

Aggregate Stability and Soil Carbon Storage as Affected by Different Land Use Practices

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Abstract: Aggregates, resulting from physico-chemical and biological interaction in soil ecosystem, can physically protect the organic carbon in inter-aggregates from decomposers. Especially, water stable aggregate has been recognized as one of standard features of soil quality, sensitive to land management practices, as well as relating to erosion, carbon dynamics, and material transport. In this study, therefore, we conducted to grasp the influences of land use management practices on the aggregate stability and soil carbon storage in Korea, belonging to temperate region. From evaluating aggregation and soil carbon storage effect of different land use types, forest with broad-leaf tree (FB) was highest and decreased in the order of forest with needle-leaf tree (FN), grass, and upland cultivation. Particularly, larger aggregate had higher organic carbon content in soils with macro-aggregation more than 0.25 mm diameter. It could be considered that macro-aggregate formation could contribute the storage of organic carbon in soils. For upland crops, soils in perennial crops such as orchard had higher water stable aggregate (WSA) than annual upland crops. This is presumably in reverse of cultivating intensity such as tillage, causing aggregate breakdown. WSA of bare soils with few plants, however, was lower than annual crop-cultivated soil. This indicated that the cultivation of bare soil could enhance soil aggregation. In soils with conventional annual upland crop cultivation, except sandy soils, textural effect on aggregate stability and carbon storage was not significant. In addition, compost application enhanced aggregate stability and organic carbon content in soils with both of upland and paddy fields, but their excessive application could result in nutrient accumulation such as phosphorus. By the large, we concluded that land management practices giving higher organics, necessarily considering material balance in soils such as P, and lower disturbance to soil could result in higher macro-aggregation and carbon storage.

Keywords: Aggregate stability, Soil organic carbon content, Land management practices

1. Introduction

In recent years, conservation and retention of terrestrial carbon has been highlighted by the necessity to mitigate an increase in atmospheric carbon, as well as by enhancing soil functions supporting ecosystem. Soil aggregation is the main process whereby organic matter is retained in soil, depending on organics supply such as plant residues from vegetation. Climate and soil type can strongly influence both the degree of soil aggregation and organic matter storage in soil. Especially, temperature and precipitation control plant productivity and the subsequent accumulation and decomposition of organic matter. Soil parent material and mineralogical differences can also influence the level of potential soil aggregation and consequently the degree of soil organic carbon. Land use and management, within a climatic or soil zone, can also impact on soil structure formation and storage of organic matter (Carter, 2002).

Aggregation processes across different scales give us the understanding for the sequestration mechanism of organic carbon in soil aggregates. At the atomic or molecular level, charged colloid surface, organic molecule, cation, and water molecules bridge each other and flocculate. At the microscopic level, clay and organic matter act as bridges between the sand and silt particles, producing microaggregates of soil (McLaren and Cameron, 1996). The soil microaggregates are bound together into macroaggregates by fungal hyphae, plant roots and other stabilizing agents at macroscopic level (Oades, 1984). Tisdall and Oades (1982) proposed the boundary between microaggregate and macroaggregate be 0.25 mm of aggregate diameter. Carter and Gregorich (1996) reported that turnover time of organic matter in aggregate could be much longer than that of litter remained without aggregation. Organic carbon in intra-microaggregate has longer turnover time than that in inter-microaggregate, which can be characterized by both relatively short-term storage in macroaggregates or long-term sequestration in microaggregates. In other words, organic matter or fractions thereof are

basic to the aggregation process, and consequently organic matter sequestered within aggregates is protected against degradation (Carter and Gregorich, 1996).

Aggregates resulted from the above various processes and cementing agents, however, could be broken down during natural and artificial stresses such as erosion and tillage and subsequently organic matter sequestered in them can be decomposed. Actually, macroaggregates have their own life cycles (Denef et al, 2001; Six et al., 2000), repeating formation-breakdown, depending on biological activity and fresh residue inputs (Bidisha, 2010). Nevertheless, artificial stress of various management practices including tillage and traffic with agricultural machines, as well as natural stress such as rainfall, could accelerate aggregate breakdown and inhibit aggregate formation (Bronick and Lal, 2005). Especially, aggregate stability against water is important in region under monsoon climate because aggregate break down processes including slaking is largely dependent on its water stability. Many researchers reported that water stable aggregate is one of standard features of soil quality, sensitive to land management practices, as well as relating to erosion, carbon dynamics, and material transport (Kay, 1989).

