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Field Evaluation of Compost, Sawdust and Rice Straw Biomass on Soil Physical and Hydraulic Properties

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Abstract

A field experiment was carried out to investigate the effects of compost, sawdust and rice straw biomass on soil three-phase composition, soil resistance to penetration, bulk density, near-saturated hydraulic conductivity, K (h), and soil water retention characteristics. The experimental design involved ten split blocks such that the non-amended one plot was considered as control and other nine plots were under each of compost, sawdust and straw treatments at application rates of 0.1, 0.2 and 0.3 $m^3 m^{-3}$ of apparent soil volume. Addition of compost, sawdust and straw showed potential for improvement of surface soil physical and hydraulic properties, then its effectiveness was partly dependent on amendment types and application rates. Three-phase composition of all amended soils showed solid-phase reductions and increase of total porosity. Generally, soil resistance and bulk density at all amendment plots were decreased, which was likely due to reduction in soil solid phases. A good correlation between soil resistance and bulk density was also observed. Except for sawdust applied at higher rate, the K (h) generally increased at any level of compost and straw incorporations, and this was attributed to the of reduction in solid phase of amended soils. Soil water content was relatively high at higher suction for compost amended soils, while improvement in soil water retention was limited at lower suction for sawdust, and gradually increased from low to high suction for straw amended soils, respectively.

Key words : Biomass, bulk density, near-saturated hydraulic conductivity, soil resistance, soil three-phase composition, soil water retention

1. Introduction

Application of crop and plant biomass for improving soil organic matter (SOM) and enhancing soil quality is well recognized in sustainable agriculture (Carter *et al.*, 1998 ; Kay, 1998). Although these biomasses are often regarded as agricultural wastes, development of agricultural conservation practices aimed at enhanced soil quality, however, have resulted in very diverse methods of organic residue management. Recycling of these surplus agricultural byproducts has the advantage to meet nutrient requirements for the crop and expanded use as effective soil amendments. Manure and composted manure have been studied for long time as the organic amendments. Due to labor shortages as well as increasing farm mechanization, application of manure and composted manure has been gradually decreased over the last few decades. At the same time, direct application of crop and plant biomass as soil amendments has received considerable interest. Among these types of biomass, compost, sawdust and rice straw can be used as effective soil amendments. Rice straw is usually left in the field after harvest and is subsequently burnt or used as animal feed. Sawdust obtained as byproducts of lumber mill is usually thrown into the ground or simply burned up.

During the last several decades, much attention has been paid to the utilization of crop and plant residues as soil amendments, as well as to evaluate the effects of existing organic matters on soil physical properties such as soil structure and aggregate stability (Tisdal and Oades, 1982 ; Oades, 1984 ; Martens and Frankenberger, 1992 ; Carter and Stewart, 1996 ; Debosz *et al.,* 2002), porosity and pore size distribution (Pagliai *et al.,* 1987 ; Boyle *et al.,* 1989 ; Martens and Frankenberger, 1992 ; Schjonning *et al.,* 1994 ; 2002 ; 2005), bulk density (BD) (Gupta *et al.,* 1977) and water holding capacity (Khaleel *et al.,* 1981 ; Miller *et al.,* 2002 ; Rawls *et al.,* 2003). Addition of organic matter decreases bulk density due to the dilution effect of added organic matter with the denser mineral fraction (Gupta *et al.,* 1977). From their report, yearly addition of 450 t ha^{-1} of anaerobically digested sewage sludge for two consecutive years decreased the bulk density of field coarse sandy soils by 28%. The effect of residue management on soil bulk density and soil resistance expressed as cone index has been found to be variable (Mandal *et al.,* 2004). On the contrary, Bhagat and Verma (1991) observed that incorporation of rice straw at an application rate of 5 t ha^{-1} yr^{-1} to a wheat-rice crop sequence, reduced field bulk density from 1.32 to 1.25 Mg m^{-3}. Debosz *et al.* (2002) reported the 25% increase in water stable aggregates of sandy loam soil amended with household compost at constant temperature (10℃). Several studies demonstrated with biosolids and composted biosolids suggested increased soil water retention and aggregate stability in silt loam soils (Epstein, 1975 ; Epteien *et al.,* 1976 ; Wei *et al.,* 1985 ; Lindsay and Logan, 1998). For evaluating the effects of manure addition on pore-size distribution, Schjonning *et al.* (1994) observed that farmyard manure or slurry significantly increased the volume of pores for $<$ 0.2 and 0.2 to 0.3 μm within 20 cm depth from the soil surface while they noticed no effect on pores for $>$ 30 μm. In another study, Pagliai *et al.* (1987) reported that poultry manure increased pores for 30 to 500 μm and those for $>$ 500 μm. Addition of animal manure has greater effect on macroporosity and conductivity in subsoil below plowing layer compared to plow layer (Schjonning *et al.,* 2005). For a long-term manure amended soil, Miller *et al.* (2002) reported that soil water retention was significantly increased by 5 to 48% (0–5 cm and 10–15 cm soil depths) compared with the control at different matric potentials between 0 and −1500 kPa.

The increased SOM with organic amendments applied to agricultural fields, as indicated by Boyle *et al.* (1989), improves the soil aggregation, and this improvement of soil structure favors the downward soil water flow. Although manure and composted manure as organic amendments have been addressed in several studies, very little research has been done in order to observe the effects of sawdust and straw as soil amendments on soil physical properties. To date there is little information on the effect straw and sawdust soil amendments on the hydraulic conductivity of soils (Garnier *et al.,* 2004). In particular, there might have not been any reported field studies for evaluating the unsaturated hydraulic conductivity under straw and sawdust application. For optimal land application of these biomasses as soil amendments, understanding of the influence of these amendments on soil physical and hydraulic properties is essential. Therefore, the purpose of this study was to evaluate the effects of compost, sawdust and straw incorporated as amendments on the three-phase composition of soil, bulk density and soil resistance, the hydraulic conductivity and soil water retention characteristics.

