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Influence of plant residue management on microbial properties and water-stable aggregates of two agricultural soils

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Abstract. The objective of our studies was to evaluate the effects of three plant residue management practices on the size and activity of soil microbial community and their contribution to water-stable aggregation in two agricultural soils under continuous spring barley growing. These practices included: straw harvesting, straw incorporation into a depth of 0-20 cm, and straw burning with subsequent incorporation of ash into the depth of 0-20 cm. The straw incorporation treatment, as compared to the two other ones, contributed to an insignificantly higher total amount of water-stable aggregates (0.25-10 mm) in the degraded loam Chernozem (54.1±4.7%) and the clayey loam Gleyic Fluvisol (62.1±0.7%). There were differences in the effects of the treatments on size distributions of fractions of water-stable aggregates in both soils. Among the studied treatments, the straw incorporation one led to a significantly ($p = 0.01$) higher increase in basal respiration only in the degraded loam Chernozem. Compared to the straw incorporation and harvesting treatment, the straw burning one had a significantly ($p < 0.01$) higher contribution to the accumulation of microbial biomass carbon in water-stable aggregates of the degraded loam Chernozem and the clayey loam Gleyic Fluvisol.

Keywords: management practices, organic matter, microbial community, aggregation

INTRODUCTION

Current practices for management of soil organic matter (SOM), its labile forms and plant residues can be essential for maintaining soil quality and sustainability due to the recovery of soil structure after detrimental impacts. Therefore, one of the key objectives for soil aggregation research is to evaluate the effects of different management practices on these forms of SOM in order to evaluate their functional roles in soils. In many studies of the key indicators of soil quality a priority is given to interdisciplinary microbiological, biochemical and biophysical studies (Anderson, 2003; Dąbek-Szreniawska *et al*., 2002). Such studies enable to make a reasonable selection of robust soil indicators to distinguish trends in changes of soil quality in various agro-ecosystems (Nortcliff, 2002).

Plant residues, roots and root hairs, apart from soil microorganisms and clay minerals, can be important agents of formation and stabilization of soil structure (Bending *et al.*, 2002; Bossuyt *et al*., 2001; Denef and Six, 2005; Six *et al*., 2004). Hence, a quantitative contribution of these organic substances to a soil structural stability and a soil microbial biomass should be taken into account if there is a need for selection of effective soil management practices.

The objective of the present studies was to evaluate the effects of three plant residue management practices on the size and activity of soil microbial community and their contribution to water-stable aggregation in two agricultural soils.

MATERIALS AND METHODS

Soil sampling was carried out in October of 2002 on plots with continuous growing spring barley (*Hordeum vulgare* L.) at the Ivanovice (49°18 N, 17°5 E) and Zabcice (49°1 N, 16°37 E) experimental stations of the Mendel University of Agriculture and Forestry, Brno (Czech Republic). At the Ivanovice experimental station, mean annual temperature and precipitation were 8.4°C and 556 mm, whereas at the Zabcice experimental station, these parameters reached 9.3°C and 470 mm, respectively. The soil of the Ivanovice experimental station is a degraded loam Chernozem (Luvic Chernozem, FAO). The Zabcice experimental station is located on a clayey loam Gleyic Fluvisol (Fluvi-Gleyic Phaeozem, FAO). Long-term field experiments at these sites were established in 1965 and 1970, respectively. At both

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locations, composite soil samples, consisting of 9-10 subsamples, were randomly collected with a shovel from a 0-20 cm depth of plots with conventional mouldboard tillage (to a depth of 20-22 cm). The following plant residue management practices were included in our studies: straw harvesting (removal), straw incorporation (into a depth of 0-20 cm), and straw burning (with subsequent incorporation of ash into the depth of 0-20 cm). No mineral fertilizers were incorporated into the plots on the degraded loam Chernozem, while the rate of N fertilizers for growing spring barley on the clayey loam Gleyic Fluvisol was equal 30 kg N ha^{-1}.

