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Short communication

Tillage and fertilization practices affect soil aggregate stability in a Humic Cambisol of Northwest France

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ABSTRACT

Reduced tillage and organic fertilizer application usually result in an increase in soil aggregate stability (AS). However, the magnitude of the effects can vary with soil properties and season. The aim of this study was to investigate AS dynamics over three seasons in a soil under various tillage and fertilization practices. The study was performed under three tillage practices (moldboard plowing (MP), surface tillage (ST) and no-tillage (NT)) and two types of fertilizer (poultry manure and mineral) seven and eight years after their establishment in Northwest France. AS was measured in three different seasons: spring, summer and winter. Soil properties that potentially influence AS such as organic carbon (OC), hot-water extractable carbohydrates (HWEC), water content (WC) and water repellency (WR) were also studied. On average, for all sampling dates, AS was 34% higher under NT than MP. Conversely, the effect of ST on AS varied with sampling date with values close to NT in mid-spring and summer, and values close to MP in early spring and winter. Poultry manure increased AS by an average of 12% regardless of sampling date or tillage practice. Variations in AS due to management practices were related to OC ($r = 0.92$) and HWEC ($r = 0.88$). Differences in AS between sampling dates were slightly greater than the effects of management practices. On average across management practices, AS increased by 47% from early spring to summer and decreased by 59% in winter. These variations were related to soil WC ($r = -0.67$) and WR ($r = 0.72$) at time of sampling. We suggest that seasonal variations in AS were at least partly due to variations in WC which acted physically by modifying the water entry rate into the aggregates and slaking effects. In contrast, the long-term AS dynamics were related to the organic matter dynamics, which are controlled by management practices. Because of the predominant effect of climate on AS, we suggest measuring AS in winter and summer to better estimate the effects of management practices on soil erodibility in this region.

1. Introduction

Aggregate stability (AS) is considered to be a good indicator of a soil's susceptibility to erosion (Le Bissonnais, 1996; Barthès and Roose, 2002). AS is an important soil property that contributes to the maintenance of a porous soil structure and associated water movement (Dalal and Bridge, 1996; Bronick and Lal, 2005).

Numerous studies have shown that AS is higher under reduced tillage practices such as direct seeding or non-inversion shallow tillage than conventional tillage (e.g. moldboard plowing) (Bullock et al., 1988; Angers et al., 1993; Daraghmeh et al., 2009; Bottinelli et al., 2010) and under organic than mineral fertilization (Blair et al., 2006; Tejada et al., 2008). The magnitude of changes in AS varies depending on initial soil properties, amount and quality of fertilizer source as well as the duration of the experiment (Whalen et al., 2003; Abiven et al., 2009; Bhogal et al., 2011; Duong et al., 2012).

Few studies have looked at the combined effects of reduced tillage and organic fertilization on AS (Bissonnette et al., 2001; Whalen et al., 2003; Mikha and Rice, 2004; Jiao et al., 2006), and

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yet these practices need to be investigated together because crop production systems generally involve the simultaneous selection of tillage and fertilizers. In France, there has been increased interest in the use of reduced tillage practices (Soane et al., 2012). Due to the presence of livestock production in Northwest France, these reduced tillage practices are often combined with manure amendments. Studies are still needed for a more comprehensive understanding of the variability of the soil response to tillage and fertilization. This is especially the case in the context of mixed livestock-arable agriculture in Western Europe, where no such studies have been carried out so far.

The effects of agricultural practices on AS may decrease and even disappear in some periods of the year. Usually lower values are found during winter and higher values in spring/summer periods (Bullock et al., 1988; Chan et al., 1994). Seasonal variations have sometimes been found to be as large or even larger than the changes observed between agricultural management practices (Bullock et al., 1988; Guidi et al., 1988; Perfect et al., 1990; Angers et al., 1993; Chan et al., 1994; Daraghmeh et al., 2009).

The objective of this study was to investigate AS dynamics over three seasons in a soil that had been under different tillage and fertilization practices for seven years. A range of factors, namely, soil organic carbon, hot-water extractable carbohydrates, water content and water repellency were also studied and related to the observed differences in AS.

2. Materials and methods

2.1. Experimental site

The study was conducted at the Kerguéhennec Experimental Station (47°53 N, 02°44 W) (Chambre Régionale d'Agriculture de Bretagne) located in Brittany (Northwestern France). The area has an oceanic climate with an annual average temperature of 11.7 °C and an average total annual precipitation of 900 mm from 2000 to 2007. The soil is classified as a Humic Cambisol (FAO classification) with a loamy texture (17% clay, 42% silt, 41% sand in the A-horizon). The experiment was established in 2000 in a field that had been continuously moldboard plowed to 25 cm depth before plot establishment. At that time, the soil pH was 5.2 and the soil organic carbon content was 25 g kg^{-1} in the first 25 cm.

