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Full Length Research Paper

Effect of land use patterns on stability and distributions of organic carbon in the hilly region of Western Sichuan, China

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Soil aggregation is important for the resistance of land surfaces to erosion, and it influences the ability of soils to remain productive. At the same time, it is also an important process of carbon sequestration. The objectives of this study were to elucidate the effects of different land use patterns on soil aggregate stability and the distribution of organic carbon in different aggregate fractions in order to prove that the different land use patterns enhance soil aggregate stability. Five kinds of soil samples were collected from the hilly area of western Sichuan under different land use patterns, such as abandoned farmlands, eucalyptus plantations, Chinese fir plantations, tea plantations and loquat orchards. The results demonstrated that the five land use patterns had high proportions of aggregates at the size of >2 mm after dry sieving, and had high proportions of aggregates at the size of < 0.5 mm after wet sieving. The aggregation abilities of the soils were significantly different depending on land use patterns. Water-stable aggregate stability was highest in the Chinese fir plantations, followed by eucalyptus plantations and tea plantations. Water-stable aggregate stability was the lowest in loquat orchards and abandoned farmlands. Except for coarse particle, soil particle contents of the same size were affected according to the different land use patterns. As the size of aggregates decreased, the organic carbon content of the soil aggregates in tea plantations increased after a decrease, and then reduced again. However, the organic carbon contents of soil aggregates in other land uses increased continuously with the decreasing size of aggregates. Organic carbon content of the soil aggregates was strongly increased in land areas that had been converted from abandoned farmland to Chinese fir plantations, tea plantations and loquat orchards, while it was decreased when abandoned farmland was converted to eucalyptus plantations. The results provided the basis of implementation of returning farmland to forest and the process of carbon sequestration in the study areas.

Key words: Soil aggregate, soil aggregate fractions, soil aggregate stability, organic carbon content of the soil aggregates, land uses.

INTRODUCTION

Soil structure consists of an aggregate formed by the arrangement of soil particles, and depends on the interactions between primary particles and organic constituents to form stable aggregates (Caravaca et al., 2004). Soil aggregates, which have significant influence on soil physical and chemical properties, are the most basic units of soil structure and an important component of the soil (Tisdall and Oades, 1982). Thus, the recognition of soil aggregate size distribution and soil aggregate stability is important to properly interpret soil structure. Macroaggregates often form, not only around particles of undecomposed soil organic matter (SOM), but also from microaggregates because of binding agents such as

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Abbreviations: SOC, Soil organic carbon; **SOM,** soil organic matter.

polysaccharides and fungal hyphae (Tisdall and Oades, 1982; Beare et al., 1997). Macroaggregates are very sensitive to land use changes and agricultural practices since they are less stable than micro-aggre-gates, due to stronger binding of the latter (Tisdall and Oades, 1982). The stability of aggregates has substantial effects on soil fertility, quality and sustainability, and it is also a fundamental property that determines its productivity and resistance to erosion and degradation (Raine and So, 1997; Six et al., 2000). Aggregate stability is a highly complex parameter influencing a wide range of soil properties, including carbon stabilization, soil poro-sity, water infiltration, aeration, water retention, resistance to erosion by water and overland flow, management practices and land use patterns (Wei et al., 2006). Maintaining high stability of soil aggregates is essential for preserving soil productivity, minimizing soil erosion and degradation, and thus minimizing environ-mental pollution as well. Arshad and Cohen (1992) described aggregate stability as one of the soil physical properties that can serve as an indicator of soil quality. Soil can be source or sink of atmospheric carbon depending on land use, cropping system and manage-ment practices (West and Marland, 2002; Lal, 2003; Singh and Lal, 2005). Loss of soil organic carbon (SOC) with cultivation is connected to the destruction of macroaggregates (Elliott, 1986), as a result, soil becomes more susceptible to erosion since macroaggregates are disturbed (Six et al., 2000). SOC effect on global climate change was less than the effect of human activities discharging to atmosphere with the declining of SOC gradually (An et al., 2007). Different particle sizes of soil aggregates have different storage capacities for organic carbon. SOC might enhance soil aggregation states, increase soil moisture retention and the activity of soil organisms, and at the same time, could improve soil fertility and productivity (Kaden et al., 1997). Organic matter influences soil structure and stability by binding soil mineral particles, reducing aggregate wet ability, and influencing the mechanical strength of soil aggregates, which is the measure for the coherence of inter-particle bonds (Onweremadu et al., 2007). Thus, the distribution and the change of soil organic carbon in soil aggregates have drawn great attention.

