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Improvement of Physical Condition of Soil with Cattle Slurry Fertilization—Mechanical Strength and Water-stability of Soil Aggregates

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Abstract

We investigated the strength of air-dried mixtures of sand and cattle slurry using unconfined compression and slaking tests, and obtained the following results : 1. The sand and cattle slurry mixtures hardened when dried. 2. A significant correlation was found between unconfined compression strength and mixed slurry concentration. 3. Air-dried samples showed water-stability. 4. The unconfined compression strength of re-wetted samples (moisture content about 300 $g kg^{-1}$) was less than that of air-dried samples. These results show that the organic matter in cattle slurry facilitates aggregation.

Key words : Aggregation, Cattle slurry, Organic matter, Unconfined compression test, Water-stable aggregate

1. Introduction

Dairy farmers in the Konsen area of Hokkaido prefecture spray a mixture of cattle dung and urine on their grasslands as a cattle slurry fertilizer. Cattle slurry is an important organic nutrition fertilizer. Harada (1990) reported that cattle slurry acts as a nitrogen and potassium fertilizer. The effects of the organic matter in slurry fertilizer on the physical and chemical conditions of soil are well known. Continuous spraying of cattle slurry on grassland is effective in increasing soil fertility and soil aggregation. Kobayashi (1980) suggested that decayed roots and some secretions from living plant roots form an aggregated soil structure. The aggregated structure is stabilized by the pressure of roots elongating into the pores between soil particles and by soil water extraction. It is also known that soil animals and soil microorganisms have important effects on the formation of soil aggregate.

The purpose of this study is to clarify the function of cattle slurry as an adhesive agent in soil aggregate formation. To achieve this, unconfined compression and slaking tests were carried out on air-dried mixtures of silica sand and cattle slurry.

2. Materials and Methods

1) Preparation of cattle slurry

Manure from Japanese short-horn cattle was collected twice, once in May as a spring sample, and once in July as a summer sample, at the experimental farm of Kitasato University. The herd was fed corn silage during spring and fresh grass during summer. The fresh dung was collected from the floors of stalls and a mixture of urine and washing water was collected from a urine storage tank. Twenty-five liters each of the fresh dung and the liquid were mixed. The content of total suspended solid (TS) in the cattle slurry mixtures, after

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Table 1 Chemical composition of cattle slurry samples

	Sampling season	TS*1 (g kg⁻¹)	pH	EC (dS m⁻¹)	P_2O_5*2 (mg L⁻¹)	K^+ *3 (mg L⁻¹)	NH_4^+ *3 (mg L⁻¹)	T-C*4 (g kg⁻¹)	T-N*4 (g kg⁻¹)	C/N
Unconfined compression test	Spring	9.4	7.80	1.18	177.2	338.9	81.3	—	—	—
	Summer	11.4	7.41	1.66	19.5	326.0	47.0	4.3	0.3	15.89
		28.0	7.32	3.51	53.1	930.0	79.0	10.5	0.6	17.20
Slaking test	Summer	9.9	8.68	1.67	17.2	283.2	79.0	4.0	0.2	23.41
		29.6	8.52	4.06	53.3	931.0	242.8	12.0	0.5	23.90

Methods of analysis
*1 : Evaporation dryness (TS=Total content of suspended solid substance in cattle slurry)
*2 : Truog molybdenum blue reaction
*3 : Ion chromatography
*4 : Nitrogen-Carbon analyzer

