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Full Length Research Paper

Fractal dimensions of soil structure and soil anti-erodibility under different land use patterns

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Soil structure fractal features and soil anti-erodibility were studied by the combinative means of field investigation and laboratory analysis under different land use patterns. The results showed that fractal dimensions of mechanical composition were greater than that of micro-aggregates, and fractal dimensions of water-stable aggregates were greater than that of dry aggregates. Five land use patterns had a high proportion of aggregates measuring >2 mm after dry sieving and <0.5 mm after wet sieving. Soil dispersion was mainly reflected in aggregates that measure between 0.05 to 0.001 mm. Soil anti-erodibility in the Chinese fir plantation and Eucalyptus plantation were higher than those of the tea plantation, loquat orchard and abandoned farmland. Stability of water-stable aggregate was highest in the Chinese fir plantation, followed by the eucalyptus and tea plantations, and it was lowest in the loquat orchards and abandoned farmland. With the exception of coarse dust, changes in the composition of other soil particles of the same size varied according to different land use patterns. Changes in the status of aggregates and the degree of aggregation were inversely related to changes in the dispersive coefficient. Water stability indices and contents of soil organic matter in the Chinese fir plantation, the eucalyptus plantation and loquat orchard were higher than those of the abandoned farmland and tea plantation. From the results, it can be concluded that land use patterns of the Chinese fir and eucalyptus plantations are a reasonable manner for the increases in soil anti-erodibility and improvements in soil structure in the study area.

Key words: Soil aggregates, soil fractal feature, soil water stable index, soil organic matter, land use patterns.

INTRODUCTION

Soil erosion is a serious environmental problem threatening future development of agriculture and society. Not only is it responsible for the long-term degradation of land quality, it is also a major source of non-point water pollution. Land use is one of the main factors that impact physical, chemical and biological processes of soils (Garcia et al., 1994; Masciandaro et al., 1998; Caravaca et al., 2002). Land use is the most direct way humans interfere with natural processes, and it can either improve or hinder soil erosion. Based on a study conducted in a 2008 integrated science expedition to investigate soil erosion and ecological security, soil erosion in China affects up to 3,569,200 km^2 or 37.19% total land area, which includes water erosion of 1,612,200 km^2. Area of soil erosion is up to 5310000 km^2 in the Yangtze River watershed. This could cause soil loss, such as vegetation destruction and the disappearance of the herbaceous layer. The study also reported that there was a good correlation between soil erosion and its inherent anti-erodibility (Zhang et al., 2007; Zheng et al., 2008). Anti-erodibility is the resistance of soil to be dispersed or suspended by water. It is closely related to the physical and chemical properties of the soil, and it is regarded as an important parameter to evaluate the resistance of soil to erosion. Given its importance, soil resistance is of intense interest (Yu and Shi, 2000; Cotler and Ortega-Larrocea, 2006; Xue et al., 2009; Gong et al., 2009).

Fractal theory has been applied to various geological phenomena that display large scale invariant and self-

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Table 1. Basic characteristics of area under study.

Land use patterns	Elevation (m)	Slope gradient (°)	Canopy density	Herb coverage (%)	Year (a)	Organic matter (g/kg)	Vegetation types
C	740	30	—	50	5	28.19	Setaria palm leaves, fern, Mountain
L	738	30	0.40	80	6	36.40	Eucalyptus, fern, Four Seasons bamboo, etc.
N	728	31	0.85	65	6	43.27	Fir,oil camphor, Eurya, pine, hawthorn, etc.
T	742	30	0.60	45	5	29.11	Tea tree, scattered fir
Y	751	30	0.60	50	5	35.84	Loquat, a small fern, Four bamboo Seasons