Temporal and spatial heterogeneity and complexity in soil continuum make it difficult directly to measure the aggregation and carbon storage in soil (Bronick and Lal, 2005). Water stability test of aggregate is an indirect and discrete method for estimating aggregation, which could give us a simple and fast answer for understanding the management effect on aggregation and carbon storage. In this study, therefore, we conducted to grasp the influences of land use management practices on the aggregate stability and soil carbon storage in Korea, belonging to temperate region and monsoon Asia.

2. Soil organic carbon and their relationship to structure under different types of land uses

1) Study sites selections and analysis methods

To evaluate aggregation and soil carbon storage effect of different land use types, we chose seven regions across Korean inland, considering sea level altitude, and then, in each region, five sites with different land use types including forest with broad-leaf tree (FB), forest with needle-leaf tree (FN), pasture, upland with annual crops, and paddy rice fields in April, 2008. Pines and oaks are dominant species of needle leaf and broad leaf forest in sites studied. Soil core samples with three replicates were taken from soil surface to a depth of 15cm, and were analyzed for determining soil structure and physico-chemical properties, following the procedures in NIAST (2000)^[11]. Plant residues on the topsoil such as were sampled in FB, FN, and pasture land use types because conventional management of upland and paddy rice fields commonly includes crop residue removal for harvesting and so there are rarely plant residues in next spring season in Korea.

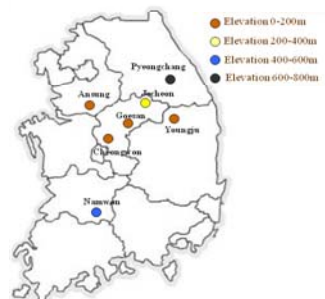


Fig. 1. Location of study sites

Soil organic carbon content was measured with wet-digestion method. The light fractions in soil organic carbon were investigated, referred from Gregorich and Ellert (1993)^[12], which was isolated from soils by flotation on dense liquid. The carbon content and C/N ratio of plant residues and light fractions were quantified using elementary analyzer (Flash EA1112, USA).

Water stable aggregate distribution was measured with wet-sieve analysis (Yoder, 1936) using bulk soils passed through 8mm sieve and a nest of sieves mesh openings of 2.0, 1.0, 0.5, 0.25, 0.1 mm respectively, which is described in NIAST (2000). The contents of water stable aggregate more than 1mm or 0.25mm were mainly used to analyze the relationships between soil organic carbon and aggregation.

For calculating 3 phases and 4 components of soil structure, the particle densities of minerals and organics in soils were used as 2.65 and 1.3 Mg m⁻³, respectively (Scott, 2000).

2) The effects on land use types on organic carbon fractions of soils used

Korea is a mountainous peninsula with high complexity in topography, and about 80 percents of Korea inland is in regions where the altitude of the summit ranges from 300 to more than 1,000 meters. High land could have higher organic carbon content than low land, due to lower temperature. In this study, soils taken in Pyeongchang region had higher organic matter content than other soils. The textural classes of soils studied distributed from sandy soils to clay loam soil (Table 1).

Table 1. Physical-chemical properties of soils used

Land use types	pH	Organic matter content (g kg ⁻¹)	Particle size distribution (g 100g ⁻¹)		
			Sand	Silt	Clay
FN	5.0 (4.4~5.8) *	32 (14~48)	45.1 (23.6~60.0)	36.9 (5.0~63.5)	18.0 (5.0~26.5)
FB	4.9 (4.3~5.7)	46 (9~95)	43.9 (23.3~71.6)	39.6 (23.1~61.7)	16.5 (5.4~26.1)
Pasture	5.2 (4.4~6.0)	28 (9~86)	46.2 (15.6~76.2)	37.6 (15.7~60.1)	16.2 (8.1~24.4)
Upland	5.7 (5.2~6.4)	17 (3~38)	56.6 (14.0~76.1)	29.3 (13.9~59.0)	14.0 (6.4~27.0)
Paddy	5.8 (5.4~6.4)	19 (12~30)	41.9 (14.8~89.9)	39.8 (17.4~62.6)	18.3 (6.4~27.8)

*Parenthesis indicate the range of each property of soils used

FN: needle-leaf forest; FB: broad-leaf forest; WSA: water stable aggregate

Table 2. Soil organic carbon and light fractions as affected by different land use types.