2. Materials and Methods

2.1 Site Description and Experimental Design

The experiment was conducted in an upland fallow field at the Iwate University Experimental Station, Morioka, Japan. The field was not subject to under tillage practices during the last two decades. Before cultivation the field was prepared to cut tall grass down to ground level. The soil is volcanic ash soil, andisol and clay loam in texture (43.8% sand, 42.1% silt & 14.1% clay). The average values of soil properties measured at the beginning of the experiment within 0–5 cm soil depth were as follows : particle density 2.71 $Mg\,m^{-3}$; bulk density 1.20 $Mg\,m^{-3}$; total carbon 106 $g\,kg^{-1}$; and total nitrogen 1.68 $g\,kg^{-1}$ (dry soil basis).

The rectangular field of approximately 100 m^2 was arranged as a split block design. Total ten plots each comprising an area of 1.5 by 2.0 m were established in this study. Amendment types and rates were considered as treatments in nine plots and the other one non-amended control plot was used for measurement and result comparison purposes. Field experiment was performed from July 2005 to June 2006. Amendments were applied once in the middle of July 2005 to these nine plots. We did not cultivate any crop but periodical weeding management was performed in every three months interval. Sampling and measurements of soil physical and hydraulic properties were carried out in June 2006, i.e. at the end of one year.

2.2 Amendment Types and Application Rates

Amendment types applied to treatment plots included three different biomasses : compost, sawdust and fresh rice straw. Compost used as soil amendment in this study was a mixture of rice straw, cow excrement and wood bark. Sawdust obtained from a lumber mill was predominantly Japanese cedar waste, and used as soil amendment in this study. Water content and particle density of compost and sawdust was 0.75 $kg\,kg^{-1}$, 2.70 $Mg\,m^{-3}$ and 0.43 $kg\,kg^{-1}$, 1.71 $Mg\,m^{-3}$, respectively. Rice straw (*Japonica*) was collected from the farm at Takizawa, a neighboring village of Morioka. Straw was air-dried and then cut into 1–2 cm pieces. The values of water content and particle density of rice straw were 0.19 $kg\,kg^{-1}$ and 1.60 $Mg\,m^{-3}$. Water content was measured on dry-weight basis.

All soil amendments using compost, sawdust and rice straw were applied on apparent soil volume basis and spread manually over each amendment treatment plot. The amendment volume was calculated for each plot by multiplying the plot area with a constant incorporation plow depth of 15 cm. Amendments were applied on a random basis to all nine treatment plots. Each of compost, sawdust and straw incorporated amendments was applied to three treatment plots. Three application rates expressed as 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ of the soil volume (apparent) were assigned to these three treatment plots of each amendment, respectively. Briefly, we calculated the apparent soil volume of each plot by multiplying the area to the depth of incorporation. Then we incorporated each biomass (volume basis) to the 0.0, 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ of apparent soil volume of each plot. A small tractor implemented with a rotavator was used to incorporate amendments into the top 15 cm of the soil profile. The non-amendment control plot was also tilled to the same soil depth as the treatment plots. As our study was limited to the changes of physical and hydraulic properties due to compost, sawdust and straw amendment, therefore, we did not investigate crop yield response to these amendments.

2.3 Measurement of Soil Physical and Hydraulic Properties

Bulk density for all plots was determined from soil core samples. Samples were collected from top 5 cm of each plot, by commercial core samplers of 5 cm diameter, and 5.1 cm in length. However, for each plot bulk density were not measured for several sample series. Collected samples were dried in a force-vent oven at 105

℃ for 24 h and dry weights were recorded for bulk density computations. In-situ soil resistance was measured for each plot within the top 5 cm soil depth using a Yamanaka hand-held cone penetrometer, and measurements were taken at five points following on a circular array. For each plot, changes in the phase composition of soil matrix were estimated from collected undisturbed soil cores. Approximately 1 cm of the topsoil was scraped and one undisturbed core was taken at the top 6 cm soil depth for each plot. Disturbed soil samples were also collected at the same time for gravimetric water content measurements. Collected samples were weighted immediately and were oven-dried for determining the solid mass. The mass of solid, water and amendments were estimated for 100 cm^3 total soil sample using the average water content obtained from disturbed soil samples. This mass weight was converted to volume proportion of solid, water and organic amendments by using the particle density of soil amendments mixture. Subtracting the volume of solid, water and amendments from the total sample volume of 100 cm^3 resulted in an estimate of the gas phase volume. The volume proportion of solid, water, gas and amendments was then converted into percentage.

