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Soil hydrophysical properties as affected by solid waste compost amendments: seasonal and short-term effects in an Ultisol

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Abstract: Application of compost is known to improve the hydraulic characteristics of soils. The objective of this study was to examine the seasonal and short-term effects of solid waste compost amendments on selected hydrophysical properties of soil during dry and rainy seasons and to explore any negative impacts of municipal solid waste compost (MSWC) amendments on soil hydrophysical environment concerning Agriculture in low-country wet zone, Sri Lanka. Eight (T1–T8) MSWC and two (T9, T10) agricultural-based waste compost (AWC) samples were separately applied in the field in triplicates at 10 and 20 Mg ha^{-1} rates, with a control (T0). Field measurements (initial infiltration rate, I_i; steady state infiltration rate, $I_{SS;}$ unsaturated hydraulic conductivity, k; sorptivity, S_W) were conducted and samples were collected (0–15 cm depth) for laboratory experiments (water entry value, h_{we}; potential water repellency: measured with water drop penetration time, WDPT) before starting (Measurement I) and in the middle of (Measurement II) the seasonal rainfall (respectively 5 and 10 weeks after the application of compost). The difference in the soil organic matter (SOM) content was not significant between the dry and rainy periods. All the soils were almost non-repellent (WDPT = <1–5 s). The h_{we} of all the samples were negative. In the Measurement I, the I_i of the T0 was about 40 cm h^{-1}, while most treatments show comparatively lower values. The I_{SS}, S_W, and k of compost amended samples were either statistically similar, or showed significantly lower values compared with T0. It was clear that all the surface hydraulic properties examined in situ (I_i, I_{SS}, S_W) were higher in the Measurement I (before rainfall) than those observed in the Measurement II (after rainfall). Water potential differences in soils might have affected the surface hydrological properties such as S_W. However, water potential differences would not be the reason for weakened I_{SS} and k in the Measurement II. Disruption of aggregates, and other subsequent processes that would take place on the soil surface as well as in the soil matrix, such as particle rearrangements, clogging of pores, might be the reason for the weakened I_{SS} and k in the Measurement II. Considering the overall results of the present study, compost amendments seemed not to improve or accelerate but tend to suppress hydraulic properties of soil. No significant difference was observed between MSWC and AWC considering their effects on soil hydraulic properties. Application of composts can be considered helpful to slower the rapid leaching by decreasing the water movements into and within the soil.

Keywords: Unsaturated hydraulic conductivity; Infiltration; Solid waste compost; Sorptivity; Water repellency.

INTRODUCTION

Recent developments in the developing countries including urbanization and industrialization have led to an accumulation of huge amounts of municipal wastes. It is reported that out of 5.2 million tons of the world daily generation of solid wastes, 3.8 million tons are generated in developing countries (Cointreau, 2007). As the management of municipal solid waste (MSW) has become a critical problem in the recent years, numerous activities have been conducted in relation to the recycling of MSW in Sri Lanka. High requirements of energy for municipal waste incineration and the limited availability of landfills, as well as many other environmental issues, focused the attention on waste recycling and compost application to agricultural lands. The process of composting MSW reduces the waste volume, destroys malodorous compounds, kills the existing pathogens, and decreases the germination rate of weeds (Jakobsen, 1995). More than 75% of the total MSW generation in Sri Lanka are reported to be compostable wastes, confirming that the composted MSW in Sri Lanka has a high potential to be used as a good-quality soil conditioner (World Health Organization, 1999).

Municipal solid waste compost (MSWC) has been successfully used for agriculture in many countries (Ex: Grau et al., 2017; Leogrande et al., 2016). The MSWC have shown comparable physio-chemical characteristics to other composts derived from different agro-industrial by-products (Jodar et al., 2017). Application of MSWC is known to improve soil C storage (Peltre et al., 2017), availability of water and nutrient to the crops grown (Martínez-Blanco et al., 2013 and references therein), microbial biomass carbon, dehydrogenase activity values (Fernandez et al., 2007), and plant growth and fruit production characteristics (Leogrande, et al., 2016). However, regardless of the attempts that have already been made to popularize the application of MSWC to agricultural lands in Sri Lanka, it is still in a subordinate level compared with the application of chemical fertilizers and other agricultural-based waste composts (AWC). Lack of knowledge and limited research on the positive effects of locally available MSWC on soil physicochemical environment are considered to be the major reasons for such behavior.

Compost amendments are usually known to improve the physical environment of soils including hydrophysical characteristics. Reports are available to show that the amendments of MSWC enhance aggregate stability, permeability coefficient (Angin et al., 2013), hydraulic conductivity (Yazdanpanah et al., 2016), total porosity, water penetration, air circulation, and water retention (Karak et al., 2016 and references therein) of soils. Pieces of evidence are also available on negative impacts of organic amendments such as noticeable increases in water repellency (Głąb et al., 2018) and decreases in hydraulic conductivity (Maule et al., 2000).