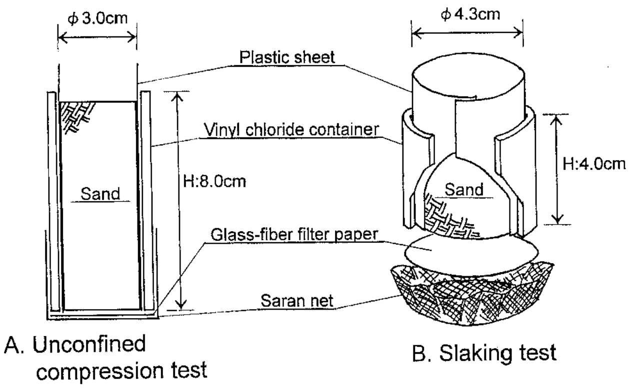

Fig. 1. Container for unconfined compression test and slaking test

aeration in an aeration tank for about 5 weeks for the spring sample and about 3 weeks for the summer sample, was 80 g kg⁻¹ for both samples. The aerated cattle slurry was divided into three samples after passing it through a screen of 4.76 mm mesh to remove impurities. Total solid contents of the three sub samples were adjusted to 10 g kg⁻¹, 30 g kg⁻¹ and 60 g kg⁻¹, respectively, by adding distilled water.

Table 1 shows the chemical compositions of the cattle slurry samples. The concentrations of ammonium and phosphorus differed greatly between the spring sample and the summer sample. It is considered that the composition difference was caused by differences in period of aeration and slurry temperature during aeration.

2) Preparation of test samples

Two sizes of tube (Fig. 1) were used to obtain test samples of the cattle slurry and silica sand mixture. The shorter tube (4.3 cm in diameter and 3.0 cm in height) was used for the slaking test and the other tube (3.0 cm in diameter and 8.0 cm in height) was used for the unconfined compression test. The characteristics of silica sand were a specific gravity of 2.63 and a diameter of 0.25 mm to 1.0 mm. The slurry samples were adjusted to 60 mL and mixed with 60 mL of silica sand in a ceramic dish, and the resulting mixtures were poured into the tubes. The filled tubes were air-dried for about 2 weeks in a dry oven at 30 degrees centigrade. The test samples were removed from the tubes after drying, and two types of samples were prepared : 3.0 cm and 4.3 cm in diameter, and 6.0 cm and 2.0 cm in height for the unconfined compression test and the slaking test, respectively. In this study, the control samples were made by adding distilled water to silica sand and treated under the same conditions as the cattle slurry samples.

3) Measurement of mechanical strength with unconfined compression test and water-stability by slaking test

The mechanical strength of air-dried samples was measured with the unconfined compression test. Five samples, L (low, 10 g kg^{-1} TS), M (middle, 30 g kg^{-1} TS), and H (high, 60 g kg^{-1} TS) with spring slurry and L and M with summer slurry, were prepared for the compression measurement. Furthermore, re-wetted samples were prepared for strength measurement under wet conditions by adding water gently to air-dried samples.

It is considered that the non-homogeneous distribution of cattle slurry constituents in a sample influences the physical characteristics of the sample. Electric conductivity (EC) as an indicator of cattle slurry constituents was measured at 1 cm depth intervals with the conventional method using an EC meter.

