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Research Article

Soil Structural Stability in relation to Soil Organic Carbon

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ABSTRACT

Built up of organic carbon (SOC) in soil in a slow process and accelerated only by adding 'external inputs' of materials to soil, which have high C concentrations on mass basis. However, availability of organic materials is uncertain and the practices that usually employed to increase SOC levels have a significant cost-bearing to the grower either directly or indirectly. Long-term organic inputs improved soil structural stability under the rice-wheat system irrespective of soil type and management practices. Although aggregates behave differently under different energy levels, fast wetting pre-treatment of aggregates, where the aggregates are suddenly immersed in water followed by slaking, appears to be the most sensitive in registering the effect of soil management and organic C changes. Total organic C is not strongly connected to soil stability, while particulate organic C fraction and Walkley-Black oxidizable C showed greater sensitivity in relation to structural modification. The oxidizable or labile C fraction, which relates to soil structural stability, can be an indicator of soil physical changes, where TOC or POC is difficult to estimate.

Key words: Water stability, aggregates, soil organic C, particulate organic C, long-term experiment

Introduction

It is now recognized that a fraction (or pool) of SOC is larger responsible than the total or bulk SOC *per se*, in imparting a better soil physical environment, especially the structural stability. Labile or readily oxidizable fraction participate more actively in soil functions, e.g. permanganate oxidizable C as indicator of soil health (Fine *et al*., 2017) and crop productivity (Hurisso *et al*., 2016); hot-water extractable C as sensitive to management practices (Ghani *et al*., 2003); free SOM-C (light fraction) for soil structural stability (Six *et al*., 2000; Jensen *et al*., 2019); or particulate organic matter-C for many soil functions including soil aggregate stability, recycling of nutrients and as a food for soil microbes (Murphy, 2014). Although these fractions are small in proportions, these have rapid turnover rates (weeks-to-months-to-few years) compared to the bulk C, which takes decades for a change to perceive (Haynes, 2005). Therefore, these pools can early indicate a change in SOM dynamics, and call for interventions before significant SOM loss takes place (Purakayastha *et al*., 2008). The effect is scale-dependant, and could be very different at micro (soil aggregates) and macro (bulk soil) levels. Small changes in SOC is reflected at bulk soil through deformation characteristics, but is not recorded at aggregate level (Chakraborty *et al*., 2014).

In tropical and sub-tropical climate, SOC has been in a declining trend due to high

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decomposition and turnover of SOM (Yang, 1996; van Keulen, 2001). This results in the loss of fertility of soil and thereby increasing the demand for mineral fertilizers. The arid and semi-arid regions of India, which also harness World's one of the largest and most intensive agricultural practices, is witnessing the global climate change, and therefore, the tropical soils of India must be given larger attention for managing its small and depleting SOC content (Bhattacharya *et al*., 2011).

In this backdrop, a study was undertaken to explore the relation between soil structural stability and organic C under two different sets of experimentation, and to identify the most sensitive organic C to soil physical changes.

Materials and Methods

Soil samples were collected from two long-term farming system experiments (AICRP-FS) at Ludhiana and Jabalpur, and were used for water stability (following three pre-treatment of aggregates: fast wetting, slow wetting and mechanical breakdown) studies. Soils in Ludhiana is sandy loam in texture with a native oxidizable organic C of 0.31%, while Jabalpur has clay soil with 0.60% organic C. Both the sites have rice-wheat in rotation, similar history of experimentation and management practices. Water stability of soil aggregates was also studied in a long-term (12 years) experiment on organic farming at IARI (soil texture: sandy clay loam).

Aggregate stability

Aggregate stability was determined following three pre-treatments, fast and slow wetting, and mechanical breakdown of the aggregates, as proposed by Le Bissonois (1996). In fast wetting (FW), oven-dried (40 °C) soil aggregate samples (3-5 mm) were weighed close to 5 g and were slowly taken to a 250 mL beaker containing 50 mL distilled water. The water was carefully siphoned off after 10 min, without disturbing the aggregates. The aggregates were then transferred to a sieve of 0.053 mm, which was already immersed in methanol in a plastic container. All the aggregates from the beaker were transferred by slowly rinsing with distilled water (due care was taken again not to disturb the wet aggregates). The sieve was gently moved up and down (5 cm) for 3 min. These particles, retained over >0.053 mm sieve, were then transferred to a paper and oven-dried at 105 0C. After that oven-dried samples were gently sieved manually through a set of sieves (2.0, 1.0, 0.5, 0.25, 0.1 and 0.053 mm) for 1 min, and weight of aggregate samples retained over each sieve was determined. The MWD of aggregates was calculated as an index of aggregation by using the following:

$$MWD = \Sigma XiWi \qquad \ldots(iv)$$

where, Xi is the mean diameter of the class (mm) and Wi is the weight of aggregates retained over sieve of Xi diameter.