The seasonal changes in Sri Lanka is mainly characterized by the dry and rainy conditions, where very high rates of average annual rainfall (~2500 mm) is common in the wet zone. As most Sri Lankan soils show very rapid infiltration rates and high hydraulic conductivities (Panabokke, 1996), further enhancements of those processes might lead to more rapid leaching of nutrients from the root zone. Considering the currents demands for information and importance in making use of MSWC, the present study aims to examine the seasonal (dry and rainy) and short-term effects of MSWC and AWC on selected hydrophysical properties of soil and to explore any negative impacts of MSWC amendments on soil hydrophysical environment concerning Agriculture in low-country wet zone, Sri Lanka.

MATERIALS AND METHODS

Compost samples and location

Basic analysis was done using 32 MSWC and 3 commonly available AWC samples collected from the compost production sites scattered throughout the country. After the basic characterization, eight MSWC samples (prepared using aerated windrow composting technique) and two AWC samples (prepared using aerated static pit composting technique) were selected for the study. Selection was done to represent composts with similar production conditions and maturity, and a wide range of pH and electrical conductivity (EC), while avoiding MSWC production sites with slaughter house- and clinical-wastes. Selected basic properties of the samples are given in Table 1. The pH of the compost samples was in a range of 6.5–9.5, the EC was in a range of 1–15 mS cm^{-1}, and the organic matter content was in a range of about 16–28 g 100 g^{-1}.

A field experiment was conducted at the Faculty of Agriculture, University of Ruhuna (6°03'29"N 80°34'13"E), located in the low country wet zone (WL2) agro-ecological region. The soil type is categorized as ‘red-yellow podzolic soils’ under the local classification and falls under Rhodudults (Soil Survey Staff, 2014). Before starting the field experiment, the soil was tested for basic properties. The soil is non-saline, loamy sand in texture, and showed fairly high bulk density of 1.37 g cm^{-3}, nearly 50% porosity, and moderately acidic soil reaction (Table 2). A fairly uniform air temperature of about 28°C and a relative humidity of about 75% are prevailing throughout the year. The mean annual rainfall is approximately 2400–2800 mm (National Atlas of Sri Lanka, 2007).

Sample treatments in field

The field was cleared and raised beds with drainage channels were prepared. Eight MSWC samples (T1–T8) and two AWC samples (T9, T10) were added into the planting beds separately in three replicates at 10 and 20 Mg ha^{-1} rates as an initial single dose, which is in agreement with the present practice in the region. Plots with no compost treatment were used as the control (T0). Fast growing Bush bean (*Phaseolus vulgaris* L.) with high germination rate were seeded in plots one week after the compost application in the inter-monsoonal dry period in 2016, before starting of the inter-monsoonal cyclonic rainfall or the North-east monsoon rainfall period. Irrigation (pH: 6.7; EC: 1.2 dS m^{-1}) was done when necessary considering the crop requirements (10–15 mm once in 5 d) before the beginning of the seasonal rainfall.

Collection of soil samples

Samples from the field were collected to determine the soil properties of the planting beds at 0–15 cm depth (drilled 0–15 cm samples, composited of 3 points) before starting (5 weeks after compost application; Measurement I) and in the middle of the seasonal rainfall (10 weeks after compost application; Measurement II). During the rainy season (Measurement II), the samples were collected after at least two consecutive dry days. Undisturbed samples were taken for bulk density measurements.

Laboratory experiments

The basic properties of the compost samples (for initial characterization) and the soil samples treated with composts were measured in triplicates using standard laboratory tests. The pH (1:2.5) and the EC (1:5) were measured using a pH meter (sensION 1, HACH Co., USA) and an EC meter (sensION+EC5, HACH Co., USA). The bulk density, particle density and texture were measured with soil core method, pycnometer method, and hydrometer method, respectively. Organic matter contents were measured using the loss on ignition (400°C, 6 h) method (Rowell and Coetzee, 2003).

The water entry value (h_{we}) was determined using the pressure head method following the procedure reported by Wang et al. (2000). A low negative pressure of –10 cm was initially applied to prevent the initial instantaneous wetting of the soils placed on a porous-based Buchner funnel using a tube connected to the funnel base. Then the pressure was gradually in-

Table 1. Selected basic properties (mean ± standard deviation) of municipal solid waste composts (T1–T8) and agricultural waste composts (T9–T10).

Compost sample	pH	EC (mS cm^{-1})	Organic matter (g 100 g^{-1})	K (mg kg^{-1})	P (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})
T1	8.53±0.06	8.40±0.01	15.7±0.8	3270±44	2352±346	171.5±6.4	65.3±18.5
T2	7.6±0.0	4.41±0.03	32.6±6.7	3463±32	2204±130	76.5±10.3	63.0±5.8
T3	8.53±0.06	15.0±0.2	25.5±8.0	1110±10	2650±92	82.3±14.9	188±21
T4	9.47±0.06	13.9±1.4	23.8±9.5	626±6	3533±195	117.2±4.7	234±12
T5	8.5±0.0	15.2±0.4	22.6±11.0	990±26	2218±357	56.1±1.6	235±28
T6	8.20±0.52	7.53±0.07	20.5±5.3	2630±52	2918±115	64.8±4.5	261±8
T7	8.5±0.0	2.69±0.36	27.5±8.2	2293±21	3462±180	64.3±1.8	26.2±9.6
T8	8.13±0.06	1.05±0.01	26.5±11.4	5326±45	1833±176	55.6±16.2	6.35±2.50
T9	7.67±0.06	6.55±0.65	18.7±1.4	1696±35	2610±43	69.0±9.7	46.6±7.5
T10	6.47±0.06	5.78±0.08	29.2±6.0	3606±129	3137±25	67.2±4.9	39.6±3.3

Table 2. Selected physical and chemical properties (mean ± standard deviation) of the field prior to the compost amendments.

