論　文

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Evaluating Influence of Different Cover Materials on Runoff and Sediment Loss from Bare Upland Soil Using Laboratory Rainfall Simulator

Taisuke ONISHI*, Makoto KATO* and Taku NISHIMURA**

* United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, 3–5–8 Saiwai-cho, Fuchu-shi, Tokyo 183–8509 Japan

** Graduate School of Agricultural and Life Science, University of Tokyo, 1–1–1 Yayoi, Bunkyo-ku, Tokyo 113–8657 Japan

Abstract

The use of composted organic matter as soil surface cover is recently viewed as a potential application for erosion control similarly to straw cover. However, limited information on the effect of these cover materials on erosion from bare soil is available. This study evaluates two cover materials, rice straw and cattle manure compost, with a focus on the relationship between soil surface coverage (expressed in areal%) and soil loss from bare upland field. A clay loam Andisol was packed into a 1.2 m×0.35 m×0.12 m soil box with a slope of 14% and subjected to simulated rainfall of 45.1 mm hr^{-1} for 100 minutes. The soil surface was either left bare or was covered with rice straw (*Oryza Sativa* L.) or cattle manure compost at a surface coverage of 30 areal % for straw, 35 areal% for compost, and 60 areal% for both materials. During the simulated rainfall, surface runoff was periodically collected to determine sediment concentration and infiltration rate. As the coverage rate increased from 30 or 35 to 60 areal%, the straw and compost covers acted to significantly reduce the sediment concentration. The observed reduction in sediment loss from the covered soils resulted from the direct interception of raindrops and trapping of sediment by the cover ; however, neither cover material was able to reduce the runoff rate. The total runoff volume was higher for compost-covered soils than for bare or straw-covered soils. This result may reflect the development of a depositional crust over the soil surface. Such crusts formed in sediment-trap areas close to pieces of the covering material.

Key words : Cattle manure compost, Surface coverage, Runoff, Erosion, Surface crust

1. Introduction

Soil erosion occurs where the bare soil surface is exposed to rainfall. Plant residues such as rice straw have been conventionally used for erosion control and soil conservation in sloping upland fields in Japan (Yamamoto *et al.,* 1995). However, in recent times, rice straws are chopped and spread over the paddy soil by using a harvesting machine while the amount of land for rice paddies has been decreasing, and biomass-energy use of the straw is considering. Under this situation, the use of straw as an organic resource for upland field soil conservation has become limited. It is therefore necessary to investigate more effective and less labor-intensive soil conservation measures using alternative materials (Nakao *et al.,* 2002).

Livestock manure compost has been traditionally applied to agricultural fields in Japan as an organic fertilizer or soil amendment. Recently, its application is accelerated as a renewable use of organic waste for sustainable farming (MAFF, 2002, Shimizu, 2005). Many studies were focused on the nutrient release performance of livestock manure compost in the soil and/or on the improvement of soil physicochemical properties (e.g. Nishida *et al.,* 1995 ; Kawata *et al.,* 1996 ; Kato and Yoneda, 2001), however, few studies have focused on the application of livestock manure compost and its effect on soil erosion upon sloping upland fields in Japan (Watanabe and Kawabata, 1980). From this perspective, an investigation of the use of animal waste compost for soil conservation as an alternative to rice straw would be valuable in Japan.

Some studies showed the performance of organic materials in minimizing sediment loss and runoff (Foltz and Dooley, 2003 ; Benik *et al.,* 2003). Foltz and Dooley (2003) showed a greater reduction in both sediment loss and runoff with a cover of wood strand (thin rectangular wood piece) than for a straw cover for the same surface coverage, 70 areal%. Other than plant residues, Agassi *et al.* (1998) showed a reduction in surface runoff rate with high application rates (60, 120, and 180 t ha^{-1} in dry weight) of composted municipal solid waste. Faucette *et al.* (2004) demonstrated reductions in runoff and sediment loss by covering the soil with a 5 cm thick layer of aged poultry litter, composted poultry litter, biosolids, and yard waste. They found reduction in runoff and sediment loss by covering with these composts except for the application of the poultry litter. Previous studies have also documented the effects of surface-applied livestock compost on runoff and soil loss from field plots (Gilley and Eghball, 1998) and laboratory soil boxes (Vadas *et al.,* 2004) under simulated rainfall. Gilley and Eghball (1998) applied simulated rainfall of 64 mm hr^{-1} for 1 hour to no-till field plots where beef cattle compost was spread over a sorghum residue at a cover rate of 23%. The application rates (dry weight basis) for the compost were either 24.7 t ha^{-1} to satisfy corn phosphorus requirement or 126 t ha^{-1} for that of nitrogen. They reported no significant difference in runoff rate and soil loss following the application of compost under the no-till conditions.

