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Aggregate water stability of sandy and clayey loam soils differently compacted with and without wheat plants

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A b s t r a c t. The objectives of our studies were to: 1) estimate the effects of compaction of sandy loam and clayey loam soils on growth parameters of winter wheat plants, 2) evaluate the resilience capacity of the root system for the water-stable aggregation of compacted soils. Soil samples at field capacity were placed into pots with an initial bulk density of 1.2 Mg m^{-3} and compacted with ground contact pressures of 51, 103 and 154 kPa using a hydraulic compressor. Five plants in each pot were allowed to grow for 7 weeks till the boot stage. Results showed that wheat roots increased the water-stable aggregation of both soils in respect to treatments without plants. The dry weight of the roots was less affected by the increasing bulk density of the clayey loam soil than it was by the sandy loam. The resilience capacity of the root system for the water-stable aggregation in the sandy loam and clayey loam soils decreased only after applying a ground contact pressure of 154 kPa. The roots affected differently the distribution of separate size fractions of water-stable aggregates of 0.25–0.5 to 5.66–9.51 mm in both soils.

K e y w o r d s: soils, texture, roots, compaction, aggregation

INTRODUCTION

Plant roots and root hairs, apart from labile organic matter (microbial biomass C, particulate organic C, carbohydrates) and fungi hyphae, are essential for maintaining and recovering water-stable aggregation as one of the key indicators of quality of soils under continuous agricultural use (Ball-Coelho *et al*., 1998; Aoyama *et al*., 1999; Chan and Heenan, 1999). The long-term maintenance of an acceptable quality of arable soils generally means that the main functions of the soil (biochemical and geochemical cycling, accumulation, distribution and release of water and nutrients, accumulation and distribution of heat, buffering) are kept on a balanced level despite adverse environmental and agricultural impacts.

According to a concept proposed by Tisdall and Oades (1982) and then modified in the recent studies of Golchin *et al*. (1995) and Christensen (2001), there are several levels of structural and functional hierarchy (or complexity) in soils, namely, primary structure (for instance, clay-silt-sand sized organo-mineral complexes and non-complexed organic matter), secondary structure (micro- and macroaggregates) and tertiary structure (intact soil resources). The roots and root hairs are mainly involved in the formation of the secondary and tertiary structures, which are sensitive to the impacts of agricultural treatments and erosion processes. Therefore the ability of the roots, defined as their resilience capacity, to create and recover the structural complexity of soils should be kept in mind if there is a need to evaluate the effects of agricultural practices on soil sustainability.

The application of heavy agricultural machinery may lead to unfavourable physical consequences for the soil (disturbances in air, water and heat regimes) and its chemical status (nutrients leaching) as well as for the microbial community and plant roots. As a result of the disturbance of soil structure, high values of bulk density and penetrometer resistance are usually observed in compacted soils. The values of penetrometer resistance of 2–3 MPa are known to be unfavourable for the growth of plant roots (Pabin *et al*., 1998). However, little information is yet available on the quantitative contribution of wheat roots in recovering aggregate water stability after compaction having been run over by wheels with different ground contact pressures. Another crucial problem is whether the favourable formation and

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stabilisation of water-stable aggregates induced by growing wheat roots can be achieved under different soil physical conditions.

The objectives of the present studies were to: 1) estimate the effects of compaction of sandy loam and clayey loam soils on growth parameters of winter wheat plants and 2) evaluate the resilience capacity of a root system for the water-stable aggregation of compacted soils.

MATERIALS

Disturbed field moist samples of sandy loam and clayey loam soils were taken in March 2002 from the A horizons (0–20 cm) of plots cultivated with winter wheat (*Triticum aestivum* L., var. Pandas) plants at the Fagna and Vicarello experimental centres of the Experimental Institute for Soil Survey and Soil Conservation (Florence) with soils classified as sandy loam Typic Udorthents and clayey loam Vertic Xerorthent, respectively, according to Soil Taxonomy (USDA, 1975). After air-drying, all the soil samples were passed through a 2 cm sieve to obtain sub-samples with uniform distribution of aggregates. Prior to pot experiments, soil sub-samples were moistened to field capacity, which was equal to 20% (of weight) in sandy loam soil and to 27% in clayey loam soil. Each of the experimental PVC pots had a volume of 1440 cm^3 (9.7 cm in external diameter and 19.5 cm in height). The moistened soil sub-samples were placed into the pots at an initial bulk density of 1.2 Mg m^{-3} and then compacted with ground contact pressures of 51, 103 and 154 kPa which were applied to the soil surface using a hydraulic compressor. The selected ground contact pressures corresponded to those normally exerted by conventional agricultural machinery (tractors, harvesters) in Italy (Marsili *et al*., 1998). After compaction, eight seeds (with 0.5–1.0 cm roots in length) recently germinated on Petri dishes were planted in each pot up to a depth of 1 cm. Afterwards, five plants in each pot were allowed to grow for 7 weeks till the boot stage in the first set of the experimental layout. As a control, a second set of pots was kept without plants during the same period of 7 weeks. Three replicates of pots were used in each set of experiments.

