EFFECT OF BARLEY STRAW ON THE WATER-STABILITY OF SOIL AGGREGATES IN A LONG TERM FERTILIZATION EXPERIMENT

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Abstract

Degradation of soil structure and decline of structural stability are frequently caused by tillage, crop management and excessive wetting. As an indicator of structural stability, the water-stability of soil particles is often determined by wet sieving. Because of differences between field and laboratory circumstances and therefore lack of comparability, the former results are questionable. An optimised wet sieving method initiated by Six (2000) was adapted by us to investigate changes in soil structure and quality caused by different kinds of added organic matters. Samples originated from the long-term fertilization experiments of Keszthely, Western Hungary. The texture of the investigated soil is sandy loam, the type of soil is an Eutric Cambisol (WRB classification), or Alfisol (Soil Taxonomy). Barley straw was added as organic fertilizer in the experiment. According to data soil structure is improved by adding this readily decomposable organic matter since its decay produce gluing compounds. Mineral particles and microaggregates are bound together making new or bigger macroaggregates and the water-stability of existing macroaggregates increased.

Introduction

Soil fertility has a crucial role to supply the food for the human population (Várallyay, 2002) which has grown explosively mostly in the past hundred years. Soil fertility is partly influenced by the structure of soil. Soil structure is built up by groups of primary particles that cohere to each other, and which are called aggregates (Kemper and Rosneau, 1986). Soil structure is optimal for crop management in the case when the whole soil mass is built up by single aggregates which are bigger than 250-500µm (Di Gléria et al., 1957). The improvement of soil fertility has a historical tradition using both natural and man-made fertilizers. These materials have effects on soils in different ways. The effects of organic and mineral fertilizers on soil structure were investigated since the last century. Returning crop residues or farmyard manure i.e. organic matters to soils may amend soil structure since their decay produce gluing compounds. Mineral fertilizers affect soil structure in antagonistic ways: phosphatic fertilizers and phosphoric acid may favour soil structure by the formation of Al and Ca phosphate bindings contrary to high concentrations of fertilizer NH_4^+ destructs soil structure through dispersing clay colloids (Haynes and Naidu, 1997). Furthermore any kind of organic matter added to soils improves soil structure in direct or an indirect way. Crop residues, i.e. readily decomposable organic matter improves soil structure in a direct way, producing gluing compounds with their decaying, therefore mineral particles are bound together making new or bigger aggregates and the water-stability of existing aggregates increases. Different kinds of added organic matter cause different changes in soil structure: it is correlated with the amount and biochemical composition of the crop residues (Martens, 2000). The less decomposable compounds occur in them ameliorate soil structure the more. Farmyard manure with its former fermentation has lost its capability to stimulate the formation of organic binding compounds in a direct way but it stimulates the activity of microbes, which produce mucilage substrates indirectly.

Wetting of aggregates could be severely disruptive, because compounds gluing the bigger particles together may dissolve and during rapid wetting the air escaping from the pores of the aggregate generates high pressure, which blows up the aggregate. So aggregates are decomposed into fragments of aggregates and primary particles (Emerson, 1977). Therefore quality and stability of soil structure depend much on the stability of aggregates in water. This property may be ameliorated by fertilizers and often investigated by wet sieving.

The wet sieving method used to calculate the Normalised Stability Index (NSI) proposed by Six (2000) excludes the confounding effects and standardises the method for assessing of water-stability of aggregates. To make the results comparable, (1) the different sized structural units of different soil types have to be broken into a given size range, (2) the differently moist field samples have to be air-dried, (3) the air-dry samples have to be moistened to a given moisture content. To make the different mineral particle distribution of different sites comparable, (4) the mineral fraction is excluded. The NSI characterises aggregate stability by comparing the aggregate distribution before and after the use of a standardised disruptive force and two different wetting methods. The same sieving time and the same sieving frequency ensures the standardised disruptive force. The two different wetting methods are: (1) fast wetting, namely rapid immersion in water (Slaking (S)), which disrupts the aggregates to the highest extent, therefore produce the lowest aggregate amount; and (2) slow wetting, namely capillary wetting (Capillary (C)) to field capacity, which disrupts the aggregates to the lowest extent and therefore achieves the highest aggregate amount. The capillary wetting method was earlier tried by us to get different size fractions to evaluate the distribution of soil organic matter in soils (Huisz et al., 2006)).

In this paper our aim is to test the standardised wet sieving method proposed by Six (2000). We investigated the effect of barley straw addition on soil structure and its quality and on the stability of aggregates.