After sampling, composite soil samples were air-dried and divided into two parts. One of the parts was passed through a sieve with a diameter of openings of 2 mm and stored for biochemical and biological analyses (Bending *et al.*, 2002; Chen *et al.*, 2009; Melero *et. al.*, 2006). Air-dried composite soil samples of the second part were sieved through a set of sieves with openings diameters of 0.25, 0.5, 1.0, 2.0, 5.0 and 10.0 mm in order to determine the distribution of size fractions of dry-stable aggregates. Before the wet sieving, 50 g of the dry-stable aggregates were capillary-wetted for 10 min on a filter paper placed on the largest sieve to avoid their disruption by air bubbles during the wet sieving. Then the set of sieves was submerged into water and the filter paper was gently removed. The water-stable aggregates (WSA) were separated by vertical oscillation of sieves for 1 min (40-50 mm stroke length, 10 cycles min^{-1}) according to a wet sieving method (Vadjunina and Korchagina*,* 1986). Afterwards WSA from 0.25-0.5 to 5.0-10.0 mm size classes were air-dried, gently ground, and passed through sieves to remove those sand particles whose diameters were within the above-mentioned size classes of WSA. Then each WSA size fraction was weighed and stored for biochemical and biological analyses in air-dried state (De Gryze *et al.*, 2005).

SOM content was determined by a wet digestion method using a 0.4 N $K_2Cr_20_7$ solution plus concentrated sulphuric acid for oxidation of soil organic substances (Rastvorova *et al.*, 1995). Basal and substrate-induced respirations (both as CO_2 production rates) were measured in whole soil samples and in WSA (a mean-weighted composite amount of their 0.25-10.0 mm fractions). To measure the basal respiration, 4 g of the air-dried whole soil samples and WSA fractions were moistened to field capacity, placed into hermetically closed 40 cm^3 glass vials, and incubated at 30°C for 24 h (Wright *et al.*, 2009). The basal CO_2 production rates were determined by a gas chromatograph Chrom-5. To calculate the microbial biomass carbon (MBC) content, measurements of the substrate- induced respiration rates in whole soil samples and WSA fractions were done after adding glucose (5 mg g^{-1} soil) and their 3 h incubation in the same glass vials at 22°C according to the method of Anderson and Domsch (1978), using a gas chromatograph.

All the measurements of soil parameters were made in three replicates. Means and standard deviations were calculated for each parameter within each treatment. Significance of differences between treatments was estimated by analysis of variance (one-way ANOVA) at $p \leq 0.05$. Relationships between soil parameters were assessed with a linear regression analysis using computer statistical package.

RESULTS AND DISCUSSION

Plant residue management practices are usually regarded as rather effective tools for maintaining satisfactory organic carbon sequestration and water-stable aggregation in agricultural soils (Chan *et al.*, 2002). The organic carbon sequestration in soils generally means that fresh organic matter derived from plant residues and manures will be included with time within micro- and macroaggregates (Knicker and Skjemstad, 2000). However, the extent of SOM changes in response to plant residue management practices can vary between climatic conditions, soils and crops.

The results of dry sieving of soil samples did not distinguish any significant differences in the total amount of dry-stable aggregates (0.25-10 mm) between the three treatments in the degraded loam Chernozem (92.2±2.4 to 94.4±2.1%) and the clayey loam Gleyic Fluvisol (94.3±2.3 to 94.9±1.7%). The straw incorporation treatment, as compared to the two other ones, contributed to an insignificantly higher total amount of WSA (0.25-10 mm) in the degraded loam Chernozem (54.1±4.7%) and the clayey loam Gleyic Fluvisol (62.1±0.7%), perhaps as a result of slightly greater contribution of SOM and its labile forms to the formation of WSA (Degens *et al.*, 1994; De Gryze *et al.*, 2005). In the degraded loam Chernozem and the clayey loam Gleyic Fluvisol the total amount of WSA also varied insignificantly from 51.9±1.0% (straw burning treatment) to 53.1±2.7% (straw harvesting treatment) and from 60.22.3% (straw burning treatment) to 60.7±5.6% (straw harvesting treatment), respectively. Mean-weight diameter (MWD) of WSA changed insignificantly ($p = 0.06$) from 0.40±0.03 to 0.54±0.05 mm in the degraded loam Chernozem and significantly ($p < 0.001$) from 0.96±0.05 mm (straw burning treatment) to 1.33±0.06 mm (straw incorporation treatment) and 1.39±0.18 mm (straw harvesting treatment) in the clayey loam Gleyic Fluvisol. Earlier studies of other scientists showed that WSA could be formed around fresh plant residues (Six *et al.*, 1998).