similar characteristics (Mandelbort, 1982; Turcotte, 1986). In particular, fractal theory has been shown to appropriately model the fragmentation process of both rocks and soils as a result of either natural processes or anthropogenic disturbances (Perfect, 1997). Applications of fractal geometry in soil science have shown that soil exhibits fractal characteristics: porous with compositions of different particles, such as irregular shapes and self-similar structures (Rieu and Sposito, 1991; Tyler and Wheatcraft, 1992; Kravchenko and Zhang, 1998). Fractal geometry has been widely used to describe heterogeneity in a wide range of natural processes, including physical systems of soil. In recent years, the possibility of characterizing particle size distribution, pore size distribution and aggregate size distribution based on fractal theory has been explored by many researchers (Perfect and Kay, 1991; Millan et al., 2003; Guber et al., 2004; Montero, 2005; Filgueira et al., 2006). These studies showed that fractal theory is a useful tool in quantifying soil structure, soil erodibility, and soil permeability (Rieu and Sposito, 1991; Tyler and Wheatcraft, 1992; Perfect, 1995; Huang and Zhan, 2002). Soil structure, which is the basis of soil fertility, affects soil permeability, soil anti-erodibility, and capacity of water supply (Gong et al., 2009). Soil often exhibits fractal features due to the complexity of soil structure and micro-scale differences of inherent factors (Cheng et al., 2007; Li et al., 2007). Pachepsky et al. (1995) reported that simulated soil degradation caused an increase in fractal dimensions in one or more intervals of fractal behaviour. Fractal parameters were also found to be affected by long-term management practices such as conventional cash grain system with soybean-corn rotation, recommended fertilizers (Pachepsky et al., 1996).

Changes in management practices often cause changes in soil structure that may in turn affect how effective these practices can be carried out (Filgueira et al., 1999). Though soil structure has been well-studied with fractal theory, only few studies focus on the influence of land use patterns on the fractal dimension of soils. Since the 1990s, plans to revert farmlands to forests have been implemented through the construction of ecological barriers based on local natural conditions, in the upper portion of the Yangtze River. The structure of land use in hilly areas of the western Sichuan benefited much from projects that not only include the reversion of farmland to forests or tea plantations but also the protection of natural forest, economic development, and population growth. These projects also economically and socially transformed western Sichuan, along with improvements to its ecological environment. Quantitative description of soil structure has since become an important aspect of evaluating the effects of human activities on the ecological environment based on the fractal theory.

The objectives of this study were to (1) apply the fractal method to quantify fractal dimensions of soil structure under different land use patterns, (2) assess and quantify the effects of different land use patterns on the anti-erodibility of soil in the hilly areas of the western Sichuan. These studies can provide the theoretical basis for the effective implementation of converting farmland to forests, coordinating regional land use and combating soil erosion.

MATERIALS AND METHODS

Description of the study area

The study was carried out in the Zhongfeng town of Ya'an city. The experimental area is located in the subtropical monsoon climate zone at the latitude (103°11' to 103°13') and longitude (30°12' to 30 °13'). The mean altitude is 700 m. The average annual temperature is 15.4℃, and the frost-free period is 294 days. There is more than 1500 mm of annual rainfall, which occurs mostly between July and September (72.6%). The study area is seated in a hilly region, and the surface layer is composed mainly of sedimentary rocks formed after the Mesozoic era. The soil type is a yellow soil formed in the older alluvium. Five types of land use were studied: 1) abandoned farmland (C), 2) eucalyptus plantation (L), 3) Chinese fir plantation (N), 4) tea plantation (T) and 5) loquat orchard (Y). Table 1 summarizes the basic characters of the area under study.

Soil sampling

Soil samples were collected in September 2007. Sampling design involved the selection of five sites that each represent a specific land use pattern. All sites were located on the same physiographical unit with similar slope aspects. These sites were either adjacent to one another or across country roads. Each site included five land use patterns. Twenty-five random soil samples were collected from 0 to 20 cm deep in each site with the aid of a spade to maintain the soils in their natural aggregates. These

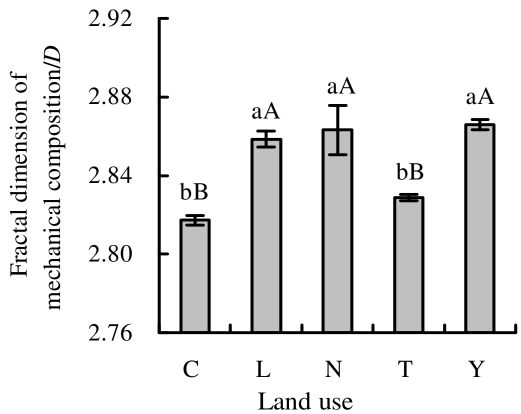

Figure 1. Fractal dimensions of soil mechanical composition under different land use patterns. Small and Capital letters indicate significant differences (p < 0.05 or p < 0.01, respectively).