From 1990s, the project of returning farmland to forests or tea plantations had been implemented to build the ecological barrier of the upper Yangtze River according to the local natural conditions. At present, the study on the soil organic carbon of soil aggregates mainly focuses on the influence of different fertilizer processing, vegetation restoration and erosion of soil organic carbon (Zheng et al., 2007); however, there is less studies focused on reductions in soil aggregates' stability and their relationship to SOM content under different land uses in Western Sichuan. In addition, since different aggregate fractions are selectively removed during erosion, characterizations of these aggregates are needed in understanding carbon dynamics during fertility erosion. Therefore, we assume that the conversion of cultivated land to forests and tea plantations or abandoned farmland will cause rapid change of dry aggregate size distribution, soil carbon stocks and distribution in the aggregate fractions.

This study was aimed at assessing and quantifying the effects of different land uses on soil structure, related to the distribution and SOC storage in dry aggregate size classes. This would provide a theoretical basis for the effective implementation of converting farmland to forests and tea plantations or abandoned farmland, coordinating regional land use and global carbon cycle.

MATERIALS AND METHODS

Study area description

The study was carried out in the Zhongfeng town of Ya'an city. The experimental area is located at the latitude (103°11 '-103°13') and longitude (30°12' - 30°13'), and the mean altitude is 700 m. This area belongs to a subtropical monsoon climate zone. The average temperature is 15.4°C and the frost-free period is 294 days. There are more than 1,500 mm of annual rainfall, and the rainfall between July and September reaches 72.6% of the yearly rainfall. The area is seated in a hilly region and the exposed layer is sedimentary rocks mainly formed after the Mesozoic age. The soil type is yellow soil formed in the older alluvium. Because of long-term human activities, most of the natural vegetation has been destroyed. Five types of land uses were studied, including abandoned farmland (C), eucalyptus plantations (L), Chinese fir plantations (N), tea plantations (T) and loquat orchards (Y). Table 1 summarizes the basic characteristics of the study areas.

Soil sampling

Soil samples were collected from 0 to 20 cm depth in Ganxigou catchment in September 2008. The soil sampling design involved selection of five sites from each land use pattern. All sites were located on the same physiographical units with the same slope aspects. These sites were either adjacent to one another or across the country roads, with a maximum distance of 1000 m. Each site included five land use patterns. Twenty five (25) soil samples were randomly collected at each site with the aid of a spade to maintain the soils, relatively, in their natural aggregates. These represent five replications for each land use pattern. Soil samples were sealed in plastic boxes and transported to the laboratory, where they were air dried at room temperature for 1 week. One aliquot was sieved at 2 mm for analysis of soil particle distribution and some selected soil chemical properties. Another aliquot was passed through a 5 mm screen for the measurement of aggregates.

Laboratory studies

Aggregate size distribution and composition

After removing the small lumps, plants, small stones and large animals, worms etc, soil aggregate distribution was determined by routine dry sieving and wet sieving (Department of Soil Physics, Institute of Soil Science, Chinese Academy of Sciences, 1978). There were six size classes used: < 0.25, 0.25 - 0.5, 0.5 -1.0, 1.0 - 2.0, 2.0- 5.0, > 5.0 mm. The mean weight diameter (MWD) and the geometric mean diameter (GWD) of the soil aggregates were

Table 1. The basic characters of studying area.