In the above-cited studies, the composts were applied to soil surface with huge amount ($\geq$60 t ha^{-1}) (Agassi *et al.,* 1998) or to form grossly thick surface compost-layer above soil (Faucette *et al.,* 2004). Too much compost application, however, might cause a risk of nitrate pollution of ground water and may create anaerobic condition following rainfall event (Faucette *et al.,* 2005) which is harmful to plant seed germination. And in Japan, some studies pointed out that too much compost application may cause the problem of excess potassium and phosphorous application to soil (i.e. Goto and Eguchi, 1997 ; Nanzyo and Yamada, 2005), which diminishes plant growth. Also, too much application of composts may rise risk of ground water pollution by leaching of compost derived chemicals. From this point of view, compost application should be limited and a surface cover rate might be less than 100%. It is therefore important to evaluate the relationship between soil surface coverage by livestock manure compost and erosion rates in sloping upland fields in Japan. Investigations of the effectiveness of various surface coverages in terms of minimizing soil loss may help farmers to adopt more effective practices, especially for soil conservation purpose, of surface mulching. Previous studies have reported reductions in soil loss with increasing soil surface coverage (Singer and Blackard, 1977 ; Greene *et al.,* 2004), however, the single effect of compost applied at relatively low rate (i.e. low coverage rate) on runoff and soil loss from bare soil remains unclear. Also, the relationship between surface coverage and changes in surface runoff and infiltration rate is still not fully understood and requires further study (Ruan *et al.,* 2001 ; Greene *et al.,* 2004).

The objective of the present study is to evaluate two cover materials, cattle manure compost and rice straw in relatively small amounts, from the relationship between soil surface coverage, runoff and sediment loss from bare upland soil. We also discuss changes in fundamental soil surface hydrological properties following the application of cattle manure compost.

Furthermore, soil erosion is complicated phenomenon, and many factors, such as antecedent soil moisture content and timing and intensity of rainfall, affect soil loss. In this study, we employed laboratory experiment under simulated rainfall to control experimental condition for precise discussion on interrill erosion as interacted by surface treatments. Also in evaluating surface coverage, a grid sampling method (Singer and Blackard, 1977 ; Foltz and Dooley, 2003), similar to the photographic method (Laflen *et al.,* 1981), has often been employed. However, it can involve operator-induced and systematic errors in determining surface coverage and be less accurate (Han and Hayes, 1990). It is necessary to adopt precise evaluation of coverage to consider relations among extent of soil surface coverage, surface cover material and soil loss. Recent image analysis technique can help to improve accuracy of surface coverage evaluation and was employed in this study.

2. Materials and Methods

2.1 Soil and soil-box preparation

In the present study, we used a clay loam Andisol (48.9% sand, 33.9% silt, and 17.2% clay) as a typical sloped upland soil in Japan. The soil was sampled from an upland field of the Field Science Center of the Tokyo University of Agriculture and Technology (TUAT). Soil passed through a 3 mm mesh screen was packed into a soil box of 1.2 m in length, 0.35 m in width, and 0.12 m in depth (Fig. 1) at a bulk density of 0.62 Mg m^{-3}. The soil was packed at a mass wetness of 75% using a wooden soil tamper at an increment of 1.5 cm layers to form a 6 cm thick soil layer upon a 5 cm thick gravel layer. A cotton cloth was inserted at the boundary of the soil and gravel layers to support the soil structure. Discontinuities between the four 1.5 cm thick layers were minimized by disturbing the surface of each layer (Singer and Walker, 1983) using a sharp metal rod prior to packing the overlying layer. The box had a slope of 14% (8°), which is an upper-limit of the standard slope for reclaimed upland fields in mountainous areas of Japan (MAFF, 2006). A metal flume at the lower end of the box and drainage outlets (ϕ=15 mm) at the lower front of the box were connected to collect surface water and percolated water. In this study the packed soil represents a flat surface such as seed bed, which is particularly vulnerable to erosion (Kleinman *et al.,* 2004), especially under the high rainfall intensity. However, it is our intention to evaluate different contributes of cover materials to runoff generation or sediment transport under such an erosive condition.