Land use types	SOC* (g C kg ⁻¹)	Light fraction in SOC		Plant residue C/N	WSA>0.25mm (g 100g ⁻¹)
		content (g C kg ⁻¹)	C/N		
FN	20	5.6	24	43	54.1
FB	27	5.4	20	27	56.8
Pasture	16	1.9	16	21	48.5
Upland	10	0.9	16	NA [§]	35.8
Paddy	11	0.8	18	NA	45.8

*Soil organic carbon; [§]Not analyzed; FN: needle-leaf forest; FB: broad-leaf forest; WSA: water stable aggregate

Five land use types studied were different each other in both of vegetations and land management practices, which could determine the quality and quantity of soil organic carbon. Especially, in natural vegetation, plant residue has been known as primary source of soil organic carbon (Lorenz and Lal, 2005), and its quality such as C/N ratio largely influences the dynamics of soil organic carbon (Brady and Weil, 2008). Table 1 shows the average values of soil organic carbon content and light fractions for each land use types. Soil organic carbon content was averagely highest in FB, and decreased in FN, pasture, paddy rice, and upland fields. The soil organic carbon in light fractions had higher value in soils under forest than other land use types. Light fraction is a transitory pool of organic matter between fresh residues and humified, stable organic matter (Gregorich and Janzen, 1996). In other words, the 'free' or uncomplexed organic matter in soils is that had not undergone significant transformations and can be separated by density using heavy liquids. In this

study, the light fractions of FN were higher than those of FB, which is the reverse of soil organic carbon. It could indicate that the decomposition and humification of litters from needle-leaf trees was slower than from broad-leaf trees and that humified stable organic carbon was larger in soils under FB than under FN. van Breemen and Finzi (1998) showed that broad-leaf litter decomposed rapidly compared to needle-leaf due to its larger amount of calcium ions, and that the calcium ions, the decomposition products, returned to soils under the trees. Besides, carbon to nitrogen (C/N) ratio has been paid attention to us as an important factor of organic matter decomposition. From Table 2, FN had higher C/N ratio than FB in both of plant residues and light fractions, with positive relationship each other. Pine leaf, needle-leaf, has often higher polyphenol content than other tree leaf. Lignin and polyphenol has been reported that they have an inhibitory effect of litter decomposition, similar to high C/N ratio. This result means, therefore, that broad-leaf trees could give more favorable condition for soil organic carbon formation than needle-leaf trees.

Soils under pasture had lower organic carbon content than soils under forest. This is probably due to grazing by animals or periodic removal of residues for feeding livestock. Upland with annual crops and paddy fields are commonly named as cropland with annually disturbed by human and agro-machines. Pasture converted to arable land under conventional cultivation commonly has a decrease in organic carbon content, because the amount of organic material returned to the soils is considerably lower than that under pasture and tillage enhance the decomposition of native soil organic matter (Dalal and Bridge, 1996). Paddy soils with periodic submergence were slightly higher in organic carbon content than upland soils.

Table 3 shows the comparison of organic carbon content between different aggregate sizes of highland soils with higher carbon content than other regions. The content of water stable aggregate more than 0.25mm diameter was also highest in FB and decreased in the order of FN, pasture, paddy and upland land use types, similar to soil carbon content. Particularly, larger aggregate had higher organic carbon content in soils with macro-aggregation more than 0.25 mm diameter (Table 3). It could be considered that macro-aggregate formation could contribute the storage of organic carbon in soils (Carter and Gregorich, 1996).

Table 3. The organic carbon content of different aggregate sizes of high land soils in Pyeongchang region as affected by different carbon sources.

