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Biomass of fine roots and its relationship with water-stable aggregates in a composite ecosystem of triploid *Populus tomentosa* in the conversion of farmland to forest

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Abstract A study on the biomass of fine roots and its relationship with water-stable aggregates (WSA) was conducted in two herbaceous models, triploid *Populus tomentosa*+*Lolium multiflorum* (TL) and triploid *P. tomentosa*+natural grass (TN). Both of the model triploid *P. tomentosa* stands were four years old converted from agriculture. Unconverted steep slope farmland was used as a control site. Results showed that the biomass of fine roots (≤ 1 mm) in different layers varied in the following descending order: upper layer, middle layer and lower layer, at approximate ratios of 50:30:20. The average annual biomass of fine roots in ryegrass was twice that of the mixed natural grass-forest land. The total amount of natural grass roots was 4.4 times that of the ryegrass model. Water-stable aggregates of the upper, middle and lower layers and the unconverted farmland did not show any significant differences, whereas the amounts of water-stable aggregates of big-particles in the upper and middle layers were much larger than those of unconverted lands. The amounts of water-stable aggregates of natural grass-forest lands (TN model) were higher than those of managed grass-forest lands (TL model). Two-way analysis of variance indicated that fine roots (≤ 1 mm) could significantly enhance water-stable aggregates and total water-stable aggregates. We conclude that the program of

converting agricultural lands to forest-grass lands is an effective way in improving soil anti-erosion capability.

Keywords fine root, grass root, biomass, water-stable aggregate

1 Introduction

Soil anti-erosion, as one of the parameters for the evaluation of soil anti-erosion capability, is related to its physical and chemical properties. Water-stable aggregates are the best index for the evaluation of soil anti-erosion capability (An, 2000). Exudation of fine root (≤ 1 mm diameter) and organic matter formed from dead roots could bind micro aggregates and other particles into macro aggregates, which can improve soil anti-erosion capability (Li et al., 1998; Liu and Li, 2003). The objective of our research is to evaluate the dynamics of water-stable aggregates, the distribution of roots and their relationships in the early stages of converting farmlands to forest (grass). It is important to assess the ecological benefits, as well as the water and soil conservation functions of different mixed forest-grass planting models.

2 Study area

Our study area is the scientific and experimental demonstration station of the conversion program from farmland to forest (grass) of the Sichuan Agricultural University, located at the western edge of the Sichuan basin (30°01'N, 102°48'E), near Heyuan Village, Tianquan County, Sichuan Province, China. The elevation is 700–800 m with a southeast slope of 26°. The dominant soil type is a red-purple mud, one of the purple soils in the Sichuan basin, and the effective soil layer is 30 to 50 cm thick. The area has a subtropical humid climate. The mean annual precipitation is 1736 mm, the mean annual evaporation is

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923 mm and the mean annual temperature is 15.1°C, with a mean monthly temperature of 5.1°C in January and 24.1°C in July. Gales, hail and downpours often occur in the summer and autumn with disastrous flood and mud-rock flows. It is therefore an important zone for the re-establishment of ecological defenses on the upper reaches of the Yangtze River.

3 Materials and methods

The project of converting farmland to forest (grass) was carried out in April in 2000 in the study area. In May, triploid *Populus tomentosa* were planted at a density of 3 m × 3 m and afterwards rye grass (*Lolium multiflorum*) seeds were sown into the soil at a concentration of 40 kg/hm² in September. No seeds were sown in an adjacent experimental field, only planted with triploid *P. tomentosa*, where natural grass grew. Before sampling, in this triploid *P. tomentosa* + *L. multiflorum* (TL) mixed planting model, the average tree height of the triploid *P. tomentosa* was 6.1 m, the diameter at breast height (DBH) was 6.0 cm and canopy shade density was 0.6, and the ground cover was 100% for *L. multiflorum* with a height of 0.2 m. The ryegrass was cut randomly and fertilized in November before the onset of winter. There was no irrigation during the entire year. For the planting model of triploid *P. tomentosa* + natural grass (TN), the average tree height was 5.5 m, the DBH was 5.0 cm and the canopy cover was 0.5. The dominant natural grasses include *Imperata cylindrical*, *Deyeuxia beauv* and *Microlepis strigosa* with a height of 0.4 m and 100% ground cover. The farmland on the unconverted steep slope, near the experimental field, was used as a control site, where corn, rice and rape seeds were planted during different seasons.

