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Experimental and simulated soil mineral N dynamics for long-term tillage systems in northern France

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Abstract

Soil N mineralization was quantified in two long-term experiments in northern France, in which no-till (NT) and conventional tillage (CT) had been differentiated for 33 years (Site 1) and 12 years (Site 2). Both sites had the same soil type but differed in crop rotation. N mineralization kinetics were assessed *in situ* in bare soil in both systems for 254 days (Site 1) and 555 days (Site 2) by taking frequent measurements of water and nitrate contents from soil layers and using the LIXIM calculation model. The N mineralization potential was also determined in soil samples incubated under controlled laboratory conditions. Small or non-significant differences in water and nitrate contents between NT and CT were apparent within the soil profiles on both sites. Net mineralization did not differ significantly between sites or tillage treatments. The amount of N mineralized from August 2003 to April 2004 was 67 $\pm$ 10 kg N ha^{-1} on Site 1 and 74 $\pm$ 5 kg N ha^{-1} on Site 2, and 161 $\pm$ 6 kg N ha^{-1} from August 2003 to February 2005 on Site 2. The kinetics of N mineralization versus normalized time (equivalent time at constant temperature of 15 °C and water content at field capacity) were linear during the shorter period (254 days corresponding to 120 normalized days). The slope (N mineralization rate) did not differ significantly between treatments and sites, and the average rate was 0.57 $\pm$ 0.05 kg N ha^{-1} nd^{-1}. The kinetics were non-linear on Site 2 over the longer period (555 days corresponding to 350 normalized days). They could be fitted to an exponential model with a slope at the origin of 0.62 kg N ha^{-1} nd^{-1}. The N mineralization kinetics obtained in laboratory incubations for 120–150 normalized days were also almost linear with no significant differences between treatments. Assuming that mineralization took place in the ploughed layer (in CT) or over the same soil mass (in NT) they were in good agreement with the kinetics determined *in situ* on both sites. The calculated water drainage below the sampled profile was slightly greater in NT due to lower evaporation. The calculated leached N was slightly higher in NT than CT on Site 1, but did not differ between treatments on Site 2. It is concluded that N mineralization and leaching in NT and CT were similar, despite large differences in N distribution within the soil profile and a slight difference in organic N stock.

Keywords: No-till; Conventional tillage; N mineralization; N leaching; Field experiment; Soil incubation; Modelling

1. Introduction

Reduction of tillage intensity by abandoning mouldboard ploughing and adopting conservation tillage techniques (reduced tillage or no tillage) has become increasingly popular in France over the last

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decade (Trocherie and Rabaud, 2004). Motivations can be economic (reduction of cost and working time) and/or agronomic or environmental (reduction of erosion, improvement of soil structure and increase of water holding capacity). Modifications of the tillage system can also change agricultural practices of fertilization, weed control and seeding. Farmers need information on variations in soil N supply in order to optimize fertilizer management.

The effect of reduced tillage on soil N supply in cropping systems remains unclear. Soil tillage affects the physical and biological functioning of soil and therefore C and N dynamics (Blevins and Frye, 1993; Martens, 2001). Crop residues are located at the soil surface in no tillage (NT), whereas they are incorporated in the ploughed layer in conventional mouldboard ploughed systems (CT). Decomposition of crop residues at the soil surface is generally slower than that of incorporated residues (Blevins and Frye, 1993; Burgess et al., 2002) and residue placement in the soil may affect the balance between N immobilization and mineralization (Franzluebbers et al., 1995; Burgess et al., 2002). Moreover tillage reduction promotes the accumulation of crop residues at the soil surface and organic matter in the upper layer of the soil profile (Pekrun et al., 2003). It also changes the distribution and amount of potentially mineralizable N as well as microbial activities (Doran, 1987; Franzluebbers et al., 1995; Kandeler et al., 1999). The combination of these modifications with soil physical conditions (particularly temperature and water potential) affects the net mineralization of organic N and the soil N supply. However, considerable variability in the effects of tillage on soil N supply have been observed. This may be due to variations in climatic conditions, crop rotations, soil types, tillage techniques and duration of differentiation. Most studies have shown that potential N mineralization, measured under controlled temperature and moisture conditions, is comparable in different tillage systems when the entire plow layer is considered (Carter and Rennie, 1982; Rice et al., 1986; Doran, 1987). No-till situations have also increased potential N mineralization (Franzluebbers et al., 1995), decreased mineralization under field conditions (Brye et al., 2003), and have not affected mineralization (Rice et al., 1986). Some studies have not revealed any differences in nitrate content between different tillage systems down to 100–150 cm depth (Zihlmann et al., 2001; Fuentes et al., 2003).

The aim of our work was to quantify soil N mineralization in two long-term experiments in northern France, in which tillage treatments had been differentiated for 12 and 33 years. N mineralization was assessed in two ways: (i) N leaching and mineralization calculated by combining the LIXIM model with frequent measurements of water and nitrate contents in the soil layers and (ii) N mineralization potential estimated in soil samples incubated under controlled laboratory conditions.

2. Materials and methods

2.1. Experimental sites

The two experimental sites were located at Boigneville (northern France, 48°33′N, 2°33′E). Mean temperature during the experimental period (3 August 2003–8 February 2005) was 11.1 °C and cumulative rainfall and potential evapotranspiration were 827 and 1020 mm, respectively. The Boigneville soil is a Haplic Luvisol (FAO-UNESCO, 1987) with a deep loam overlaying cracked calcareous material. The calcareous material at Sites 1 and 2 was found at 1.2–1.5 m and 0.8–0.9 m depth, respectively.

2.2. Treatments and experimental design

Before the start of the experiments, the fields had been under cultivation for many years and had been mouldboard ploughed to 30 cm depth. At Site 1, the soil treatments were differentiated since 1970 and consisted of no tillage (NT), conventional tillage (CT) and superficial tillage (ST). Site 1 was cropped with a maize (*Zea mays* L.)–winter wheat (*Triticum aestivum* L.) rotation with two replications: when the first replicate was under maize, the other replicate is under winter wheat. Thus as only one replicate per whole system could be investigated, two additional treatments (CT_{rep} and NT_{rep}) were included. The difference was that in CT_{rep} and NT_{rep} crop residues were exported from 1983 to 1994, whereas they were always returned to the soil in CT and NT treatments. At Site 2, soil management systems (CT and NT) were differentiated in 1991. Site 2 was cropped with a spring pea (*Pisum sativum*)–winter wheat–spring barley (*Hordeum vulgare* L.) rotation, with half the plots receiving a catch crop (*Sinapis alba*) during the autumn period. Each experimental treatment was replicated three times. Characteristics of the different tillage systems and soil properties at Sites 1 and 2 are described in Tables 1 and 2, respectively.

At Site 1, soil measurements were only done between wheat harvest and maize sowing, i.e. from August 2003 to April 2004 in order to avoid any crop effects on N dynamics (e.g. rhizodeposition and N accumulation in roots). Three microplots (10 m × 4.5 m) were set up in