In slow wetting (SW) pre-treatment method, ~5 g soil samples were taken and kept at 1 kPa matric potential in a hanging water column for gradual wetting of aggregates. After 30 min, wet aggregates were transferred to a 0.053 mm sieve previously immersed in methanol for the measurement of aggregate size distribution and computation of MWD as described in the fast wetting procedure. In case of mechanical breakdown (MB), soil aggregates were first immersed in methanol, air-dried, transferred to a 250 ml beaker, and made up the volume to 200 ml with water. The beaker was turned upside down for 10 times. The beaker was left undisturbed for the soil to be settled, excess water was siphoned off, and the soil was transferred to 0.053 mm sieve. Aggregate size distribution and MWD was obtained following similar procedure as in fast or slow wetting.

Total organic C and Walkley-Black oxidizable organic C

Soil samples were air-dried, and passed through a 2 mm sieve. The Walkley-Black oxidizable C was determined by wet oxidation method (Walkley and Black, 1934) in which a known amount of soil was oxidized with an excess $K_2Cr_2O_7$ with presence of conc. sulphuric acid. The excess of $K_2Cr_2O_7$ not reduced by organic matter in soil sample was titrated back to know the amount of oxidizable C present in the sample. Total organic carbon (TOC) was analysed using the elemental analyzer.

Modified Walkley-Black method

Five, 10 and 20 mL concentrated sulphuric acid was used to prepare three acid-aqueous solution ratios of 0.5:1, 1:1, and 2:1 (corresponding to 12N, 18N, and 24N of H_2SO_4). This allowed comparison of oxidizable organic C extracted under increasing oxidizing conditions (Walkley, 1947). Thus four fractions of oxidizable organic C were obtained with decreasing oxidizability: 1) Fraction 1(oxidizable by 12N H_2SO_4); Fraction 2 (18N–12N H_2SO_4) – the difference in oxidizible C between 18N and 12N H_2SO_4; Fraction 3 (24N–18N H_2SO_4) – the difference in oxidizible organic carbon extracted between 24N and 18N H_2SO_4; and Fraction 4 (TOC–24N H_2SO_4) – difference between total and oxidizable C by 24N H_2SO_4.

Particulate organic C

The particulate organic C (POC) was isolated as per the procedure described by Cambardella and Elliott (1992). A 10 g of soil sample (<2 mm) was dispersed with 30 mL of sodium hexametaphosphate (5 g L^{-1}) solution and placed in a mechanical shaker for 15 h with a speed of 90 rpm. The dispersed soil samples were then passed through a 0.053 mm sieve. The fraction retained on the sieve was collected and dried at 50 ºC, and used for POC analysis.

Statistical analysis

The preliminary interpretation of data was performed by using MS Excel. The NARS SAS portal was used for testing the significance at *p=0.05* among the treatments in a location following randomised block design. The slope of the regression between the aggregate parameters and soil C was determined by using R statistical programme (2013).

Results and Discussion

Water stability of aggregates

In Ludhiana soils, MWD were the lowest in FW treatment followed by mechanical breakdown (MB) and SW, except for treatments with 50NPK+50 FYM and 50NPK+50 straw, where MWD was the largest with MB treatment (Fig. 1). In Jabalpur soils, values of MWD were the lowest in MB treatment followed by FW and SW (Fig. 2). Irrespective of treatment, average MWD was the largest at Jabalpur site (3.13 mm). Average values of MWD-FW, MWD-MB and MWD-SW at Jabalpur site was higher (2.63, 4.87, and 1.89 mm) than Ludhiana (1.15, 1.94 and 1.68 mm). Among the pre-treatments of aggregates, significant differences were obtained in FW and MB, but not in SW in both the locations. In Ludhiana, MWD was significantly higher with