In this study, the near-saturated hydraulic conductivity was determined for all plots. A disc permeameter (Perroux and White, 1988) was used for *in-situ* measurements of the unsaturated hydraulic conductivity, referred to as $K(h)$ (cm s^{-1}),where h is the suction (cm). The advantage of disc permeameter is that, the instrument is relatively simple, minimal disturbance of soil and *in situ* estimation of hydraulic conductivity is possible at or near saturated condition. The disc permeameter consisted of a reservoir tower, a bubble tower with movable air-entry point and a disc (20 cm in diameter), covered with a highly permeable nylon membrane. The air-entry tube allowed to impose the constant pressure head conditions with a pressure head being below the atmospheric pressure. A thin layer of highly permeable coarse sand was used to ensure good hydraulic contact between the disc and the soil. Since removal of surface crust, soil clods and roots from the soil surface was reported effective for achieving a leveled surface for tension infiltrometer (Ankeney, 1992), the top 1 cm soil was removed before the measurement of infiltration. Infiltration was recorded by measuring the water level drop in the reservoir for a sequence of preset time step. The time step was set at 15 seconds for few initial readings and at the end water levels in the reservoir tower were recorded for every 5-minute intervals until the steady state condition was attained. Steady state flow rates, Q ($cm^3 s^{-1}$), were determined for successive suctions of −8, −4, −2 cm and 6 mm of water, because these suctions were reported to be best for describing biological activities in soils (White *et al.,* 1992 ; Murphy *et al.,* 1993). However, as the suctions approached close to saturation it was very difficult to notice, because the steady state condition prevailed during very short run time. Therefore, data observed at suctions of −2 cm and 6 mm of water were not presented in this study.

The K (h) was determined using steady state flow data from the disc permeameter under the different suctions applied (Reynolds and Elrick, 1991). According to their study, the piecewise slope and intercept can be described by :

$$\alpha_{xy}=\frac{\ln(Q_x/Q_y)}{(h_x-h_y)} \tag{1}$$

$$K_{xy}=\frac{G_d\alpha_{xy}Q_x}{r(1+G_d\alpha_{xy}\pi r)(Q_x/Q_y)P} \tag{2}$$

where $P=h_x/(h_x-h_y)$; K_{xy} is the piecewise intercept ($cm\,s^{-1}$) ; α_{xy} (cm^{-1}) is the piecewise slope of the plots of lnQ against h ; Q is the flow rate ($cm^3 s^{-1}$) ; G_d is the dimensionless shape factor for tension infiltration from a surface disc and is equal to 0.25 ; and r is the radius of the disc (cm). The values x (=1, 2, 3, - - -) and y (=x+1) are integers, which are used to denote piecewise sequences. By assuming a simple exponential relationship between the hydraulic conductivity and pressure head (Gardner, 1958), the K(h) is given by :

$$K(h) = K_{xy}\exp(\alpha_{xy} h) \quad (3)$$

The K(h) was calculated as the average of −8 and −4 cm of water of applied suctions. Steady State flow rate (Q) for each suctions were obtained as the slope of the curve of cumulative infiltration volume versus elapsed time, which is shown in Fig. 1. Assuming that the sorptive number α is constant over the interval between the two successive suctions, the piecewise linear regression analysis were carried out which is shown in Fig. 2. The slope and intercept value of piecewise regression plot were taken

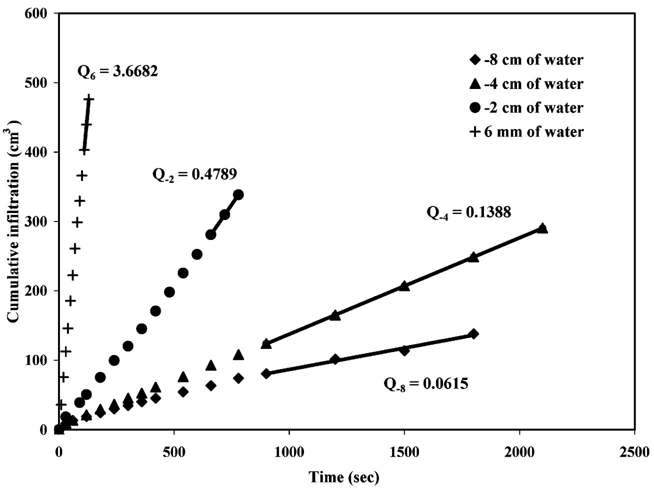

Fig. 1 Cumulative infiltration at successive supply pressure head measured at each treatment plot using disc permeameter. Steady state flow rate (Q) is taken as slope of the linear portion of the curve.

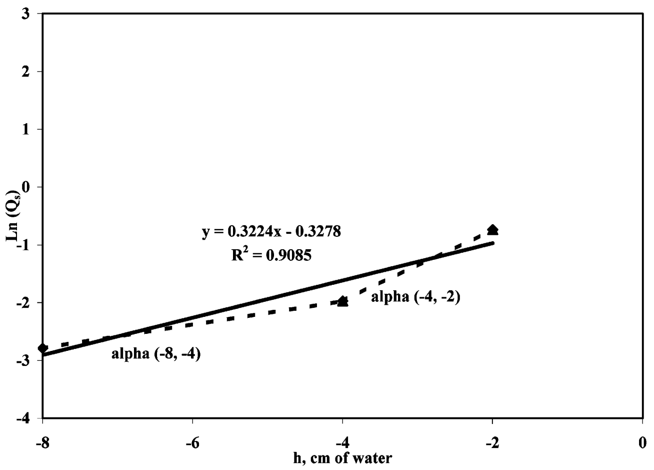

Fig. 2 Natural logarithm of steady state flow rate (Q) versus supply pressure head (h) for obtaining the α based on the piecewise exponential relationship expressed in the Eq.3. The values of α and K_{xy} in Eq.3 are the slope and intercept of two successive pressure heads, respectively.

as equal to the value of α_{xy} and K_{xy} in Eq.1 and Eq.2. Unsaturated hydraulic conductivity, K (h) were calculated using Eq.3 as the average of -8 and -4 cm of water of applied suctions.