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.

Physical and chemical properties of soil aggregate

After removing the small lumps, plants, small stones and large animals worms etc, soil aggregate distribution was determined by routine dry and wet sieving (Institute of Soil Science, 1978). The soils were categorized by six size classes: <0.25, 0.25 to 0.5, 0.5 to 1.0, 1.0 to 2.0, 2.0 to 5.0, >5.0 mm. Mechanical composition and micro-aggregates of soil were determined by the pipette method. Soil organic matter was determined by oxidation with potassium dichromate and heat treatment (Lu, 2000). Water stability index was determined by the collapse method (Institute of Soil Science, 1978).

Fractal dimension calculation

Fractal dimension of soil structure was estimated from this equation (Yang and Luo, 1993; Rieu and Sposito, 1991):

$$W(\delta > \bar{d}_i) = V(\delta > \bar{d}_i)\rho = \rho A[1 - (\bar{d}_i / k)^{3-D}] \quad (1)$$

where $W(\delta < \overline{d_i})$ is the mass of the weight of > $\overline{d_i}$, $\overline{d_i}$ is the average of the diameter of d_i and d_{i+1}, δ is the yard measure, A and k are the constants to describe the shape, scale of soil, and soil that was omitted, that is, the difference of ρ_i (soil bulk density) and ρ_{i+1} (soil bulk density) $\overline{d_i}$ of the different soil particle, W_0 is the sum of soil weight in different diameter, $\lim_{i \to \infty} \bar{d}_i = 0$ from the defines, the equation can be expressed in the form:

$$W_0 = \lim_{i \to \infty} W(\delta > \bar{d}_i) = \rho A \quad (2)$$

From (1) and (2) draw the equation:

$$W(\delta > \bar{d}_i) / W_0 = 1 - (\bar{d}_i / k)^{3-D} \quad (3)$$

where $\overline{d_{max}}$ is the largest average diameter, $W(\delta > \overline{d_{max}}) = 0$, substituting this into Equation (3), Equations 4 and 5 can be drawn:

$$W(\delta > \bar{d}_i) / W_0 = 1 - (\bar{d}_i / \overline{d_{max}})^{3-D} \quad (4)$$

$$\lg(\rho_i / \rho_0) = (D - 3)\lg(d_i / d_0) \quad (5)$$

where ρ_i is the bulk density (mg/m^3) of size class, ρ_0 is the bulk density of the largest aggregates, d_i is the mean aggregate diameter (mm) of size class *i*, and d_0 the mean diameter of the largest aggregates. The scale dependency of aggregate density increases as the value of D decreases. The mean aggregate diameter is used as the arithmetic mean of the upper and lower sieve sizes. From Equations (2) and (5), we draw Equation 6:

$$(3 - D)\lg(\frac{\bar{d}_i}{\overline{d_{max}}}) = \lg \frac{W(\delta < \bar{d}_i)}{W_0} \quad (6)$$

$\lg\left(\frac{W(\delta < \overline{d}_i)}{W_0}\right)$ is vertical axis and $\lg\left(\frac{\overline{d}_i}{\overline{d_{max}}}\right)$ is horizontal axis, and the slope of line was (3-D) by the linear regression. We can obtain the value of D. The fractal dimension difference is determined by fractal dimensions of soil dry aggregates and fractal dimensions of soil-water stable aggregates.

Statistical 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 with SPSS software (Ver.11.0). Means were compared by least significant difference (LSD) at p < 0.05 level.

RESULTS AND DISCUSSION

Fractal characteristics of soil structure

Fractal dimension of soil mechanical composition estimated in our work ranged from 2.187 to 2.866 under different land use patterns. The highest soil fractal dimension occurred in the loquat orchard and the lowest in the abandoned farmland (Figure 1). Based on mechanical composition analysis, changes in the amount of clay were similar to that of fractal dimension of soil mechanical composition (Figure 1 and Table 2). Soil mechanical composition is the basic unit of soil structure. It is also an important component of soil structure, and it is closely related to the intensity of soil erosion (Cheng et al., 2008). Composition of soil sand increased and

Table 2. Soil particle distribution under different land use patterns.