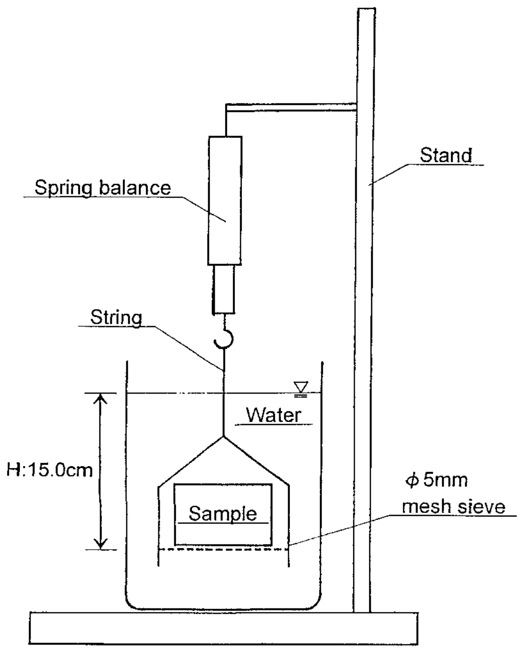

Fig. 2. Apparatus used for slaking test

The slaking process of test samples in water was observed as an indicator of the water-stability of cattle slurry mixture. Two air-dried samples L and M were prepared with summer slurry. Fig 2 shows the apparatus used for the slaking test, which employs the conventional method for recording weight using a spring balance. The air-dried samples taken from the tube were placed on the sieve of the apparatus and soaked in water for 24 hours. During this period, the weight of samples was recorded at elapsed times of 1, 2, 5, 15, 30, 60, 240 and 1440 minutes. The remaining part of each sample was taken out of the water carefully and photographed. The collapse ratio was calculated from the weight of the remaining part of the sample after 24-hour soaking.

3. Results and Discussion

1) Physical and chemical characteristics of the test samples

Test samples taken from the tube after air-drying are shown in Photo 1. The samples with cattle slurry added maintained their columnar shape when removed from the tube regardless of the slurry concentration. On the other hand, the sample mixed with distilled water collapsed as soon as it was removed from the tube. It was considered that cattle slurry adhered to the surface of the silica sand particles and that the organic matter in the slurry glued the particles together like an adhesive during air-drying.

It is generally known that organic matter forms aggregates, and this was demonstrated in this experiment. The mass-ratios of organic matter among the silica sand particles as an adhesive agent were 3.6 g kg^{-1} (1.3 g kg^{-1} in total carbon), 11.0 g kg^{-1} (4.1 g kg^{-1}) and 22.7 g kg^{-1} (8.4 g kg^{-1}) for L, M and H. These values were calculated from the TS of cattle slurry and the sand particle's specific gravity. This indicates that the organic matter of cattle

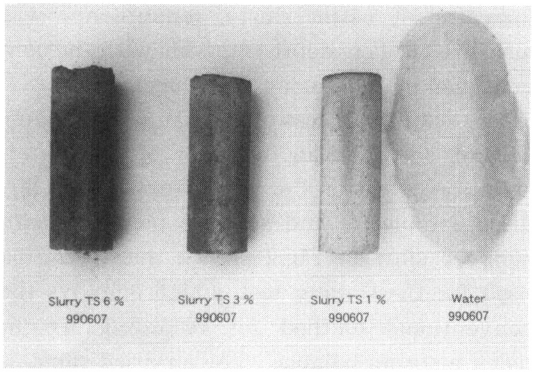

Photo 1. Silica sand and cattle slurry after mixing and drying (From the left, Sample H, Sample M, Sample L, and Water*1)
*1 : The sample mixed with distilled water collapsed as soon as it was removed from the tube

slurry can combine with silica sand particles from 44 to 280 times its weight. M.M. Kononova (1976) found that the amount of water-stable aggregate in soil was increased by adding humic acid with 0.7 to 1.0 g of total carbon per 1 kg soil. Yokose and Yamada (1977) stated that organic matter caused coarse aggregate formation, but if the amount was more than 50 g kg^{-1}, the organic matter hindered aggregate formation. The amount of organic matter in sample L is more than the value of Kononova and the amount in sample H is less than the highest value of Yokose and Yamada.

On the other hand, Kobayashi (1989) stated that organic matter from plant roots is effective for aggregate formation. Our examination also showed that the organic matter in cattle slurry causes aggregate formation.

2) Measurement of mechanical strength with unconfined compression test

The unconfined compression strength of each test sample is shown in Fig. 3. The strengths of samples L, M and H were 26.2±6.7 kN m^{-2}, 74.7±6.8 kN m^{-2} and 131.0±10.3 kN m^{-2}, respectively. There was a significant correlation between unconfined compression strength and the TS of the added cattle slurry. The

