 26 g dw soil) using a 1.75 g cm^{-3} solution of NaI, and was washed in 0.1 M $CaCl_2$ and distilled H_2O (Strickland and Sollins, 1987). After drying in an 80°C oven, sub-samples of the plant materials and the LFOM were weighed before being milled to a fine powder (<500 µm). Approximately 5 mg samples were analysed for total C and N content at the Scottish Crops Research Institute (SCRI), Dundee, UK using a Roboprep automatic C/N analyser (Europa Scientific, Crewe, UK).

The ^{15}N atom % content of the plant materials, 0.5 M K_2SO_4 extracts and LFOM were determined at SCRI-Dundee, using a Micromass 622 mass spectrometer (VG Isogas, Northwich, Cheshire, UK). The N in each pool that was derived from the plant inputs, and the % crop residue-N recovered in each pool, were calculated according to Ehaliotis et al. (1998).

Statistical analysis

The data was not normally distributed, and was subject to log transformation prior to statistical analysis. The statistical significance of differences in the effect of crop residue and soil type on net N mineralization, the amount of LFOM C and N between treatments and the proportion of crop residue N incorporated into LFOM were determined by Analysis of Variance. All statistical analysis was conducted using GenStat (7th edition, VSN International Ltd.) software.

Results

Formatted: Indent: First line: 36 pt

Deleted: ,

Deleted: original

Deleted: enrichment

Deleted: the

Deleted: LFOM

Deleted: All data was

Deleted: transformed

Deleted: between treatments

Composition of crop residue materials

There was variation between the crop residue types with respect to most quality attributes (Table 1). Ryegrass had a low C/N (15), and was rich in cellulose. Brussels sprout shoot had a high C/N (28) and a large soluble carbohydrate content. Sugarbeet had an intermediate C/N (20) and comparable cellulose and soluble carbohydrate contents to Brussels sprout and ryegrass respectively. All three crop residues types had over 9 % ^{15}N atom content.

Deleted: enrichment

Mineralisation of N

Most net mineralisation of N from ryegrass and sugarbeet occurred within the first 28 d following incorporation (Fig 1 a, b). For Brussels sprout there was little net mineralisation of N within the first 28 d, with most net mineralisation occurring between 56 and 112 d in FC soil, but between 28 and 56 d in FM soil. Nitrogen mineralisation was significantly affected ($P<0.001$) by the type of crop residue incorporated and soil type, and there were significant interactions between all of the variables, including crop residue type and soil, and soil and harvest time ($P<0.001$).

Light fraction organic matter

Deleted:

Light Fraction Organic Matter N and C in unamended FM soil were 14.1 and 5.8 times higher respectively than in FC soil, with LFOM C/N ratios of 38.9 and 14.6 in FC and FM soils respectively (Table 2). Light Fraction Organic Matter C and N content, and C/N were significantly ($P<0.01$) affected by both crop residue and soil. In the case of N and C/N there were significant interactions between crop residue and soil.

In FC soil, incorporation of crop residues significantly (P<0.05) increased net amounts of LFOM N, with increases in the ryegrass treatment twice that in the Brussels sprout and sugarbeet treatments. Incorporation of ryegrass, but not the other materials, increased LFOM C content. Differences in the net enrichment of LFOM C and N resulted in a significant decrease in the LFOM C/N of all treatments. In the FM soil, crop residue incorporation had no effect on net amounts of LFOM C or N, or C/N.

Results of ^{15}N analysis showed that both the amount and the % crop residue N incorporated into LFOM were significantly affected (P<0.001) by crop residue and soil type (Table 3). A significantly larger (P<0.001) proportion of crop residue-N was incorporated into the LFOM N pool in FM soil relative to FC soil, with amounts of crop residue derived N in the LFOM pool ranging between 25.9 to 35.3 % and 38.9 and 68.5 % in FC and FM soils respectively. In FM soil, significantly more (P<0.05) ryegrass N was incorporated into LFOM relative to N from sugarbeet and Brussels sprout, but this represented a lower proportion of the crop residue-N added. In FC soil, the amount of ^{15}N derived from crop residues (Table 3) very closely matched the increase in total LFOM N (Table 2) resulting from crop residue incorporation, accounting for between 92.4 and 96.6 % of the increase in total LFOM N.