Aggregates (mm)	FN		FB		Pasture		Upland		Paddy		
	WSA (%)	org-C (g kg ⁻¹)	WSA (%)	org-C (g kg ⁻¹)	WSA (%)	org-C (g kg ⁻¹)	WSA (%)	org-C (g kg ⁻¹)	WSA (%)	org-C (g kg ⁻¹)	
Macro	4-2	16	62	8	52	19	61	4	4	7	45
	2-1	21	24	25	45	20	41	9	11	7	24
	1-0.5	21	27	28	42	19	41	13	13	13	21
	0.5-0.25	9	34	11	41	8	40	12	17	19	15
Micro	0.25-0.1	5	41	7	50	5	49	12	17	21	11

FN: needle-leaf forest; FB: broad-leaf forest; WSA: water stable aggregate >0.25mm diameter

3) Soil structure factors and their relation to organic carbon in soils used

Soil structures, composed of solid and pore, namely porous media, have spatial-temporally heterogeneous and complex architectures in different edaphic and environmental conditions. Although much information in the soil structure leave out, we can simplify the structure as 3 phases 4 components in volume basis for comparing between land use types. Figure 2 shows them. The bulk density was highest in upland and decreased in the order of paddy, pasture, FN, and FB, which is the same order to solid phase and the inverse order of porosity, consisting of liquid and gas. This order is probably related to cultivation intensity and traffics including tillage frequencies, crop residue removals, and heavy agro-machines. This difference in bulk densities between land use types resulted in some change in the order of organics share percentage in soil volume from that of soil organic

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carbon content. Organics share in soil volume was highest in FB, and decreased in the order of pasture, FN, paddy, and upland. In the other words, volumetric organics shares of pasture and FN land use types, despite of small turn around, inverted from gravimetric organics shares due to the differences of bulk density. This gives us an importance of bulk density in calculating volumetric carbon sequestration from soil test value in weight basis

Mineral shares had a similar trend with bulk density, occupying larger portion in cropland with relatively dense structure. Liquid phase, volumetric water content in field retained water at sampling time, shared highest portion in paddy and decreased in the order of FB, upland, pasture, and FN land use types. On the contrast to this, FN had highest gas phase share and decreased in the order of FB, pasture, upland, and paddy land use types. Except paddy, FB with high organic shares was also high values in field retained water and air-filled porosity. In fact, sharing percentages of the liquid and gas phases can change with biotic and abiotic factors including climate and plant water uptake. Nevertheless, the result could be useful for comparing between land use types in a climate condition.

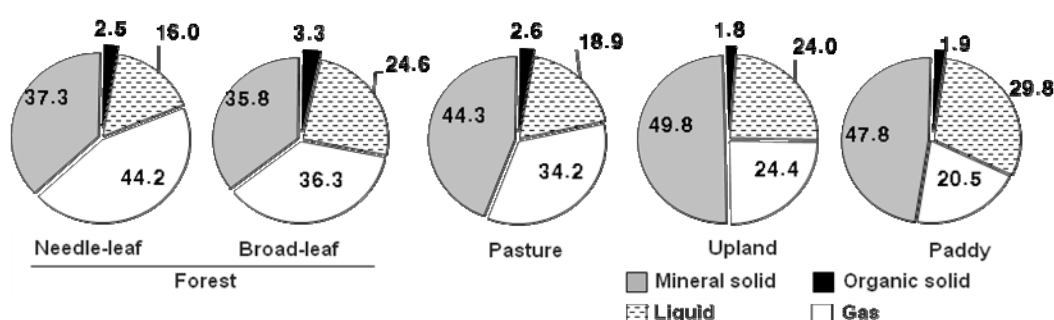


Fig. 2. Soil three phase and four component percentages in different land use types.

The correlation analysis between structure factors and organic carbon shows in table 4. In FN and FB land use types, soil organic carbon content was positively correlated with liquid phase, silt, clay, and WSA content, but negatively correlated with bulk density, solid phase, and sand content. Gas phase, however, represented no correlation with soil organic carbon content. This result means that higher organic carbon could combine with lower bulk density and higher field retained water and WSA. The content of sand, coarse primary particle, had the opposed effect on soil carbon retention to fine primary particles including silt, and clay. Silt and clay can join in organic-mineral complex formation with organics in soils, whereas not to sand. This shows the close relationship between soil structure and soil organic carbon. Unlike forest, however, soils under pasture land use types did not have a significant correlation between bulk density and soil organic carbon. In upland, soil organic carbon had a significant correlation only with clay and WSA contents, and only with clay content in paddy land. This is probably due to an increase in cultivation intensity and traffics with changing from forest, close to natural vegetation, to cropland, belonging to conventional intensive arable land. In other words, soil structure could be deformed by an intensive management practices in crop land, which mask the soil organics effect on structure.