2.2 Rainfall simulation

Simulated rainfall was applied using a nozzle-oscillating-type rainfall simulator (Niebling *et al.,* 1981) from 1.8 m above the soil surface. We used two veejet 80100 nozzles (Spraying System CO., USA). The rainfall was set at an av-

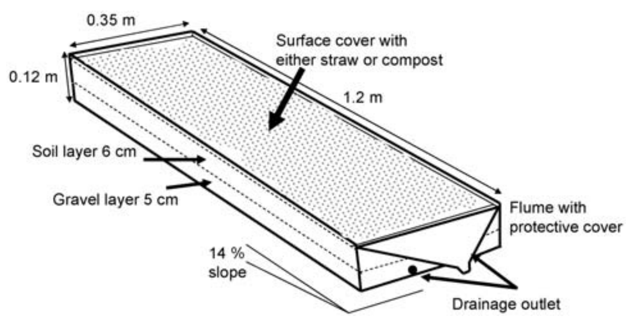

Fig. 1 Schematic of the soil box used in this experiment.

erage of 45.1 mm hr^{-1} for 100 minutes. The rain intensity had a coefficient of variance of 0.03 within the 1.2×0.35 m rainfall area, as determined from 65 small rain gauges with a cross-sectional area of approximately 19.6 cm^2. Meyer and Harmon (1979) reported this rainfall simulator can represent raindrop size distribution and rainfall energy of gentle natural rainfall in southern part of USA with operating water pressure of 41 KN m^{-2} and water drop hight of 2.4 m. In this study, we selected water operating water pressure of 34.5 KN m^{-2} instead of 41 KN m^{-2}, since former number could give us more even distribution of rainfall intensity. Also, height of the rainfall simulator was 1.8m due to dimension of the experimental room. Thus, expected rainfall energy was a little bit lower than the natural rainfall. For the simulated rainfall, we used tap water with a mean electrical conductivity of 0.2 dS m^{-1}.

Runoff and subsurface drainage were collected at 5-minute intervals during the simulated rainfall. Samples of surface discharge were collected and weighed to determine the runoff rate and sediment concentration. To determine the infiltration rate, the runoff rate was subtracted from the rain intensity. The steady-state was determined as the final 20 minutes of the total 100-minute rainfall event according to the observed changes in runoff hydrographs for five surface conditions. Four replicates were made for bare soil, three for applied straw, and two for applied compost.

The surface cover materials were applied by hand to obtain the desired surface coverage (0, 30 or 35, and 60 areal%). This was done immediately prior to the start of the rainfall. Several hours following the half of rainfall period when rapid drainage from the soil had ceased, undisturbed soil samples (n=10) were taken from the box using a stainless steel cylinder, 5.1 cm in diameter and 5.0 cm in length, to measure the saturated hydraulic conductivity of the surface soil by the falling head method (Klute and Dirksen, 1986).

2.3 Cover materials and determination of the coverage rate

Rice straw (*Oryza Sativa* L.) and cattle manure compost that had been composed for six months were obtained from the Field Science Center of TUAT. Wood shavings and chips were mixed with the cattle manure to control moisture content. The carbon/nitrogen ratio of the soil was 11.3 while that of the compost was 10.3 as determined by using a CN coder (MT-700Mark2, Yanaco CO., Kyoto, Japan). Dried rice straw was cut into lengths of 10–15 cm prior to application. The carbon/nitrogen ratio of the dry rice straw was not determined in this study. It is typically much higher than that of the cattle manure compost, and about 50 (Nishida *et al.*, 1995), or in some case more than 70 (Fujiwara, 2003).

Prior to the experiment, two different methods to determine the soil surface coverage, image analysis using ImageJ software version 1.24o, which is public domain software produced by the National Institute of Health, USA (Reinking, 2001), and conventional grid sampling method (Foltz and Dooley, 2003) were compared and evaluated. Surface photographs consisting of covered and uncovered regions were used for image analysis. The separation of these two area-types was made using an automated binarization routine implemented to the ImageJ software. The threshold adjustment is similar to that described by Chen *et al.* (2004). For calibration, we took sample photographs of straw cover within 0.42 m^2 quadrate frames installed at the soil surface. In the grid sampling method (GS), a clear gridded screen was projected onto a photograph of the straw cover. The surface coverage is then determined by dividing the number of grids that contain straw bodies by the total number of grids (Singer and Blackard, 1977).

Figure 2 shows the relationship between application rate in dry weight and surface coverage rate. The plotted surface coverage, as a function of application rate for both compost and rice straw, is fitted by a power equation (Y

$=aX^b$, where Y is the surface coverage, X is the application rate, and a and b are constants). The dry mass weight of the cover materials applied to the soil surface prior to the rainfall experiment and corresponding coverage rates are summarized in Table 1. The error of the GS in the obtained surface coverage is demonstrated by changes in the coverage rate of straw as determined by using two different grid sizes, 121 and 36 grid points for the same area (Fig. 2). The surface coverage rate of the GS with 121 grid points are greater than that of the GS with 36 grid points for each application rate of the rice straw. The total number of grid points was changed from 121 to 36 by doubling the grid interval after determining the coverage with 121 points. The GS with 121 grid points showed similar result to the result of Singer and Blackard (1977) that employed the same grid interval as the GS with 121 grid points in this study. To achieve a more consistent determination method, image analysis was used to determining the coverage rate of applied compost in the present study.