Soil water retention characteristics for each plot were determined from the undisturbed core samples (5.1 cm length and 5.0 cm diameter) using the hanging water column and centrifuge method. It is to be mentioned that, water retention characteristics were not measured for several sample series. Saturated cores were transferred to the hanging water column and placed on a porous ceramic plate. Lowering a hanging water column connected to the plate induced a step change in suction at the bottom of the plate. The water column was setup as lower as at 4.5 cm, 50.1 cm and 96.0 cm measured from the mid-point of the sample. High suctions such as 5.0×10^2, 1.0×10^3 and 2.5×10^3 cm were applied by centrifuge and suctions at 3.16×10^5 and 1.0×10^7 cm were taken as air dry and oven dry condition. Volumetric water content at fully saturated condition was calculated from the three-phase composition such that the soil matrix is perfectly saturated with water, and then assumed as 0 cm suction. So the air volume at each mixing level was assumed to be zero and the volumetric soil water content was calculated by subtracting the solid volume from the total volume.

3. Results and Discussion

3.1 Three-Phase Composition of Soil

Compared to the non-amended control plot (represented by 0.0 application rate), soil three-phase compositions (solid, water and air) of compost, sawdust and rice straw amended plots incorporated at application rates of 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ (volume basis) were shown in Fig. 3, Fig. 4 and Fig. 5, respectively. Despite application rates of compost, sawdust and straw incorporation, the soil phase composition, as shown in Figs. 3–5, generally changed in all amended treatment plots compared to the control. However, the most distinct change of solid, water and air phases was observed in compost incorporated amended plots. The solid phase was markedly reduced with the application rate of compost incorporation (Fig. 3)

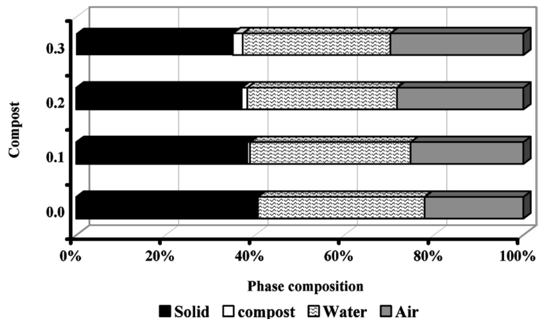

Fig. 3 Soil three-phase composition of compost incorporated plots at 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ of apparent soil volume

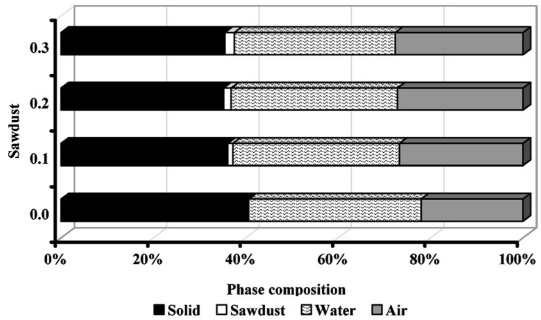

Fig. 4 Soil three-phase composition of sawdust incorporated plots at 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ of apparent soil volume

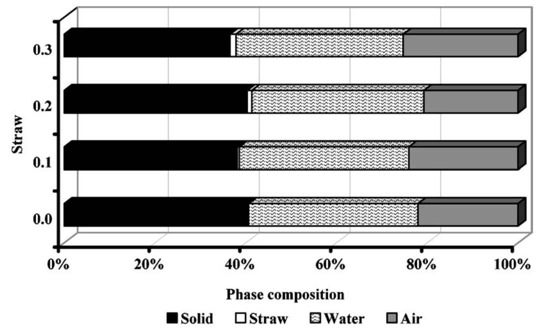

Fig. 5 Soil three-phase composition of straw incorporated plots at 0.1, 0.2 and 0.3 $m^3\,m^{-3}$ of apparent soil volume

For compost, application rate at $0.3\,m^3\,m^{-3}$ yields 2.20% composition of the total volume. At this application rate the solid phase reduced up to 5.60%, while the air phase increases to 7.64% (Fig. 3). This may be attributed to the composition of compost, which was made of straw, cow excrement and wood bark. Generally cow excrement is more decomposable than straw and wood bark ; as a result it may leave a blend of fibrous materials that occupies more pore space.

Sawdust amended at 0.1, 0.2 and $0.3\,m^3\,m^{-3}$, shown in Fig. 4, indicated the similar trend as compost incorporations. However, the reduction of the soil solid phase at $0.3\,m^3\,m^{-3}$ level of incorporation was slightly less. The $0.3\,m^3\,m^{-3}$ of sawdust incorporation corresponded to 2.02 % of the total volume, which causes 5.16% reduction in the soil solid phase. The air phase of sawdust-amended soils also increases to 5.62 % compared to the control plot. For straw amendments, the trend of phase changes varied abruptly at different level of incorporation. As shown in Fig. 5, the soil solid phase decreased by 2.50% (from 40.6% to 38.1%) at $0.1\,m^3\,m^{-3}$ incorporation level ; remained almost constant (40.6% to 40.3%) at $0.2\,m^3\,m^{-3}$ and then reduced to 5.10% (from 40.6% to 35.5%) at $0.3\,m^3\,m^{-3}$ level of straw incorporation.

3.2 Soil Resistance and Bulk Density

Table 1 showed values of soil resistance and bulk density at different level of compost, sawdust and straw amendment. Soil resistance and bulk density generally decreased due to compost, sawdust and straw amendments, compared to the non-amended soil. Average soil resistance decreased from 572 kPa to 376 kPa, and bulk density decreased from $1.20\,Mg\,m^{-3}$ to $0.95\,Mg\,m^{-3}$ as affected by the incorporation of $0.1\,m^3\,m^{-3}$ compost (Table 1). Similarly, soil resistance and bulk density for the incorporation of $0.3\,m^3\,m^{-3}$ compost decreased sharply to 86.0 kPa and $0.84\,Mg\,m^{-3}$, respectively, compared with the control plot.

