Soil organic matter management for tackling desertification

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In the present world, land degradation proceeds everywhere. The phenomenon similar to desertification is not restricted to the arid or semi-arid zone. It occurs very quickly, when mankind disturbs the natural ecosystem such as tropical rain forest or coastal mangrove area. Desertification also occurs even in a very fertile cultivated land in a temperate zone due to the intensification of agricultural practice. Organic matter is lost from soil due to decomposition and erosion. Thus, the organic matter management will be a key practice to fight desertification. Humic substances, polysaccharides, and soil microbial activity are very important factors contributing to the formation of soil aggregates, which increase the stability of soil against soil degradation. Practice preventing the decrease in soil organic matter level should be undertaken in agriculture. Some tactics are proposed in the conclusion.

Keywords: humic substances, soil aggregate, soil degradation, soil organic matter, land use

1. INTRODUCTION

The land degrades very rapidly. In South Sumatra, Indonesia, it was only 30 years ago that the emigration policy was started to move highly dense population in other islands to sparsely inhabited Sumatra. To provide living foundation for emigrants, drainage canals were constructed in the lowland area and mangroves and peat lands were turned into paddy fields. Forests were cleared in the hilly area for creating plantation lands of coffee and pepper. Due to salt problem, however, rice was not successful in lowlands, and rice fields have been turned into shrimp ponds. In the hilly area, the fertility of land has been lost by severe soil erosion (Syam *et al*., 1997).

In Khon Kaen, northeast Thailand, they suffer from land degradation due to salt accumulation on soil surface (Plate 1) (Kohyama *et al*. 1993). Before the World War II, this area was covered by a dense tropical forest, which prevented water evaporation from the soil surface and the moving up of salts from salt bearing rock layers. After the World War II, many people were settled in this area, and forests were cleared for development of crop lands (cassava fields and paddy fields). Political tensions between the neighboring countries also urged the necessity for clearing forests in the border area.

Organic matter contained in soil is a product of long soil formation process. Age of soil organic matter can be dated back to several thousands of years within a meter of depth (e.g. in Andisols, chernozemic soils, and peat soils). This means that several hundreds of years are required for the soil organic matter to be accumulated within ten centimeters of soil profile. However, once soil degradation takes place, ten centimeters of surface soil can be lost within 10 - 50 years depending on the cropping system applied to field (Cox & Atkins, 1979).

Most popular causes for desertification are considered to be over-grazing of domestic animals and forest clearing. Soil began to be disturbed also by cultivation. The form of agriculture was at first the “slash and burn” with mixed crops. However, it changed to more intensive and continuous one. The impact of agriculture on the environment increased. Improper irrigation is also a cause for desertification as recognized in Far East and central Asia.

Plate 1. Salt accumulation on the surface of cultivated land in Khon Kaen, northeast Thailand (Photo by K. Tsutsuki)

Desertification brings about the decrease in soil organic matter, soil biomass and microbial activity, and destruction of soil physical structure. Salts and alkaline elements accumulated in plowed layer, and land became infertile. Terrible dry climate itself is not the cause but the result of desertification initiated by human activity.

From the cause and results of desertification, it is easily understood that organic matter management will be a key practice to fight desertification.

2. DYNAMICS OF ORGANIC MATTER ON EARTH

Table 1. Stock of carbon on the earth (adapted from Paul and Clark, 1989 & Eswaran et al., 1993)

Carbon stock			Abundance (10^9 Mg)
Terrestrial			
Plant biomass			550
Soil organic carbon			1500
Atomosphere	1850 AD	(CO_2 285 ppm)	602
	1900 AD	(CO_2 297 ppm)	626
	1950 AD	(CO_2 312 ppm)	658
	1999 AD	(CO_2 367 ppm)	772
Ocean			
Dissolved carbonate			38000
Dissolved organic matter			600
Solid suspension & organic matter in sediments			3000
Earth crust （fossil fuel）			4000

CO_2 concentration is according to the analyzed value of the air dissolved in the antarctic ice at Law Dome (http://cdiac.esd.ornl.gov/).