Land use	Elevation (m)	Slope (°)	Canopy density	Herb coverage (%)	organic matter ($g \cdot kg^{-1}$)	Vegetation type
C	740	30	—	50	28.19	Setaria palm leaves[1], fern[2], Mountain[3]
L	738	30	0.40	80	36.40	Eucalyptus[4], fern, Four Seasons bamboo[5], etc.
N	728	31	0.85	65	43.27	Fir[6],oil camphor[7], Eurya[8], pine[9], hawthorn[10], etc.
T	742	30	0.60	45	29.11	Tea tree[11], scattered fir
Y	751	30	0.60	50	35.84	Loquat[12], a small fern, Four bamboo Seasons.

(1) *Setaria palmifolia* (koen.) *Stapf*, (2) *Pteridium aquilinum* (Linn.) *Kuhnvar.latiusculum* (Desv.) *Underw.ex Heller*, (3) *Miscanthus sinensis* Anderss, (4) *Eucalyptus* spp. (5) *Oligostachyum lubricum* (Wen) *Keng f.*, (6) *Cunninghamia lanceolata* (Lamb.)*Hook.*, (7) *Cinnamomum inunctum* (Nees)*Meissn*, (8) *Eurya japonica* Thunb., (9) *Pinus massoniana* Lamb., 10) *Fructus Crataegi pinnatifidae*, 11) *Camellia sinensis*, 12) *Eriobotrya japonica* (Thunb.)*Lindl.*

calculated according to the following formulas (Qiu et al., 2006):

$$MWD=\frac{\sum_{i=1}^{n}\overline{R_i}w_i}{\sum_{i=1}^{n}w_i} \qquad (1)$$

$$GMD=Exp\left[\frac{\sum_{i=1}^{n}w_i\ln R_i}{\sum_{i=1}^{n}w_i}\right] \qquad (2)$$

Where, $\overline{R_i}$ is the mean diameter of each size fraction (mm), and w_i is the proportion of the total mass in the corresponding size fraction after deducting the weight of stones.

Analysis of soil physical and chemical properties

The undisturbed soil samples for determining the soil bulk density were oven-dried at 105°C to a constant weight. Soil pH value was determined by a glass electrode with a l: 2.5 soil: water ratio. SOC was analyzed following the standard procedures (Liu, 1996). The SOC was determined using the wet combustion method. 5 ml 0.8 M $K_2Cr_2O_7$ solution and 5 ml H_2SO_4 were added into the weighed soil and then boiled at 170 to180°C for 5 min. The remaining $K_2Cr_2O_7$ was titrated with 0.2 M $FeSO_4$.

Data analysis

Each physical and chemical soil property in composite samples for each site of different land use patterns was averaged at soil depths of 0 to 20 cm to perform statistical analysis. Analysis of variance was performed using SPSS (16.0) software after the method of logarithmic transformation. Two-way ANOVA followed by the LSD test (P<0.05) was used to compare the sites representing different land uses and aggregates.

RESULTS

Effect of land use on aggregation size distribution

The size distribution of dry-aggregates after logarithmic transformation under different land uses is shown in Table 2. The five land uses had high proportions of aggregates at the size of > 5 mm after dry sieving, and the total percentage of > 5 mm aggregates was 54.05±10.36% The coarse fraction (5-2 mm) had a mean value of 20.21%, and the smallest fraction (0.5-0.25 mm) with a mean of 6.24%. The proportion of aggregates increased after a decrease, and then decreased again with decreasing particle size in general for all land uses. The distribution did significantly differ between aggregates at the size of > 5 mm and the fractions of soil aggregates (5-2, 2-1, 1-0.5, 0.5-0.25 and <0.25 mm) for all land uses. They had the same change between aggregates at the size of 5-2 mm and the fractions of soil aggregates (1-0.5, 0.5-0.25 and <0.25 mm) for all land uses. They had the significant difference between aggregates at the size of 1-0.5 mm and the fractions of soil aggregates (2-1 and 0.5-0.25 mm) for all land uses. However, they lacked significant difference between different aggregate fractions (0.5-0.25 and <0.25 mm) of abandoned farmland, eucalyptus plantations and tea plantations.