Land use patterns	Particle distribution in different sizes (%)			
	1~0.05 mm	0.05~0.01 mm	0.01~0.001 mm	<0.001 mm
C	19.04	19.00	35.87	26.09
L	16.24	19.24	30.50	34.02
N	16.66	18.18	32.17	32.99
T	21.50	18.02	31.53	28.95
Y	13.09	20.83	30.20	35.88

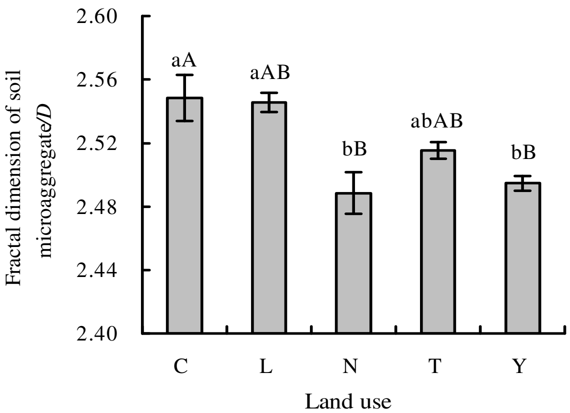

Figure 2. Fractal dimensions of soil micro-aggregates under different land use patterns. Small and Capital letters indicate significant differences (p < 0.05 or p < 0.01, respectively).

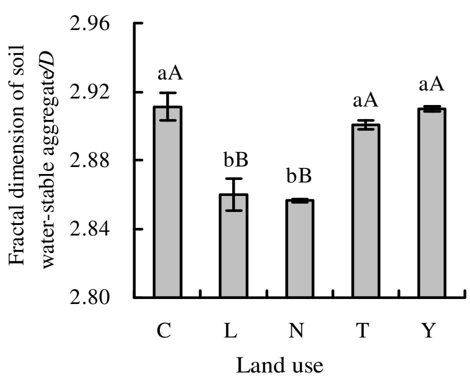

Figure 3. Fractal dimensions of soil water-stable aggregates under different land use patterns. Small and Capital letters indicate significant differences (p < 0.05 or p < 0.01, respectively).

composition of soil clay decreased in the returning forest to abandoned farmland and tea plantation. The amount of clay was reduced the most in the loquat orchards, followed by the Chinese fir plantation, the eucalyptus plantation, the tea plantation, and the abandoned farmland (Table 2). This may be attributed to the increasing human activities in tea plantation, as it would reduce to soil structure stability. With the exception of coarse dust, other composition of soil particle of the same size had different changes under different land-use patterns. Our results support previously reported findings (Wang et al., 2006; Zou et al., 2002) and showed that human activities cause marked differences in soil mechanical composition among the different land patterns.

Previous studies showed that the fractal dimension of mechanical composition is significantly and positively correlated with the amount of clay following a linear trend (Millan et al., 2003). Huang and Zhan (2002) reported that the fractal dimension of mechanical composition increased with increasing clay content but decreased with increasing sand content. In our study, with the exception of the abandoned farmland, fractal dimension of soil mechanical composition in the tea plantation were the lowest, while the other three land use patterns had no significant differences. From the results presented, it is clear that the increasing disturbance resulting from management practices might reduce the fractal dimension of soil mechanical composition. Figure 2 showed that fractal dimensions of soil micro-aggregate ranged from 2.489 to 2.549 under different land use patterns. There was a negative correlation between fractal dimensions of soil micro-aggregate and the content of > 0.001 mm particles. Fractal dimensions of soil micro-aggregate reduced with the increasing micro-aggregate content of > 0.001 mm particle. Soil structure also improved gradually. Fractal dimension of soil micro-aggregate was highest in the Chinese fir plantation, followed by the loquat orchard, the tea plantation and eucalyptus plantation, whereas it was the lowest in the abandoned farmland. The results showed that agricultural activities of tea plantation and forest played a significant role for the formation of soil structure. Soil structure and stability of tea plantation was worse than that of loquat orchard, and better than that of abandoned farmland.