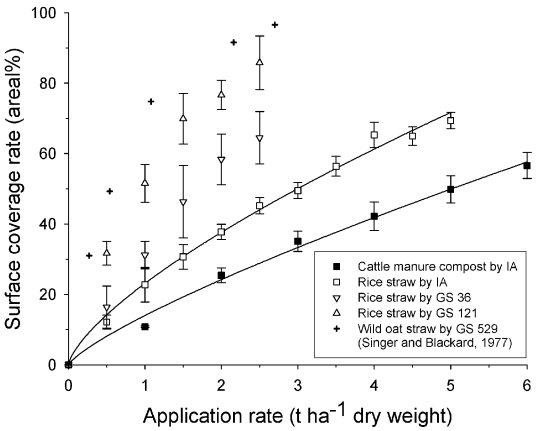

Fig. 2 Relationship between mass application rate of cover materials (dry rice straw and dry cattle manure compost) and soil surface coverage. For rice straw, the data were determined by image analysis (IA) and grid sampling (GS) with two total grid point numbers (36, 121), measured at nine different locations over the test area. The data presented by Singer and Blackard (1977) with the GS (529 grid points) is also shown (vertical bars denote standard deviation).

2.4 Data analysis

We analyzed saturated hydraulic conductivity, steady-state runoff, and infiltration rates among the different surface conditions (bare soil, coverage of 30 or 35, and 60 areal% for the two materials) using the non-parametric Mann-Whitney U-Test to identify significant differences ($P < 0.05$ or 0.01). In this study, saturated hydraulic conductivity after rainfall had a non-parametric distribution for all surface conditions. For the runoff rate, a series of measured data collected at 5-minute intervals during the steady-state was averaged among replicates of each surface condition and paired among all the conditions to analyze the measured differences. Only the average values of steady-state runoff and infiltration rates are reported for each condition.

3. Results and Discussion

3.1 Patterns of runoff, sediment concentration, and soil loss

The packed soil had a high saturated hy-

Table 1 Dry weight of each cover material with given surface coverage applied on a soil box.

	Cover materials and surface coverage as determined by image analysis			
	Rice straw 30 areal % (SC 30 areal %)	Rice straw 60 areal % (SC 60 areal %)	Cattle manure compost 35 areal % (CC 35 areal %)	Cattle manure compost 60 areal % (CC 60 areal %)
Dry weight (t ha^{-1})	1.5	3.5	3.0	6.0
g m^{-2}	150	350	300	600

draulic conductivity (74.2 mm hr^{-1}) that was much greater than the rainfall intensity of the experiment (45.1 mm hr^{-1}). Despite this, runoff occurred during the simulated rainfall for all the surface treatments (Fig. 3). Runoff rates during the 100 minutes of the rain event are shown in Fig. 3. Vertical bars in the figure show the standard deviations of replicates. The runoff rate for compost-applied soil exceeded that for bare soil. This result is contrary to the general concept that surface contact cover may reduce surface runoff if the cover is sufficiently close to soil surface and not be carried away by the runoff (Marshall *et al.,* 1996). All soil surface conditions showed near steady-state runoff when cumulative rainfall of approximately 30 mm was applied.

Figure 4 shows changes in sediment concentration during the rainfall event for each surface condition. Sediment concentrations were calculated as the mass of transported solid particles per unit volume of runoff water, i.e., grams per liter of runoff. Sampled sediments contained both soil particles and particles derived from composted material. Very few coarse compost materials were transported into bed of the flume, while finer particles from the compost were mostly suspended in runoff water. It was easy to identify the color of runoff water from the soils with and without ap-

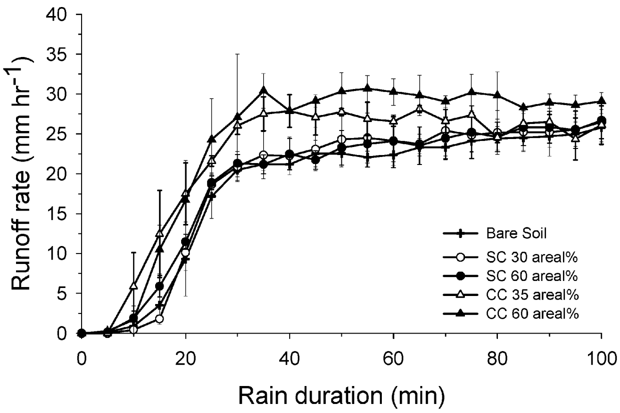

Fig. 3 Runoff from Andisol with different surface coverage and mulching material. Rain intensity was 45.1 mm hr^{-1} (vertical bars denote standard deviation).