There were no significant differences between the fractions of soil aggregates (>5, 5-2, 2-1 and 1-0.5 mm) under different land uses. There were significant differences in aggregates at the size of 0.5-0.25 mm between Chinese fir plantations and eucalyptus plantations, while there were no significant differences in aggregates at the size of 0.5-0.25 mm among the other three land uses. The contents in aggregates at the size of <0.25 mm were significantly higher in the Chinese fir plantations and eucalyptus plantations than in the abandoned farmland, loquat orchards, tea plantation. The proportion of aggregate fractions (> 5 mm) on abandoned farmland and eucalyptus plantations was about 5% higher than those of tea plantations, Chinese fir plantations and loquat orchards, while the proportion of

Table 2. Distribution characteristics of dry-aggregates under different land uses.

Land use	Aggregate fraction (%)						
	>5 mm	5-2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	<0.25 mm	>0.25 mm
C	57.27a^{b}	19.60a^{c}	5.96a^{e}	8.99a^{d}	4.10ab^{f}	4.08c^{f}	95.92a^{a}
L	57.76a^{b}	20.51a^{c}	4.71a^{e}	8.33a^{d}	3.71b^{e}	4.99bc^{e}	95.01a^{a}
N	50.95a^{b}	20.00a^{c}	4.36a^{e}	10.37a^{d}	5.63a^{e}	8.69a^{d}	91.31a^{a}
T	52.92a^{b}	19.67a^{c}	5.24a^{e}	10.29a^{d}	5.01ab^{e}	6.88ab^{e}	93.12a^{a}
Y	51.37a^{b}	21.25a^{c}	5.74a^{ef}	10.28a^{d}	4.81ab^{f}	6.55b^{e}	93.45a^{a}

Small letters indicated significant difference at the 0.05 level for the different land uses, and superscript letters indicated significant difference at the 0.05 level for the different particle sizes after logarithmic transformation.
C, Abandoned farmland; L, eucalyptus plantations; N, Chinese fir plantations; T, tea plantations; Y, loquat orchards.

Table 3. Distribution characteristics of water-stable aggregates under different land uses.

Land use	Aggregate fraction (%)						
	>5 mm	5-2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	<0.25 mm	>0.25 mm
C	6.92bc^{d}	4.56b^{d}	1.12b^{e}	5.65b^{d}	16.40a^{c}	65.36a^{a}	34.64a^{b}
L	8.75ab^{c}	8.86a^{c}	2.05a^{d}	7.01ab^{c}	15.49a^{b}	57.84a^{a}	42.16a^{a}
N	13.62a^{bc}	8.01a^{d}	2.33a^{e}	8.80a^{cd}	16.64a^{b}	48.61a^{a}	49.39a^{a}
T	9.09ab^{d}	5.64ab^{d}	2.14a^{e}	6.55ab^{d}	13.07a^{c}	63.50a^{a}	36.50a^{b}
Y	5.12c^{d}	6.11ab^{d}	1.56ab^{e}	4.70b^{d}	15.65a^{c}	66.85a^{a}	33.15a^{b}

Small letters indicated significant difference at the 0.05 level for the different land uses, and superscript letters indicated significant difference at the 0.05 level for the different particle sizes after logarithmic transformation.
C, Abandoned farmland; L, eucalyptus plantations; N, Chinese fir plantations; T, tea plantations; Y, loquat orchards.