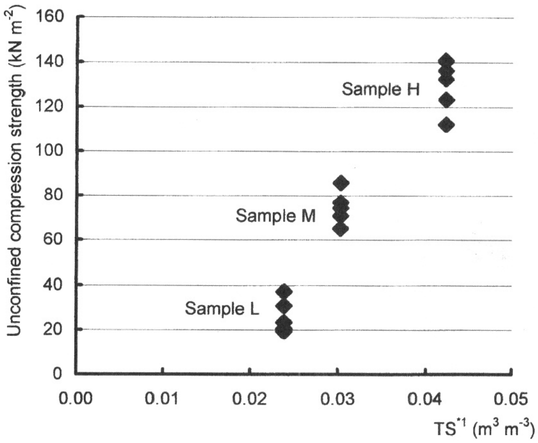

Fig. 3. Relationship between unconfined compression strength and TS of air-dried samples

strength of samples M and H were similar to that of the surface soil of northern Kanto loam (60 kN m^{-2} to 160 kN m^{-2}) and less than that of Ando-soil aggregate (over 500 kN m^{-2} under fresh undisturbed conditions).

The averaged strengths of the unconfined compression test of the re-wetted sample and air-dried sample are shown in Table 2. Fresh samples after the cattle slurry and silica sand mixed collapsed as soon as it was removed from the tube. On the other hand, re-wetted samples (average moisture content of 317.9±5.6 g kg^{-1}) maintained their columnar shape and its unconfined compression strength was 11.6±0.8 kN m^{-2}, less than that of the air-dried sample, which was 40.8±3.4 kN m^{-2}. This result shows that the unconfined compression strength decreased with increasing moisture content, and the adhesive strength of the organic matter decreased under wet conditions. The cattle slurry and silica sand mixture maintained their columnar shape after drying and re-wetting.

When the unconfined compression strength was compared between spring and summer samples of cattle slurry with the same TS, the summer sample strength was greater than the spring sample strength by 15 kN m^{-2}. This difference might be due to the difference in

Table 2 Relationship between unconfined compression strength and moisture content of samples

Sampling season	Sample	TS*1 (g kg^{-1})	Moisture treatment	Moisture content (g kg^{-1})	Unconfined compression (kN m^{-2})	Standard deviation
Summer	L	11.4	Air-dried	0.0	40.8	3.4
	M	28.0		0.6	90.1	5.7
	L	11.4	Re-wetted	317.9	11.6	0.8
	M	28.0		300.7	9.9	0.2

*1 : TS=see Table 1

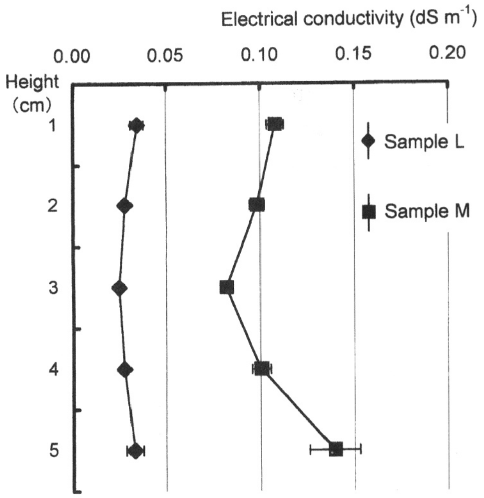

Fig. 4. Difference in electrical conductivity of air-dried samples

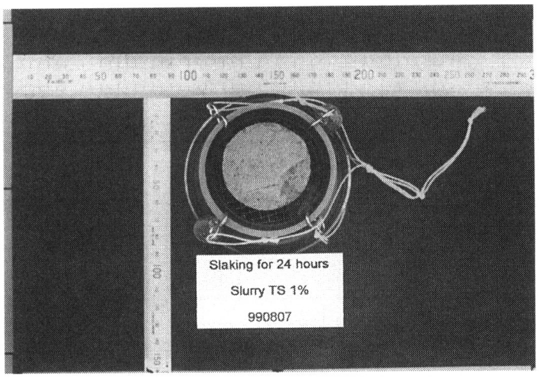

Photo 2. Sample L after slaking for 24 hours

cattle feed, and slurry preparation period. Harada *et al.* (1998) reported that the cattle manure compost preparation period affects the formation of organic matter such as cellulose and lignin by the compost process. Therefore, it appears that more organic matter with high adhesion remained in summer slurry than in spring slurry.

