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Short communication

Stabilization and plant uptake of N from ^{15}N-labelled pea residue 16.5 years after incorporation in soil

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Abstract

The decline of N from ^{15}N-labelled mature pea residues was followed in unplanted soil over 16.5 yr. Eight years after residue incorporation, 24% of the residue ^{15}N input was still present in the soil and, after 16.5 yr, 16% of the residue ^{15}N input remained. A double exponential model successfully described the decay of N from ^{15}N-labelled pea residues. The total residual ^{15}N declined with average decay constants of 1.45 yr^{-1} for the 30 d to 1 yr period and of 0.07 yr^{-1} for the 1–16 yr period. Sixteen years following incorporation of the residues, indicator plants growing in residues-amended soils were obtaining 1.7% of their N from residue N. This is, to our knowledge, the longest study on decay of N in soils from ^{15}N-labelled crop residues. The current study thus provides a unique data set for our empirical understanding of N-dynamics in agricultural systems, which is a prerequisite to parameterize and validate N-simulation models.

Keywords: ^{15}N-labelled crop residue; Soil nitrogen; Residue decomposition; Nitrogen uptake; Double exponential decay; *Pisum sativum*

The decomposition of crop residue in soil can be typically described in two phases. First, the rapid decomposition of more readily degradable compounds and derived microbial cells occurs. A second slower phase, or lag-phase, follows, associated with the decomposition of the recalcitrant crop residue components and of stabilized microbial products (Voroney et al., 1989; Heal et al., 1997). There are many reports on soil nitrogen dynamics in the early period following incorporation of crop residue (Jensen 1994a, b, 1996), but there are very few reports on long-term (10 yr+) stabilization and availability of fertilizer and crop residue-derived N in soil (Jenkinson et al., 2004). The objectives of this study were to measure residual organic nitrogen decline in soil and to measure residue N availability to reference plants, up to 16.5 yr after residue incorporation.

Jensen (1994a) studied the fate of nitrogen from ^{15}N-labelled pea residue in unplanted soil over a 3 yr period in Denmark. Two sub-experiments were carried; experiment 1 (Expt 1), in which residue were chopped to 10 mm pieces and incorporated in September 1987, and experiment 2 (Expt 2), in which residue were ground to less than <3 mm and incorporated in September 1988. Parallel experiments, carried out in planted soil, allowed to determine the availability of residue ^{15}N to subsequent crops during the same 3 yr period (Jensen, 1994b). The present paper is a follow-up of these two publications. Details on residue composition, experimental procedures and calculations are presented in Jensen (1994a, b).

Decomposition of the plant material originally took place within six PVC tubes (length 50 cm and 31.5 cm i.d.) inserted 45 cm in soil (Jensen, 1994a). The results presented here were obtained at the end of the initial 3 yr studies by Jensen (1994a, b). Tubes were then excavated and soil columns were allowed to gently slide out. The top 10 cm of soil was cut and transferred to plastic buckets (30 cm i.d.) that were placed outdoor on the ground, close to the field location and in a shaded place to prevent large soil temperature fluctuations. No manipulations mimicking soil tillage were done after transfer to the buckets. The buckets had bottom-openings (5 cm i.d.) that allowed water

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drainage. There were three replicates for each of the two experiments; a total of six buckets were thus sampled. The soil was a sandy loam soil (Typic Hapludalf) with 11.4% clay, 13.6% silt, 48.6% fine sand and 24.6% coarse sand; 1.1% total C and 0.13% total N, pH (water) = 6.9; bulk density = 1.4 g cm^{-3}.

Duplicate soil samples were taken from each bucket on the 7 May 1996 and on 1 March 2004. Total soil N content and soil mineral N values were measured along with their respective ^{15}N enrichment. Two different procedures were used to determine availability and uptake of residual organic ^{15}N by plants: (1) In May 1996, actively growing weeds were harvested from the buckets and used as indicators. (2) In May 2004, the soil material leftover in buckets was split in two portions which were placed in plastic bags. Four barley plants (*Hordeum vulgare*) cv. Barke were grown in each bag in a greenhouse (25 °C, 12 h of light). The soil was watered daily to 75% of its water holding capacity. The barley plants were harvested 2 months after emergence, at early flowering. The plant material (weeds and barley) was dried at 80 °C and finely ground for analyses of N content and ^{15}N enrichment. The new measurements were added to the ones already presented in Jensen (1994a, b) (Figs. 1 and 2).

Three years after residue incorporation, 30% and 45% of the residue ^{15}N input remained in the top 0–10 cm soil of Expt 1 and Expt 2, respectively (Jensen, 1994a). The medium-term measurements revealed that 21% (Expt 1, 8.5 yr) and 27% (Expt 2, 7.5 yr) of the residue ^{15}N input was still present in the soil. At final assessment, 16% (Expt 1, 16.5 yr; Expt 2, 15.5 yr) of the residue ^{15}N input remained (Fig. 1).