Soil resistance and bulk density did not decreased gradually for different level of sawdust incorporation (Table 1), compared to the control plot. For instance, both soil resistance and bulk density decreased to 288 kPa and 1.06 $Mg\,m^{-3}$ at $0.1\,m^3\,m^{-3}$ sawdust, and to 109 kPa and $0.84\,Mg\,m^{-3}$ at $0.2\,m^3\,m^{-3}$ sawdust incorporations, respectively. On the contrary, soil resistance and bulk density increased to 376 kPa and $0.98\,Mg\,m^{-3}$, respectively, for the addition of $0.3\,m^3\,m^{-3}$ sawdust. As shown in Table 1, addition of straw at any level, sharply decreased soil resistance and bulk density. For instance, both soil resistance and bulk density decreased to 67.5 kPa and $0.73\,Mg\,m^{-3}$, respectively, at of $0.3\,m^3\,m^{-3}$ incorporation level.

Figures 6, 7 and 8 showed the relationships between soil resistance and bulk density for all treatment plots derived from simple linear regression analysis, indicating a good correlation between soil resistance and bulk density at all applied amendments. For compost and straw amendments soil resistance decreased gradually with the decrease in bulk density at any level of incorporation. However, sawdust incorporated at $0.2\,m^3\,m^{-3}$ application rate re-

Table 1 Average soil resistance and bulk density for compost, sawdust, and straw incorporation

Application rate (%)	Soil resistance (kPa)				Bulk density ($Mg\,m^{-3}$)			
	Control	Compost	Sawdust	Straw	Control	Compost	Sawdust	Straw
0	572 (67.0)	—	—	—	1.2	—	—	—
10	—	376 (83.6)	288 (71.0)	400 (170)	—	0.95	1.06	0.98
20	—	116 (73.3)	109 (31.0)	79.0 (10.0)	—	0.92	0.84	0.90
30	—	86.0 (33.0)	376 (84.0)	67.5 (26.0)	—	0.84	0.98	0.73

Values in parentheses are standard deviation of the sample mean

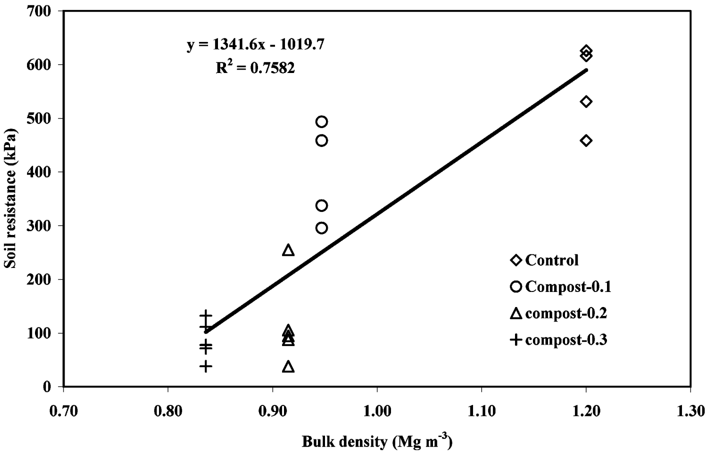

Fig. 6 Relationship between soil resistance and bulk density for compost amended soils incorporated at application rates of 0.1, 0.2 and 0.3 $m^3 m^{-3}$.

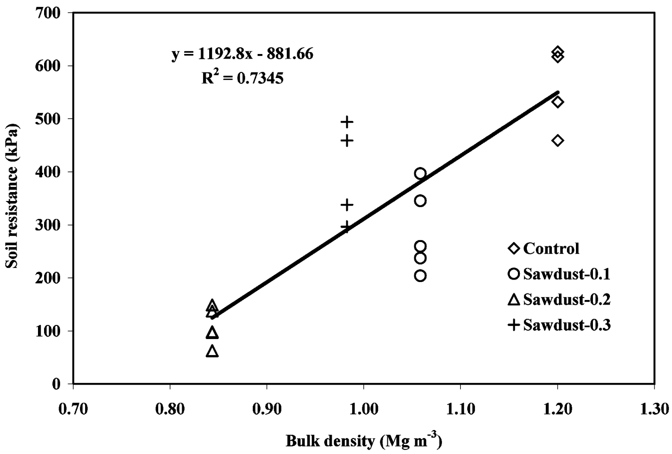

Fig. 7 Relationship between soil resistance and bulk density for sawdust amended soils incorporated at application rates of 0.1, 0.2 and 0.3 $m^3 m^{-3}$.