Formation and distribution of soil water-stable aggregates under different land use patterns are shown in Figure 3. Fractal dimensions of soil water-stable aggregates decreased in the order of treatments: Chinese fir plantation < eucalyptus plantation < tea plantation < loquat orchard < abandoned farmland. Fractal dimension of soil water-stable aggregates was the lowest in the Chinese fir plantation; however, the content of soil water-stable macro-aggregates was the highest. The importance

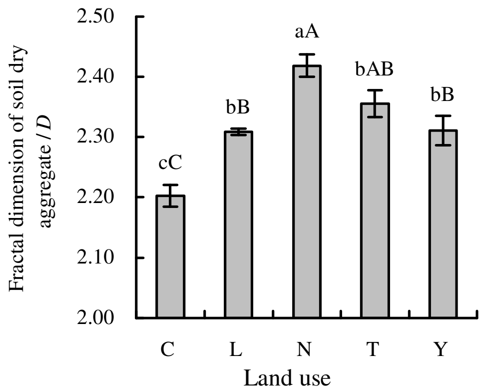

Figure 4. Fractal dimensions of soil dry aggregates under different land use patterns. Small and Capital letters indicate significant differences (p < 0.05 or p < 0.01, respectively).

of the contents of organic matter to aggregate formation and stabilization is widely accepted (Six et al., 2004; Noellemeyer et al., 2008). This is likely due to the fact that large amount of matters were returned to the soil every year. There was a higher coverage in the Chinese fir plantation based on our field survey (Zheng et al., 2009). Therefore, the physical, chemical, and biological properties of the soil improved with the increase activity of organisms found within the soil, increased decom-position and transformation rate of compost in the Chinese fir plantation. Fractal dimension of soil water-stable aggregates was also relatively low in the eucalyptus plantation. Increments in soil organic matter content due to the eucalyptus plantation increased the proportion of litters and induced its water-holding capacity, which resulted in decreased fractal dimensions of soil water-stable aggregates. Fractal dimensions of soil water-stable aggregates for tea plantation were signify-cantly higher than those of eucalyptus plantation and Chinese fir plantation.

However, there were no significant differences between the loquat orchard, the tea plantation or the abandoned farmland in terms of fractal dimensions of soil water-stable aggregates. The results showed that the soil anti-erodibility of the eucalyptus plantation and Chinese fir plantation was higher than that of the loquat orchard, tea plantation and abandoned farmland. Soil organic matter content of the tea plantation was relatively lower due to the traditional tillage, lower herb coverage and other farming activities. Soil organic matter content of tea plantation was only 79.97% of the eucalyptus plantation and 67.28% of the Chinese fir plantation, respectively. Meanwhile, artificial management practices strengthened soil compaction, and it was difficult to form better soil structure.

Fractal dimensions of soil dry aggregates were shown in Figure 4. Fractal dimensions of soil dry aggregates ranged from 2.233 to 2.421 under different land use patterns, with a variation coefficient of 3.37%. These results were not consistent with what have been reported under degraded soil after reforestation of *Pinus massoniana* (Wu and Hong, 1999). This may be due to different soil properties and the environment of the studied geographical area. Fractal dimension of soil dry aggregates was the highest in the Chinese fir plantation and the lowest in the abandoned farmland. The soil was easily penetrated by rain and formed soil crust in the abandoned farmland with lower herb coverage. Fractal dimension of soil dry aggregates reduced with increasing soil aggregate content.