During the earlier phase of decomposition, residue with smaller particles (Expt 2) decomposed more slowly, probably due to a better protection of the residue and biomass by clay minerals (Jensen, 1994a, c). At the last

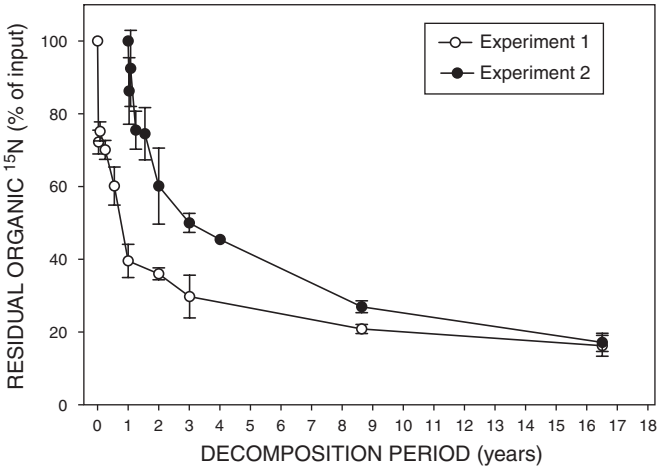

Fig. 1. Residual organic N (% of input) from pea residue in the topsoil (0–10 cm) during 16.5 yr of decomposition in unplanted soil. Expt 1(○); Expt 2 (●). Double exponential decay curves were fitted to the data. Bars indicate standard deviations. Measurements at 8.5 and 16.5 yr were added to previous observations by Jensen (1994a).

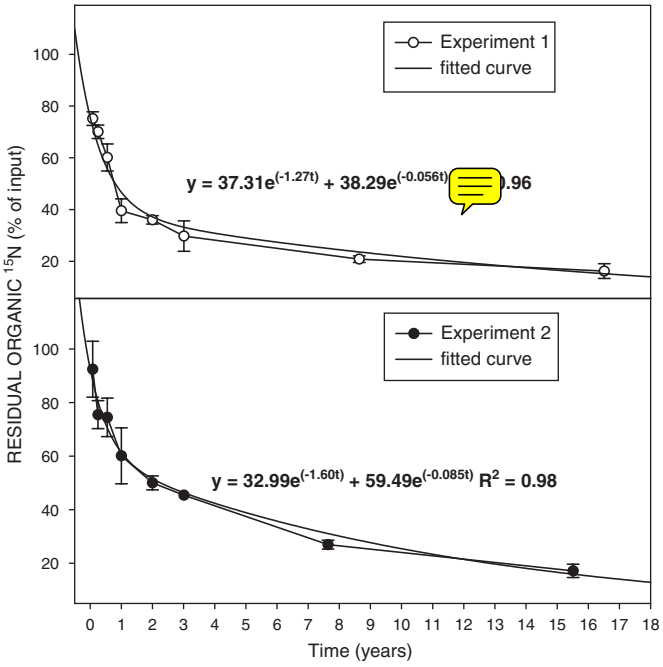

Fig 2. Double exponential decay curves describing the decline of residual organic N (% of input) from pea residue in topsoil (0–10 cm) from 30 d to 15.5 yr (Expt 2) and from 30 d to 16.5 yr (Expt1) after incorporation in soil: Expt 1(○); Expt 2 (●).

measurements, 16.5 yr after incorporation, the percentage of residue ^{15}N input remaining in soil was not significantly different between Expt 1 and Expt 2 (Fig. 1).

The results obtained are in the same range as the values reported in other long-term experiments on stabilization of N from crop residue in soils. At four field sites in South Australia, 22–31% of residual organic ^{15}N from the forage legume *Medicago littoralis* remained in the top 10 cm of a soil kept free of vegetation, 8 yr after its incorporation (Ladd et al., 1985). A faster decline was observed during decomposition of labeled wheat straw in soils of various sites in Saskatchewan (Canada), as 13% to 16% of the residue ^{15}N input remained in soil 10 y after incorporation (Voroney et al., 1989). In this last example, the soils were managed and cropped following conventional practices for wheat production in the area. The soils in the present experiment were not tilled, which can partially explain, along with climatic and soil differences, the slower decline observed.

A two-pool model of N decay was obtained by fitting double exponential decay curves to the data (Voroney et al., 1989). The first component of the model describes the decay of the labile fraction of residues N (from 30 d to 1 yr), and the second component describes the decay of the recalcitrant fraction of residues N (from 1 yr on) (Fig. 2).