A moisture regime corresponding to the field capacity of both soils was assigned to the pots and maintained by regular watering from above during the whole growing period. All the experiments were performed in the period from the 21st of March till the 24th of June 2002 under the climate conditions of Florence with daily temperatures from 10–15 to 30–35°C.

Aggregate water stability was measured in three replicates by wet sieving of dry stable aggregates passed through a set of sieves with diameter of openings of 0.25, 0.5, 1.0, 2.8, 5.66 and 9.51 mm. Prior to wet sieving, 50 g of dry stable aggregates, 0.25–9.51 mm in diameter were subjected to a 10 min capillary saturation on a filter sheet and afterwards placed on top of a set of the above-mentioned sieves, immersed directly in water and mechanically oscillated for 10 min. The aggregate water stability of both soils was not measured immediately after loading. However, after finishing the pot experiments, the following soil and root characteristics were determined: 1) soil moisture content by the gravimetric method, 2) bulk density by measuring the linear dimensions of the soil sub-samples in the pots, 3) penetrometer resistance in each of the pots by the 'Eijkel- kamp' penetrometer with a cone diameter of 1.6 cm, cone angle of 60°, and an average penetration speed of 2 cm s^{-1}, 4) aggregate stability by wet sieving and 5) the weight of dry roots separated from the soil by rinsing in running water and subsequently oven-drying at 40°C. The dry weight of the roots was measured only in two replicates.

RESULTS AND DISCUSSION

The results shown in Fig. 1 demonstrate that the average volumetric moisture content of the sub-samples of both soils differed more or less pronouncedly from the initially predetermined field capacity by the end of growing period. The moisture content ranged from 30 to 40% (sandy loam soil) and from 22 to 31% (clayey loam soil). This was probably due to differences in soil permeability with depth and too high variations in daytime temperatures.

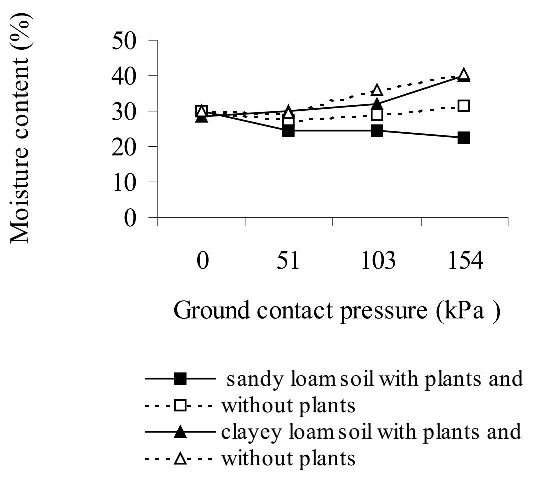

Fig. 1. Final moisture content of sandy and clayey loam soils after compaction with different ground contact pressures.

The final bulk density of both soils markedly increased with increasing ground contact pressures on the soil surface (Fig. 2).

The dry root weight drastically declined in the sandy loam soil at a bulk density of 1.56 Mg m^{-3} after applying a ground contact pressure of 103 kPa. In contrast, despite the increase of bulk density of the clayey loam soil up to 1.63 Mg m^{-3}, there were no differences in the dry root weight.