However, the soil was protected well with the higher herb coverage and a large number of litters in the Chinese fir plantation. Thus, fractal dimensions of soil dry aggregates were the highest. There were significant differences in the fractal dimensions of soil dry aggregates between the Chinese fir plantation, the tea plantation and the abandoned farmland, while there were no significant differences between the loquat orchard, the tea plantation and the eucalyptus plantation. Hevia et al. (2007) reported that dry aggregation was different in a soil submitted to different management practices. Our results showed that there were no significant differences in the soil structure among the loquat orchard, the tea plantation and the eucalyptus plantation. Fractal dimensions of soil water-stable aggregates were higher than those of soil dry aggregates under different land use patterns, which indicated that soil aggregates were dominated by macro-aggregate in dry and wet sieving. It indicated that a large number of non-water stable aggregates had been decomposed into small aggregates under water immersion. Fractal dimension differences between soil dry aggregates and soil water-stable aggregates were the highest in the abandoned farmland, followed by the loquat orchards, while the Chinese fir plantation was the lowest. This change was consistent with the damage rate of the soil structure. The results showed that soil structure stability and soil anti-erodibility were poor in the abandoned farmland, and vice-versa in the Chinese fir plantation. Based on correlation analysis, there was a significantly positive correlation between the damage rate of soil structure and the difference in fractal dimensions.

Soil anti-erodibility

To determine water stability of soil aggregates, we measured the capacity of raindrop impact, runoff disperse, and suspension. The five land use patterns had a high proportion of aggregates at the size of >2 mm after dry sieving and at the size of <0.5 mm after wet sieving (Table 3). The proportion of water-stable aggregates was 65% of total aggregates. The results showed soil dry aggregates caked when it dried and dispersed, when it was watered in the study area.

Table 3. Distribution and stability of soil aggregates under different land use patterns.

Land use patterns	Treatment	Aggregate distribution (%)						Damage rate of soil aggregate ①(%)	Damage rate of soil aggregate②(%)	*MWD* ③(mm)
		> 5 mm	5~2 mm	2~1 mm	1~0.5 mm	0.5~0.25 mm	<0.25 mm			
C	Wet sieving	6.92	4.56	1.12	5.65	16.40	65.36	63.87^{aA}	80.10^{aA}	0.88^{bAB}
	Dry sieving	57.27	19.60	5.96	8.99	4.10	4.08			
L	Wet sieving	8.75	8.86	2.05	7.01	15.49	57.84	55.65^{bB}	70.85^{bAB}	1.18^{abAB}
	Dry sieving	57.76	20.51	4.71	8.33	3.71	4.99			
N	Wet sieving	13.62	8.01	2.33	8.80	16.64	48.61	45.89^{cC}	61.73^{cB}	1.53^{aA}
	Dry sieving	50.95	20.00	4.36	10.37	5.63	8.69			
T	Wet sieving	9.09	5.64	2.14	6.55	13.07	66.85	60.77^{abAB}	73.37^{abAB}	1.09^{abAB}
	Dry sieving	52.92	19.67	5.24	10.29	5.01	6.88			
Y	Wet sieving	5.12	6.11	1.56	4.70	15.65	66.85	64.46^{aA}	80.29^{aA}	0.80^{bB}
	Dry sieving	51.37	21.25	5.74	10.28	4.81	6.55			

Small and capital letters indicate significant differences ($p < 0.05$ or $p < 0.01$, respectively) ① damage rate of soil aggregates (> 0.25 mm); ② damage rate of soil aggregates (>0.5mm); ③mean weight diameter.

The proportion of dried aggregate fractions and water-stable aggregates (2 to 1 mm) was the lowest because coarse sand was the main soil mechanical composition of different land use patterns. These aggregates could readily disintegrate into smaller units under wet sieving. It was mainly because the soil particles in large aggregates were of low stability and persistence because they were weakly cemented by soil organic matter (Six et al., 2000; Wagner et al., 2007).

Under different land use patterns, the relative proportions of water-stable aggregate fractions (>0.25 mm) after both treatments increased in the order of Chinese fir plantation > eucalyptus plantation > tea plantation > abandoned farmland > loquat orchards. The proportion of water-stable aggregate fractions (>0.5 mm) was significantly higher in Chinese fir plantation, and in the eucalyptus plantations, the water-stable aggregate fractions (>0.5 mm) were significantly higher than those of the abandoned farmland and the loquat orchards. There was no significant difference between the eucalyptus plantations and the tea plantation, or between the abandoned farmland and the loquat orchards, in terms of the proportion of water-stable aggregate fractions. The mean weight diameter (*MWD*) of the Chinese fir plantation was the highest, being 1.29, 1.40, 1.74 and 1.91 times higher than the eucalyptus plantation, tea plantation, abandoned farmland and loquat orchard, respectively. However, changes in the damage rate of soil water stable aggregate (>0.25 mm and >0.5 mm) were inversely related with the *MWD*. The results showed that the proportion of water-stable aggregate fractions (>0.25 mm and >0.5 mm) formed readily in the returning farmland to forest soils. Soils with a higher *MWD* were more likely to have a greater resistance to soil degradation and erosion (Celik, 2005). This may be attributed to its effect on the composition, decomposition and conversion of soil organic matter in aggregate fractions for returning farmland to forest and abandoned farmland.