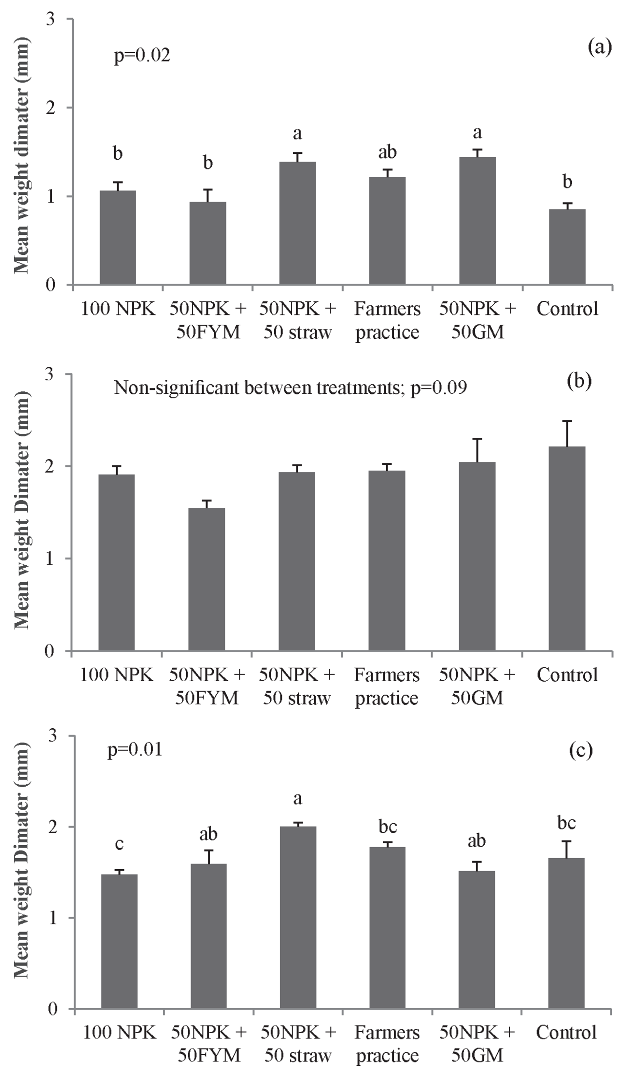

Fig. 1. Water stability of soil aggregates under pre-treatment of fast wetting (a), slow wetting (b) and mechanical breakdown (c) in long-term fertilizer