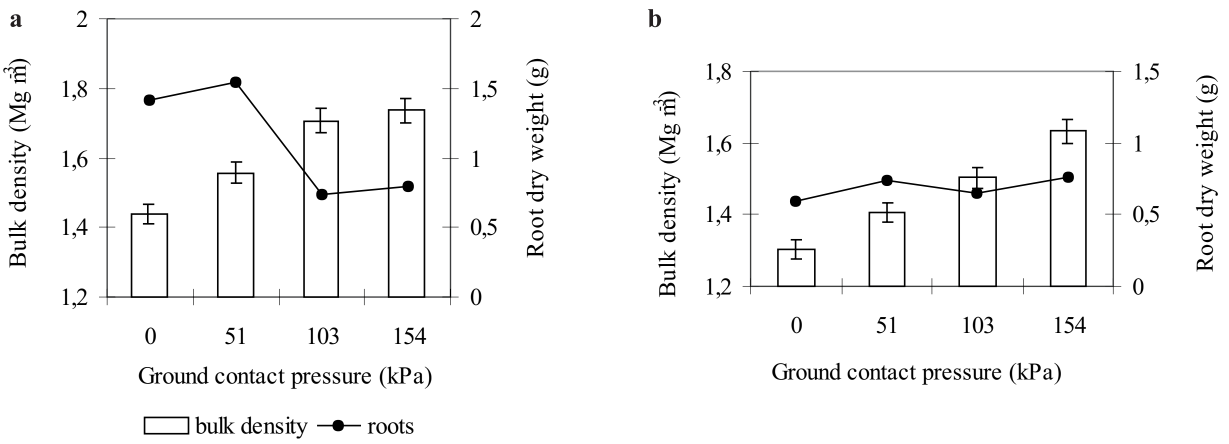

Fig. 2. Bulk soil and root dry weight of wheat plants in: a) sandy loam and b) clayey loam soils after loadings with different ground contact pressures. Error bars are standard deviations, P<0.1, n=9.

The critical values of soil penetrometer resistance of ~2 MPa were only observed in both soils at ground contact pressures of 103 and 154 kPa (Fig. 3). The distribution of penetrometer resistance at depth was not uniform in the sandy loam and clayey loam soils after all the loadings.

The results obtained showed that the wheat root system contributed to an increase of aggregate water stability of sandy loam soil and clayey loam soil in respect of: 1) initial aggregate water stability, where the ground contact pressure did not exceed 103 kPa and 2) treatments without plants (Fig. 4).

The resilience capacity of the wheat root system at the boot stage was sufficient for the formation and stabilisation of water-stable aggregates in both soils compacted with ground contact pressures of 51 and 103 kPa. At compaction with a ground contact pressure of 154 kPa, the root system was already unable to maintain the water-stable aggregation of the soils even at the initial level.

In the experiments without plants, a decrease in aggregate water stability was usually observed after compaction. However, the decrease in aggregate water stability in clayey loam soil was less pronounced than in sandy loam soil at compaction with ground contact pressures of 51 and 103 kPa. This was probably due to the more effective stabilisation of water-stable aggregates in clayey loam soil than in loamy sand soil.

The strong association of clay and silt particles with organic substances derived from root exudates and residues probably induced a stronger stabilisation of aggregates in fine-textured soils than in coarse-textured soils (Schnitzer *et al*., 1988; Golchin *et al*., 1995; Parfitt *et al*., 1999). Thin roots and fungi hyphae might also contribute to the stabilisation and formation of new water-stable aggregates as compared with soils without plants (Guggenberger *et al*., 1999; Bearden and Petersen, 2000). After applying the ground contact pressure of 154 kPa, the worst physical soil conditions possible diminished the favourable effects of the roots and root exudates on the aggregate water stability even in the clayey loam soil.