Five sampling sites (20 m × 20 m) were set up in both model stands. The biomass of fine roots was estimated by core sampling every month. Samples were collected every month in 2004. Every month, three average trees of the triploid *P. tomentosa* were chosen at the site, circling these trees, three to five soil columns (10 cm × 10 cm × 30 cm) were sampled at distances of 50, 100 and 150 cm from each of the three selected trees. The soil samples were

separated into the upper 0 to 10 cm of the soil layer, followed by the middle 10 cm layer and the lower layer from 20 to 30 cm, then transferred in plastic bags and stored in a deep-freezer until processing. Fine roots were carefully washed under a gentle flow of tap water over a 0.5 mm mesh sieve to remove adhering soil. Living roots were lighter in color and had greater resilience than dead roots. The dry mass (24 h at 80°C) of each sample was determined and expressed as t/hm² of soil.

Soil samples were collected at all sampling sites and the adjacent control site (unconverted steep slope farmland), following an “S” pattern sampling method for the three different depth layers (the upper: 0 to 10 cm, middle: 10 to 20 cm and lower layer: 20 to 30 cm) in January, May, July, September and December (the fine root biomass was the greatest in May and September and least in January, July, December) according to the results of a preliminary experiment. The three soil samples collected at every layer were submitted for laboratory analysis. After the removal of coarse roots and stones and air drying at room temperature, the water-stable aggregates were measured by using dry and wet sieving. The increment of water-stable aggregates was expressed as *A*:

$$A = \frac{(B - C) \times 100}{C} \quad (1)$$

where *B* is the amount of aggregate in the forest (%) and *C* the amount of aggregates in the unconverted steep slope farmland (%). The results were evaluated using Excel and SPSS 11.5.

4 Results and analysis

4.1 Vertical distribution and monthly variation of fine roots biomass

From Fig. 1, it can be seen that the total biomass of fine roots in the upper layer shows a double-peaked curve with separate apices in May and September. The maximum amounts in the TL model were 0.252 and 0.282 t/hm² and in the TN model 0.103 and 0.174 t/hm². The total biomass of fine roots in the middle layer shows a

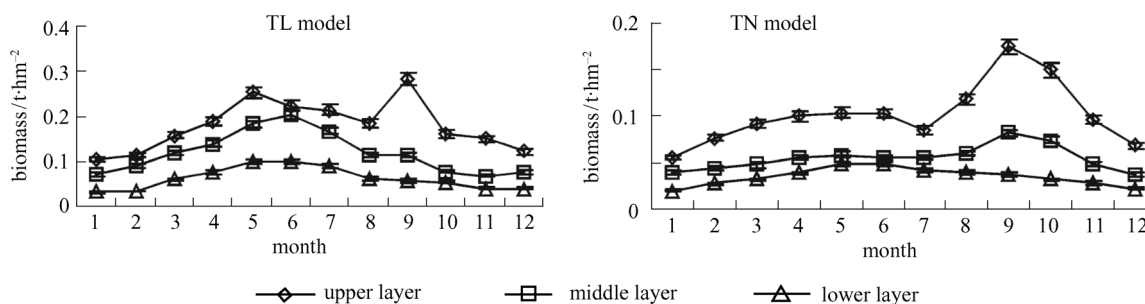


Fig. 1 Monthly changes and vertical distributions of the biomass of fine tree roots (≤ 1 mm)

single-peaked curve in both models, with maxima of 0.202 t/hm² appearing in June and 0.081 t/hm² in September in the TL and TN models, respectively.

The fine root biomass in the lower layer in the TL model shows a single-peaked curve with its maximum appearing in June. The fine root biomass of the TN model ranged from 0.02 to 0.05 t/hm² and showed little variation during the entire year. In other words, the fine root biomass of the TL model was higher than that of TN in all three layers. The variation is obvious. The average biomass of fine roots of TL and TN were 0.359 and 0.189 t/hm² with a ratio of nearly 2:1. At the same time, the ratios of upper, middle and under layers were 50:30:20, which is close to the results obtained by Zhang et al. (2000).