Material and methods

Site description

The soil samples originate from the “International experiment for organic and mineral fertilization” long-term field experiment in Keszthely, Hungary . The investigated soil type is a sandy loam Eutric Cambisol (soil type FAO), Alfisol (soil order USDA). The soil of the experimental field is low in available phosphorus, moderate in potassium, low in OM (1.7%). Soil pH_{KCl} 5.9; the content of $CaCO_3$ 0.5-0.6%; and the percentage of clay (<0.002mm fraction) 24%. In this paper mixing of straw of the formerly grown barley crop has been investigated and compared to a not straw-added treatment as a reference. N mineral fertilizer was not used in either of the treatments. Both sites have been tilled by autumn ploughing to 25cm depth. Soil samples were taken from two different depth layers: the first from the depth of tillage (called upper layer: 0-20 cm) and a 10cm wide second layer under the depth of tillage (called lower layer: 20-30 cm). The experiment was set up in the 1983. Crop rotation was maize – winter wheat – winter barley. Samples were taken from the maize field, when maize was at the stage of 6-8 leaves. Addition and mixing of barley straw into soil were done in every year: barley straw was brought from other fields when the investigated field had a different crop. Crop residue mixing was done simultaneously with the autumn ploughing to 25cm depth.

Method

Soil samples were taken with a spade. We stuck down two times with the spade in a distance of 15-20cm, take out the soil block from the two lateral walls, then we take sample from the undisturbed frontal wall: in 3-5cm distance from it we stuck down once more. Soil samples were delivered in plastic boxes to avoid pressing of the natural structure. Field moist soil samples were manually gently broken apart into pieces smaller than 3-5cm diameter to avoid drying them into clods. Air dry soil were dry sieved in a 7mm sieve, parts bigger than this size were manually broken with a mortar to reach this size. Two different pre-treatments were investigated. (1) ±300g of air dry soil was rapidly immersed in tap water for 5min (Slaking (S)). (2) ±300g of air dry soil was capillary wetted to field capacity and left overnight to weight equilibrated (Capillary (C)). After the pre-treatments each sample was wet sieved for 2min in an analytic sieve shaker with the following aperture sizes: 2mm, 250μm, 53μm. Therefore we got 4 fractions: (1) the >2000μm large macro-, (2) the 250-2000μm small macro-, (3) the 53-250μm microaggregates, and (4) the <53μm silt and clay fraction. (1)-(3) fractions were gently back washed into pre-weighted aluminium pans. The supernatant was taken out after settling. The (4) fraction flowing out from the sieve shaker machine was collected in a bucket, left to settle for some days, washed into a pre-weighted aluminium pan after the removing of the supernatant. All fractions were dried on hot plates at 60°C, and left overnight in a drying machine at 60°C to weight equilibrated. Sand size distribution for the (1.) - (3.) fraction was determined by dispersing the aggregate fractions with sodium hexametaphosphate (5 g L^{-1} for 18 hours). Mineral fractions were back washed into pre-weighted aluminium pans and dried at 105°C to weight equilibrated. Aggregate-sized mineral fraction was subtracted (this method is called ‘sand correction’).

Results and discussion

Soil samples were taken from three replicate plots of each treatment and depth layer. Different pre-treatment methods were done in three replicates. Therefore there were altogether nine replicates for treatments. In this paper we present our results before the sand correction. Results of experiments were accepted when their variances were less than 5% compared to the other two members of the triplicate. Data were analysed with F-probe and depending on its value with 2 sampled T-probe or Welch-probe. Statistical significance was determined at $P < 0.05$. In the case of barley straw addition values were significantly different from the corresponding ones only at the Capillary (C) pre-treatment in the >2000μm large macroaggregate fraction in the upper layer at 0.05 significance level.

Figure 1- 4 show the amount of soil dry matter in the isolated fractions for each treatment and depth layer respectively. Table 1 shows the changes in dry matter amount of fractions for the effect of barley straw addition treatment (in the % of the Control treatment).

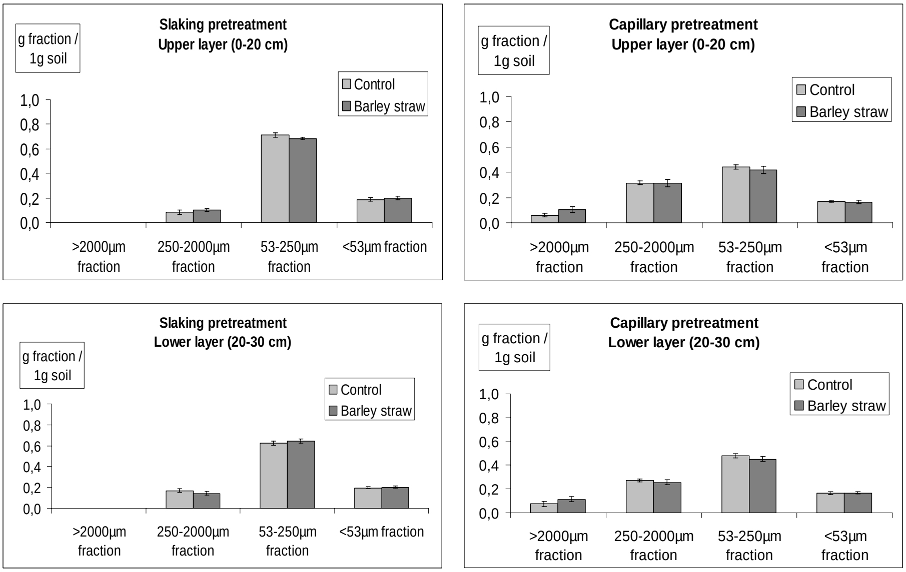

Figure 1-4. Size fractions (g fraction 1 g^{-1} soil, and the standard deviation at P>0.05) obtained by the different pre-treatment methods of the investigated treatments in the upper (0-20 cm) and the lower (20-30 cm) depth layers

Table 1. Changes in dry matter amount of fractions as the result of the addition of barley straw (in % of the Control treatment). Asterisk (*) indicates significant effect on the water-stability of aggregates caused by barley straw addition at P>0.05. Number of replicates was 9.