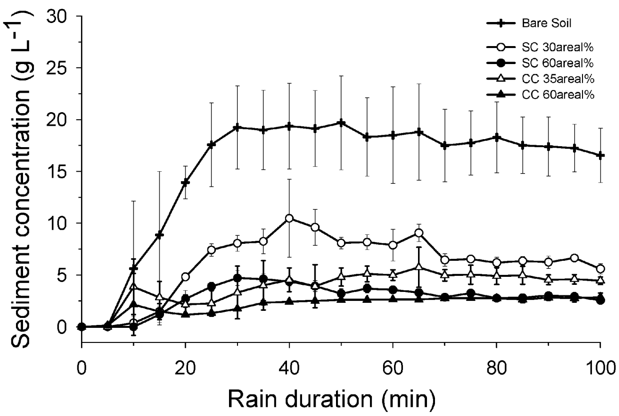

Fig. 4 Changes in sediment concentration of Andisol with different surface coverage and mulching material. Rain intensity was 45.1 mm hr^{-1} (vertical bars denote standard deviation).

plied compost during the rainfall simulation. In all conditions, the sediment concentration decreased slightly with increased rainfall duration.

Progressive changes in cumulative sediment-loss for each surface condition during the 100 minutes of rainfall are compared in Fig. 5. Sediment loss from covered soils was significantly less (approximately 50%) than that lost from bare soil, even with just 30 (for straw) or 35 (for compost) areal% surface coverage.

Sediment loss was greatly reduced when the soil surface was covered at a surface coverage of 60 areal%. This held true for applications of both rice straw and cattle manure compost. For straw-covered soil, we observed the direct interception of raindrops by pieces of straw. This mechanism acted to reduce soil detachment by raindrop impact, and accordingly led to a reduction in soil loss (Singer and Walker, 1983). As reported previously, straw lying across-slope can capture transported soil particles as a microsediment pond (Meyer *et al.,* 1970 ; Singer and Walker, 1983). We also observed the interception of raindrops and capture of sediments by applied compost material. Fibers of waste wood mixed into the cattle manure compost contributed to the interception of raindrops. During the runoff event, some solid composted matter was disintegrated by raindrop impact, while a portion of the waste wood fraction was displaced from its original position by raindrop impact.

The relationship between the average steady state runoff rate of each surface condition during the final 20 minute of rainfall and soil surface coverage rates is shown in Fig. 6. The observed changes in steady state runoff rates were not significantly different ($P < 0.05$) between the various surface conditions except for the application of compost at a surface coverage of 60 areal%, which showed greater steady-state runoff than the other covered conditions and bare soil (Fig. 6). Cumulative sediment loss at the end of rainfall event for all surface conditions and varying surface coverage rates are plotted in Fig. 7. Sediment loss was reduced with increasing surface coverage for both covering materials (Fig. 7). However, extent of the reduction in sediment loss may have been smaller for the compost cover than that of the straw covers.

3.2 Changes in soil surface permeability

The hydraulic conductivity of the uppermost 5 cm layer of soil decreased significantly during the rainfall event. The saturated hydraulic conductivity of the surface soil prior to rainfall was 74.2 mm hr^{-1}, decreasing to 17.3–27.0 mm hr^{-1} following rainfall. However, there was no significant difference ($P < 0.01$) in the

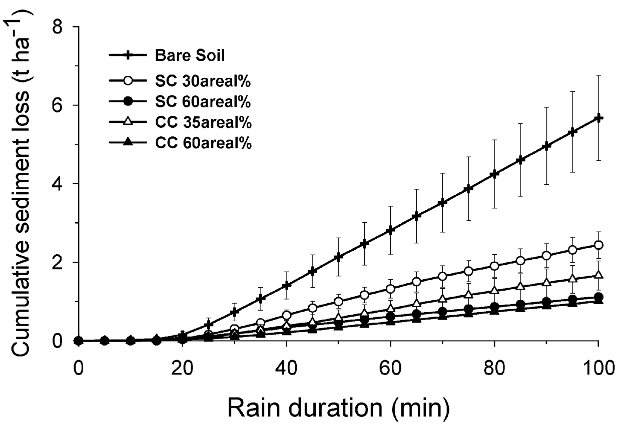

Fig. 5 Cumulative sediment loss of Andisol with different surface coverage and mulching material. Rain intensity was 45.1 mm hr^{-1} (vertical bars denote standard deviation).

saturated hydraulic conductivity of soil samples among uncovered, straw-covered, and compost-covered conditions (Table 2). A significant difference ($P<0.01$) was only observed for soils with compost application at 35 and 60 areal%. Cover materials that remained on the surface of the soil were carefully removed prior to taking undisturbed soil core samples to alleviate breaking soil structure upon inserting the steel cylinder. This could have enhanced the saturated hydraulic conductivity of the undisturbed soil. The removal of covering material, both compost and straw, that acts as an impermeable media potentially enhanced hydraulic conductivity.