Soil micro-aggregates are the initial stage and base of the granular structure formation, and the ratio of its value and mechanical composition might reflect the degree of soil anti-erodibility (Zhang et al., 2007). Studies have reported that the contents of macro-aggregates are usually positively associated with contents of soil organic

Table 4. Soil micro-aggregate composition and dispersion characteristics under different land use patterns.

Land use patterns	Micro-aggregate composition (%)				Status of aggregation (%)	Degree of aggregation (%)	Rate of dispersion (%)	Dispersive coefficient (%)
	1~0.05 mm	0.05~0.01 mm	0.01~0.001 mm	<0.001 mm				
C	49.24	40.31	5.87	4.56	30.21cB	61.04bcB	62.67aA	17.56aA
L	60.68	23.77	9.91	5.63	44.44abAB	73.10abAB	47.03bcAB	16.66abA
N	57.60	33.68	5.16	3.56	40.93abcAB	69.93abcAB	51.40abcAB	10.81bA
T	54.29	38.08	3.35	4.28	32.79bcB	59.69cB	58.21abAB	14.84abA
Y	63.74	23.80	8.13	4.33	50.65aA	79.12aA	41.80cB	11.84abA

Small and capital letters indicate significant differences ($p < 0.05$ or $p < 0.01$, respectively).

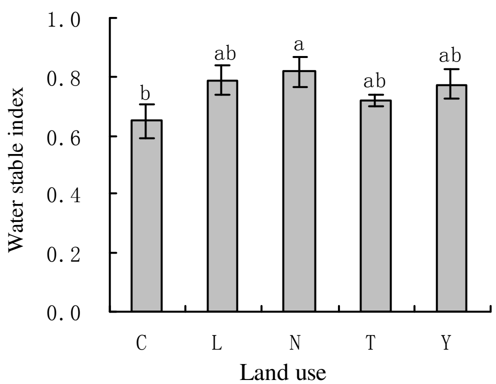

Figure 5. Change characteristic of water stability index under different land use patterns.

matter (Puget et al., 2000; Green et al., 2005; De Gryze et al., 2008). Status of aggregation and degrees of aggregation in the loquat orchard were significantly higher than those of the tea plantation and the abandoned farmland. There were no significant differences between the loquat orchard, eucalyptus plantation and Chinese fir plantation. However, the rate of dispersion in the loquat orchard was significantly lower than that of the tea plantation and abandoned farmland. The loquat orchard, eucalyptus plantation, and Chinese fir plantation showed similar findings. The results showed that the rate of soil dispersion was lower and the soil particle coagulation was higher in the loquat orchard, eucalyptus plantation and Chinese fir plantation (Table 4).

Soil anti-erodibility was also higher. This may be attributed to the contents of soil organic matter under different land use patterns (Table 1). Rates of dispersion were up to 40% and dispersive coefficients were less than 18% under different land use patterns.