In the degraded loam Chernozem, an insignificantly higher amount of large (from 1.0-2.0 to 5.0-10.0 mm) fractions of WSA was observed in the straw incorporation treatment, as compared to those from the two other treatments (Fig. 1a). In contrast, the straw incorporation treatment did not result in any greater amount of these large WSA fractions in the clayey loam Gleyic Fluvisol (Fig. 1b). However, we observed significant differences in total amounts of WSA ($p < 0.01$) and their MWD ($p < 0.01$) between these soils, probably as a result of their differences in soil texture.

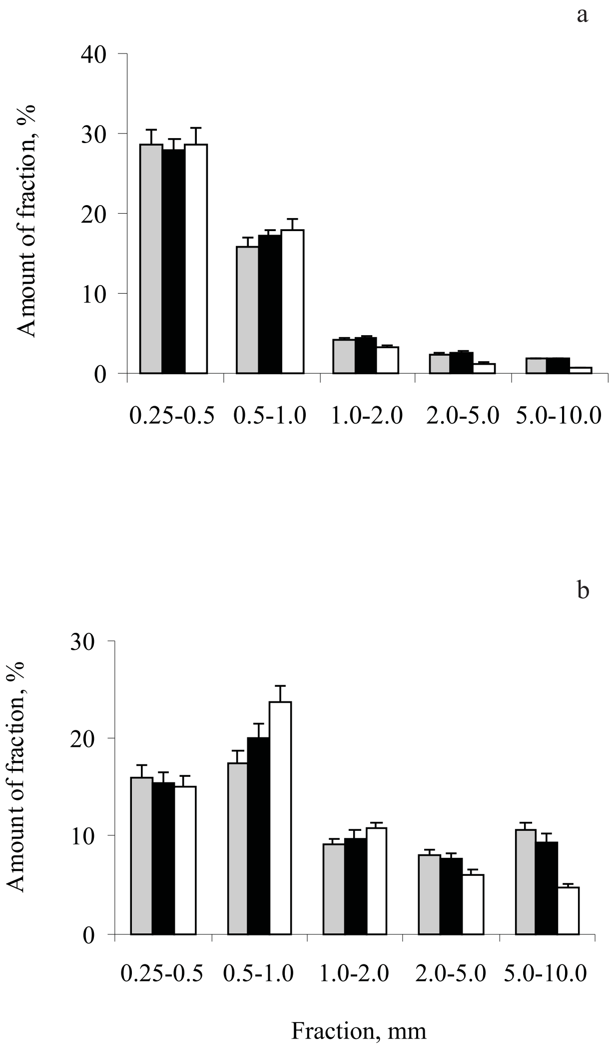

Fig. 1. Distribution of size fractions of water-stable aggregates in a degraded loam Chernozem (a), and a clayey loam gleyic Fluvisol (b) at straw harvesting (grey columns), straw incorporation (black columns) and straw burning (white columns) treatment (bars are standard deviations at $p < 0.05$, $n = 3$).