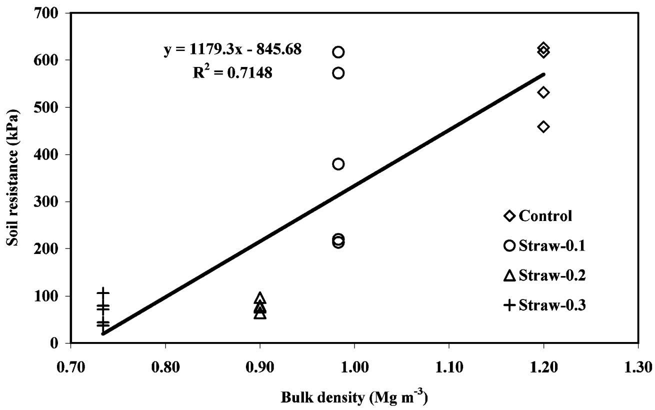

Fig. 8 Relationship between soil resistance and bulk density for rice straw amended soils incorporated at application rates of 0.1, 0.2 and 0.3 $m^3 m^{-3}$.

sulted the maximum reduction in soil resistance and bulk density values compared to other 0.1 $m^3 m^{-3}$ and 0.3 $m^3 m^{-3}$ of sawdust incorporations. Relatively better correlation ($R^2 = 0.7148$) between soil resistance and bulk density obtained for straw amended soils. Variations in the reduction of soil resistance and bulk density values for compost, straw and sawdust amended soils may be explained from the changes of their phase compositions at different level of incorporations (section 3.1). Bulk density is inversely proportional to total porosity (Carter and Ball, 1993), which provides a measure of the total pore space left in the soil for air and water movement. Lower bulk density generally reduces the soil resistance because of relatively less unconfined compressive strength of the soil. The reduction in the solid phase at any level of compost, sawdust and straw incorporations was higher than the non-amended control soils. The decrease in solid phase increased the air phase resulted a subsequent increase in total porosity. For instance, at 0.3 $m^3 m^{-3}$ additions as compost, sawdust and straw incorporations reduced soil solid phases by 5.60, 4.08 and 5.16%, and thereby increasing the total porosity by 4, 3 and 4%, respectively. In addition, decomposition rates of these biomasses may be a reason of variable soil resistance and bulk density of amended soils, which is evident in sawdust amendments.

3.3 Near-Saturated Hydraulic Conductivity

The effect of compost, sawdust and straw incorporations on near-saturated hydraulic conductivity, *K(h)*, was shown in Fig. 9. Since the similar trend was observed under different applied suctions, the effect of compost, sawdust and straw incorporation on near-saturated hydraulic conductivity, *K(h)*, at −6 cm of water suction (average of −8 and −4 cm suction) was demonstratively shown. The ability of soil to transmit water depends on the porosity and the arrangement of soil particles. Addition of organic amendments usually leads to an increase in soil aggregation and porosity, therefore, *K(h)* is expected to be greater in organic matter amended soils. As shown in Fig. 9, both compost and straw incorporations increased *K(h)* remarkably at different application rates though significant difference in data among treatment variables were not tested. For compost amended soils, the *K(h)* sharply increased to 25.4 cm d^{-1} at level of 0.1 $m^3 m^{-3}$ incorporation and then gradually increased to maximum 40.4 cm d^{-1} at 0.3 $m^3 m^{-3}$ addition (compared to

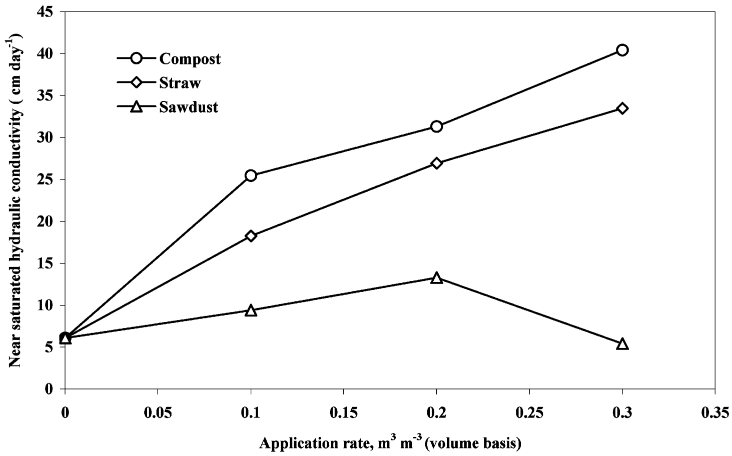

Fig. 9 Effect of the different incorporation rates of compost, sawdust and straw amendments on the near-saturated hydraulic conductivity of the soil, K(h), observed at a suction of 6 cm of water.

the non-amended control plot). Straw incorporations showed the similar trends. Compared to the control plot, a steep increase of the *K(h)* was observed at 0.1 $m^3 m^{-3}$ straw incorporation (18.3 cm d^{-1}) and then exhibited the maximum 33.5 cm d^{-1} at 0.3 $m^3 m^{-3}$ incorporation. In contrast, the trends of the *K(h)* increments with increasing sawdust additions were not consistent. As shown in Fig. 9, the *K(h)* gradually increased from 6.10 cm d^{-1} (control plot) to 9.40 and to 13.3 cm d^{-1} at 0.1 $m^3 m^{-3}$ and 0.2 $m^3 m^{-3}$ incorporation levels, respectively, and then suddenly decreased to 5.40 cm d^{-1} at 0.3 $m^3 m^{-3}$ incorporation level. This sudden decrease in the *K(h)* for sawdust amended soil at higher application rate may be attributed to either measurement error or at higher rate applied and suspended solids or microorganisms which may likely to block the water conducting pores (McAuliffe *at al.,* 1982 ; Lehrsch *et al.,* 1996). Notably, as shown in Fig. 9, K(h) values for sawdust amended soils was also lower than compost and straw amended soils incorporated at 0.1 $m^3 m^{-3}$ and 0.2 $m^3 m^{-3}$ rates.

