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Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil

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ABSTRACT

The objective of this study was to compare the effects of repeated field applications of three urban compost amendments and one farmyard manure amendment over a 9-year period on aggregate stability in a silty loam soil initially characterized by low clay and initial organic matter contents and poor aggregate stability. Three different aggregate stability tests with increasing disruptive intensities (fast wetting > mechanical breakdown > slow wetting tests) and different disaggregation mechanisms, were used. All of the amendments, which were applied at approximately 4 Mg C ha^{-1} every other year, increased the organic carbon content and improved the stability of the aggregates against the disruptive action of water, as determined by each of the stability tests. However, the year-to-year variations in the aggregate stability that related to factors other than the organic inputs were greater than the cumulative increase in aggregate stability relative to the control. The positive effects of the tested amendments on aggregate stability were linked to their contribution to soil organic C contents ($r = 0.54$ for the fast wetting test and $r = 0.41–0.42$ for the mechanical breakdown and slow wetting tests; $p < 0.05$). The addition of urban composts had a larger positive effect on aggregate stability than farmyard manure at the majority of sampling dates. The addition of biodegradable immature compost, such as municipal solid waste (MSW), improved the aggregate stability through an enhanced resistance to slaking. The addition of mature composts, such as the co-compost of sewage sludge and green wastes (GWS) or biowaste compost (BW), improved the aggregate stability by increasing interparticular cohesion. The MSW compost was the most efficient in improving aggregate stability during the first 6 years of the experiment (average improvements of +22%, +5% and +28% in the fast wetting, mechanical breakdown and slow wetting tests, respectively, compared to the control treatment); this result was likely due to the larger labile organic pool of the MSW compost that was highly effective at stimulating soil microbial activity. After the first 6 years, the two other composts, GWS and BW, became more efficient (average improvements of +25%, +61% and +33% in the fast wetting, mechanical breakdown and slow wetting tests, respectively, compared to the control treatment), which was probably linked to the greater increase in soil organic C contents. Therefore, the application of urban compost to silty soil that is susceptible to water erosion was effective at improving aggregate stability and thus could be used to enhance the resistance of soil to water erosion.

1. Introduction

Water erosion affects more than 5 million hectares of arable soils in France including areas with a moderate or uneven relief (Le Bissonnais et al., 2002). In silty soils, which are widely represented in northern Europe, crust formation increases the risk of sheet erosion and has been linked to the low stability of aggregates (Le Bissonnais et al., 1998; Bresson et al., 2006). In these soils, organic matter is the principal agent that contributes to aggregate stability (Tessier et al., 1998), and significant correlations between aggregate stability and soil organic matter content have been established (Loveland and Webb, 2003). Various organic fractions participate in aggregate stabilization including microbial biomass (particularly fungi), microbial-derived polysaccharides, particulate organic matter, humic substances and lipids (Baldock, 2002; Bronick and Lal, 2005; Abiven et al., 2009).

Intensive cultivation can lead to a decline in soil organic matter content (Hanegraaf et al., 2009), resulting in a decrease in aggregate stability and a related increase in the soil erosion risk (Le Bissonnais

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and Arrouays, 1997; Gajic et al., 2006). Composts resulting from the biological treatment of organic municipal wastes represent valuable sources of exogenous organic matter that could be applied to soils to increase their organic matter contents (Lashermes et al., 2009) and restore their physical properties, including soil aggregate stability (Aggelides and Londra, 2000), especially in areas where traditional sources of exogenous organic matters as manures are scarce. Indeed, the application of exogenous organic matter has been shown to improve soil aggregate stability and protect against the disruptive action of water in both laboratory and field experiments. A broad variability of improvements in aggregate stability have been observed that corresponds to the soil type and the quality of the amendments applied (Darwish et al., 1995; Aggelides and Londra, 2000; Annabi et al., 2007; Abiven et al., 2008; Ojeda et al., 2008). Few mid- to long-term experiments have been performed to monitor changes in aggregate stability with different organic inputs, which have mainly included animal manures (N'Dayegamiye and Angers, 1990; Darwish et al., 1995; Gerzabek et al., 1995; Aoyama et al., 1999; Albiach et al., 2001; Whalen and Chang, 2002) and peat or wood residues (N'Dayegamiye and Angers, 1993; Diaz et al., 1994). Only two previous studies have addressed the use of urban compost and sewage sludge (Albiach et al., 2001; Ojeda et al., 2008). In most cases, positive effects were found without a clear differentiation between the mechanisms involved in aggregate stabilization. Most often, improvements in aggregate stability were linked to an increase in the soil organic matter content (Darwish et al., 1995; Gerzabek et al., 1995; Aoyama et al., 1999; Albiach et al., 2001). Soil microbial activity and that of fungi in particular, has also been demonstrated to be involved in aggregate stabilization (N'Dayegamiye and Angers, 1990). A recent review by Abiven et al. (2009) highlighted the lack of a clear and universal relationship between the improvement of soil aggregate stability following organic inputs, the induced aggregative factors and the mechanisms that are involved. The biochemical characteristics and related biodegradability of the organic inputs partly explain the observed differences in aggregate stabilization after organic amendment additions and also enable the prediction of aggregate stability evolution after the addition of a specific amendment (Annabi et al., 2007; Abiven et al., 2008).