Analysis of ^{15}N enrichment allowed us to determine how much of the LFOM N present in the soil prior to crop residue incorporation remained as LFOM after 112 days. Crop residue type had no significant effect on the % of this original LFOM N which remained at the end of the incubation period. However, significantly less of the original LFOM N remained in FM relative to FC soil (P<0.05). The greatest loss of original LFOM N was seen in the sugarbeet treatment, in which only 65.8 % of the original LFOM N remained in the FM soil.

Formatted: Indent: First line: 36 pt
Deleted: -
Deleted:
Deleted: -
Deleted: S
Deleted: amounts
Deleted: were
Deleted: -
Deleted: relative to the other materials
Formatted: Superscript
Deleted: LFOM-
Deleted: net
Deleted: -
Deleted: a
Deleted: -
Formatted: Indent: First line: 36 pt, Tabs: 127.6 pt, Left
Formatted: Superscript
Deleted: the
Deleted: -
Deleted: remaining
Deleted: -
Deleted: -
Deleted: -
Deleted: ¶

Formatted: Indent: First line: 36 pt, Tabs: 127.6 pt, Left

Incorporation of crop-residue N into soluble and heavy fraction organic matter pools

N in the soluble pool represents both mineral N and dissolved organic N. Both crop residue type and soil affected the proportion of crop residue N contained in the soluble pool after 112 days (Table 4). Significantly ($P<0.001$) less crop residue N from ryegrass was incorporated into the soluble N pool than was the case for sugarbeet and Brussels sprout leaves. Significantly less crop residue N became incorporated into soluble N in FM relative to FC soil ($P<0.001$).

Since N losses via denitrification are known to be minimal following incorporation of green manures in the soil type and experimental conditions used (Rahn et al., 2003), incorporation of N into heavy fraction organic matter (HFOM) was determined by calculating the N remaining once amounts incorporated into the LFOM and the soluble N pools had been summed. It was found that significantly ($P<0.001$) more crop residue N was incorporated into HFOM in FC relative to FM soil. Crop residue type also affected amounts of N incorporated into HFOM. Amounts of sugarbeet and Brussels sprout leaf N incorporated into HFOM were similar, at 15.6 and 17.9 % and 1.5 and 2.5 % in FC and FM soil respectively. However, much larger amounts of N from ryegrass became incorporated into HFOM, representing 30.8 and 38.1 % of the crop residue N incorporated in the FM and FC soils respectively.

Formatted: Tabs: 127.6 pt, Left

Discussion

Light Fraction Organic Matter represents partially degraded, unprotected plant materials and microbial tissues and products (Golchin et al, 1994; Marriott and

Deleted: ,

Wander 2006), and quantification of the amount of crop residue C and N which was incorporated into HFOM provides information on the extent to which the added materials had been mineralised or converted to other more recalcitrant SOM pools. Furthermore, changes in the amounts of C and N in pre-existing LFOM provides information on the susceptibility of LFOM to microbial activity resulting from decomposition of the plant materials, and hence its lability.

The FM and FC soils showed qualitative and quantitative differences in organic matter, reflecting contrasting mechanisms of incorporation of organic material into soil. In the case of FC soil, fresh litter is introduced by tillage, while in FM soil, litter is incorporated into soil through mixing of partially degraded litter. Our data shows that the characteristics of plant material incorporated into soil, together with differences in soil organic matter and microbiology resulting from differences in management, determined the amount of crop residue C and N remaining as LFOM following the end of net mineralisation of N from the crop residues. Although greater amounts of crop residue N became incorporated into LFOM in the FM soil, there were net increases to LFOM N only in the low SOM FC soil. In the case of sugarbeet and Brussels sprout there was only net enrichment in LFOM N in FC soil, while for ryegrass, both C and N were increased. Furthermore, both crop residue type and soil influenced amounts of N entering the HFOM pool, which is has greater physical protection than LFOM, and is considered more stable (Six et al., 200)

Differences between crop residues in the relative amount of C and N immobilised into the LFOM and HFOM pools may relate to differences in the biochemical quality of the materials incorporated. Bending et al. (1998) showed that cellulose content was a good predictor for net increases in LFOM C and N content following decomposition of a range of crop residue materials in soil. In the current

Deleted: ,

Deleted: LFOM

Deleted: have

Formatted: Indent: First line: 36 pt

Deleted: differences in the

Deleted: corporated

study, the cellulose content of ryegrass was over a third higher than sugarbeet and Brussels sprout, and ryegrass was associated with greater immobilization of both crop residue C and N into LFOM, and N into HFOM, than the other materials.