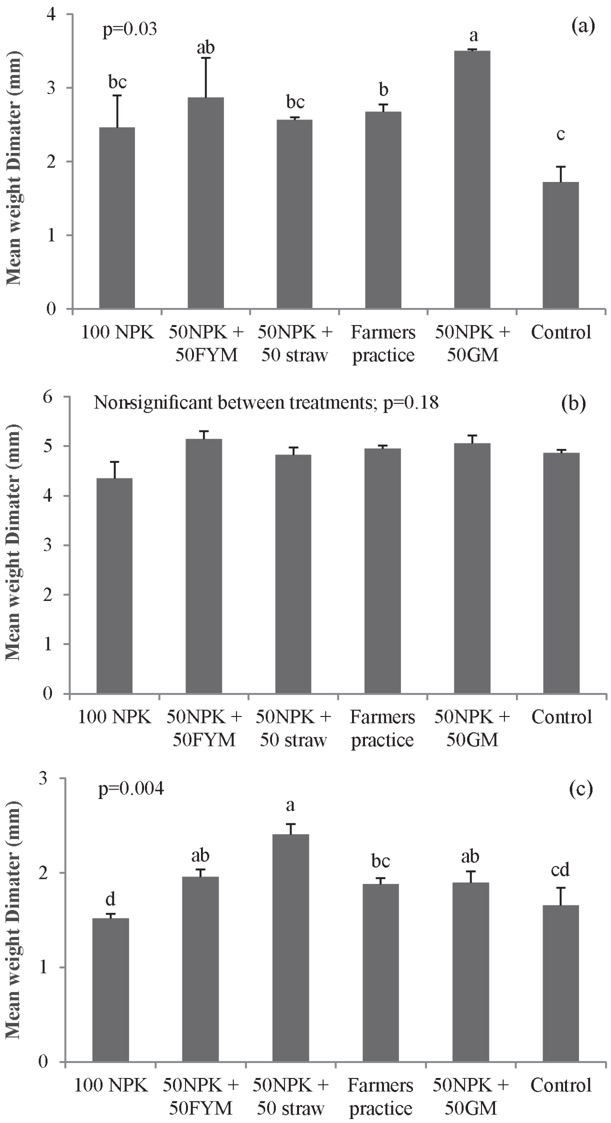

Fig. 2. Water stability of soil aggregates under pre-treatment of fast wetting (a), slow wetting (b) and mechanical breakdown (c) in long-term fertilizer experiments in Jabalpur

the addition of straw (64% higher in 50NPK +50straw) and green manure (69% higher in 50NPK+50GM) along with fertilizers, compared to control with the FW treatment. Addition of FYM along with fertilizers, or exclusive application of fertilizer showed similar MWD with respect to the control. In Jabalpur soils, the MWD-FW increased with addition of green manure (103% higher in 50NPK+50GM) or FYM (67% higher in 50NPK+50FYM) along with fertilizers and farmers' practice (55% higher) compared to the control. In the MB pre-treatment both at Ludhiana and Jabalpur site, 50NPK +50straw and 100NPK resulted significantly higher (13-45%, $p<0.05$) and lower (3-22%, $p<0.05$) MWD of aggregates compared to other treatments.

Average values of MWD (average of MWD under the FW, SW and MB pre-treatments) were higher for 50NPK+50straw in Ludhiana and 50NPK+50GM in Jabalpur soils (Fig. 3). In Ludhiana, 50NPK+50straw, 50NPK+50GM and farmers' practice did not show any difference among these, while lowest value was recorded in 50NPK + 50FYM. In Jabalpur, treatment differences were better reflected by the average MWD values (p <0.01). The MWD was the highest in 50NPK+50GM followed by 50NPK +50FYM, 50NPK+50straw, farmers' practice, 100NPK and Control. Treatments with 100NPK and control values were lower than other treatments.

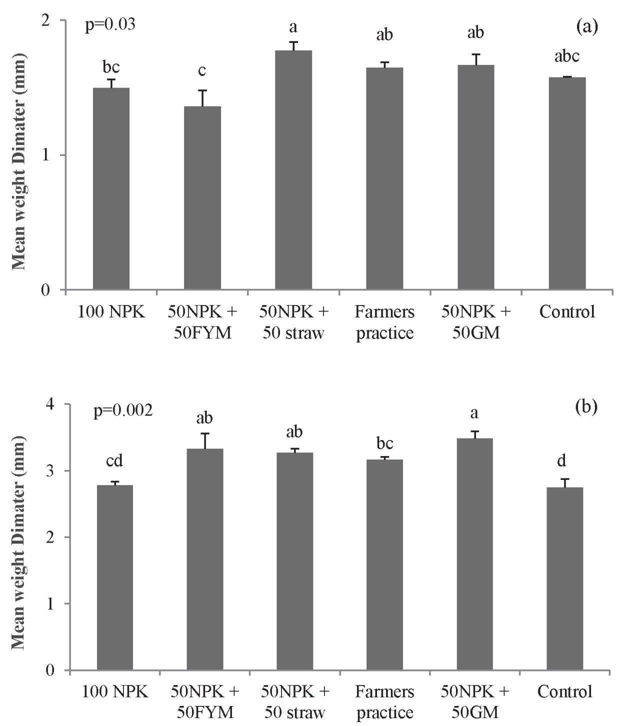

Fig. 3. Effect of long-term fertilizer experiments on water stability of aggregates in Ludhiana (a) and Jabalpur (b) [Average of aggregate stabilities under fast wetting, slow wetting and mechanical breakdown of aggregates]