The decay values for the more recalcitrant fraction were initially calculated to be of 0.15 yr^{-1} (1–3 yr) in Expt 1 and Expt 2, respectively, (Jensen, 1994a) and were re-evaluated at 0.056 yr^{-1} (1–16.5 yr) in Expt 1 and 0.084 yr^{-1} (1–15.5 yr) in Expt 2 (Table 1). This revealed a slower

Table 1
Decay constants (yr^{-1}) for decomposition of ^{15}N-labelled pea residue N

	Experiment 1	Experiment 2
30 days–year 1[a]	1.38	1.17
year 1–year 3[a]	0.15	0.15
30 days–year 1[b]	1.27	1.60
year 1–year 16.5[b]	0.056	0.085

[a]Calculated using data of Jensen (1994a, b)
[b]Calculated from current data, illustrated in Fig. 2.

calculated decay of the recalcitrant fraction of residual ^{15}N than previously reported. Models based on data from short-term studies, i.e. studies of less than 3 yr duration, could lead to overestimation of the decay constants describing the decline in nitrogen of the recalcitrant component of the residues.

Jensen reported that, 3 yr after incorporation, plants from winter crops and summer crops sequences were deriving, respectively, 3.4% and 4.0% of their total N content from plant available residue N, respectively (Jensen, 1994b). New measurements revealed that weeds were deriving 1.2% and 2.4% of their total N content from plant available residue N in Expt 1 and Expt 2, 8.5 and 7.5 yr following residue incorporation, respectively (Fig. 2). The barley indicator plants were deriving 1.7% of their total N content from the labelled pea residue N in both Expt 1 and in Expt 2, 16.5 and 15.5 yr after residue incorporation, respectively. It is likely, however, that the relative contribution of residue N to plant available N was overestimated for the two last measurements since the plants were grown in buckets or pots containing only the top 10 cm of soil from the field that were directly amended with the ^{15}N-labelled residues. This topsoil, having been directly amended with the residues are more likely to contain the products of their decomposition. Inversely plants grown in the open-bottom cylinders in the field (1–3 yr) had access to supplemental N sources in deeper soil layers that will dilute ^{15}N from the residues in comparison to plants grown only in the top 10 cm. Measures of KCl-extractable N confirmed the presence of residue-derived N available to plant; mineral N had δ ^{15}N values of 60‰ and 25‰ at weed and barley sampling, respectively. The lower values obtained in the curve of Expt 1 at 8.5 yr vs those at 16.5 yr were due to some weeds having a small portion of their roots extending out of the bucket, this diluted their ^{15}N enrichment (Fig. 3).

Long-term studies on dynamics of incorporated residue-N in agricultural systems are sparse. The current study is, to our knowledge, the longest study on decay and availability of N derived from ^{15}N-labelled crop residue in soil. The study thus provides a unique data set for our empirical understanding of N-dynamics in agricultural systems, which is a prerequisite to parameterize and validate N-simulation models.

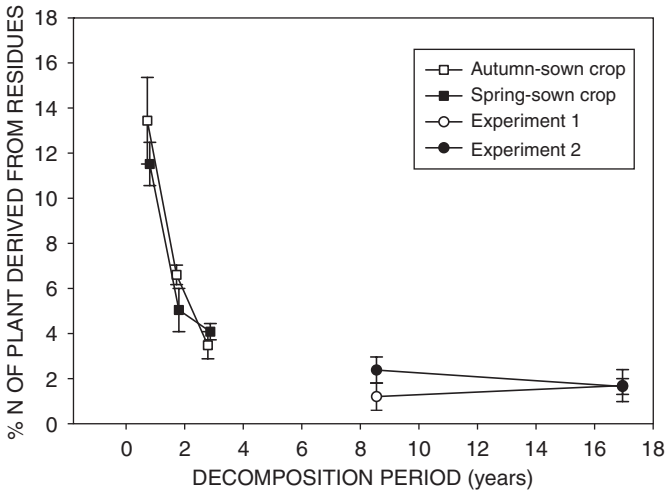

Fig. 3. Proportion of total N in above-ground plant parts obtained from ^{15}N-labelled pea residue. Measurements at 8.5 and 16.5 yr were taken from plants growing in the previously unplanted soils of Expt 1(○) and Expt 2 (●). These new data were added to previous observations of plant uptake of residue N made by Jensen (1994b), from year 1–3, in cropped soils of the same field with autumn-sown crops (□) and spring-sown crops (■). The lines are discontinuous due to methodological differences; from year 1 to 3, plants were grown in the field and measurements at 8.5 and 16.5 yr were taken from plants grown in pots. Bars indicate standard deviation.

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