aggregate fractions (1-0.5 mm) was about 2% lower than those of the tea plantations, Chinese fir plantations and loquat orchards. There were also no significant differences between the fractions of soil aggregates at the size of > 0.25 mm under different land uses after dry sieving. In this study, the results demonstrated that the change of soil aggregates after dry sieving was relatively small through the measures of returning farmland to tea plantation, returning farmland to forests and returning farmland to abandoned farmland. So, the effect of land uses on this soil was more related to very coarse size aggregates in the >2 mm size classes after dry sieving. The size distribution of water-stable aggregates after logarithmic transformation under different land uses is shown in Table 3. The five land uses had high proportions of aggregates at the size of < 0.25 mm after wet sieving, and the total percentage of < 0.25 mm aggregates was 60.43±4.20%. The coarse fraction (0.5-0.25 mm) followed with a mean value of 15.45%, and the fraction (2-1 mm) was the lowest with a mean of 1.84%. The proportion of aggregates increased after a decrease with decreasing particle size in general for all land uses.

There were no significant differences in the fractions of soil aggregates between 0.5-0.25 and <0.25 mm under different land uses after wet sieving. The distribution in aggregates at the size of > 5 mm did significantly differ between loquat orchards and Chinese fir plantations, eucalyptus plantations, tea plantations, while they lacked significant difference among Chinese fir plantations, tea plantations and eucalyptus plantations. The content in aggregates at the size of 5-2 mm was significantly lower in the abandoned farmland than in Chinese fir plantations and eucalyptus plantations, while there were no significant differences among Chinese fir plantations, eucalyptus plantations, loquat orchards and tea plantations. There were significant differences in aggregates at the size of 5-2 mm between abandoned farmland and eucalyptus plantations, Chinese fir plantations, while there were no significant differences among abandoned farmland, loquat orchards and tea plantations. There were significant differences in aggregates at the size of 2-1 mm between abandoned farmland and eucalyptus plantations, Chinese fir plantations, tea plantations, while there were no significant differences among eucalyptus plantations, Chinese fir plantations, tea plantations and loquat orchards. The content in aggregates at the size of 1-0.5 mm was significantly higher in the Chinese fir plantations than in abandoned farmland and loquat orchards, while there were no significant differences among the other four land uses. There were no significant differences in aggregates at the size of 0.5-0.25 mm and < 0.25 mm under different land uses.

Aggregates at the size of > 0.25 mm were generally regarded as the granular structure of soil, and there were positive correlations between the quantity of aggregates

Table 4. *MWD* and *GMD* of aggregates under different land uses.

Treatment	Index	Land use				
		C	L	N	T	Y
Dry sieving	*MWD*/mm	5.16±0.37aA	5.20±0.55aA	4.70±0.37aA	4.84±0.74aA	4.79±1.03aA
	GMD/mm	3.59±0.45aA	3.63±0.69aA	2.82±0.40aA	3.14±0.92aA	3.20±0.99aA
Wet sieving	*MWD*/mm	0.88±0.24bAB	1.18±0.44abAB	1.53±0.63aA	1.09±0.30abAB	0.80±0.12bB
	GMD/mm	0.26±0.03bB	0.35±0.09abAB	0.47±0.19aA	0.30±0.05bAB	0.25±0.01bB

Superscript letters indicate significant difference at the 0.05 level and capital letters indicate significant differences at the 0.01 level in a same row.
MWM, Mean weight diameter; GMD, geometric mean diameter.

and soil stability (Yang et al., 1993). The results demonstrated that the proportions of water-stable aggregate fractions (> 0.25 mm) changed in the following order of treatments: Chinese fir plantations > eucalyptus plantations > tea plantations > abandoned farmland > loquat orchards, while there were no significant differences in aggregates at the size of >0.25 mm under different land uses. Therefore, after converting farmland to forest and tea plantations, the water stable aggregate fractions of at size > 0.25 mm increased greatly.