Incorporations of compost, sawdust and straw to soils generally decreased the solid phase and increased the water and gas phase (Fig. 3, Fig. 4, and Fig. 5, respectively). Hence, the total porosity increased with the increase in incorporation rates. The increase in the total porosity might have an effect on the increasing trend of the *K(h)* for compost, straw and sawdust amended soils. As water flow rates in soil pores (cylindrical) is proportional to the fourth power of the radius, near saturated porosity would account for most of the water movement in unsaturated condition (Brady, 1974). The total porosity ratio for compost, straw and sawdust amended soils at 0.3 $m^3 m^{-3}$ incorporation was 1.06, 1.05 and 1.06, respectively, compared with control plot. At the same level of incorporation, the *K(h)* increased by 6.6, 5.5 and 0.9 times than non amended soil, thus indicating that the *K(h)* change was much higher than the porosity expansion. Therefore, it is clear that the effect of organic matter incorporations on the *K(h)* may be attributed to the porosity along with pore radius expansion.

3.4 Soil Water Retention Characteristics

Soil water retention curves for different application rates of compost, sawdust and straw amended soils compared to the control plot were presented in Fig. 10, Fig. 11, and Fig. 12, respectively. Compared to the control plot, compost incorporation at higher application rate retained larger amount of water than sawdust and straw. For instance, the 0.3 $m^3 m^{-3}$ incorporation of compost caused 0.06 $m^3 m^{-3}$ (from 0.47 $m^3 m^{-3}$ to 0.53 $m^3 m^{-3}$) increase in water content at a low suction (at 4.5 cm) ; remained almost constant at 0.05 $m^3 m^{-3}$ (from 0.35 $m^3 m^{-3}$ to 0.40 $m^3 m^{-3}$) at 5.0×10^2 cm suction, and then increased to 0.14 $m^3 m^{-3}$ (from 0.15 $m^3 m^{-3}$ to 0.29 $m^3 m^{-3}$) at 3.16×10^5 cm suction (Fig. 10). However, sawdust incorporation effect was limited to relatively at low suction. As shown in Fig. 11, at 0.3 $m^3 m^{-3}$ sawdust incorporation level, water content increased by 0.04 $m^3 m^{-3}$ (from 0.48 $m^3 m^{-3}$ to 0.52 $m^3 m^{-3}$) at 4.5 cm ; remained constant 0.04 $m^3 m^{-3}$ (0.35 $m^3 m^{-3}$ to 0.39 $m^3 m^{-3}$) at 5.0×10^2 cm and then decreased by 0.01 $m^3 m^{-3}$ (0.15 $m^3 m^{-3}$ to 0.16 $m^3 m^{-3}$) at 3.16×10^5 cm suction. For straw amended soils (Fig. 12) increments in water content was lower than compost amended soils at higher suction. However, at relatively lower suction, volumetric water content of straw and compost amended soils were almost same. For instance, addition of straw at the 0.3 $m^3 m^{-3}$ incorporation level increased water content by 0.05 $m^3 m^{-3}$ at 4.5 cm, remained constant at 0.05 $m^3 m^{-3}$ at 5.0×10^2 cm, and then increased to 0.06 $m^3 m^{-3}$ at 3.16×10^5 cm suction, respectively.

The effect of compost, sawdust and straw incorporations on changes in soil water retention behaviors may be explained from the capillary pore size and porosity expansion considerations of amended soils. Assuming that the soil is behaving as a bundle of capillary tubes, then capillarity would be sufficient to describe the relationships between the capillary pressure head and soil pore radii. According to the

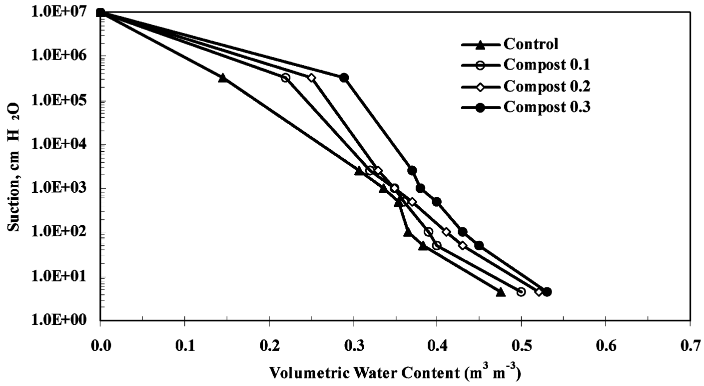

Fig. 10 Soil water retention curve of compost amended treatment plots at different suctions.

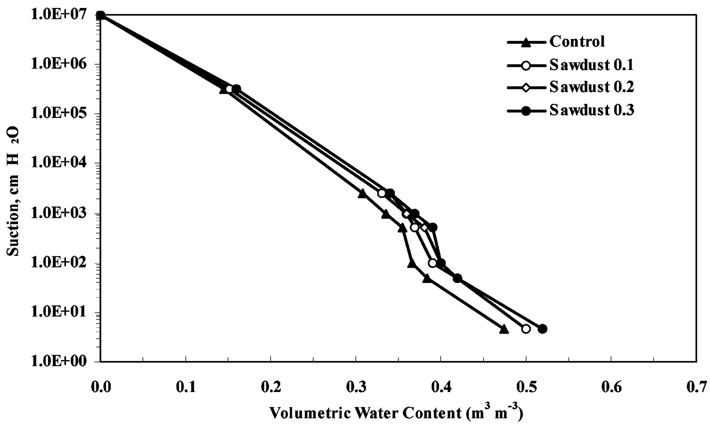

Fig. 11 Soil water retention curve of sawdust amended treatment plots at different suctions.