Table 1 shows the stock of carbon on the earth. Soil organic matter is the largest pool of carbon (1.5×10^{15} kg) in the terrestrial ecosystem. It is three times as large as plant biomass (0.55×10^{15} kg) and twice as large as atmospheric CO_2 carbon (0.77×10^{15} kg). However, it is deduced that the stock of soil organic carbon was as large as 2.1×10^{15} kg in the pre-historical age, when human being has not started agriculture (Buringh, 1984).

In the past 20 years, atmospheric CO_2 kept on increasing at a rate of 3.5×10^{12} kg carbon per year, 2/3 of which came from fossil fuel combustion, and 1/3 was due to land use change and soil organic matter decay. Thus, soil organic matter may seem very stable, but it is lost very quickly due to the interference by human activities, such as forest clearing, and intensive agriculture depending on chemical fertilizers.

Table 2. Turnover of soil carbon in three different climate zones (Paul and Clark, 1989)

	England (Rothamsted)	Western Canada	Brazil
Climate zone	temperate	cool-temperate	tropical
Soil types		mollisol	spodsol
Crop	continuous wheat	wheat-fallow	sugar cane
Soil weight (Mg ha^{-1})	2200	2700	2400
Organic carbon (Mg ha^{-1})	26	65	26
Carbon input (Mg ha^{-1} $year^{-1}$)	1.2	1.6	13
Turn over rate of soil carbon (years)	22	40	2

Table 2 shows the turnover of soil carbon in three climatic zones (Paul and Clark, 1989). In spite of very large carbon input, stock of organic carbon is very little in the tropic soils of Brazil, which resulted in a very short mean residence time (2 years). The reverse tendency applies to the cold temperate soil in West Canada, where input was small but stock was large which resulted in a long mean residence time (40 years). This infers the fragile nature of tropical ecosystem.

Soil temperature and moisture are the two most important factors affecting soil organic matter accumulation. Soil organic matter accumulation depends on the difference between production and destruction of organic matter under each climatic condition. Under aerobic condition, the destruction of soil organic matter increases and the accumulated amounts of soil organic matter decreases. Under submerged condition, the decomposition of soil organic matter decreases, and the accumulated amount of soil organic matter increases. Under the aerobic soil condition in the tropics, the decomposition rate of soil organic matter exceeds that of soil organic matter production. Therefore, soil organic matter does not accumulate in tropical soils if no protection mechanism exists. Shading under forest prevents the rise in soil temperature and keeps soil moisture, which retards soil organic matter decomposition. Clearing of forest means the removal of protection mechanism for soil organic matter.

Fig. 1 shows the relationship between input and stocked amounts of carbon in soils under various climate zones, calculated according to Rothamsted model by Jenkinson *et al*. (1991). Amount of stocked soil carbon increased in the colder climate zones due to the suppression in organic matter decomposition under cold temperature. A reciprocal relationship can be observed between the input and the stocked amounts of soil carbon. However, the plots of sites were also aligned to the direction of desertification within the distributing area for each climate zone. This also suggests that desertification may occur in any climate zone.