Table 4. Correlation between soil organic carbon content and structure factors.

Land use types	Correlation coefficient [§] with soil organic carbon (r, N=21)								WSA >0.25mm (g 100g ⁻¹)
	Bulk density (Mg m ⁻³)	Solid (%, v/v)		Pore (%, v/v)		Particle size distribution (g 100g ⁻¹)			
		Mineral	Organic	Liquid	Gas	Sand	Silt	Clay	
FN	-0.76	-0.83	+0.93	+0.69	-0.17	-0.67	+0.60	+0.61	+0.72
FB	-0.92	-0.96	+0.97	+0.66	+0.12	-0.92	+0.90	+0.51	+0.91
Pasture	-0.37	-0.61	+0.99	+0.87	-0.69	-0.54	+0.63	+0.48	+0.80
Upland	-0.10	-0.33	+0.99	+0.11	+0.19	-0.36	+0.31	+0.45	+0.63
Paddy	-0.25	-0.32	+0.85	+0.38	-0.27	-0.76	+0.82	+0.52	+0.12

^s0.55>r>0.43 : * $P<0.05$; $r>0.55$: ** $P<0.001$; FN: needle-leaf forest; FB: broad-leaf forest

The contents of water stable aggregate in paddy land did not correlation with soil organic carbon content. Unlike other land use types, paddy field had periodic submergence by water and puddling processes commonly in a year. In fact, the role of puddling is to destroy the soil structure, especially macroaggregate, which effectively reduces the hydraulic conductivity of soil for saving leaching water loss. Dispersed clays can solidify to a hard clod, apparently similar to aggregate, when rapidly drying from extremely wet status (Kay, 1989). This makes it difficult for us to discriminate water stable aggregate from clods in paddy field. So, we need to find other test more proper to interpret the organic carbon and aggregation in paddy field. Dispersibility test has been reported as a substitute of water stable aggregate content. Middleton's dispersion ratio is one of dispersibility test, showed a significant correlation with water stability in Hyun et al. (2007).

3. Soil organic carbon and aggregation in uplands under different management practices

1) Comparison of aggregation between perennial and annual crops in upland cultivation

In view of land use in upland field, Han et al. (2007) reported that the content of water stable aggregates was higher in orchard than in annual upland crops. This is presumably in reverse order of cultivating intensity such as tillage. It has been reported that stable macro-aggregate in wet sieving of tilled soils is lower than that of no-tilled soils (Pagliai et al., 2004; Greenland, 1981; Kay, 1989; Dalal and Bridge, 1996), due to aggregate breakdown in tillage process. Recently, cover crops and minimum tillage in slope land of Korea has been studied for reducing soil erosion and conserving water. It has been reported that an increase in organics returned to soil from cover crops and reduction of soil disturbance from adopting minimum tillage can contribute to increase aggregation and carbon storage in soils.

WSA of bare soils with little impact of human was lower than upland crop-cultivated soil (Han et al., 2007). Actually, organic amendments like compost in upland cultivating practices have been associated with the increase of aggregate stability (Pagliai et al., 2004). This indicated that the cultivation of bare soil with few plants could enhance soil aggregation. In soils with annual upland crops, significant differences of WSA between different groups of textures except sandy soils were not shown. That means that WSA could not discriminate the effect of texture from mixed effect of crops, climate, textures, and artificial management practices. The little WSA of sand texture, however, indicates the importance of colloidal clay for soil aggregate formation.

2) Soil organic carbon and aggregation as affected by fertilization

Long-term fertilization study is useful for assessing current practices and planning sustainable management practices in future, considering crop yields and environmental impacts. Figure 3 shows

the change in organic matter content as affected by chemical fertilizer, compost, and lime. In 2002, lime application had lowest soil organic matter content, and increased in the order of chemical fertilizer and combined application of chemical fertilizer and compost. This result indicates that compost can contribute soil organic carbon storage but that lime applications have negative effect on carbon storage in soils.