Soil parameter	Value
Bulk density (g cm^{-3})	1.37±0.05
Particle density (g cm^{-3})	2.55±0.03
Porosity (%)	48.8±0.8
Sand (%)	83.3±0.5
Silt (%)	8.9±0.7
Clay (%)	7.8±0.7
Soil texture	Loamy Sand
pH	5.7±0.2
Electrical conductivity (μs cm^{-1})	58.8±2.5
SOM (g 100 g^{-1})	2.4±0.1

creased until the water starts to enter into the soil matrix, which is the point of water entry, and the pressure head at the point was measured as the h_{we} (Liyanage and Leelamanie, 2016).

Water repellency of samples was determined by using water drop penetration time (WDPT) test (Doerr et al., 2000, and references therein). For the WDPT test, a drop of distilled water (50±1 μl) was placed on the surface of soil samples (from a height of about 10 mm) using a burette. The time taken for the water drop to complete the penetration into the soil was recorded.

Field experiments

The infiltration rates, unsaturated hydraulic conductivity (*k*), and sorptivity (S_{W}) of the soils were determined using Mini disk infiltrometer (Decagon devices, Inc.) in the cultivated field, before starting (5 weeks after compost application; Measurement I) and in the middle of the seasonal rainfall (10 weeks after compost application; Measurement II). In the Measurement II, field was exposed to rainfall for more than 3 weeks, and care was taken to conduct the experiments in the field at least after two consecutive dry days.

The *k* and S_{W} were estimated from the cumulative infiltration data obtained in the field at a suction head of 6 cm (for a loamy sand texture). The method proposed by Zhang (1997) was used to determine the *k* of the soils (Lichner et al., 2007a, b). The method requires measuring cumulative infiltration versus time and fitting the results with the function:

$$I = C_1\, t + C_2 \sqrt{t} \tag{1}$$

The parameters C_1 (m s^{-1}) and C_2 (m s$^{-1/2}$) are respectively related to the *k* and the soil S_{W}. The *k* for the soil is then computed from:

$$k = C_1/A \tag{2}$$

where C_1 is the slope of the curve of the cumulative infiltration versus the square root of time, and A is a value that relates the van Genuchten parameters for a given soil to the suction rate and the radius of the infiltrometer disk. The slope of the curve of the cumulative infiltration versus the square root of time and the hydraulic conductivity were calculated based on the infiltration data gathered with the support of Microsoft Excel spreadsheet published by Decagon (www.decagon.com/macro). The linear approximation of the cumulative infiltration versus the square root of the time relationship (Eq. 3) was used to estimate the slope, which would be the S_{W}.

$$I = S_W \sqrt{t} \tag{3}$$

Data analysis

Results from laboratory tests and field experiments were statistically analyzed with ANOVA and correlation at 5% level of significance ($P < 0.05$) (Microsoft Excel and SAS package).

RESULTS AND DISCUSSION

Bulk density

The bulk density of the control field (T0) was 1.30 and 1.32 g cm^{-3} in the Measurement I and II, respectively. It was slightly lower in compost amended samples showing values ranging from 1.23–1.28 g cm^{-3} at 10 Mg ha^{-1} application rate and 1.20–1.27 g cm^{-3} at 20 Mg ha^{-1} application rate in Measurement I. It ranged from 1.26–1.30 g cm^{-3} and 1.24–1.28 g cm^{-3}, respectively at 10 and 20 Mg ha^{-1} application rates, in Measurement II, without any significant difference among compost treatments. Therefore, it was clear that the type of the compost did not affect the bulk density. This might be because all the compost samples used in this study were high in maturity levels.

Soil organic matter (SOM) content

The SOM contents of the soils at two application rates for both Measurements I and II are presented in Figure 1. The SOM content of the untreated soil (T0) was about 1.7 g 100 g^{-1}. Results showed that the SOM levels increased with composts