Pre-treatment	Layer	>2000 µm fraction	250-2000 µm fraction	53-250 µm fraction	<53 µm fraction
Slaking (S)	Upper (0-20cm)	0	22.44	-3.61	5.34
	Lower (20-30cm)	0	-15.51	3.44	3.72
Capillary (C)	Upper (0-20cm)	73.23*	-1.40	-5.30	-3.23
	Lower (20-30cm)	52.37	-5.65	-6.06	1.56

The addition of crop residue, i.e. readily decomposable organic matter improves soil aggregation since their decay produce gluing compounds; therefore mineral particles are bound together making new or bigger aggregates and the water-stability of existing aggregates increases. Barley straw contains easily decomposable organic matter therefore significant amelioration in the water-stability was expected. Investigations were done by two differently pre-treated wet sieving methods.

According to our expectations, the higher disrupting effect of the Slaking (S) pre-treatment caused the total disruption of >2000µm large macroaggregate fraction. Statistically different changes were indicated in the other, Capillary (C) pre-treatment (Table 1).

As shown in Table 1, in the upper layer, in the Slaking (S) pre-treatment the incorporation of barley straw has increased the ratio of the 250-2000μm small macroaggregate fraction (22.44%), but the 53-250μm microaggregate fraction and the <53μm silt and clay fraction have not changed in a great extent (only with -3.61% and 5.34%). All these changes were not significantly different. In this pre-treatment changes of the lower layer were not significantly different either. The amount of >2000μm large macroaggregate fraction was negligible in both depths. In the lower layer the amount of 250-2000μm small macroaggregate fraction has decreased by 15.51%, but this data is questionable because of the high standard deviation. The other 53-250μm and <53μm fractions have not changed to a great extent.

The only significantly different effect on the water-stability of aggregates was caused in the case of Capillary (C) pre-treatment in the upper layer: in the 250-2000μm small macroaggregate fraction. This fraction has grown with 73.23%. All the other fractions decreased negligible (with 1.4%, 5.3% and 3.23% respectively). In the lower layer the >2000μm large macroaggregate fraction has increased with 52.37%, but this result is questionable because of the high standard deviation. All the other fractions have not changed significantly. The 250-2000μm small macroaggregate fraction has decreased by 5.65%, the 53-250μm microaggregate fraction with 6.06%. The <53μm silt and clay fraction has not changed.

Summing up our results, addition of barley straw has increased the amount of large macroaggregate fraction in both investigated depths (+73.23% in the upper and 52.37% in the lower layer). The amount of the other fractions were changed only in the case of Slaking (S) pre-treatment, where it has increased with 22.44% (in the upper layer) but decreased with 15.51% (in the lower layer). The explanations of these phenomena are the followings. Adding barley straw and therefore easily decomposable organic matter stimulates the production of organic mucilage compounds and strengthens the forming of binding agents. This change is detectable first in the 250-2000μm small macroaggregate fraction, later in the >2000μm large macroaggregate fraction.

The aggregate-stabilizing effects are more expressed and better developed on the smaller particle sizes. The smaller the aggregate fraction is the higher ability it needs to resist the same disrupting forces. Therefore our results, have no dry matter in the more disruptive Slaking (S) treatment and notable amount in the Capillary (C) pre-treatment is easily understandable. The higher disruptive force in the Slaking (S) pre-treatment caused the total disintegration of the less resistant >2000μm large macroaggregate fraction. This fraction makes 250-2000μm small macroaggregate fraction, as it is described by the model of stepwise disintegration (Tisdall et al., 1982). This model describes the relative unvarying stability of 53-250μm microaggregate fraction. This is parallel with our results such as getting almost the same amounts of fractions in both pre-treatments yet depths.

The less aggregate-disintegrating pre-treatment, the Capillary (C) pre-treatment shows the high amount of the >2000μm large macroaggregate fraction. The weakness of the less stable binding agents is easily measurable comparing these results with those got by the Slaking (S) pre-treatment. Barley straw contains easily decomposable organic matter therefore significant amelioration in the water-stability was expected and proved. Mineral particles and microaggregates were bounded together making new or bigger macroaggregates and the water-stability of existing macroaggregates increased.

Our results prove the former theories and appropriate detection of aggregate-stability with this new method is hopeful. Further investigations are needed to finish it with the sand correction, and to investigate other different factors affecting water-stability of aggregates.

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