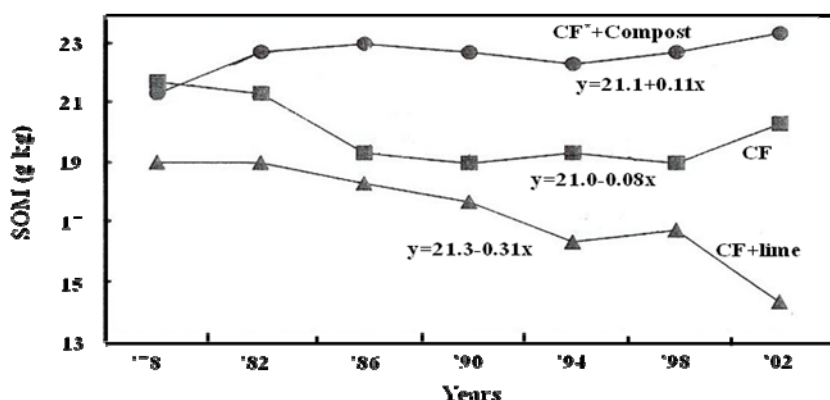


Fig. 3. Change in soil organic matter content as affected by long-term fertilization in field plots at GyeongBuk Agricultural Research & Extension Services. Soybean-barley cropping system: SOM: soil organic matter; *CF: chemical fertilizer; compost application rate 10 MT/ha; Lime 1.5Mg/ha; Silt loam soils. Data adopted from NIAST (2004)

Figure 4 shows the comparison of soil organic carbon and WSA between chemical fertilizer and combined application of chemical fertilizer and compost. Compost application enhanced soil organic carbon content and WSA in upland field studied. NIAST (2004) reported, however, that compost application had higher available phosphate than other treatment in same long-term fertilization field. Compost application enhanced aggregate stability and organic carbon content in soils with upland (Marinari et al., 2000), but their excessive application could result in nutrient accumulation such as phosphorus (Sharpley, 1995). Careful management for balanced and optimized materials inputs is essential to emphasize functional merits of carbon storage increase in soils.

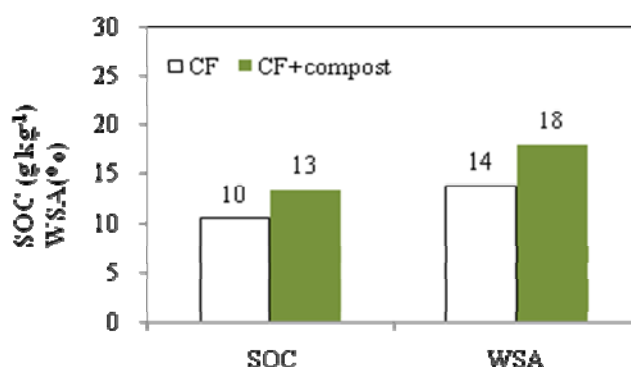


Fig. 4. Change in soil organic matter content as affected by different fertilizations in long-term field plots at GyeongBuk Agricultural Research & Extension Services. Soybean-barley cropping system; SOC: soil organic carbon; *CF: chemical fertilizer; compost application rate 10 MT/ha; Lime 1.5Mg/ha. Investigated in 2003.

4. Soil organic carbon and aggregation in paddy fields under different management practices

1) Study sites selections and analysis methods

In paddy fields, long-term fertilization study is also useful for assessing current practices and planning sustainable management practices in future, considering crop yields and environmental impacts. Especially, main grain in Korea is rice, and thereby long-term fertilization under paddy rice cultivation has been studied for longer period and more sites than under upland cultivation. Table 5 shows some sites of rice field for long-term fertilization study. The soil textures of the fields were loam or silt loam, mainly distributed in Korea inland (Table 6). The treatments were described in Table 6. Site B had green manure cultivation in winter season, the intermediate time between rice cropping seasons. Properly speaking, Site B is not long-term fertilization field. Nevertheless, green manure has been regarded as an important source to increase soil fertility, and so included in this study. Except Site B, the treatments were accomplished during rice cropping season.

Table 5. Site descriptions.