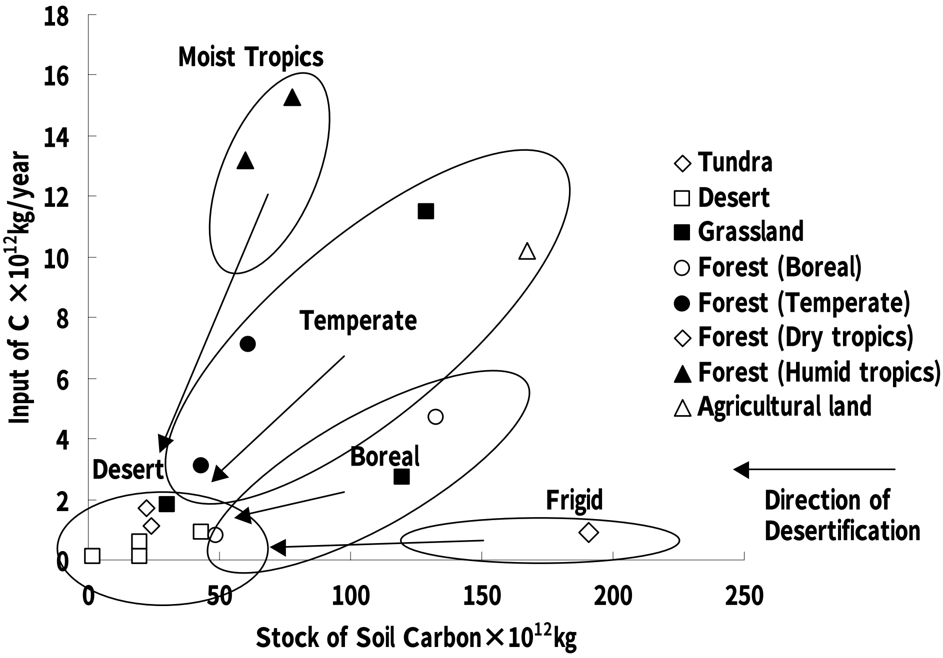

Fig. 1. Relationship between the stock of soil carbon and the amount of carbon input in different climate zones (illustrated according to the data of Jenkinson et al., 1991)

3. SOIL ORGANIC MATTER CONTENT IN ARABLE LAND IN RESPONSE TO MANAGEMENT

Dynamics of soil organic matter in temperate area is of interest in order to check any sign of desertification in our living ground. The response of soil organic matter level to organic matter management has been shown in the very famous long-term experiment at the Rothamsted experiment station in England (Jenkinson and Rayner, 1977). In their experiment, the level of SOM in a barley field continued to increase exponentially for the last one hundred years when farm yard manure (FYM) was added annually. However, it decreased rapidly, when application of FYM was stopped.

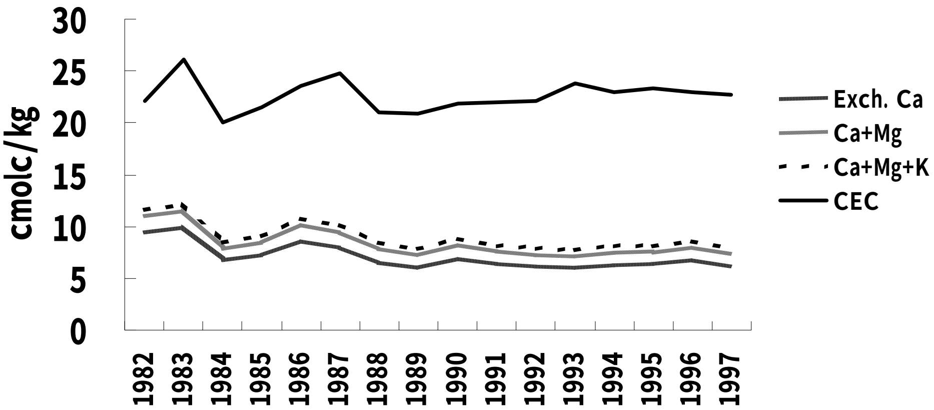

Fig. 2. Change in CEC and exchangeable cations in Andisols of Tokachi district, Hokkaido, Japan. (Data from Tokachi Federation of Agricultural Cooperatives)

Figure 2 shows the change in cation exchange capacity (CEC) and base status in the Andisols of Tokachi district in Hokkaido. The data are the averages of 2000 – 3000 analyses every year carried out in the soil analysis laboratory of Tokachi Federation of Agricultural Cooperatives for the purpose of soil diagnosis. CEC, which is closely related to soil organic matter content, has not changed remarkably during the past 20 years. On the other hand, exchangeable Ca and Mg have continued to decrease because farmers refrained from liming to prevent scab disease of potato. Same tendencies were also observed in the wet type Andisols in Tokachi area, while CEC in the wet Andisols were larger than those in the dry type Andisols.