The EC distribution of samples containing silica sand and cattle slurry is shown in Fig. 4. The EC was high in the top and bottom parts and low in the center of both samples L and M. The non-uniform distribution of the EC shows that minerals moved with water during drying. However, the difference in the unconfined compression strength cannot be attributed to the non-uniform distribution of the minerals.

3) Measurement of water-stability by slaking test

The samples L and M soaked in water for 24 hours are shown in Photos 2 and 3. The collapse ratio caused by slaking is shown in Table 3. Sample L in air-dried condition had a few cracks and some collapsing caused by slaking (See the bottom right of the sample in Photo 2). When the samples were soaked in water, the air entrapped in the samples was released, causing cracking and collapse. The entrapped air in the samples was released for about 30 minutes. However, sample L did not collapse into clods of less than 5 mm and retained its columnar shape.

The above fact suggests that organic matter in cattle slurry works as an adhesive agent, and retains its function even when soaked in water. The Chemical Handbook (Anon., 1995), indicates that volatile solvent leads to adhesion of silica sand, as the samples hardened

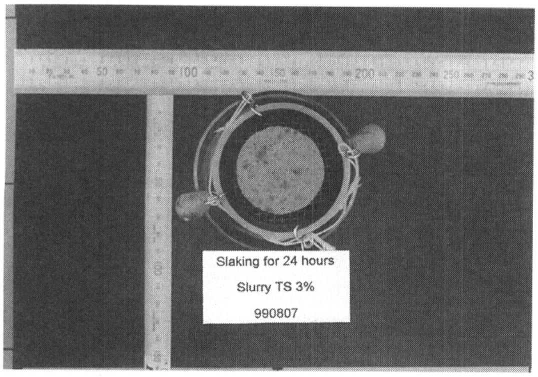

Photo 3. Sample M after slaking for 24 hours

Table 3 Collapse ratio with slaking

Sample	TS*1 (g kg^{-1})	Collapse ratio (g kg^{-1})	Remaining ratio (g kg^{-1})
L	9.9	6.41	993.59
M	29.6	1.64	998.36

*1 : TS=see Table 1

upon drying and become soft when re-wetted. This is broadly similar to the result found with cattle slurry and silica sand in this study.

Sato (1969) described that when clayey soil was dried beyond pF 4 (1000 kPa), the air release phenomenon was drastic, and the collapse ratio decreased, because the combination of the soil particles through the function of the soil colloid prevented collapse. Our results are consistent with the result of this research. Therefore, it is concluded that organic colloid in slurry causes adhesion of sand particles by drying. It is likely that this also happen in soils. Moreover, the dried organic matter of slurry samples absorbed water, and became soft when immersed in water. Organic matter in the slurry hardened in the form of a sponge, and enclosed the whole of the sand particles, and then the dried organic matter in the samples absorbed a large amount of water. Scheffer and Schachtschabel (1979) state that organic matter in soil has a high water-holding capacity, and is able to hold 3-5 times its own weight in water. The above ability is thought to have enhanced of water retention in the soil, because organic matter in slurry has a high absorption capacity.

4) Suggestion regarding the organic phase

Soil constituents are classified into solid, liquid, and gaseous phase. In this classification, organic matter is included as solid phase even when it is mixed with the soil as in the present study. However, this study clearly shows that organic matter has an adhesive function, which is different from the function of particles. In this paper, particles and organic matter are considered differently, and it is suggested that "solid phase" be classified as "organic phase" and "particle phase". Accordingly, the soil phases used in this study are "organic phase", "particle phase", "gaseous phase", and "liquid phase".