The factorial design combined three tillage practices and two fertilizer treatments (mineral and organic), resulting in six treatments replicated three times. The 18 plots were arranged in a split-plot design, with tillage practice as the main plots, and fertilizer treatment as the subplots. Each individual plot was 25 m long and 12 m wide. Maize (*Zea mays* L.), winter wheat (*Triticum aetivum* L.), rapeseed (*Brassica napus* L.) and winter wheat were grown in a 4-year crop rotation, starting with maize, and with a nitrogen catch crop of California Bluebell (*Phacelia tanacetifolia Benth*) between wheat and maize.

The tillage treatments were (i) moldboard plowing (MP, at a depth of 25 cm and rotary harrowing at a depth of 7 cm before sowing), (ii) surface tillage (ST, with chisel plowing at a depth of 12 cm before the wheat crop and California Bluebell cover-crop followed by rotary harrowing at a depth of 7 cm before the maize crop) and (iii) no-tillage (NT) which consisted of direct seeding. The mineral treatment was nitrogen (N) applied as ammonium nitrate. The organic treatment was poultry manure supplemented with mineral fertilizers when required. The poultry manure had the following characteristics: a carbon content of 37.5% of the total dry matter, a C/N ratio of 8 and a pH of 8. According to the annual N balance forecast considering the soil's organic N mineralization and crop needs, 140 kg mineral N ha^{-1} was applied as ammonium nitrate in the mineral treatment. In a same way, 17 Mg D M ha^{-1} of poultry manure combined with 50 kg mineral N ha^{-1} was applied as the organic treatment. Poultry manure applied between 2000 and 2007 contributed on average 2.2 Mg C ha^{-1} yr^{-1}. Wheat straw was not removed and it contributed almost as much in terms of C inputs as poultry manure (Viaud et al., 2011).

In 2007, the gravimetric water content at field capacity was determined with a pressure membrane apparatus at −316 hPa, on 3-cm aggregates sampled between topsoil and 7 cm depth. The means of the obtained values (4 replicates) were respectively equal to 26.07, 26.8 and 29.0% under MP, ST and NT tillage treatments and 27.9 and 29.8% under the mineral and organic treatments.

2.2. Sampling

One composite soil sample of three sub-samples was collected for each plot. A small spade was used to collect the soil from the 0–7 cm layer. Sampling was carried out on four dates from April 2007 to February 2008, during and after a winter wheat crop. Sampling dates were chosen to cover the different periods of the season while avoiding any rapid short term effects of the organic amendment or tillage: (i) 5 April 2007 (early spring), during crop growth, seven weeks after manure application (17 Mg ha^{-1} representing 3.35 Mg C ha^{-1}) and five months after sowing the wheat crop; (ii) 22 May 2007 (middle spring); (iii) 30 July 2007 (summer), four days after wheat harvesting, (iv) 17 February 2008 (winter) five months after stubble returned to the soil and California Bluebell were sowed as a cover-crop and just after its chemical destruction.

2.3. Aggregate stability

Aggregate stability (AS) was measured according to a modified version of the ISO 10930 (2012) method which is based on Le Bissonnais (1996). We used the slow wetting test which parallels field conditions of wetting under gentle rain. Five grams of 3–5 mm air dried aggregates were capillary rewetted with water before sieving in ethanol at 50 mm and dry sieving the resulting fraction (>50 μm) with a nest of six sieves (2000, 1000, 500, 200, 100 and 50 μm). The mean weight diameter (MWD) was calculated as the sum of the mass fraction remaining on each sieve after sieving relative to total soil used, multiplied by the mean aperture of the adjacent sieves.

2.4. Potential explanatory properties

Total soil organic carbon (OC) in the 3–5 mm aggregates (dried and ground < 0.25 mm) was measured with a CHN analyzer (Flash EA 1112, Thermofinningan, Milan, Italy). Hot-water extractable carbohydrates (HWEC) were determined on an extract of 1 g of 3–5 mm aggregates (crushed < 0.25 mm) suspended in 20 ml of hot water (80 °C) for 24 h. The carbohydrate content of the extract was analyzed using the H_2SO_4/phenol method (Dubois et al., 1956). The gravimetric soil water content (WC) was measured from each sample, by oven drying a subsample at 105 °C for 24 h. Water repellency of 3–5 mm aggregates (WR) was measured from the water drop penetration time (Chenu et al., 2000). Drops of 3 μl deionized water were deposited with a micro-syringe onto the surface of 60 individual airdried aggregates per plot and the time required for a drop to penetrate into each aggregate was recorded.

3. Statistical analysis

Analyses of variance using a mixed model for split plot design with repeated measures were used to determine the statistical significance of the effects of tillage, fertilizer and date of sampling, and their interactions on soil properties. Fertilizer, tillage and sampling date were included as fixed effects. Block and tillage were