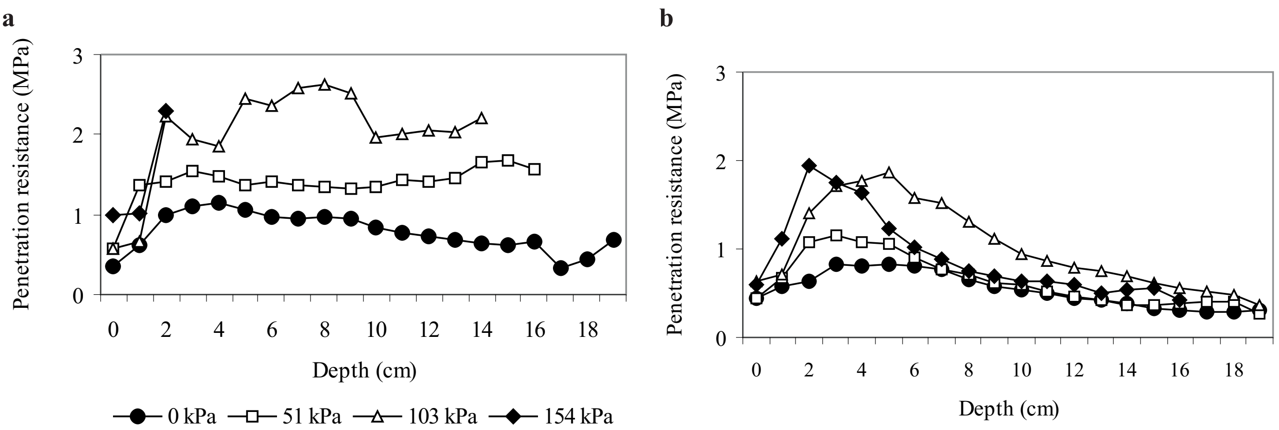

Fig. 3. Penetrometer resistance of: a) sandy loam and b) clayey loam soils without and with loadings with ground contact pressures of 51, 103 and 154 kPa.

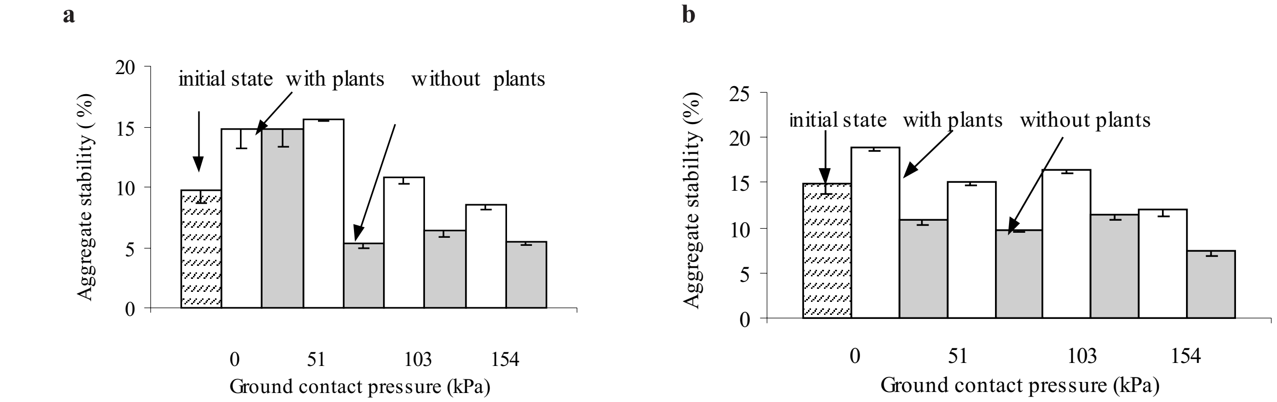

Fig. 4. Aggregate stability of: a) sandy loam and b) clayey loam soils after loadings with different ground contact pressures. Error bars are standard deviations, $P<0.1$, $n=3$.

The wheat root system differently affected the amounts of separate size fractions of water-stable aggregates in soils. In the clayey loam soil, the roots contributed to the formation of large water-stable aggregates in the dimensional ranges of 1.0–2.88 and 5.66–9.51 mm as well as to that of 0.25–0.5 mm aggregates in treatments without compaction (Fig. 5a). The same tendency was observed in the treatment with compaction at ground contact pressures of 51 and 103 kPa (not shown).

However, the amount of almost all the size fractions of water-stable aggregates decreased in this soil after applying a ground contact pressure of 154 kPa (Fig. 5b).

In contrast to the clayey loam soil, the higher water stability of small aggregates in the ranges of 0.25–0.5 and 0.5–1.0 mm was determined in the sandy loam soil in treatments without compaction (Fig. 6a) and with compaction at ground contact pressures of 51 and 103 kPa (also not shown). At compaction with a ground contact pressure of 154 kPa, the resilience capacity of the root system in this soil was probably insufficient to maintain the water stability of small aggregates even at the initial level (Fig. 6b).

The 7 weeks growing period of wheat plants was probably too short for the development of a root system which would contribute to the formation of higher amounts of large water-stable aggregates in sandy loam soil. Buchkina and Balashov (2001) reported that a 5 month growing period of grass-clover mixture and cereals contributed more to the formation of new water-stable aggregates of 3.0–5.0 to 5.0–7.0 mm than to that of smaller water-stable aggregates in loamy sand Spodosol.