Figure 3 shows the increase in soil carbon after long-term application of farm yard manure (FYM) in Tohoku Agricultural Experiment Station. The soil in this experiment plot belongs to wet type Andisol. When quite large amounts of FYM, 32t /10a, were applied annually, soil organic carbon increased from 12% to 15% after 20 years of application. On the other hand, by applying 2t and 8t of FYM for 20 years, soil organic carbon increased to 12.5 and 13%, respectively. This result suggests that additional 6t or 30t of FYM were not so effective as the first 2t of FYM with respect to the increasing effect of soil organic matter. Soil organic matter also did not change significantly since 8 years after the start of experiment.

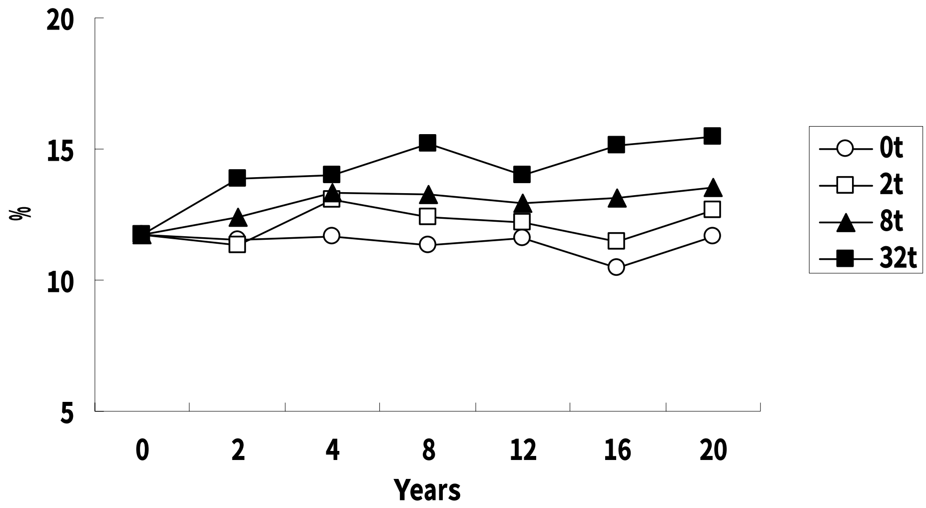

Fig. 3. Increase in soil C after long term application of FYM in Tohoku Agr Exp Stn (no chemical fertilizer plot) (analyzed by the author, unpublished data)

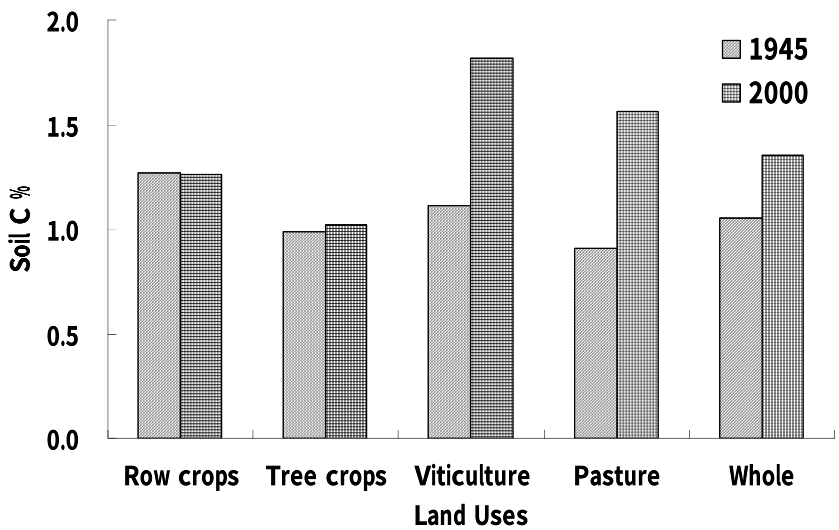

Fig. 4. Mean value of Soil C under different land uses in California for 1945 and 2001 sample dates (illustrated from the data of Clerck et al. (2002))

Clerck *et al*. (2002) analyzed archived soil samples in California, which have been preserved for 50 to 60 years, and re-sampled the soils at the same places as before, and analyzed the important soil properties again. Figure 4 shows the change in soil carbon under different land uses. In the row crop and tree crop fields, soil carbon did not change significantly, but in the viticulture and pasture/ range land it increased remarkably. In average, soil carbon content in California increased during the past 60 years in spite of intensive agriculture.