The amount of LFOM in the unamended FC soil was extremely low and had a high C/N relative to FM soil. Isotopic analysis showed that the net increase in LFOM N in FC soil following crop residue decomposition matched the amount of crop residue N incorporated into LFOM. However, in the FM soil, more N derived from the crop residues was incorporated into LFOM relative to FC soil, but there was no net increase in N content, suggesting that N present in pre-existing LFOM was replaced by N from the crop residues. This indicates that turnover of LFOM N in FC soil was not affected by the increased microbial activity resulting from decomposition of the added crop residues, but that the reverse was true in FM soil. This suggests that LFOM N in FM soil, but not FC soil, had labile components in which turnover of N was 'primed' during decomposition of the added plant materials. The high C/N of LFOM in FM soil could have reduced N availability and limited the possibility of priming effects.

Light Fraction Organic Matter represents a heterogenous pool and the flotation method used to extract LFOM extracts materials with a range of origins and recalcitrance, including residual plant debris, living and senescent microbial and faunal tissues, and charcoal (Marriott and Wander, 2006). Clearly the relative proportion of reactive and non-reactive components varied in the LFOM of FC and FM soils. This conclusion is also supported by the LFOM C/N, which was higher in FC (38.9) relative to FM soil (14.6). Differences in the characteristics of LFOM in the soils will reflect contrasting plant inputs from which LFOM is derived, and the

Deleted:

Deleted: ,

impacts of cultivation and management techniques on turnover of LFOM in the cropped soil.

Priming effects, in which incorporation of a substrate to soil changes the mineralisation rate of native SOM, have been the subject of much debate in the literature (Kuzyakov et al, 2000), and can reflect 'real' priming in which actual mineralisation rates are altered positively or negatively, or 'apparent' priming in which exchange of labelled mineral-N with unlabelled soil pools causes the apparent priming. In this case apparent priming would involve exchange of labelled mineral-N derived from the crop residues with unlabelled N in the LFOM, as the result of microbial growth and turnover. It is not clear whether the priming effect observed in the current experiment reflects real priming or apparent priming caused by pool substitution. Whichever the mechanism, the presence of a priming effect in the FM but not FC soil indicates differences in the biological activity of LFOM in each soil.

Differences in the fate of crop residue N and C in the two soils could be due to a variety of factors. For example, SOM has strong effects on soil structure and aggregate stability, which may directly influence soil texture and porosity with implications for the survival and longevity of bacterial and fungal biomass, including its protection against predators (Six et al., 2006). Furthermore SOM content may directly affect microbial community structure (Bending et al, 2002), including fungal to bacterial ratio, which increases with SOM content (Frey et al, 1999). Differences in the structure of microbial communities degrading incorporated materials could affect the characteristics of the microbial metabolites and tissues produced following growth, and therefore the nature of organic materials stabilised as SOM. For example, fungal tissues are generally considered to produce chitin rich biomass with higher C/N

Deleted: ,

Deleted: , in which

Deleted: soil

Deleted: pools causes the apparent priming.

Deleted: survival

Deleted: ,

Deleted: ,

than bacteria, which could result in increased recalcitrance and slower breakdown than bacterial biomass (Guggenberger et al, 1999; Six et al, 2006).

We conclude that the characteristics of plant material incorporated into soil, together with differences in soil organic matter and microbiology resulting from differences in management, can have a major influence on the amount of crop residue C and N incorporated into LFOM and HFOM.

Deleted: ,

Deleted: ,

Formatted: Indent: First line: 36 pt

Acknowledgements We thank the Department for Environment, Food and Rural Affairs for financial support, Charlie Scrimgeour from Scottish Crops Research Institute, Invergowri, UK for conducting ^{15}N analyses, and Julie Jones, Warwick HRI, for statistical advice.

References

Beare MH, Cabrera ML, Hendrix PF, Coleman DC (1994) Aggregate-protected and unprotected organic-matter pools in conventional-tillage and no-tillage soils. Soil Sci Soc Am J 58: 787-795.

Bending GD, Turner MK, Burns IG (1998) Fate of nitrogen from crop residues as affected by biochemical quality and the microbial biomass. Soil Biol Biochem 30:2055-2065.

Bending GD, Turner MK (1999) Interaction of biochemical quality and particle size of crop residues and its effect on the microbial biomass and nitrogen dynamics following incorporation into soil. Biol Fert Soils 29:319-327.

Bending GD, Turner MK, Jones JE (2002) Interactions between crop residue and soil organic matter quality and the functional diversity of soil microbial communities. Soil Biol Biochem 34:1073-1082.