The phase volume ratio of the dried samples is shown in Fig. 5. The volume of the organic matter in samples containing spring slurry was calculated. The bulk densities of samples L, M and H were 1.37±0.03 Mg m^{-3}, 1.29±0.01 Mg m^{-3} and 1.23±0.02 Mg m^{-3} respectively. The densities of all samples decreased as the organic matter content increased, and the ratio of organic phase increased with increase in TS of cattle slurry, while that of gaseous phase increased even more.

This study indicates that the adhesion of cattle slurry to silica sand has the following characteristics. An increase in the organic matter content results in increases in the adhesion power and the distance between the particles, and adhesion is stronger when cattle slurry penetrates between sand particles. In the case of low-concentration slurry, the space between the sand particles decreases, and the area of surface in contact with slurry increases. Conversely, in the case of high-concentration slurry, the space between the sand particles increases, but the sand is more strongly adhering because slurry penetrates the gaps between particles. Furthermore, it is suggested that slaking depends on the content of organic

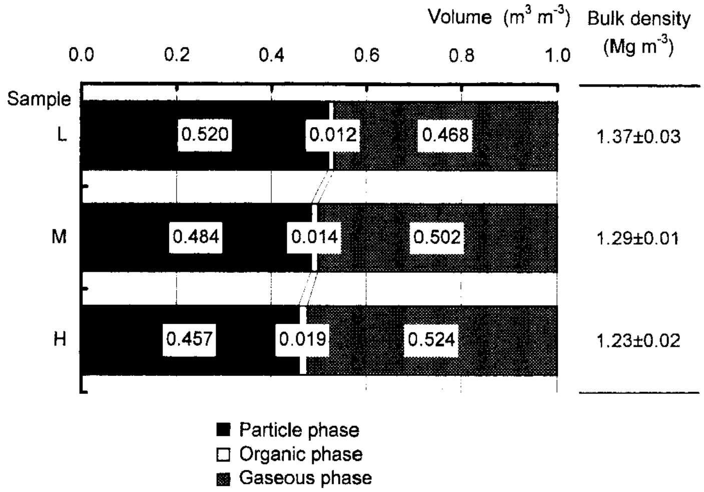

Fig. 5. Phases of dried samples

matter, which hardens the structure when dried and swells again when re-wetted.

4. Conclusion

Cattle slurry contains much organic matter that is effective in aggregation, but this organic matter has not yet been precisely identified. Also, the type of matter involved in the adhesion of soil particles is not clear. Accordingly, the identification of the organic elements, including adhesive agents, in slurry is being attempted.

5. Acknowledgments

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* : In Japanese with English summary.

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牛スラリー施用による土壌物理性改善効果に関する研究
牛スラリーによって結合したケイ砂粒子の一軸圧縮強度および耐水性

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要　　旨

牛スラリー施用が土壌の物理性に与える影響のうち，団粒形成についての検討は少なく，団粒形成因子としての牛スラリーの役割を明らかにする必要がある．本研究では，その基礎実験として，植物根や土壌生物の影響のないケイ砂培地に濃度の異なるスラリーを投与し，力学的な試験によってケイ砂粒子の結合の強さを求めた．ケイ砂粒子の結合の強さは，スラリーとケイ砂の混合体を風乾後，一軸圧縮試験とスレーキング試験から検討した．スラリーとケイ砂の混合体の力学的な特徴を次に示す．

① 風乾処理によりスラリー中の有機物がケイ砂粒子を接着して固結する．

② スラリーの全蒸発残留物濃度の増加にともない一軸圧縮強さは増加する．

③ 24時間の静水中への浸漬においてスレーキング耐性を示す．

④ 再湿潤処理後の一軸圧縮強さは，風乾時の半分以下に弱まる．

以上の結果から，スラリー中に含まれる有機物は，ケイ砂粒子間の接着物質として作用し，湿潤乾燥の繰り返しにより耐水性団粒を形成する可能性を持つと考えられる．

キーワード：一軸圧縮試験，牛スラリー，スレーキング試験，耐水性団粒，有機物

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