As seen in the above examples, soil organic matter in row crop lands did not change significantly under intensive agriculture in the temperate climate zones, and soil organic matter level could be increased by keeping lands under pasture / range condition or by adding organic matter to fields. However, soil organic matter originating from applied organic matter is readily lost again when application is stopped. We cannot be relieved by the tendency of little change in soil organic matter level under intensive agriculture, because the effect of intensive land use may be severer in the marginal area. Moreover, the deterioration of the quality of soil organic matter has not been clarified well.

4. ORGANIC MATTER AND SOIL AGGREGATE FORMATION

It is well known that aggregate structure of soil is very important to help plant root growth and soil microbial activities. It is also resistant to soil erosion.
Structure of soil aggregate is considered hierarchical. Fundamental particles of soils gather together and form a first order aggregate. Then first aggregates gather together and form second order larger aggregates. In such manner, larger aggregates in higher order are formed. Organic constituents contributing to soil aggregate formation also differ according to the size of aggregate.

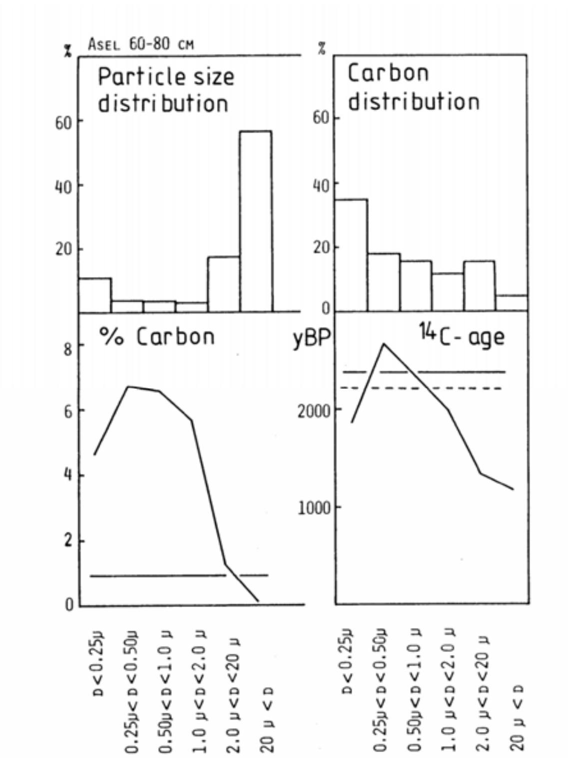

Fig. 5. Particle size distribution, carbon distribution, carbon contents & ^{14}C-ages of different particle size fractions of a forest chernozemic soil in Hildesheim, Germany (Scharpenseel et al., 1986)

Scharpenseel *et al*. (1986) and Tsutsuki *et al*. (1987) showed that proportions of soil organic matter associated with course clay and middle clay fractions increased, while soil organic matter associated with sand and silt fractions decreased with increasing soil depth in chernozemic soils. The radio carbon ages of soil organic matter was largest and the degree of humification of humic acid was highest in the course clay and middle clay fractions (Fig. 5). This means that very old humic substances are associated with course and middle clay fractions.