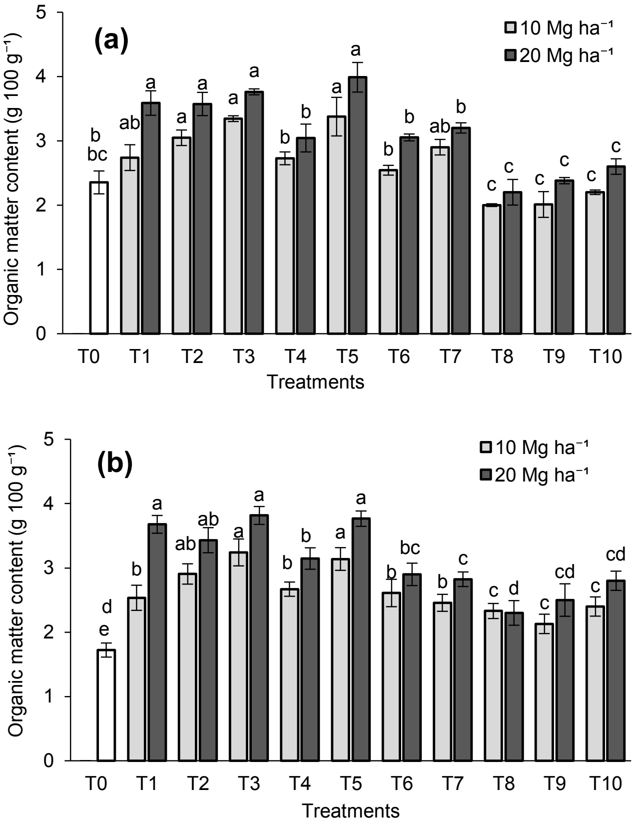

Fig. 1. Organic matter contents of the soils in (a) Measurement I and (b) Measurement II. Error bars indicate ± standard deviation. Different lower case letters indicate significant differences between treatments, where upper and lower letters on T0 are respectively related to the 10 and 20 Mg ha^{-1} application rates ($P \le 0.05$).

treatments showing higher SOM level at high rate of application (20 Mg ha^{-1}) than the low rate (10 Mg ha^{-1}) as expected, where the SOM content was in a range of 2–4 g 100 g^{-1}. Furthermore, the difference in SOM content was not significant between the Measurements I and II. Initial rapid depletion rates of SOM after amendments due to prevailing high temperature (~28°C) and humidity (~80%) in the area may cause SOM to reach almost steady level at the time of Measurement I (Leelamanie, 2014). This might be the reason for showing no significant differences in SOM between Measurements I and II.

Water repellency

The potential water repellency measurements showed that soils with all the treatments were non-repellent or very slightly water repellent with WDPTs varying from < 1 s to about 5 s. Considerable differences in water repellent levels were not observed between almost all the treatments, the two application rates and the two measurements periods except for the instant penetrations of water drops observed in the control (T0) and treatments T4, T6. The reasons for the absence of water repellent condition might be the originally highly wettable nature of the soil, low levels of compost application (10–20 Mg ha^{-1}), and low SOM levels.

Water-entry value (h_{we})

The h_{we} of samples with all the treatments were negative, which is reported to be a commonly found phenomenon in readily wettable soils (Wang et al., 2000). The h_{we} was varying from –1.0 to –2.0 cm at 10 Mg ha^{-1} application rate, from –0.5 to –1.0 cm at 20 Mg ha^{-1} rate, and –2.5 cm for the control (T0) at both Measurement I and II. The h_{we} of all the compost treatments at 20 Mg ha^{-1} rate were significantly higher than those at the 10 Mg ha^{-1} rate (low negative values), whereas no significant difference was observed between Measurement I and II. The h_{we} of control (T0) was significantly higher than all the other treatments (two rates, two Measurements). Treatments T1, T2, T3, and T5 showed significantly high h_{we} (low negative values) only at the 20 Mg ha^{-1} rate in Measurement I, while other compost treatments did not differ significantly. This might be due to comparatively high organic matter contents in these treatments (Figure 1).

Initial infiltration rate (I_{i})

Initial infiltration rates (I_{i}) of the soils are presented in Figure 2. In the Measurement I (during the dry season), the I_{i} of untreated soil was about 40 cm h^{-1}, whereas those of compost amended soils were in a range of 30–80 cm h^{-1} at 10 Mg ha^{-1} rate, and 15–90 cm h^{-1} at 20 Mg ha^{-1} rate (Figure 1a). Soils amended with two MSWC samples (T4, T6) showed a significant increase (70–80 cm h^{-1}) in I_{i} at 10 Mg ha^{-1} application rate. This might be because of the comparatively lower organic matter contents (Figure 1) and extremely wettable nature (showed by instant penetrations). Although the organic matter contents of T8, T9, and T10 were also low, they did not show highly wettable nature. All other samples did not show significant differences in I_{i} comparing with T0.

At the doubled application rate (20 Mg ha^{-1}), seven out of ten compost amended soils showed lower I_{i} compared with the T0. Compared with the 10 Mg ha^{-1} application rate, soils amended with T8, T9, and T10 showed significantly higher I_{i} than the other treatments at 20 Mg ha^{-1} rate (Figure 2a). These samples showed lower organic matter levels (Figure 1) in both application rates and lower bulk densities (1.20 and 1.21 g cm^{-3}) at 20 Mg ha^{-1} rate. On the other hand, almost all the samples showed lower bulk density at the 20 Mg ha^{-1} rate than that of the 10 Mg ha^{-1} rate (which would be a result of increased organic matter levels) although the other treatments (except T8, T9, and T10) did not show higher I_{i} levels at 20 Mg ha^{-1} rate.