McIntyre (1958) reported a decrease in saturated hydraulic conductivity related to the formation of a surface seal. In this study, we

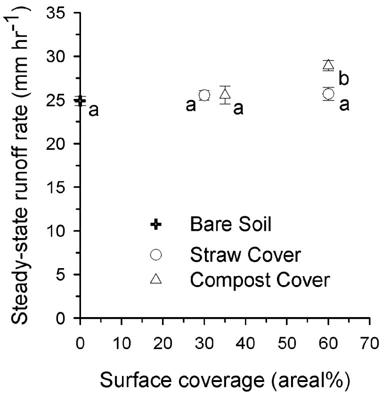

Fig. 6 Relationship between steady-state runoff rate (during 80 to 100 min. period of rain event) and soil surface coverage. Data with the same letter are not significantly different at $P<0.05$. Rain intensity was 45.1 mm hr^{-1} (vertical bars denote standard deviation).

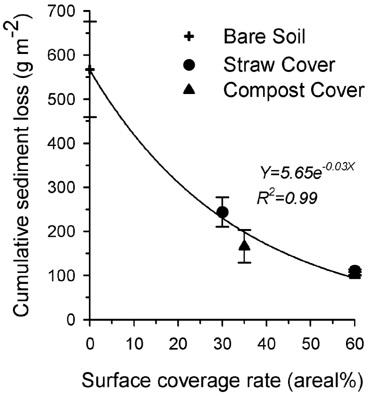

Fig. 7 Relationship between cumulative sediment loss (for 100 min.) of Andisol with different surface coverage and mulching material. Rain intensity was 45.1 mm hr^{-1} (vertical bars denote standard deviation).

Table 2 Comparison of steady-state infiltration rate and saturated hydraulic conductivity of whole core soil after rain and that of surface crust part. Average infiltration rate of each condition at the steady-state, 80 min to 100 min of runoff event, is shown. Standard deviation in parentheses.

Surface Condition	Steady-State Infiltration Rate (mm hr^{-1})*	Saturated Hydraulic Conductivity after Rainfall	
		Whole Soil Core (mm hr^{-1})**	Surface Seal Layer (mm hr^{-1})
Bare Soil	20.1 a (0.5)	21.4 a (11.7)	1.79～ 3.93
SC 30 areal %	19.5 a (0.6)	19.8 a (8.1)	ND†
SC 60 areal %	19.3 a (0.8)	23.3 a (15.8)	0.95～11.12
CC 35 areal %	19.4 a (1.0)	27.0 ab (17.9)	0.90～ 4.18
CC 60 areal %	16.1 b (0.6)	17.3 ac (8.1)	0.91～ 8.78
		Average : 21.8 (3.7)	

Mean values that have the same letters are not significantly different at ;
* the 0.05 probability level,
** the 0.01 probability level.
† ND, no data.

observed the development of a seal at the surface of covered soils. Visual observation indicated that state of the surface seal development was different between the bare soil and the covered soils. Only the bare soil surface showed the seal development over the entire area of it. The saturated hydraulic conductivity of the seal layer was calculated using a similar method to that presented by McIntyre (1958):

$$L_{tot}/K_{tot}=l_c/k_c+l_u/k_u,$$

where K_{tot} is the saturated hydraulic conductivity of the entire soil column, k_c is the saturated hydraulic conductivity of the surface seal layer, k_u is the saturated hydraulic conductivity of the layer beneath the seal, l_c is the thickness of the seal, l_u is the thickness of the underlain layer, and the total depth of the soil column was 5 cm ($=L_{tot}=l_c+l_u$). *The thickness of the surface seal layer,* l_c, was assumed to be 0.2 cm, as a distinct boundary observed between the thin dense layer at the surface and the subsoil underneath. The surface 0.2 cm thick layer was easy to remove and separate from the sub-layer. For each coverage condition, one sample for every replicate was used to determine the saturate hydraulic conductivity of the seal layer. Due to this limitation in the number of available soil core samples for measuring the hydraulic conductivity of the seal, we did not undertake a statistical comparison of differences in the permeability of seal layers among different conditions. No data could be obtained for the soil with 30 areal% cover by straw due to structural disturbance of the surface seal that occurred when collecting undisturbed core samples.