In the R-W system with fully organic inputs, MWD were significantly higher compared to sole inorganic treatments in both 0-7.5 and 7.5-15 cm (Fig. 4a). In the organic treatments, highest MWD was reported by the addition of FYM (0.62 mm) followed by VC+CR+B (0.6 mm), VC (0.55 mm), FYM+CR+B (0.5 mm), FYM+CR (0.46 mm) and VC+CR (0.45 mm) for 0-7.5 cm depth. In 7.5-15 cm of soil depth, plots treated with combinations of organic manures, crop residue and biofertilizers produced the largest MWD: 0.64 mm for VC+CR+B and 0.60 mm for FYM+CR+B. These were followed by FYM (0.58 mm), VC (0.52 mm), VC+CR (0.47 mm) and FYM+CR (0.45 mm). In the R-W-M system, differences were not evident under varying organic inputs and also between the organic and inorganic treatments in both the depths (Fig. 4b). In 0-7.5 cm depth, FYM treatment (0.49 mm) resulted in highest MWD, followed by VC+CR+B (0.46 mm), FYM+CR (0.4 mm), FYM+CR+B (0.39 mm), VC (0.38 mm), Inorganic (0.38 mm) and VC+CR (0.3 mm). In 7.5-15 cm depth, the combination of organic manures, crop residues and bio fertilizers resulted

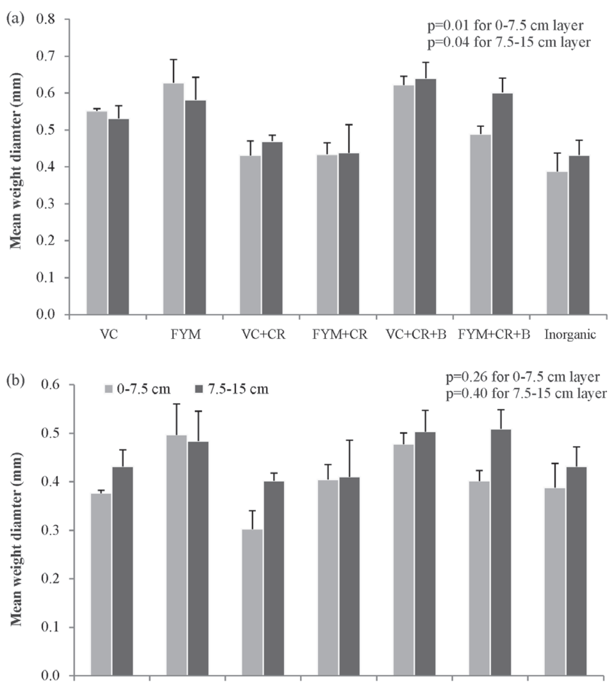

Fig. 4. Mean weight diameter of soil aggregates obtained through fast wetting and slaking under long-term organic inputs in a rice-wheat (a) and a rice-wheat-mung bean (b) rotation

in highest MWD; FYM+CR+B (0.51 mm) and VC+CR+B (0.5 mm). These are followed by FYM (0.48 mm), VC (0.43 mm), Control (0.42 mm) and lowest in treatments with the combinations of organic manures and crop residues; FYM+CR (0.40 mm) and VC+CR (0.39 mm).

Results indicated that fast wetting treatment which imitates the natural events more closely (like rainfall and irrigation), was better in defining the treatment-difference than the slow wetting of aggregates. Fast wetting treatment appears to work better in soils with relatively higher organic C content, while the slow wetting effect, which involves lower energy, is better manifested in loosely aggregated soils, which is likely to have low organic C (Le Bissonnais 1996).

Greater response to the manure and fertilization was recorded for Jabalpur soil compared to soil in Ludhiana, although both are under similar soil management practices. Soils in the experimental field of Jabalpur has higher clay content (53% compared to 18% in Ludhiana) and also twice of the amount of organic C (0.60 g $100g^{-1}$ compared to 0.31 g $100g^{-1}$ in Ludhiana). It is likely that the higher clay content played a decisive role in imparting a better water stability of aggregates in all the treatments in Jabalpur, which have manure or fertilizer application either singly or in combinations. It is to be noted that similar soil response was absent in Pantnagar soils, which although has a very high soil organic C content (1.48 g $100g^{-1}$), but lesser clay content (18%) compared to the soils in Jabalpur. Clay is possibly most closely associated with water stability of soil aggregates acting as a cementing agent through its very high surface area and high physical and chemical activities (Canasveras *et al*., 2010).