Bending GD, Putland C, Rayns F (2000) Changes in microbial community metabolism and labile organic matter fractions as early indicators of the impact of management on soil biological quality. Biol Fert Soils 31:78-84.

Bending GD, Turner MK, Rayns F, Wood M (2004) Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. Soil Biol Biochem 36:1785-1792.

Cabrera ML, Beare MH (1993) Alkaline persulfate oxidation for determining total nitrogen in microbial biomass extracts. Soil Sci Soc Am J 57:1007-1012.

Ehaliotis C, Cadisch G, Giller KE (1998) Substrate amendments can alter microbial dynamics and N availability from maize residues to subsequent crop. Soil Biol Biochem 30:1281-1292.

Frey SD, Elliott ET, Paustian K (1999) Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. Soil Biol Biochem 31:573-585.

Golchin A., Oades JM, Skjemstad JO, Clarke P (1994) Study of free and occluded particulate organic-matter in soils by solid-state C^{13} CP/MAS NMR-spectroscopy and scanning electron-microscopy. Aust J Soil Res 32:285-309.

Guggenberger G, Frey SD, Six J, Paustian K, Elliot ET (1999) Bacterial and fungal cell wall residues in conventional and no-tillage agroecosystems. Soil Sci Soc Am J 63:1188-1198.

Hassink J (1995) Density fractions of soil macroorganic matter and microbial biomass as predictors of C-mineralization and N-mineralization. Soil Biol Biochem 27:1099-1108.

Hewitt, ET, Smith JA (1975) Plant mineral nutrition. English University Press, London, 298 pp.

Janzen HH (2006) The soil carbon dilemma: Shall we hoard it or use it? Soil Biol Biochem 38:419-424.

Janzen HH, Campbell CA, Brandt SA, Lafond GP, Townley-Smith L (1992) Light-fraction organic-matter in soils from long-term crop rotations. Soil Sci Soc Am J 56:1799-1806.

Kuzyakov Y, Friedel JK, Stahr K (2000) Review of mechanisms and quantification of priming effects. Soil Biol Biochem 32:1485-1498.

Leifeld J, Kogel-Knabner I (2005) Soil organic matter fractions as early indicators for carbon stock changes under different land-use? Geoderma 124:143-155.

Malhi SS, Harapiak JT, Nyborg M, Gill KS, Monreal CM, Gregorich EG (2003) Total and light fraction organic C in a thin Black Chernozemic grassland soil as affected by 27 annual applications of six rates of fertilizer N. Nutr Cycl Agroecosyst 65:201-210.

Marriott EE, Wander M (2006) Qualitative and quantitative differences in particulate organic matter fractions in organic and conventional farming systems. Soil Biol Biochem 38:1527-1536.

O'Hara CP, Bauhus J, Smethurst PJ (2006) Role of light fraction soil organic matter in the phosphorus nutrition of *Eucalyptus globulus* seedlings. Plant Soil 280:127-134.

Deleted:

Formatted: Font: Times New Roman, 12 pt

Rahn CR, Bending GD, Lillywhite R, Turner MK (1999) Chemical characterisation of arable and vegetable crop residue material; a comparison of methods. J Sci Food Agric 79:1715-1721.

Sierra J (1996) Nitrogen mineralisation and its error of estimation under field conditions related to the light-fraction soil organic matter. Aust J Soil Res 34:755-767.

Six J, Conant RT, Paul EA, Paustian K (2002) Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant Soil 241:155-176.

Six J, Frey SD, Thiet RK, Batten KM (2006) Bacterial and fungal contributions to carbon sequestration in agroecosystems. Soil Sci Soc Am J 70:555-569.

von Lutzow M, Kogel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, Flessa H (2006) Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions - a review. Eur J Soil Sci 57:426-445.

Strickland TC, Sollins P (1987) Improved method for separating light-fraction and heavy-fraction organic material from soil. Soil Sci Soc Am J 51:1390-1393.

Whitfield WAD (1974) The soils of the national vegetable research station, Wellesbourne. In: Report of the National Vegetable Research Station for 1973, pp. 21-30.