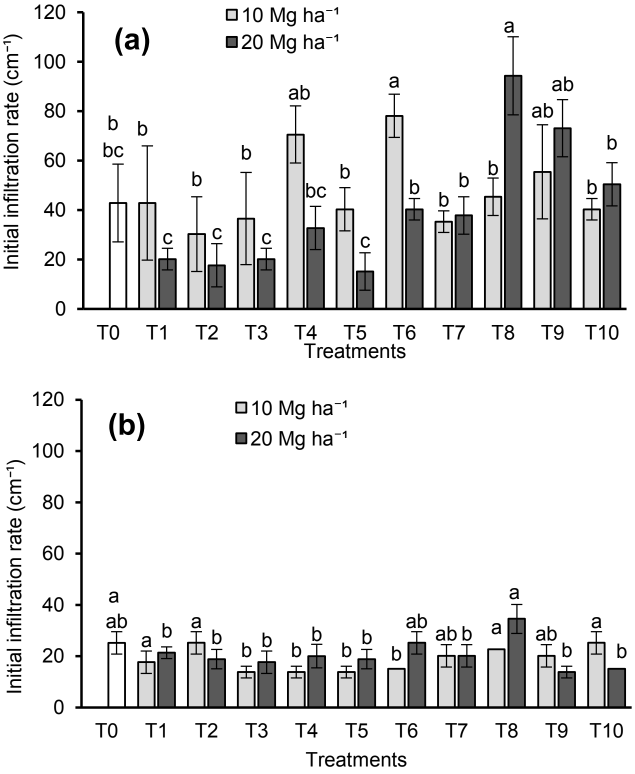

Fig. 2. Initial infiltration rates of the soils in (a) Measurement I and (b) Measurement II. Error bars indicate ± standard deviation. Different lower case letters indicate significant differences between treatments, where upper and lower letters on T0 are respectively related to the 10 and 20 Mg ha^{-1} application rates ($P \leq 0.05$).

The occurrence of high I_{i} in T8, T9, and T10 treatments at 20 Mg ha^{-1} rate might possibly have caused by the development of minuscule cracks in soil surface, which would result in lower bulk density levels.

After exposing to the rainfall for period of 3 weeks (Measurement II), the I_{i} of untreated soil was about 25 cm h^{-1}, whereas those of compost amended soils were in a range of 14–25 cm h^{-1} at 10 Mg ha^{-1} rate, and 15–35 cm h^{-1} at 20 Mg ha^{-1} rate (Figure 1b). The highest I_{i} was observed in T8 (~35 cm h^{-1}), which was in line with the result of Measurement I, and might have resulted by similar reason because the bulk density of T8 was lower than all the other treatments in Measurement II. The I_{i} of soils with most treatments showed decreased values compared with the dry season values, while almost all the treatments did not show any significant differences compared with T0.

Sorptivity (S_{W})

The S_{W} of soils at both Measurements are shown in Figure 3. In the Measurement I (Figure 3a), the S_{W} of soils with almost all the treatments showed no significant difference with T0 at 10 Mg ha^{-1} rate, except T4 and T7 where the S_{W} was significantly lower. At the 20 Mg ha^{-1} application rate, the S_{W} of four treatments (T1, T2, T3, T5) were significantly lower, while all the other treatments did not show any significant difference, compared with the T0. The treatments T1, T2, T3, and T5 showed significantly higher organic matter contents than the other treatments (Figure 1a). Therefore, the low S_W at dry condition might have caused by high organic matter levels, which may restrict the sorption of water into soils due to possible minor water repellent effects.

After the rainfall period (Figure 3b), the differences in S_W among the treatments became extremely minor, showing no significant differences among almost all of the compost amendments (except T3, T4 at 10 Mg ha^{-1} rate and T8 at 20 Mg ha^{-1} rate). All the compost treatments showed low S_W compared with T0, where the most differences were statistically significant with few exceptions (T10 at 10 Mg ha^{-1} rate; T1, T8 at 20 Mg ha^{-1} rate). Although the S_W is reported to increase as a result of organic amendments (Bhattacharyya et al., 2007), results of the present study did not show increase in S_W with compost treatments. As pointed out by Wallis et al. (1991), water entry into soils may be reduced by an order of magnitude even in the soils that are visually appeared to wet in a normal manner, indicating the hydrological significance of water repellency. Accordingly, possible minor changes with compost treatments that affect water repellent nature of the soils, although could not be quantified with WDPT measurements, can be considered as the cause of lowered values of hydraulic properties with compost applications.