Effect of land use on aggregation aggregate stability

Table 4 shows the *MWD* and *GMD* of aggregates by the dry sieving and wet sieving under different land uses. The results showed that the *MWD* changed in the following order of treatments: eucalyptus plantations > abandoned farmland >tea plantations > loquat orchards > Chinese fir plantations; the *GMD* changed in the following order of treatments: eucalyptus plantations > abandoned farmland > loquat orchards > tea plantations > Chinese fir plantations after dry sieving. However, there were no significant differences between them for different land uses. Thus, our study demonstrated that different land use effects on *MWD* and *GMD* of soil dry aggregate for all land uses under dry sieving were not significantly different.

The results showed that the *MWD* and *GMD* both changed in the following order of treatments: Chinese fir plantations > eucalyptus plantations > tea plantations > abandoned farmland > loquat orchards; the *GMD* changed in the following order of treatments: eucalyptus plantations > abandoned farmland > loquat orchards > tea plantations > Chinese fir plantations after wet sieving. There were significant differences between Chinese fir plantations, abandoned farmland and loquat orchards for different land uses. However, there were no significant differences between the others. The results showed that different land use effects on *MWD* and *GMD* of soil water stable aggregate for all land uses were significantly different. Therefore, our results showed the soil stability of Chinese fir plantations was the best and the soil stability of loquat orchards was the worst. It was demonstrated that the pattern of converting farmland to forest aids in maintaining soil stability.

Comparing abandoned farmland, eucalyptus plantations, Chinese fir plantations, tea plantations and loquat orchards, the value of *MWD* through dry sieving was 5.9, 4.4, 3.1, 4.4 and 6.0 times the corresponding wet sieving values respectively. However, the value of *GMD* through dry sieving was 13.8, 10.4, 6.0, 10.5 and 12.8 times the corresponding wet sieving values respectively. The results indicated the *GMD* and *MWD* through dry sieving were higher than through wet sieving under different land uses. This could be attributed to a large number of non-water stable aggregates that were dissolved when they soaked in the water.

Effect of land use on SOC contents of aggregate fractions

Table 5 shows the SOC contents of aggregate fractions for all land uses. SOC contents of aggregate fractions reduced as the particle sizes of soil aggregates increased under different land uses. In all land uses, higher values of SOC contents were at the size of < 0.25 mm aggregate fractions, while the lowest values of SOC contents were at the size of >5 mm or 5-2 mm aggregate fractions. SOC contents of different particle sizes in soil aggregates on the Chinese fir plantations were significantly higher than the other four land uses. These results could be attributed to the existing form of the SOC. The SOC was firmly attached to fine mineral particles and formed and organic-inorganic complex because the SOC content of free ions was relatively low. The smaller the particle size of the aggregate, the larger the specific surface area, and the greater the adsorption of organic matter. Our results demonstrated that SOC contents of small-sized aggregate fractions were higher than those of coarse grain, and it was difficult to decompose and release. These results confirmed that organic and inorganic colloid lead to the retention of small sized aggregate fractions. This result also confirmed former reports by Arrouays et al. (1995).

There were significant differences for the SOC contents of the size of >5 and <0.25 mm in soil aggregates

Table 5. SOC (soil organic carbon) contents of aggregate fractions under different land uses.

Land use	SOC content of aggregate fraction (g kg^{-1})						
	>5 mm	5-2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	<0.25 mm	>0.25 mm
C	13.42d^{e}	14.20c^{e}	19.09c^{d}	23.23cd^{c}	25.68c^{b}	27.80d^{b}	95.62d^{a}
L	15.29d^{e}	16.18c^{e}	18.86c^{d}	21.06d^{c}	22.14d^{c}	26.82d^{b}	93.54d^{a}
N	25.43a^{f}	33.47a^{e}	35.79a^{d}	41.69a^{c}	47.50a^{b}	47.57a^{b}	183.96a^{a}
T	19.54c^{d}	14.16c^{e}	20.42c^{d}	24.34c^{c}	22.82d^{c}	30.28c^{b}	101.27c^{a}
Y	22.62b^{e}	22.43b^{e}	25.40b^{d}	27.29b^{d}	29.62b^{c}	33.47b^{b}	127.36b^{a}