Among the three treatments, the straw burning one contributed to an insignificantly greater increase in the amount of the 0.25-1.0 mm WSA fractions in the degraded loam Chernozem (46.6 versus 44.7-45.0%) and in the clayey loam Gleyic Fluvisol (36.0 versus 34.1-35.8%), as shown in Fig. 1a, b. Burning of plant residues is known to lead to the formation of aromatic components (for instance, benzene polycarboxylic acids as specific markers of black carbon) which are associated with clay minerals (Glaser *et al.*, 2000; Hammes *et al.*, 2008). In the straw burning treatment, such aromatic components might be binding agents in the observed greater formation and stabilization of 0.25-1.0 mm WSA fractions (Brodowski *et al.*, 2006).

The observed trend towards a more favourable influence of straw incorporation on the total amount of WSA could be attributed to a greater contribution of this treatment to the accumulation of SOM in the degraded loam Chernozem – 18.0±0.2 g C kg^{-1} soil (whole soil) and in the clayey loam Gleyic Fluvisol – 15.2±0.4 g C kg^{-1} soil (whole soil), compared to the two other treatments. In the straw burning and harvesting treatments, SOM content was equal to:

– 17.6±0.2 g C kg^{-1} soil and 16.7±0.3 g C kg^{-1} soil in whole samples of the degraded loam Chernozem, and

– 13.6±0.3 g C kg^{-1} soil and 13.8±0.3 g C kg^{-1} soil in those of the clayey loam Gleyic Fluvisol, respectively.

There was a trend towards favourable sequestration of organic carbon in these soils at the straw incorporation and burning treatments, compared to the straw harvesting one. For instance, in the degraded loam Chernozem, SOM content in WSA was significantly greater (19.1±0.5 g C kg^{-1} soil g C kg^{-1} soil) than that in the whole soil from those two favourable treatments. In the clayey loam Gleyic Fluvisol, the straw incorporation treatment contributed to an insignificantly higher accumulation of SOM (16.2±0.4 g C kg^{-1} soil) in WSA than in the whole soil. Nevertheless, the treatment-induced differences in accumulation of SOM in WSA resulted only in insignificant ($r = 0.08$-0.12) changes in their amount in both soils.

Basal respiration is a sum of respirations by soil microbial community at a current content of available organic carbon and nitrogen. In our studies, we found that all the straw treatments had different effects on the labile forms of SOM in both soils. The use of the straw incorporation treatment could lead to a greater accumulation of easily decomposable plant residues in both soils.

However, the basal respiration in the whole samples of the clayey loam Gleyic Fluvisol showed insignificant differences (14.8-17.7 mg CO$_2$-C kg^{-1} soil h^{-1}) among the studied treatments. In contrast, the basal respiration of the whole samples of the degraded loam Chernozem demonstrated significantly ($p = 0.01$) higher values (21.6 mg CO$_2$-C kg^{-1} soil h^{-1} versus 17.2-18.0.mg CO$_2$-C kg^{-1} soil h^{-1}) in the straw incorporation treatment.

Besides, we determined a significantly ($p < 0.001$) greater basal respiration in WSA than in whole samples of both soils in all of the three plant residue treatments. Nevertheless, basal respiration in WSA of the clayey loan Gleyic Fluvisol showed no significant differences between the studied treatments varying from 22.5±3.0 mg CO$_2$-C kg^{-1} soil h^{-1} to 26.1±1.7 mg CO$_2$-C kg^{-1} soil h^{-1}. However, basal respiration in WSA of the degraded loam Chernozem demonstrated significant ($p = 0.03$) treatment-induced differences, from 25.9±1.8 mg CO$_2$-C kg^{-1} soil h^{-1} (straw incorporation) to 31.6±2.5 (straw burning) mg CO$_2$-C kg^{-1} soil h^{-1}. Despite the significant differences in basal respiration, we observed only weak correlations between the total amount of WSA and basal respiration in this soil when all three treatments were considered together.

MBC content is being currently used as a sensitive soil quality indicator (Anderson, 2003). Our results showed that, among the three treatments for the degraded loam Chernozem, none of the treatments resulted in a significant increase of MBC content (in whole soil) as presented in Fig. 2a.