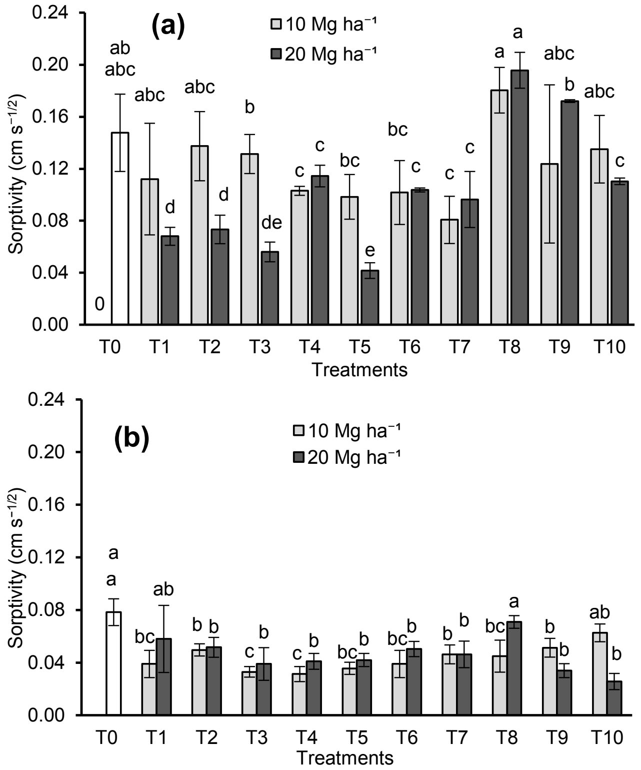

Fig. 3. Sorptivity of the soils in (a) Measurement I and (b) Measurement II. Error bars indicate ± standard deviation. Different lower case letters indicate significant differences between treatments, where upper and lower letters on T0 are respectively related to the 10 and 20 Mg ha^{-1} application rates ($P \leq 0.05$).

It was clear that all the surface hydraulic properties examined in situ (I_i, I_{SS}, S_W) were higher in the Measurement I than those observed in the Measurement II. As the organic matter contents in soils did not show any significant differences before and after rainfall, it can be considered that lowered values of hydraulic processes in the Measurement II were not caused by an increase in organic matter contents and subsequent impacts related to wetting properties of soil. Another possible reason for higher rates of water movement into soils in dry state would be the water potential differences of soils in dry and comparatively moist conditions. Theoretically, the wetting of soil with water would be accelerated when the particular soil is in more dry condition. The moisture content of the field soils (top 0–1 cm) at the Measurement I was lower (about 1–2%) than that at the Measurement II (4–6%). The ability of a soil to rapidly capture water is measured through the S_W, which is considered to be the dominant parameter governing the early stages of infiltration (Shaver et al., 2003). It is possible that the difference in moisture content in soils of the present study affected the surface hydrological properties such as S_W (Figure 3) and I_i (Figure 2), showing higher values in Measurement I.

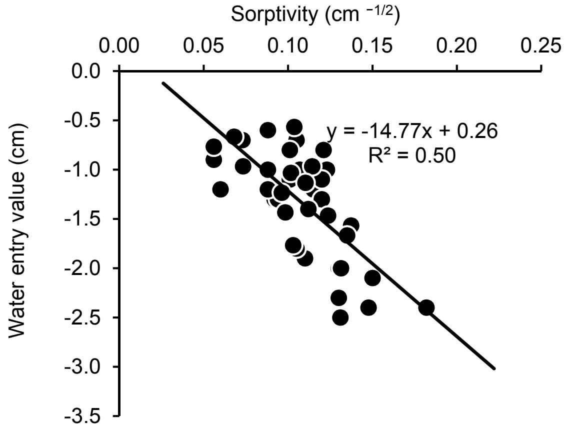

Fig. 4. Relation between sorptivity and the water entry values of the soils amended with different compost treatments.

The S_W explains the ability of a soil to rapidly capture water, or to uptake water without gravitational effects (Philip, 1969), whereas water-entry value explains a critical pressure at a point of achieving instantaneous water entry. As both h_{we} and S_W explains entering of water into the soil at different conditions, h_{we} was plotted against S_W to observe their interrelation. A moderate negative linear correlation ($R^2 = 0.50$) was observed between h_{we} and S_W (Figure 4), which was statistically significant at 0.05 probability level.

Steady-state infiltration rate (I_{SS})

As shown in Figure 5, I_{SS} did not follow the same results as I_i. In the Measurement I taken in the dry season, the I_{SS} of untreated soil was about 24 cm h^{-1}, whereas those of compost amended soils were in a range of 13–25 cm h^{-1} at 10 Mg ha^{-1} rate, and 8–25 cm h^{-1} at 20 Mg ha^{-1} rate (Figure 5a). It was clear that I_{SS} of all the compost amended samples were either statistically similar to, or significantly lower than, that of the T0 at both application rates.

At the 20 Mg ha^{-1} application rate, eight out of ten compost amended soils showed low I_{SS} values compared with those at the 10 Mg ha^{-1} application rate (Figure 5a). This might have caused by the differences in organic matter content of the compost amended soils as I_{SS} showed a negative linear correlation ($R^2 = 0.43$) with the SOM content. In the Measurement II, the I_{SS} did not show any significant difference among the treatments and application rates, showing low values about 8 cm h^{-1} (Figure 5b). Possible physical changes occur with breaking