between the eucalyptus plantations, abandoned farmland and Chinese fir plantations, tea plantations, loquat orchards. SOC content of the size of >5 mm in aggregate fraction was lowest in the abandoned farmland, while SOC content of the size of <0.25 mm in aggregate fraction was lowest in the eucalyptus plantations. There were significant differences for the SOC contents of the size of 5-2 and 2-1 mm in soil aggregates between the Chinese fir plantations, loquat orchards and the other three land uses, while there were no significant differences for the SOC contents of the size of 5-2 and 2-1 mm in soil aggregates between eucalyptus plantations, abandoned farmland and tea plantations. SOC content of the size of 5-2 mm in aggregate fraction was lowest in the tea plantations. There were significant differences for the SOC contents of the size of 1-0.5 mm in soil aggregates between the Chinese fir plantations, loquat orchards and the other three land uses, while there were no significant differences for the SOC contents of the size of 1-0.5 mm in soil aggregates between tea plantations and eucalyptus plantations, abandoned farmland. There were significant differences for the SOC contents of the size of 0.5-0.25 mm in soil aggregates between the tea plantations, eucalyptus plantations and the other three land uses, while there were no significant differences for the SOC contents of the size of 0.5-0.25 mm in soil aggregates between tea plantations and eucalyptus plantations. SOC contents of the size of 2-1, 1-0.5, 0.5-0.25 and <0.25 mm in aggregate fraction were lowest in the eucalyptus plantations.

DISCUSSION

Under different land uses, 0.25-0.5 and <0.25 mm aggregates obtained by dry sieving was lower than that by wet sieving. This showed that the amount of <0.5 mm aggregates increased after wet sieving compared with dry sieving. Dry aggregates broke down and separated into smaller aggregates or single particles in wetting treatment. It was mainly because the soil particles in large aggregates were of low stability and persistence because they were weakly cemented by SOM (Six et al., 2000; Wagner et al., 2007); such aggregates could readily disintegrate into smaller units under wet sieving. Hevia et al. (2007) found that dry aggregation was different in a soil submitted to different management practices. In our study, there were significant differences for the fractions of soil aggregates (<0.5 mm) under different land uses, while there were no significant differences for the fractions of soil aggregates (>5, 5-2, 2-1, 1-0.5 and >0.25 mm) under different land uses. The results demonstrated that land uses had little effect on dry aggregates in our study. Aggregation is influenced by land use and land use change in the way that the proportion of water stable macroaggregates is reduced (Ashagrie et al., 2007; John et al., 2005). Microaggregates, however, seem to be less influenced by land use (Besnard et al., 1996; Puget et al., 2000). In our study, aggregates at the size of < 0.25 mm of abandoned farmland, tea plantations and loquat orchards were higher significantly than those of eucalyptus plantations and Chinese fir plantations. The results demonstrated that land uses had an important effect on water stable aggregates. It could be attributed to soil formed in the older alluvium and vegetation types.