However, the straw burning treatment, compared to the two other treatments, significantly ($p < 0.01$) contributed to the highest accumulation of MBC in WSA of this soil. This was likely due to that living conditions for soil microorganisms, in terms of quantity of easily available forms of SOM, were most favourable in WSA at the straw burning treatment. Straw burning could also improve nutrient availability and soil pH for microorganisms (Chan *et al.*, 2002).

In contrast to the whole soil, MBC content in WSA of the clayey loam Fluvisol was significantly ($p < 0.01$) greater than that in WSA of the degraded loam Chernozem, possibly because of differences in soil texture (Franzluebbers and Arshad, 1997). Nevertheless, we did not distinguish any significant effects of any of the treatments on MBC content in the whole samples of the clayey loam Fluvisol. In WSA of this soil, the straw burning treatment had a significantly ($p < 0.01$) higher contribution to the accumulation of MBC in WSA, compared to effects of the two other ones (Fig. 2b).

Hence, this treatment was the most favourable for the accumulation of MBC in WSA of both soils. Perhaps the above-mentioned increase in the amount of 0.25-1.0 mm WSA fractions was also induced by the significantly highest accumulation of MBC in WSA at the straw burning treatment for the two soils.

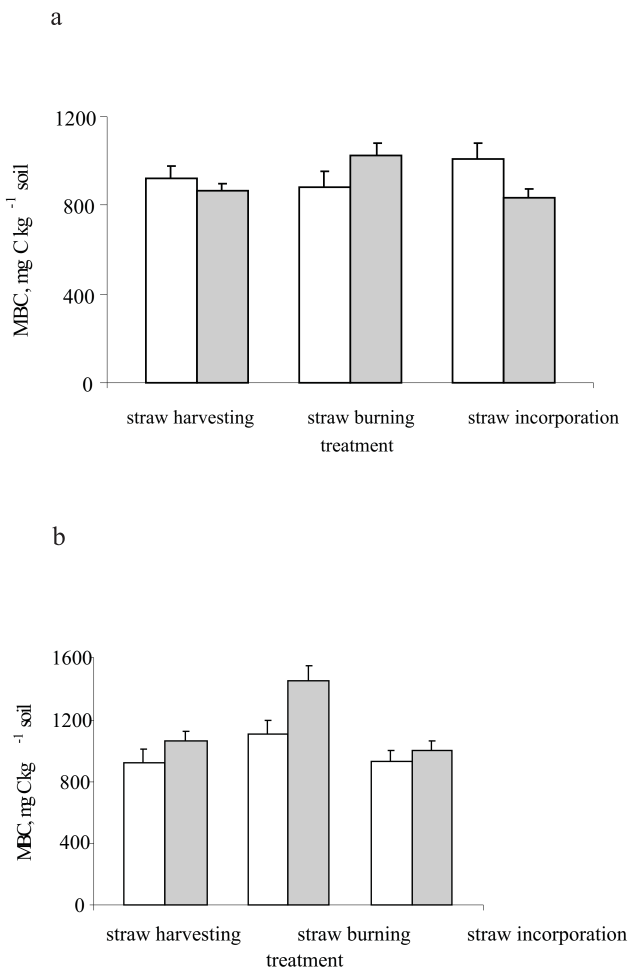

Fig. 2. MBC content in bulk samples (white columns) and water-stable aggregates (grey columns) at different plant residue treatment (bars are standard deviations at $p < 0.05$ and n=3), a – degraded loam Chernozem, b – clayey loam Gleyic Fluvisol.

CONCLUSIONS

1. None of the studied spring barley residue management treatments made a significant contribution to the total amount of water-stable aggregates (0.25-10 mm) in the degraded loam Chernozem and the clayey loam Gleyic Fluvisol.

2. There was a more favourable sequestration of SOM in both soils at the straw incorporation and burning treatments, compared to the straw harvesting one.

3. The straw burning treatment, as compared to the two other ones, contributed to a significant increase in the size of microbial community in water-stable aggregates of the degraded loam Chernozem and the clayey loam Gleyic Fluvisol.

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