Table 1 Characteristics of crop residue materials and amounts of C and N added to soil

Crop residue	C/N	%_N	% Cellulose	% Lignin	% Soluble carbohydrate	At % ^{15}N abundance	Amount of C applied to soil (mg g^{-1} dw soil)	Amount of N applied to soil (mg g^{-1} dw soil)
Ryegrass	15	3	22	3	17	9.8	5.2	0.34
Sugarbeet	20	2.3	12	3	19	9.1	3.2	0.16
Brussels sprout	28	1.7	14	4	26	9.4	4.6	0.16

Deleted:

Deleted: content

Table 2 Light fraction organic matter C and N after 112 days

FC, soil from the tilled centre of the field; FM, soil from the untilled field margin

Figures in brackets represent log transformed data to which Least Significant Difference (LSD) for soil and crop residue type relates

Treatment	Total-N ($\mu g\ g^{-1}$ dw soil)		Total-C ($\mu g\ g^{-1}$ dw soil)		C/N	
	FC	FM	FC	FM	FC	FM
Sugarbeet	94.4	439.0	1535.0	5973.2	16.3	13.6
	(4.53)	(6.07)	(7.32)	(8.68)	(2.79)	(2.61)
Brussels sprout	80.1	449.6	1366.6	6102.9	17.0	13.6
	(4.37)	(6.08)	(7.20)	(8.69)	(2.83)	(2.61)
Ryegrass	128.1	578.2	2998.9	8904.6	23.4	15.6
	(4.84)	(6.34)	(7.99)	(9.08)	(3.15)	(2.74)
Unamended	34.0	482.0	1214.3	7069.0	38.9	14.6
	(3.42)	(6.12)	(7.05)	(8.81)	(3.63)	(2.69)
LSD (P<0.05)	0.37		0.34		0.14	

Significance of main treatment effects

Main effects and interaction	Significance		
	C	N	C/N
Crop residue	***	***	***
Soil	***	***	***
Crop residue x soil	NS	***	***

Deleted: ¶

Deleted: ANOVA

Table 3 Fate of crop residue-N in the Light Fraction Organic Matter (LFOM) pools

FC, soil from the tilled centre of the field; FM, soil from the untilled field margin

Figures in brackets represent log transformed data to which Least Significant Difference (LSD) for soil and crop residue type relates

Treatment	N from crop residue (μg g^{-1} dw soil)		% crop residue-N in LFOM		% original LFOM N remaining	
	FC	FM	FC	FM	FC	FM
Sugarbeet	62.5	121.7	35.3	68.5	93.7	65.8
	(4.10)	(4.77)	(3.53)	(4.20)	(4.53)	(4.18)
Brussels sprout	48.7	92.6	28.2	53.5	92.4	74.1
	(3.86)	(4.52)	(3.32)	(3.97)	(4.50)	(4.27)
Ryegrass	101.8	153.4	25.9	38.9	77.3	88.1
	(4.61)	(5.03)	(3.24)	(3.66)	(4.30)	(4.44)
LSD (P<0.05)	0.31		0.31		0.35	

Significance of main treatment effects

Main effects and interaction	Significance		
	N from crop residue	% crop residue-N in LFOM	% original LFOM N remaining
Crop residue	***	***	NS
Soil	***	***	*
Interaction	NS	NS	NS

Deleted: FOM

Deleted: o

Deleted: and soluble (mineral and dissolved organic-N)

Deleted: ¶

Deleted: LSD relate¶

Deleted: -

Deleted: ¶
ANOVA

Table 4 Incorporation of of crop residue-N into the soluble and Heavy Fraction Organic Matter (HFOM) pools

FC, soil from the tilled centre of the field; FM, soil from the untilled field margin

Figures in brackets represent log transformed data to which Least Significant Difference (LSD) for soil and crop residue type relates

Treatment	% crop residue in soluble pool		% crop residue N in HFOM	
	FC	FM	FC	FM
Sugarbeet	49.1	46.5	15.6	1.5
	(3.89)	(3.83)	(2.09)	(1.26)
Brussels sprout	53.9	47.3	17.9	2.5
	(3.98)	(3.85)	(2.81)	(1.41)
Ryegrass	35.9	30.2	38.1	30.8
	(3.58)	(3.41)	(3.63)	(3.41)
LSD (P<0.05)	0.10		0.31	

Significance of main treatment effects

Main effects and interaction

	% crop residue in soluble pool	% crop residue N in HFOM
Crop residue	***	***
Soil	***	***
Interaction	NS	NS

Formatted Table

Figure legends

Fig 1 Mineralisation of N following incorporation of crop residues

(●, Sugarbeet; ▼, Brussels sprout; ■, Ryegrass; ♦, unamended)

Bars represent +/- standard error of the mean

a) Mineral-N pool in FC soil

b) Mineral-N pool in FM soil