Sites	Location	Cultivated onset year	Soil series (Soil taxonomy)
A	Field plots at NAAS ^a , Gyeonggi-do	1954	Gangseo (Coarse loamy, Fluvaquentic Eutrudepts)
B	Field plots at NICS ^b , Gyeonggi-do	2002	Gangseo (Coarse loamy, Fluvaquentic Eutrudepts)
C	Field plots at NICS, JeonBuk	1979	Jeonbug (Fine silty, Fluvaquentic Endoaquepts)
D	Field plots at NICS, GyeongNam	1967	Pyeongtaeg (Fine silty, Typic Endoaquepts)

^aNational Academy of Agricultural Science; ^bNatural Institute of Crop Science

Table 6. Soil textures based on USDA analysis of experimental site soils.

Named site	Sand (%)						Silt (%)	Clay (%)	Texture
	size(mm)								
	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	Total			
A	1.2	5.4	10.5	16.0	12.3	50.9	32.6	16.5	Loam
B	2.4	7.7	9.1	9.5	6.7	35.4	44.6	19.9	Loam
C	0.9	2.5	1.8	1.7	2.3	9.1	68.3	22.6	Silt loam
D	0.8	1.7	3.1	5.4	7.8	18.8	56.0	25.2	Silt loam

Table 7. Treatments

Site	Treatments
A	T0 NPK (standard chemical fertilization)
	T1 Rice straw compost (15MT/ha)
B	T0 Conventional cultivation
	T1 Green manure (hairy vetch)
C	T0 NPK (standard chemical fertilization)
	T1 Fresh straw (5MT/ha)
	T2 Rice straw compost (10MT/ha)
D	T0 No fertilization
	T1 Rice straw compost (10MT/ha)
	T2 NPK (standard chemical fertilization)
	T3 NPK + Rice straw compost (10MT/ha)

Table 8. Soil organic carbon and physical properties under different management practices in paddy fields.

Site		SOC [*]	DR [§]	BD ^a	Vs ^b	Vw ^c	Va ^d	TPS ^e	MP ^f	AP ^g	Yamanaka hardness
		g C kg ⁻¹		Mg m ⁻³		%				cm sec ⁻¹	mm
A	T0	10	25.4	1.47	55.6	40.0	4.4	44.4	2.7	0.08	13.4
	T1	15	13.6	1.12	42.2	46.1	11.6	57.8	12.0	0.23	12.4
B	T0	18	14.0	1.13	42.8	39.6	17.6	57.2	22.2	0.70	14.8
	T1	20	7.9	1.12	42.4	43.1	14.5	57.6	30.5	0.75	13.8
C	T0	8	38	1.22	46.0	43.1	10.9	54.0	10.4	0.23	16.0
	T1	11	31	1.21	45.8	45.2	9.0	54.2	12.9	0.34	16.0
	T2	12	35	1.04	39.3	39.5	21.3	60.7	16.9	0.42	15.4
D	T0	16	31.0	1.32	49.8	30.2	20.0	50.2	18.0	0.45	22.6
	T1	21	22.5	1.14	43.0	41.9	15.1	57.0	17.1	0.65	16.8
	T2	17	16.4	1.28	48.3	39.3	12.4	51.7	10.0	0.58	17.0
	T3	23	16.1	1.01	38.0	31.4	30.5	62.0	22.3	0.95	16.6

^{*}Soil organic carbon; [§]Middleton's dispersion ratio; ^aBulk density; ^bVolume ratio of solid phase; ^cVolume ratio of liquid phase; ^dVolume ratio of gas phase; ^eTotal pore space; ^fMacroporosity; ^gAir permeability. Data adopted from Kim et al. (2004), Han (2009) and NIAST (2004)

The chosen field plots were investigated for soil organic matter content and physico-chemical properties including bulk density (BD), air permeability (AP), macroporosity, and hardness, following procedures described in NIAST (2000). For testing water stability of aggregate, Middleton's dispersion ratio (DR) was measured described in NIAST (2000). The contents of water stable aggregate in paddy land did not correlation with soil organic carbon content in Table 4. Han (2009) reported that Middleton's dispersion ratio was correlated with organic carbon in paddy soils. In this study, therefore, we analyzed DR instead of WSA for evaluating soil organic carbon and aggregation in paddy soil.

3) Soil organic carbon and physical properties as affected by different management practices

Table 8 shows soil organic carbon physical properties in plots with different treatments in fertilization or green manure cultivation. Compost, fresh straw, and green manure cultivation treatment increased soil organic carbon content. Plots with organic inputs such as compost had lower DR values that without organic inputs. Higher DR values indicate lower aggregate stability against water. In other words, organic inputs in Table 7 enhanced aggregate stability of soils, as well as carbon stock increase. Lee et al. (2009) showed an increase in soil organic carbon content and water stable macroaggregate more than 1mm by compost application for paddy field.