The surface seal layer showed significantly low saturated hydraulic conductivity, with values ranging from approximately 1 to 10 mm hr^{-1} in the bare soil and the three covered soils (Table 2). The considerable low saturated hydraulic conductivity of the surface seal resulted in reducing the soil surface permeability. However, this function of the surface seal could be more significant in the bare soil surface than that in the covered soils where the seal formation is limited to partial area of the soil surface.

The steady-state infiltration rates and saturated hydraulic conductivities of core samples are summarized in Table 2. For bare soil, the steady-state infiltration rate was close to the saturated hydraulic conductivity of the undisturbed core soil sample. There was no significant difference between steady-state infiltration rates ($P<0.05$) and the saturated hydraulic conductivities ($P<0.01$) of the soil under all covering conditions except the 60 areal% compost cover for the infiltration rate. The difference between the average infiltration rate under 60 areal% compost cover and the average hydraulic conductivity of all five conditions was 5.7 mm hr^{-1}. This is greater than the difference between the average infiltration rate (19.6 mm hr^{-1}) for all other conditions and the average hydraulic conductivity of all five conditions (21.8 mm hr^{-1}, Table 2). Our observations indicated that wet compost clumps acted to seal the soil surface and provided obstacles to infiltration of surface water. The presence of compost clumps as an additional seal appears to explain the low degree of infiltration observed for a compost cover of 60 areal%.

3.3 Effects of surface cover on surface hydrological processes and sediment transport

3.3.1 Sediment concentration - infiltration relation

Figure 8 shows the relationship between infiltration rate and sediment concentration at 5-minute sampling intervals during the 100-minute rainfall event for all soil surface treatments. Different trends were observed for the covered and uncovered soil. The uncovered bare soil showed a decline in infiltration rate with increasing sediment concentration, while covered soils showed a sharp fall in infiltration rate at lower sediment concentrations relative to bare soil. For bare soil, only eroded and deposited fine soil particles were considered to

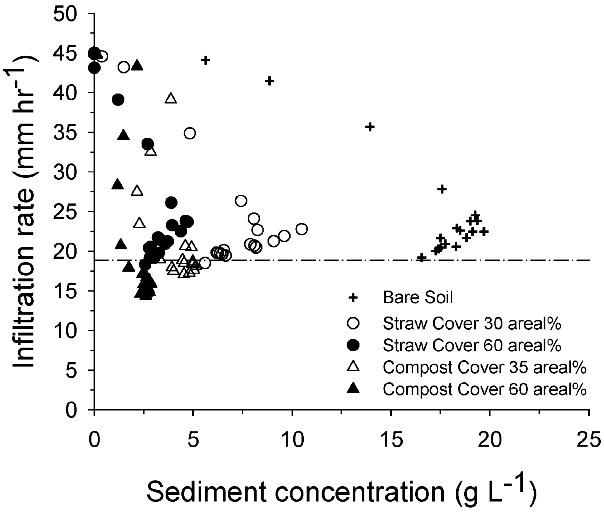

Fig. 8 Trends of infiltration rate with sediment concentration for each treatment. Dash-dot line indicates average infiltration rate of all treatments at steady-state. Mean rain intensity was 45.1 mm hr^{-1}.

reduce the infiltration rate of the soil by clogging pores and developing seal. At the same time, some of the deposited fine particles were re-detached by raindrop impact or runoff water. Steady-state infiltration rates were similar for covered and uncovered soils, with average rates of 18.6 and 20.1 mm hr^{-1}, respectively. For average steady-state infiltration of all the treatment, as indicated by the dash-dot line in Fig. 8, the sediment concentration of soil with a coverage rate of 60 areal% was approximately 25% that of uncovered soil. If the fine soil particles transported in runoff is a main cause for soil pore clogging and thus for the decrease in infiltration rate, the sediment concentration of the covered soil should be as high as that of the bare soil since both soil showed similar reduction in permeability. However, the soils covered by straw or compost showed rather low sediment concentration (Fig. 4). As mentioned above, some of the detached finer soil particles in the covered soil were transported by runoff, trapped by surface cover, and deposited on the soil surface. In this way, soil loss could be reduced, and trapped soil particles locally form depositional crust that could reduce infiltration rate. The depositional crust was developed mostly in sediment-trap areas close to the covering material fractions. Fig. 9 shows compost applied to the soil surface. The photograph shows the partial formation of a surface seal, which is visible as the relatively smooth area in the photograph.