This was attributed to that fine roots depend on environmental factors. The growth of fine roots will be affected by the difference in the supply of water and nutrition and by temperature. In its vertical distribution, the changes in the biomass of fine roots in the upper layer are clearly greater than those in middle and lower layers because variation of environmental factors in the upper layer is obviously greater than in the middle and lower layers. Also, the TL model was disturbed by human actions (such as fertilization). The biomass of fine roots in each layer in the TL model was higher than that in TN. It proves that fine roots are the most active growth part in all roots and its total biomass is strongly affected by environmental factors (Zhang, 2001).

4.2 Vertical distribution and monthly changes of grass root biomass

The roots of *L. multiflorum* are only distributed in the upper and middle layers (Fig. 2). The grass root biomass in the upper layer showed a double-peaked curve, where the biomass of this layer accounted for 84.6% of the total biomass. The maximum amounts were 0.138 and 0.119 t/hm² appearing in May and September when water and temperature conditions were better. The minimum was 0.098 t/hm² in August. The biomass of the middle layer showed a smooth single-peaked curve.

The grass roots in the TN model are distributed in all three layers, but largely in the upper layer. The biomass of the grass roots of the upper layer accounted for 69.7% of

the total grass root biomass. There was little difference in the biomass between the middle layer and lower layer, accounting for 16.5% and 13.7% respectively. The maximum amounts of the upper layer appeared in May and September, similar to the TL model, but the natural grass root biomass was far higher than that of *L. multiflorum*, i.e., 0.547 and 0.520 t/hm². In the middle layer, the root biomass was the same as in the lower layer and except for July, the differences are small. It is obvious that the biomass of natural grass roots was far higher than that of *L. multiflorum*. In the upper layer, the average natural grass root biomass was 0.372 t/hm² three times as large as that of *L. multiflorum* with 0.102 t/hm². In the middle layer, the natural root biomass was 0.088 t/hm², almost five times as large as that of *L. multiflorum* with 0.019 t/hm². The biomass of natural grass in the lower layer was 0.073 t/hm², while the corresponding value of *L. multiflorum* was 0. To sum up, the average grass root biomass of natural grass over the entire year was 0.533 t/hm², 4.4 times that of *L. multiflorum* with 0.120 t/hm².

4.3 Vertical distribution and monthly changes of biomass of roots with diameter ≤ 1 mm

The average biomass of total roots in the upper layer was 0.281 t/hm² (Fig. 3), of which fine roots accounted for 64%; the average biomass of the middle layer was 0.136 t/hm², with fine roots accounting for 86% and the average biomass of the lower layer, all in fine roots, was 0.062 t/hm². In the TN model, the average biomass of roots in the upper, middle and lower layer were 0.473 t/hm², 0.142 t/hm² and 0.107 t/hm², respectively, and the biomass of fine roots accounted for 30% to 44% of the total. The biomass ratio of all three layers in both forest lands was 60:25:15.

In the upper layer, the total fine root biomass in the TL model showed a double-peaked curve and the maxima appeared in May and September. The grass root biomass decreased rapidly with the increase of soil depth, to the point that there were no grass roots at all in the lower layer, so the variation in total root biomass was the same as for fine roots. In the TN model, the biomass of grass roots in all three layers was far higher than that of fine roots, so that the variation of total root biomass was similar to that of the grass roots.