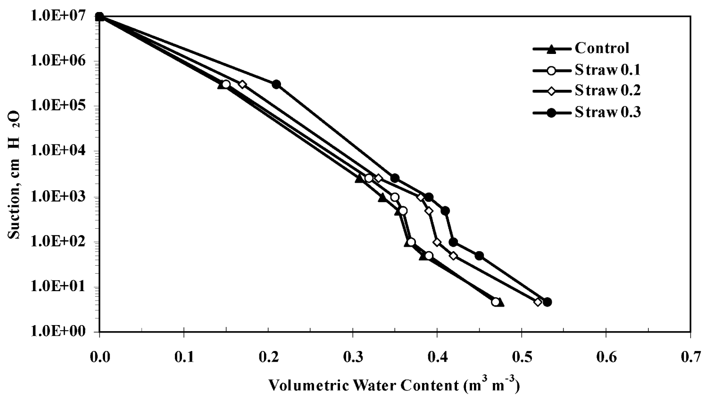

Fig. 12 Soil water retention curve of straw amended treatment plots at different suctions.

Young-Laplace equation, the capillary pressure head in a capillary tube is proportional to the height of h above the free water surface and inversely proportional to the capillary radius r, which is given as follows :

$$h_c = \frac{2\gamma \cos\alpha_v}{g(\rho_l - \rho_g) r} \quad (4)$$

where ρ_g is the density of gas (generally neglected), ρ_l is the density of water, γ is the surface tension, g is the acceleration due to gravity and α_v is the contact angle. The equivalent capillary tube radius r_e at different suctions can be estimated using this Young-Laplace, such as $r_e = 0.24$ mm for 4.5 cm, and 1.45 μm for 5.0×10^2 cm suction. However, at high suction such as at 3.16×10^5 cm, the equivalent capillary radius drops down to 2.35 nm, which is not an actual capillary size but surface adsorption scale that forms a hydration envelope over the particle surface. As the soil was predominantly clay in this study, the incorporation effect of organic matters appears in fine pore system of nm scales, and enlarges its porosity to at least 1.74%. The porosity expansion is also evident from three-phase compositions of compost and sawdust amended soils (Fig. 3 and Fig. 4, respectively), such that, the 0.3 $m^3 m^{-3}$ incorporation caused 3.40% and 3.13% increase in the porosity, respectively. In contrast, straw incorporation at the same 0.3 $m^3 m^{-3}$ application rate increased the porosity to 2.74%. Among three biomasses incorporated to the clay soils in this study, compost and sawdust amendments showed an increase in capillary pore sizes of the soil.

4. Conclusion

The field experiment conducted in this study showed that additions of plant and composted biomass such as compost, sawdust and rice straw at different application rates of 0.1, 0.2, and 0.3 $m^3 m^{-3}$ (apparent soil volume basis) to clay loam soils led to a substantial improvement of soil physical and hydraulic properties. The extent of their effectiveness for improving soil physical and hydraulic properties was partially dependent on application rate ; in such as way that higher application rate of these biomasses provided greater improvement in soil properties. Compared to the control plot, three-phase compositions of compost, sawdust and straw amended soils showed the reduction in soil solid phases, and thereby increased the total porosity. Additions of all amendments also decreased soil resistance and bulk density, which were likely due to the reduction in solid phases of amended soils. A good correlation between soil resistance and bulk density was observed for all amended plots. Except for sawdust addition only at higher application rate, near-saturated hydraulic conductivity, K (h), increased for all application rates of compost and straw incorporations. The increment in the K(h) might be attributed to the reduction in solid phases of compost, sawdust and straw amended soils and thus the increase in the total porosity. Improvements in soil water retention were varied among amendment types and application rate. Compost amended soils retained large amount of water even at higher suctions. However, improvement in soil water retention characteristics for sawdust-amended soils was limited at lower suction. For straw amended soils, water retention capacity increased steadily from low to high suction.

This field study showed that compost, sawdust and straw had different interactions to the basic soil physical and hydraulic properties when incorporated to clayey loam soil. Although different agricultural practices and crop yields under applied biomass incorporations have not been considered as indicators, results concerned with the effect of incorporated compost, sawdust and straw biomass amendments on soil physical and hydraulic properties investigated and presented in this study will extend our ideas for the effective application of these biomasses in order to improve soil quality.

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植物やコンポスト化したバイオマスの施用が土壌の物理的・水理的特性に及ぼす影響―圃場での評価

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要　　旨

コンポスト，木くず，稲わらというバイオマス資材を圃場の土に混入したとき，これが土の三相分布，硬度，保水性や透水性に及ぼす影響を実験的に検討した。岩手大学内圃場（クロボク土）に見かけの体積比で，10 : 1，10 : 2，10 : 3 となるように各資材をすき込んだ。混入して約 1 年後，全区画から各 3 個の試料を 100 cc サンプラーにて採取し，変水頭透水試験の後，吸引法，遠心法により水分特性曲線を求めた。また各成分の密度を用いて，試料の三相分布と乾燥密度を得た。一方，現地区画での土壌硬度を山中式硬度計により求めた。

全般的に，バイオマス資材の混入により全区画で土壌硬度と乾燥密度は低下し，これは試料中の固相率減少によることが分かった。また土壌硬度と乾燥密度のデータ間にも良い相関関係が見られた。透水係数についても多くの場合，混入率の増加に応じて増大した。これも固相率の減少に起因するものと考えられる。同様の理由により水分特性曲線も影響を受け，体積含水率は増加した。ただしその変化の程度と傾向は資材の種類により異なるものであった。

キーワード : バイオマス，土壌の三相分布，土壌硬度と乾燥密度，近飽和での透水係数，土壌水分サクション

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