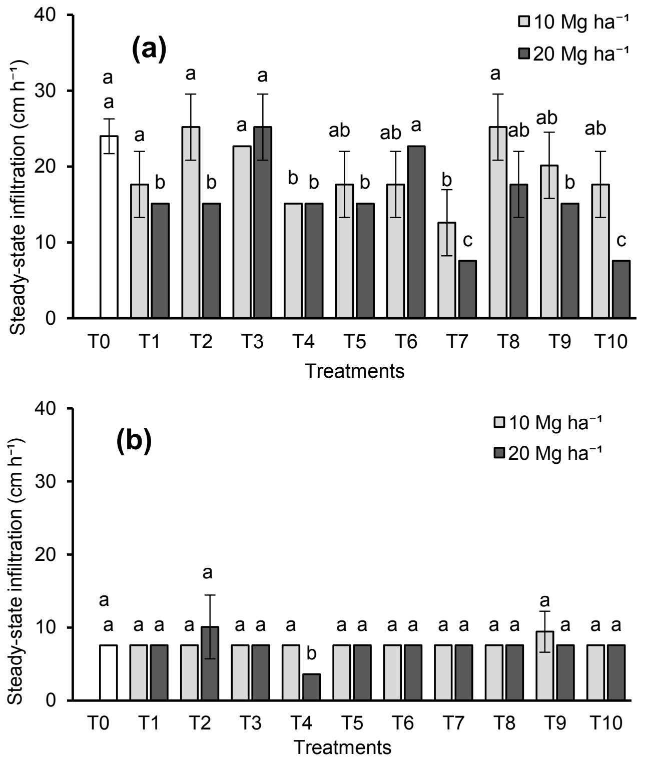

Fig. 5. Steady-state infiltration rates of the soils in (a) Measurement I and (b) Measurement II. Error bars indicate ± standard deviation. Different lower case letters indicate significant differences between treatments, where upper and lower letters on T0 are respectively related to the 10 and 20 Mg ha^{-1} application rates ($P \leq 0.05$).

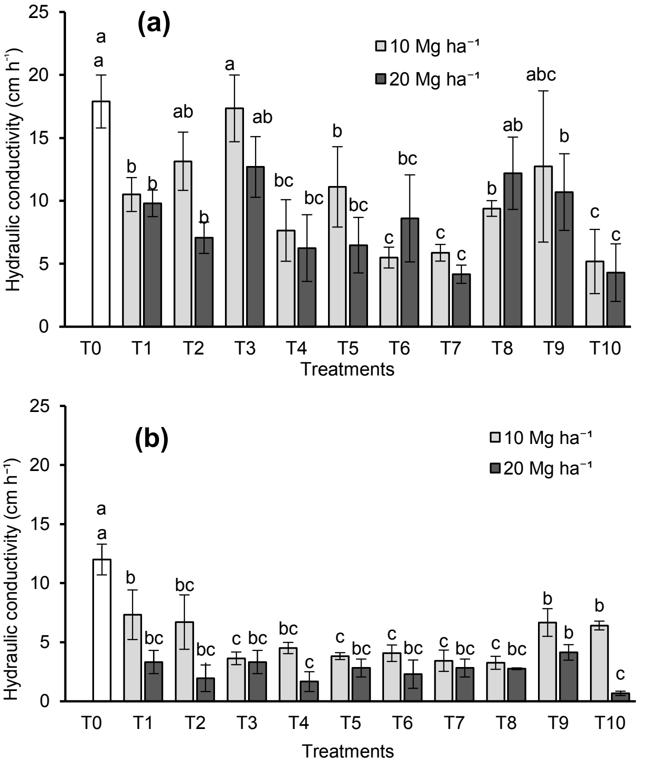

Fig. 6. Unsaturated hydraulic conductivity of the soils in (a) Measurement I and (b) Measurement II. Error bars indicate ± standard deviation. Different lower case letters indicate significant differences between treatments, where upper and lower letters on T0 are respectively related to the 10 and 20 Mg ha^{-1} application rates ($P \leq 0.05$).

down of aggregates, and other subsequent processes would take place on the soil surface as well as in the soil matrix might be the reason for the weakened I_{SS} in the Measurement II.

Unsaturated hydraulic conductivity (*k*)

The *k* of soils in both dry and wet periods is shown in Figure 6. During the dry period (Figure 6a), the *k* of the control (T0) was 18 cm h^{-1}. At 10 Mg ha^{-1} rate, the *k* under compost treatments were either statistically similar, or significantly lower, compared with T0.

The *k* of compost treatments (except T6 and T8) decreased at the higher application rate (20 Mg ha^{-1}). All the compost treatments at the 20 Mg ha^{-1} rate showed lower *k* values compared with T0, where most of the differences were statistically significant (except T3, T8). Soils treated with T8 showed high values for most tested hydraulic properties (Ex. I_i, S_W) that might have resulted from the development of minuscule cracks not only on the soil surface, but also in the matrix, which is shown by lower bulk density. As soils with T3 did not show low bulk density levels, low organic matter levels, or low values in any other tested surface hydraulic property, possible reasons for showing k values that are statistically similar to T0 is not clearly understood. However, there might be a possibility of macro-pore development in the soil matrix, which could not be confirmed in the present study.

After the rainfall (Measurement II), plots with all the treatments showed lowered *k* values (Figure 6b). All the compost treatments showed significantly lower *k* values compared with the T0 at both 10 and 20 Mg ha^{-1} application rates, where the *k* was higher at 10 Mg ha^{-1} than that of 20 Mg ha^{-1} for all the treatments. As similar cultivation practices conducted in all the plots including control (T0), the decreased values of *k* are considered to be caused by compost treatments, showing lower values at higher rates. Application of organic manure, including MSWC, is known to enhance porosity, water retention characteristics and saturated hydraulic conductivity (Głąb, 2014; Karak et al., 2016 and references therein; Yazdanpanah et al., 2016) of soils. In contrast to those reports, *k* in the present study showed decreasing trend with compost treatments.