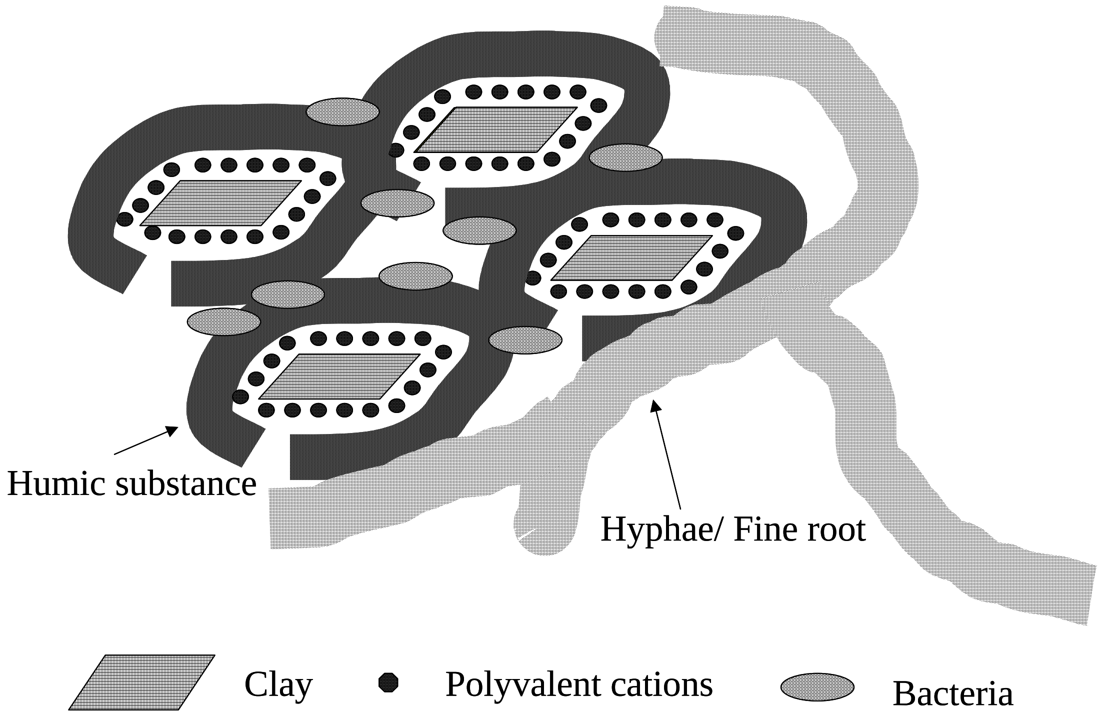

Fig. 6. Concept of soil aggregate structure

Figure 6 illustrates how soil aggregates are formed. Negative sites on clay surface attract polyvalent cations. Then, humic substances are adsorbed to clay through the bridge of polyvalent cations. These humus-clay complex units are bound together by polysaccharides excreted from soil microbes and plants. Larger aggregates are bound further by hyphae of fungi or fine roots.

Therefore, clay, polyvalent cations, humic substances, polysaccharides, bacterial cells, fungi hyphae, and fine roots contribute to soil aggregate formation. Clay, polyvalent cations, humic substances contribute to small aggregates strongly bound together. Polysaccharides, bacterial cells, fungi hyphae, and fine roots contribute to larger aggregates with weaker bonds. Existence of larger aggregates indicates that the soil is biologically active and productive.

To promote aggregate formation, only organic matter application is not sufficient. Enhancement of organic matter transformation in soil is also necessary. For this purpose, soil microbial activity should be promoted. Soil improvement through vegetation or crop itself is also recommended.

5. CONCLUSION

Desertification is not only a natural phenomenon, but it has been caused largely by human activity. It has been proven to be a myth that mankind can create a superior or more persistent production system than a natural ecosystem. To prevent or rehabilitate desertification, we have to learn from the natural ecosystem. What lack in man-made ecosystem are the heterogeneity of species and the return of crop residue and animal feces to soil by saprophilic members of ecosystem.

To keep soil organic matter level while activating soil microbial activity may seem contradictory, but it is necessary for tackling desertification and creating fertile agricultural soils with stable aggregate structure. For this purpose, not so large input of organic matter is necessary, but efforts should be made not to decrease soil organic matter level.

Tactics for preventing desertification are proposed as follows:

1) Multiple/rotation cropping system including grasses qnd legumes. Tree crops should also be introduced.
2) Preserve and grow forest in the agricultural area.

3) Combination of animal production and crop production for providing organic sources to cultivated lands.
4) Promote the recycling of biological residues (resources) through soil ecosystem.

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