It is interesting to note that organic inputs had no visible impact on water stability of aggregates in a rice-wheat-mung bean system. In rice-wheat rotation, where mung bean was not included in the system, application of vermicompost, FYM, crop residue and biofertilizer in different combinations has improved the water stability of slaked aggregates compared to treatments where only inorganic fertilizers were applied. It could be that inclusion of mung bean over the years has benefitted to the system where no organic inputs were added, and therefore the effect of organic inputs could not be perceived. As the experiment is continuing for a long time (12 years), it is highly probable that the soil has reached to a balanced state and further changes in water stability may not happen. This also implies that continuous addition of organic inputs may not improve the soil condition infinitely, and equilibrium is soon reached. High organic matter level of soil through organic inputs over long years could be one of the reasons for not receiving the effect of legume (Blanco-Canqui and Jasa, 2019).

Soil organic C and soil structural stability

Regression lines were fitted between mean weight diameters (fast wetting, MWD-FW; slow wetting, MWD-SW; and mechanical breakdown, MWD-MB of aggregates) and total and particulate organic C for Ludhiana and Jabalpur soils. In Ludhiana, none of the cases have exhibited significant relations between mean weight diameters and TOC, while only the slow wetting shows a significant decline with POC. In Jabalpur soils, the mean weight diameter of fast-wetted aggregates increased with increase in both TOC and POC, in rest of the cases, no relation was observed. However the ease of slaking (MWD-SW minus MWD-FW) was associated with change in both TOC and POC in both the soils. In both soils, ease of slaking decreased with increase in either total or particulate C, but the slopes differ (all are significant at $p<0.05$). Rate of decrease is faster with POC (three times and two times in soils of Ludhiana and Jabalpur, respectively).

The total organic C could not explain the variation in MWD of slaked aggregates (fast wetting of aggregates) when data were pooled from R-W and R-W-M rotations (Table 1). However, MWD increase was significant with an increase in particulate C (R^2 of regression = 0.38; p=0.021). The association is also positive for labile fraction, following Chan *et al*. (2001) (R^2=0.22; p=0.048) and Walkley-Black C (R^2=0.31; p=0.016).

The POC levels represent organic C associated with the sand fraction (>0.053 mm), and therefore, have low colloidal protection. In addition, POC is considered a labile fraction of soil organic matter, as it has a fast cycling rate and consists mainly of partially humidified plant residues (Haynes, 2005). Particulate organic C accounts for about 18% of the TOC, implying that only a small fraction of TOC consists of more labile organic forms. Trends in MWD in none of long-term experiments followed TOC contradictory to general view. Though TOC were the highest in FYM+CR, MWD did not show a similar trend.

Similarly, MWD of aggregates through either of the pre-treatments (slaking through fast wetting, capillary wetting and breakdown of aggregates mechanically, and not by slaking action of water) did not show relations with POC. However, the ease of slaking (difference between fast wetting/slaking and slow capillary wetting), found significant correlations with both TOC and POC content of soils.

Table 1. Slope of linear regression, between mean weight diameter of slaked aggregates and soil organic C (total and fraction) in treatments with organic inputs under the rice-wheat and rice-wheat-mung bean rotations (N=15)

Soil organic C	Slope	R^2 of regression	p-value
Total	0.93	0.10	0.169
Particulate organic C	1.05	0.38	0.021
Labile fraction (Chan *et al*., 2001)	1.20	0.22	0.048
Walkley-Black C	0.82	0.31	0.016
Recalcitrant C	0.75	0.18	0.059

Mean weight diameter of slaked aggregates as affected by different organic inputs for a long time, found no relation with total organic C content, but POC has significant impact. Variation in MWD could also explain through changes in labile and Walkley-Black oxidizable C fractions. Therefore significant differences between treatments were implicit in terms POC, and POC developed significant correlation with water stability of aggregates. This is corroborated with reports that POC could be a sensitive indicator of changes in the soil organic matter level due to modifications in management practices (Banger *et al*., 2010; Covaleda *et al*., 2011; Rossi *et al*., 2012). Both the POC and water stable aggregates had wide variations, but treatments which improved the MWD of aggregates also had higher POC. The present data did not have POC in the soils under the tillage and residue management, which might further improve the relation between this pool of organic C and soil structural stability. Analysis of TOC and POC involves time and cost, and therefore Walkley-Black C can be rightfully used for quantifying the management-induced changes in soil physical condition.

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