To examine the relation of SOM levels to the unsaturated water movement in the soil matrix, the *k* was plotted against SOM content. The *k* showed moderate negative linear correlation with the log SOM content for the Measurements I ($R^2 = 0.50$) and II ($R^2 = 0.51$) periods (Figure 7). Comparing the Measurements I and II, *k* showed higher sensitivity to the increasing SOM contents at the Measurement I conducted in the dry period, indicating higher slope in the linear regression line compared with the Measurement II conducted during the rainy period (standard errors of the slopes are 6.11 and 2.02 for dry and rainy periods, respectively).

Compost treatments made to the top soil (1–10 cm) seem to affect most of the investigated hydraulic properties (h_{we}, I_i, I_{SS}, S_W) on the soil surface as well as in the soil matrix (*k*). In case of *k*, this effect was more explicit in both Measurements showing lower values in all the compost amended soils compared with T0, and higher rate of application compared with the lower rate. This effect can be confirmed considering the negative linear relationship between log organic matter content and the *k* (Figure 7).

Altogether, the in situ investigated hydraulic properties (such as I_i, I_{SS}, S_W, *k*) showed greater values before the start of the rainy season than afterwards. As the differences in SOM

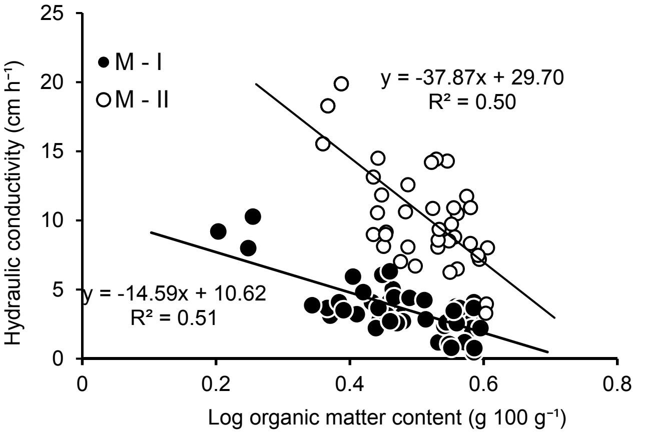

Fig. 7. Relation between logarithmic organic matter content measured as g 100 g^{-1}, and the unsaturated hydraulic conductivity of the soils amended with different compost treatments at Measurement I (M -I) and Measurement II (M -II).

contents were not significant before and after rainfall, it can be considered that lowered values of hydraulic properties in the Measurement II were not caused by an increase of organic matter contents and subsequent impacts related to wetting properties of soil. Although water potential difference is a potential factor, it seemed not a possible reason here because I_{SS} also decreased in the Measurement II (Figure 5). The I_{SS} should be remain similar in Measurements I and II, because it represents a situation near saturation, where the initial levels of moisture in soils would not have any effective impact. Furthermore, when the moisture content is high in a soil, water movement through the pores would be easier than that in a comparatively dry soil, improving hydraulic water movement. In contrast, *k* showed significant decrease in the Measurement II. Accordingly, it can be considered that although the water potential differences might have important effects, it would not be the solitary reason for weakened hydraulic movements in the Measurement II, where the soils were exposed to rainfall for a period of more than 3 weeks.

Dry soils that face rainfall would be subjected to different kinds of physical changes. Aggregates that have been produced in the dry soil would be dissipated producing sludge due to precipitation, and other subsequent processes would take place on the soil surface as well as in the soil matrix, such as particle rearrangements, clogging of pores, and formation crusts. These kinds of changes in soil physical environment might be the reason for the weakened I_{SS} in the Measurement II. Moreover, these effects can be considered as the reasons for the linear regression line between log organic matter content and the *k* to demonstrate a high slope in the Measurement I compared with that in the Measurement II.

CONCLUSIONS

Data obtained through direct field and laboratory measurements with soils of cultivated plots amended with ten types of composts samples at two rates (10 and 20 Mg ha^{-1}) with control (T0) showed that the processes such as water entry, infiltration rates, *k*, and S_W are affected by the compost amendments. Considering the overall results of the present study, compost amendments seemed not to improve or accelerate but tend to suppress hydraulic properties of soil, especially at the higher rate of application.

Results revealed that there is a significant difference between measurements made in dry and rainy seasons, which might have caused mainly by physical changes incurred due to the impacts of rainfall. No improvement in hydraulic properties were observed with AWC treatments compared with MSWC. However, the SOM contents seemed lower in AWC treatments (T9, T10) than most of the MSWC.

Providing high organic matter content to the soil is also important as the original organic matter levels in the soil is very low. Considering the results, T1, T2, T3, and T5 are the treatments that result in high SOM contents. On the other hand, the tested soil was a coarse-textured loamy sand soil where the soils are facing very high average annual rainfall (2400–2800 mm). Water drains through very easily making the soil more prone to leaching, removing plant available nutrients from the root zone with the possibility of contaminating groundwater. Therefore, considering the importance of lowering the hydraulic water movements as well, T3 and T5 might be considered as best suited for the tested soil conditions.

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