Aggregates at the size of > 0.25 mm changed in the following order of treatments: abandoned farmland >eucalyptus plantations >loquat orchards>tea plantations>Chinese fir plantations after dry sieving, and there were no significant differences for different land uses. However, aggregates at the size of > 0.25 mm changed in the following order of treatments: Chinese fir plantations > eucalyptus plantations > tea plantations >abandoned farmland >loquat orchards after wet sieving, and there were also no significant differences for different land uses. *MWD* and *GMD* were highest in the abandoned farmland after dry sieving, while *MWD* and *GMD* were highest in the Chinese fir plantations after wet sieving. Soil aggregate stability can be influenced by the content of >0.25 mm water-stable aggregates, *MWD* and *GMD*, which is obtained by fractioning the soil material into aggregate classes by wet sieving (Kemper and Chepil, 1965; Bonifacio et al., 2006). In our study, the content of >0.25 mm water-stable aggregates, *MWD* and *GMD* of wet sieving showed the consistency in all the five land uses. Table 1 shows that the content of soil organic matter (OM) in the Chinese fir plantations was 43.27 g·kg^{-1} which was nearly twice of the abandoned farmland. It could be attributed to the input of additional organic matter. Soil organic matter plays a key role in the formation and stabilisation of soil aggregates (Lu et al., 1998). At the same time, a large part of macroaggregates (>5 and 5-2 mm) had broken into small aggregates and single particles after wet sieving, suggesting that the stability of aggregates was poor, with a relatively small *MWD* for tea plantations, loquat orchards and abandoned farmland. It was demonstrated that soil aggregate stability of the pattern of converting farmland to forest was better than that of the pattern of converting farmland to tea or orchards. Pattern of converting farmland to forests would help to maintain soil stability. However, there were large areas of loquat orchards and tea plantations due to the economic benefits of owning them in study areas. Thus, rational land use was one of the key factors in maintaining soil stability. We should consider the economic benefits and ecological benefits in the implementation of returning farmland to forest at the same time. These results confirmed earlier observations that greater water-stable aggregation can be ascribed to resistance of aggregates to slaking (Chenu et al., 2000). Dry aggregates are found to be useful for studying soil degradation, and they show similar trends as those indicated in the literature for water-stable aggregates (Noellemeyer et al., 2008). The apparent contradiction with our results might be explained by the climatic regime and clay contents that favor high carbon stocks.

In our study, the SOC contents of small aggregates were relatively high, and similar results were reported by Holeplass et al. (2004), while Saroa and Lal (2003) reported that organic carbon increased with increasing aggregate sizes. It could be attributed to soil character and different land uses. Soil is yellow soil formed in the older alluvium and it is made up of clay-size particles with which the OM was associated. In this instance, the cementing agent involved in macroaggregate formation was dominantly inorganic in nature (Barral et al., 1998). As a result, the OM contents of small aggregates were relatively high, and similar results were reported by Bartoli et al. (1992) and Barral et al. (1998). The Chinese fir plantations were evergreen coniferous forests. Thus, a greater amount of litter exists, which was useful for the accumulation of SOC content. Because of this, the soil SOC content was higher. The loquat orchards were broad-leaved forests, which would aid in the accumulation of organic matter due to artificial fertilization and irrigation. In the abandoned farmland, the vegetation was sparse and scattered, but almost all of the litter was returned to the soil each year. Previous studies had shown that grass roots in the plant residues and debris were conducive to the accumulation of organic carbon (Jennifer, 2004). It has been reported by various authors that grass roots and deep residues are advantageous in the organic carbon accumulation (Song et al., 2002). The eucalyptus plantation was evergreen and young with small crowns and less forest litter, however, its root system was expansive and the secretions were abundant in the study area. Well-developed root systems might provide better habitats for soil biology, and produce more secretions to improve soil microbial activity and strengthen the decomposition of organic residues (Zhu et al., 2002). In the tea plantations, the litter was less than that of Eucalyptus plantations because the tea trees were shrubs. However, the accumulation of organic matter easily occurred due to regular fertilizing.

Summary

After dry sieving, soil aggregates were dominated by > 5 mm particle sizes and the changes of soil aggregates were from decreasing to increasing and decreasing again with the decreasing of particle size for all the land use types. After wet sieving, soil aggregates were dominated by < 0.25 mm particle size and the changes of soil aggregates were from decreasing to increasing with the decreasing of particle sizes for all the land use types. Land use types affected soil stability, and greater water-stable aggregation could be regarded as resistance of aggregates to slaking. The soil stability of Chinese fir plantations was the best and the soil stability of loquat orchards was the worst. In addition, SOC contents of aggregate fractions reduced as the particle sizes of soil aggregates increased under different land uses, land use types would affect accumulation and distribution of SOC in the macroaggregates first, and the response was more sensitive to the herb coverage change and land use types.

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