Our results showed that soil dispersion was mainly reflected in aggregates measuring 0.05 to 0.001 mm. Figure 5 shows changes in the characteristics of the water stability among the different land use patterns. The water stability index in the Chinese fir plantation was significantly higher than that of the abandoned farmland, while it remained similar amongst the eucalyptus plantation, tea plantation and loquat orchard. Our results showed soil anti-erodibility was the highest in Chinese fir plantation because the capability of soil dispersion was relatively lower when soil aggregates were submerged in the water. However, soil anti-erodibility was the lowest in the abandoned farmland because soil aggregates were easily collapsed. This may be attributed to the difference of soil humus, root content and root exudates under the different land use patterns (Zheng et al., 2009). Based on our field survey, soil root biomass in the eucalyptus plantation was up to 9.58 g/1000 cm^3, and it was 2.1 times that of the abandoned farmland. The tea plantation had formed a unique ecosystem due to human management and root exudates. Mineral particles and organic matter were bonded together by a number of temporary cementation agents such as mycorrhiza and mycelium in tea plantation, thereby increasing the water stability index. Water stability index was low due to vegetation dominated by *Setaria* palm leaves, and there was flourishing and disappearance of seasonal change. Therefore, the time of soil exposed on the surface was longer, which accelerated the turnover rate of organic matter, making it difficult to form water-stable aggregates. Soil organic matter is the major cement material of water stable aggregates, and it could promote the formation of soil aggregate structure. Figure 6 shows soil organic matter content is significantly different between the different land use patterns. Soil organic matter content is highest in Chinese fir plantation, followed by the plantations and loquat orchards. Soil organic matter content of the Chinese fir plantation, eucalyptus plantation and loquat orchard increased by 53.5, 29.1 and 27.1% in

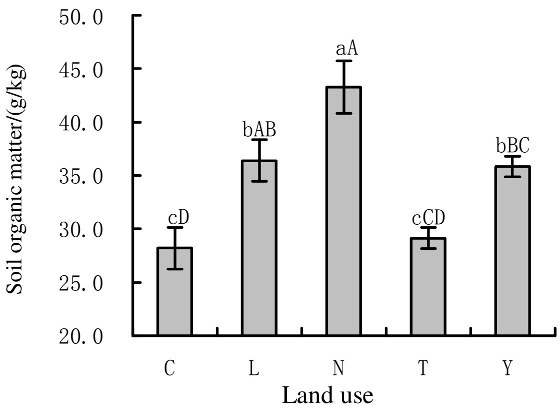

Figure 6. Change in the contents of soil organic matter under different land use patterns. Small and Capital letters indicate significant differences ($p < 0.05$ or $p < 0.01$, respectively).

corresponding abandoned farmland, respectively. Soil anti-erodibility increased because of rich soil organic matter, better structure, good aeration and water permeability in the Chinese fir plantation, eucalyptus plantation and loquat orchard. Conversion and decomposition of soil organic matter was faster in the eucalyptus plantation because of increased forest litter and smaller crown, high transmittance, forest weeds, soil animal and microbial community structure (Zhao et al., 2010). Soil organic matter accumulated readily in the Chinese fir plantation compared to the eucalyptus plantation, because the Chinese fir plantation formed a forest with a large canopy. Decomposition rate of litter was faster, although the amount of litter was less than that of the eucalyptus plantation (Zheng et al., 2011).

Previous studies have shown that grass roots in the plant residues and debris were conducive to the accumulation of organic matter (Jennifer, 2004). In the tea plantation, litter was relatively small, and it almost had no weeds due to smaller crown and clean tillage planting. Therefore, transformation and decomposition rate of soil organic matter was slow, animal and microbial structures were relatively single (Shen et al., 2010). In addition, soil was easily compacted due to farming activities such as pruning and harvesting, thereby decreasing the input of organic matter in the tea plantation. Litter was up to 3400 g/m^2 in the eucalyptus plantation. The Chinese fir plantation had 1.9 or 2.5 times more litter than the tea plantation or the abandoned farmland, respectively. Soil organic matter content was gradually enriched due to decomposition and transformation of soil animal and microbial activities.

Conclusions

Fractal dimensions of soil mechanical composition were significantly higher than those of soil micro-aggregate under different land use patterns. The water stability index and soil organic matter content in the Chinese fir plantation, eucalyptus plantation and loquat orchard were higher than that of the abandoned farmland and tea plantation.

It is thus clear that adjustments of land use patterns can result in the increases in soil anti-erodibility and improvements in soil structure. Soil anti-erodibility was higher in the eucalyptus and Chinese fir plantations, followed by the tea plantation and loquat orchard. Soil anti-erodibility was lowest in the abandoned farmland. Soil and water conservation function and soil fertilization in the tea plantation were relatively poor, and we should improve soil fertility to achieve a balanced development of social, economic, and ecological benefits for artificial management of tea plantations.

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