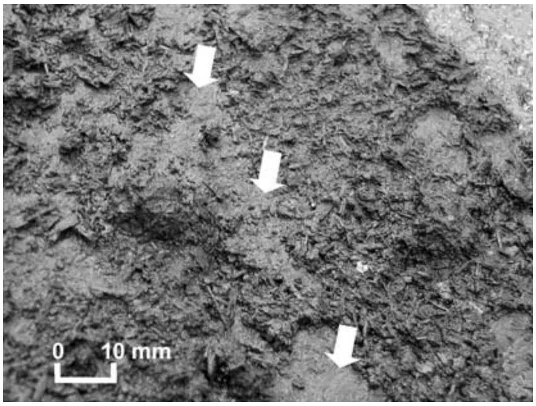

Fig. 9 Morphological feature of soil surface with compost application after rainfall. Arrows indicate where transported particles are deposited to form surface seal (relatively smooth area).

3.3.2 Effects of cover-material on runoff generation

A decrease in infiltration rate under surface-covered condition can be attributed not only to sealing but also to runoff-generation process induced by the characteristics of the cover material. As stated previously, we observed suspended compost particles in runoff water for the case with applied compost. These fine particles may also have clogged surface soil pores and thereby acted to reduce the infiltration rate. Barrington and Madramootoo (1989) investigated changes in infiltration rate for a clay loam soil under water-ponding conditions by pouring sterilized manure solution onto the soil surface. They found that a decrease in infiltration rate resulted from the trapping by soil pores of particles derived from the manure. Moreover, they reported that retention of manure-derived solids by pores was influenced by the adsorption of manure-derived organic particles by clay components of the soil.

In the present study, the straw-covered soil showed a decrease in infiltration rate with a lesser increase in sediment concentration than that recorded for bare soil (Fig. 8). The lower concentration of sediment was due to the trapping of sediment by straws, as the microsediment pond. Under rainfall, the microsediment pond was puddled by raindrop impact. Particles were displaced and sorted according to particle size during the puddling that formed a depositional crust (Le Bissonnais *et al.,* 2005) in the vicinity of pieces of straw. Therefore, the straw-covered soil showed a decrease in infiltration rate and increased runoff with lower sediment concentrations (Fig. 8).

4. Conclusions

Two soil cover materials with different surface coverage, rice straw as conventional mulching material and cattle manure compost as an alternative, were applied to a clay loam Andisol with a slope of 14%. Under simulated rainfall, soil loss was significantly reduced by surface cover even with low soil surface coverage. The compost cover at 35 areal% which corresponds to the application rate of 3 t ha^{-1} in dry weight could reduce the cumulative sediment loss less than 50% of that from the bare soil. However, surface runoff from the soils covered with rice straw or cattle manure compost was not reduced at coverage rates of 30 or 35, and 60 areal%. Trends in soil loss described in the present study involve a decrease with increasing surface coverage rate, however, runoff behavior varied more with the nature of the surface-covering material than with coverage rate.

The results of this laboratory study showed an adverse impact of the surface cover, which is generally considered to improve rain infiltration thus reduce runoff, on surface runoff. In this study, a decrease in infiltration and related runoff increase were observed for soil with a compost cover at 60 areal% (6 t ha^{-1} in dry weight). The increased runoff could be a major factor to transport fine compost particles into downward slope, and then utility of the compost as organic resource could be degraded. Regarding the effects of slope, rain intensity, and soil type used in this study on simulated runoff, soil conservation benefit is not assured for the compost cover at 60 areal%. Further investigations on the transport of fine solids and nutrients in runoff from surface applied compost under different experimental conditions (i.e., slope, rain intensity) would be needed.

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異なる地表面被覆が室内人工降雨試験下における傾斜裸地からの侵食に及ぼす影響

大西泰介*・加藤　誠*・西村　拓**
* 東京農工大学大学院連合農学研究科　〒183-8509 東京都府中市幸町 3-5-8
** 東京大学大学院農学生命科学研究科　〒113-8657 東京都文京区弥生 1-1-1

要　　旨

傾斜土壌槽（8 度）と人工降雨装置を用いた実験を行い，裁断稲ワラまたは木質混合牛糞コンポストによる被覆が裸地表土の降雨下における地表面流出，土壌流亡発生に及ぼす影響を地表面被覆率との関係から考察した。土壌槽充填の黒ボク土に各々の被覆材について異なる被覆率，0，30（稲ワラ被覆）または 35（コンポスト被覆），および 60（両被覆材）areal%，で被覆を行ない，直後に平均 45.1 mm hr^{-1} で 100 分間の降雨を与えた。その結果，全被覆条件について無被覆条件に比べ侵食量が抑制された。他方，被覆の有無，程度による地表面流出量の抑制は無く，逆に，牛糞コンポスト被覆 60 areal% は，無被覆よりも多い地表面流出量を示した。地表面流出が増えた原因として局所的に被覆物傍らに形成された堆積クラストによる透水性低下が観察された。

キーワード：牛糞コンポスト，被覆率，地表面流出，土砂流亡，表面クラスト

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