The wet sieving method (Kemper and Chepil, 1965; Kemper and Rosenau, 1986) has been used in most studies to assess water-stable aggregates. This method mainly highlights the resistance of an aggregate to slaking due to the compression of air entrapped inside the aggregates during wetting. The "Le Bissonnais" method (Le Bissonnais, 1996) combines three disruptive tests that are characterized by different wetting conditions and energies that differentiate three disaggregation mechanisms: slaking, mechanical breakdown by raindrop impact and disaggregation induced by differential swelling. Using this method, Ojeda et al. (2008) showed that the addition of sewage sludges with differing properties reduced soil disaggregation through different mechanisms.

There were three main goals of this study: (i) to quantify the effects of repeated applications of three urban composts and one farmyard manure amendment on aggregate stability in a silty loam soil during a 9-year field experiment; (ii) compare the mechanisms involved in the improvement of aggregate stability by using the three tests of the "Le Bissonnais" method to measure aggregate stability; and (iii) link the observed effects to the evolution of organic carbon contents in the amended soils.

2. Materials and methods

2.1. Experimental site

The QualiAgro long-term experiment has been initiated in 1998 to assess the environmental impacts and positive effects of urban composts on soil quality and fertility (Houot et al., 2002). The experimental site is located at Feucherolles, 35 km west of Paris, France (48°53′47″N, 1°58′21″E). The mean annual rainfall and temperature are 570 mm and 11 °C, respectively. The soil is a glossic luvisol (WRB-FAO classification) that is representative of many northern French soils used for cereal cropping. The soil had a silty loam texture in the plowed layer with the following characteristics at the beginning of the experiment: 150 g kg^{-1} clay, 783 g kg^{-1} silt, and 67 g kg^{-1} sand (using the Robinson pipette method for soil dispersion and the destruction of organic matter by H_2O_2); a pH of 6.9 (in water); and an average initial organic carbon content of 11 g C kg^{-1} (elemental microanalysis after combustion on a CHN analyzer). The experimental field site has been cropped with a wheat-maize succession since the beginning of the experiment. Wheat crop residues have been exported, whereas the maize residues have been returned to the soil.

Four different organic amendments are applied: (1) a municipal solid waste compost (MSW) made from residual municipal wastes after the selective collection of dry and clean packaging; (2) a biowaste compost (BW) made from the selectively collected fermentable fractions of municipal wastes co-composted with green wastes; (3) a compost resulting from the co-composting of sewage sludge, green wastes and wood chips (GWS); and (4) a farmyard manure (FYM) obtained from dairy farm. Detailed information on the composting processes has been previously presented (Annabi et al., 2007). These four organic treatments are compared to a control treatment that does not receive organic input. Each treatment is replicated four times, and the experimental plots arranged in a randomized complete block design. Each 10 m × 45 m plot is separated by 6-m-wide cultivated bands and the blocks by 25-m-wide cultivated bands.

Since 1998, the organic amendments have been spread in early September on wheat stubble at a two-year frequency (1998, 2000, 2002, 2004, 2006). The intended applied dose was equivalent to 4 Mg C ha^{-1}, corresponding to 1.5 to 2-times the doses that are typically applied by farmers. After five applications, a total of 22.6, 19.4, 18.5 and 22.8 Mg C ha^{-1} of GWS, MSW, BW and FYM had been applied, respectively.

The organic amendments were disk-plowed into the soil (10 cm deep) within two days after their application. The soil was then plowed in November to a depth of 29 cm using a four-furrow moldboard plow. The soil was left bare until early April when the maize seedbed was prepared to a depth of 10–15 cm using a tined cultivator. Maize was sown in late April to early May and harvested at the end of November. The soil was then plowed again (29 cm deep); the wheat seedbed was prepared (10–15 cm deep) and wheat was sown in early November. A low level of mineral nitrogen (60 kg N ha^{-1}) was applied to the wheat as a starter, but no mineral nitrogen was added to the maize crops.

2.2. Characterization of the amendments

All amendments were sampled during their application, and analyses were performed on dried and ground (<1 mm) samples. Total organic carbon (TOC) and total nitrogen (N_{tot}) contents were determined after further grinding to <0.2 mm followed by combustion on a CHN analyzer (Carlo Erba NA 1500, Italy). The pH of the compost samples was measured in water (1/5, v/v).

Total organic matter contents were measured as the mass loss on ignition at 480 °C. The proportions of soluble organic matter (SOLU) and hemicellulose-like (HEMI), cellulose-like (CELL), and lignin-like (LIGN) fractions were determined by crude-fiber analysis (Van Soest and Wine, 1967) as described in the French XPU 44 162 standard (AFNOR, 2009).

The kinetics of organic matter mineralization of the applied amendments were monitored during 91-day laboratory