CONCLUSIONS

The obtained results showed that an increase in bulk density up to 1.6 Mg m^{-3} at field capacity did not affect the dry root weight in clayey loam soil after the 7 weeks growing period. In contrast, the dry root weight decreased with the increasing bulk density of sandy loam soil from 1.3 to 1.5 Mg m^{-3}. The resilience capacity of the root system of winter

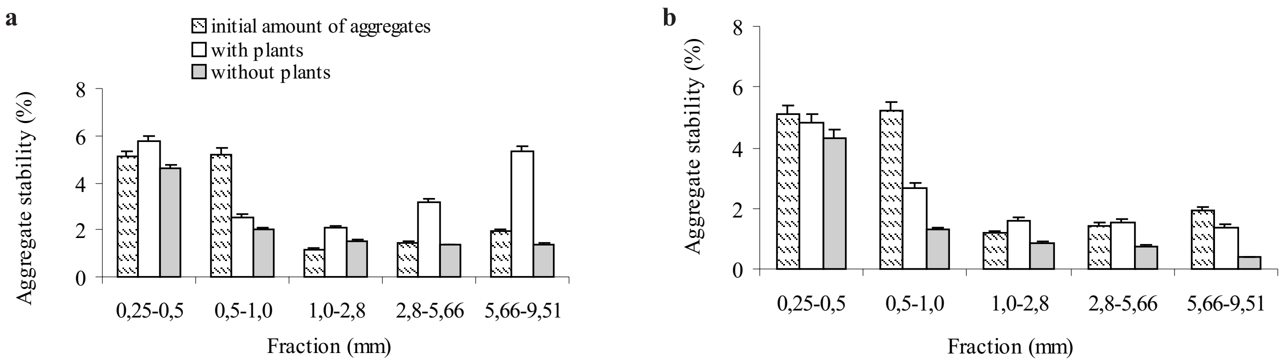

Fig. 5. Distribution of size fractions of water-stable aggregates in clayey loam soil: a) without compaction and b) compacted with ground contact pressure of 154 kPa. Explanations as in Fig. 4.

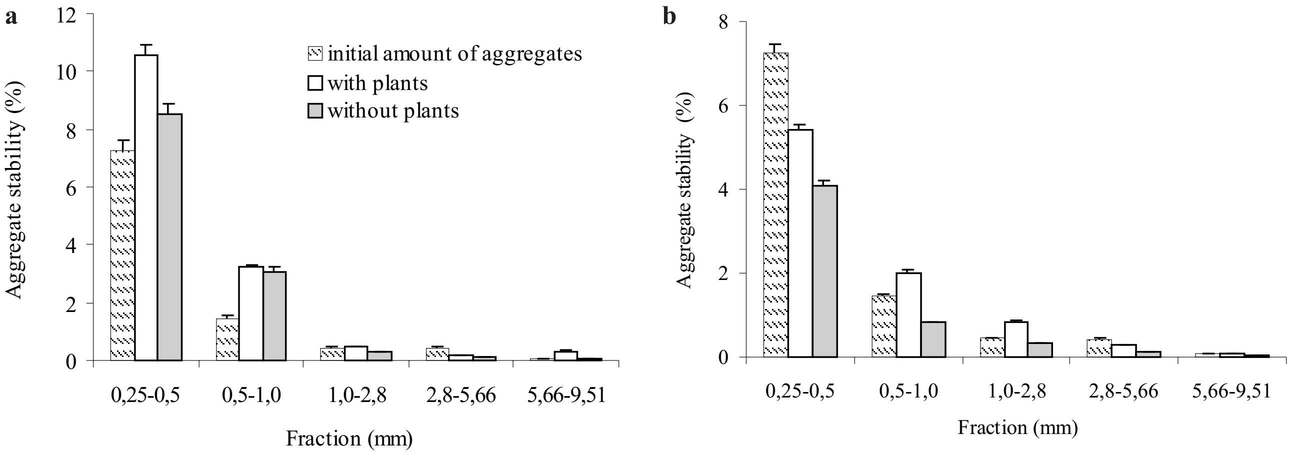

Fig. 6. Distribution of size fractions of water-stable aggregates in sandy loam soil: a) without compaction and b) compacted with ground contact pressure of 154 kPa. Explanations as in Fig. 4.

wheat plants at the root stage was sufficient to maintain and even increase the water-stable aggregation of both soils compacted with ground contact pressures not exceeding ~100 kPa.

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