Site C had relatively higher DR values than other sites, which is probably due to their higher sodium content (table 9). Plots with green manure cultivation had lowest DR values, namely, highest aggregate stability. In case of fresh straw, higher aggregation effect showed in Site C, compared to rice straw compost. In Site D, combined application of chemical fertilizer and compost had higher organic carbon and aggregate stability than individual application of compost (Bulluck III et al., 2002)^[30]. This means that structure stability could increase with increasing the fertility of soils. As increasing the amount of total inputs to soils, nutrient status including available phosphate also increased (Table 9).

Similar to upland, the available phosphate content increased with compost application (Table 9). Figure 5 shows the change of DR and available phosphate content according to compost application rate. The DR rapidly decreased with lower application rate of compost, whereas the available phosphate content linearly increased with increasing rate of compost application. This result indicates that we need to find an optimized level for minimizing nutrient accumulation, as well as ameliorating physical properties of soils.

Table 9. Chemical properties of plot soils in experimental sites.

Sites		pH (1:5)	Avail. P ₂ O ₅ mg kg ⁻¹	Exch. Cations				CEC
				K	Ca	Mg	Na	
				cmol kg ⁻¹				
A	T0	6.3	12	0.07	4.0	0.7	0.4	7.4
	T1	5.7	179	0.09	4.2	0.7	0.4	9.2
B	T0	5.6	118	0.37	4.9	0.9	0.5	11.2
	T1	5.5	147	0.26	4.6	0.8	0.4	9.4
C	T0	7.0	86	0.26	5.1	1.9	1.6	9.9
	T1	6.6	96	0.23	5.2	1.9	1.6	10.2
	T2	6.8	130	0.25	5.3	1.6	1.9	11.5
D	T0	5.3	4	0.08	3.6	0.8	0.3	10.0
	T1	5.1	81	0.35	3.8	0.8	0.3	11.8
	T2	5.2	130	0.12	4.0	0.9	0.3	10.6
	T3	5.2	218	0.29	4.4	1.0	0.3	12.2

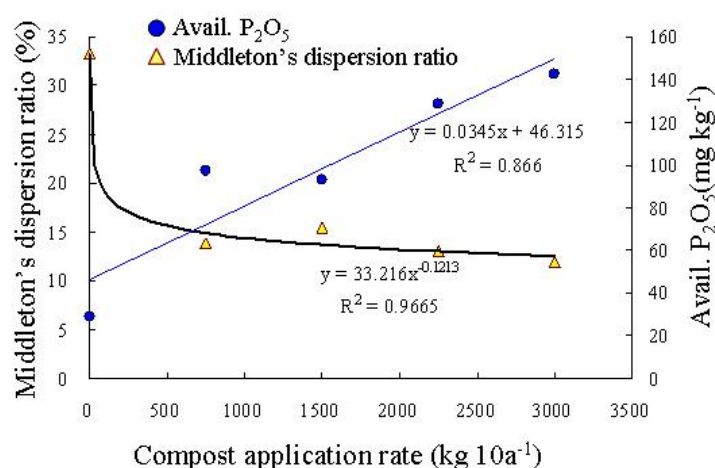


Fig. 5. The Middleton's dispersion ratio and available phosphate content of loamy paddy soils as affected by compost application rate. Middleton's dispersion ratio indicates [(%silt+%clay) after dispersion of soil in water]/ [(%silt+%clay) in soil] x 100. Data adopted from Han (2009).

5. Conclusions

Soil organic carbon content largely depends on the amount of organic inputs according to vegetation types and organic amendments. Aggregate stability and soil organic carbon each other was correlated, provided the method of stability test was properly chosen considering the characteristics of aggregate formation-breakdown in different land use types, especially paddy field. It could be considered, therefore, that aggregate stability test with verified method is useful for assessing organic carbon and aggregation in soils. In addition, we concluded that land management practices giving higher organics, necessarily considering material balance in soils such as P, and lower disturbance to soil could result in higher macro-aggregation and carbon storage.

6. References

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