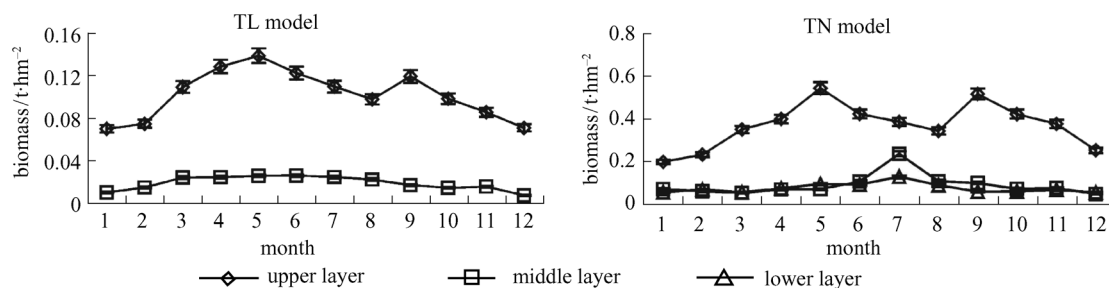


Fig. 2 Monthly change and vertical distribution of biomass of grass roots

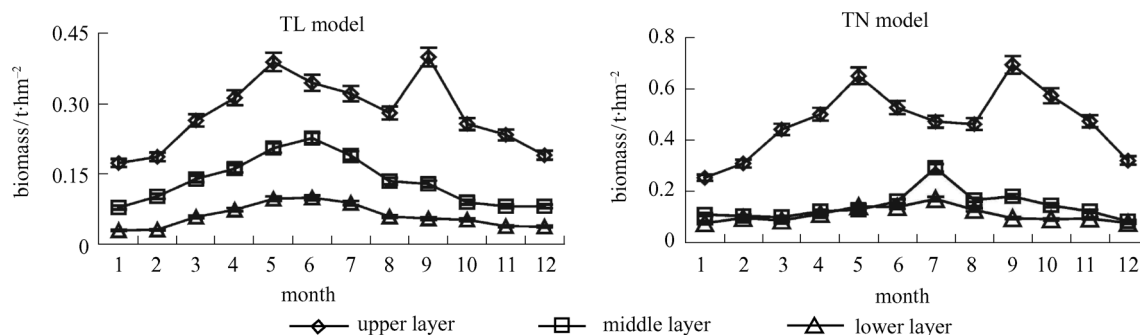


Fig. 3 Monthly changes and vertical distribution of fine root biomass

4.4 Amounts of water-stable aggregates in two kinds of forest land and unconverted farmland

In both models, the triploid *P. tomentosa* + *L. multiflorum* (TL) and the triploid *P. tomentosa* + natural grass (TN) models, the amount of water-stable aggregates (WSA) was varied in the following descending order: upper layer > middle layer > lower layer, while no regular changes in the unconverted farmland were detected. This is related to the distribution of fine roots and grass roots in the soil (60% in the upper layer, 40% in the middle layer). No significant differences ($P > 0.05$) (Table 1) were observed in any of the measurements between the two models and unconverted farmland.

The larger the particle size of granular structures, the stronger the anti-erosion of soil when the amount of WSA is the same. Although the amounts of water-stable aggregates were not significantly different between the TL model and TN model but were lower than those of the unconverted farmland, the amounts of water-stable macro-aggregates in the two models were higher than those of the unconverted farmland (Table 1). In January, May, July, September and December the amounts of water-stable aggregates > 5 mm in the upper layer of the triploid *P. tomentosa* + *L. multiflorum* model and the triploid *P. tomentosa* + natural grass model were 6.5% to 49.65% and 34.61% to 95.44% greater than those of the unconverted farmland. In the middle layer of the two models the amounts of WSA were 22.64% to 149.42% and 19.42% to 156.91% and in the lower 0.72% to 87.45% and 18.4% to 91.47% greater than those of the unconverted farmland.

Production of fine roots is quite high and their turnover rate is about 2.2 to 5.0 times greater than that of litter. The input of organic matter from fine roots decomposition is slightly larger than that of litter (Zhang et al., 2000). Fine roots perform a more effective function than litter for soil fertility maintenance (Harris et al., 1977; Grier et al., 1981; McClaugherty et al., 1984; Aber et al., 1985; Vogt et al., 1986). Because natural grass in the TN model grew well and the amount of root biomass was greater than that of *L. multiflorum*, and natural grass which had not been

harvested but died naturally, more organic matter and inorganic nutrients can be returned in the TN model compared to the TL model, therefore it can improve soil structure. *L. multiflorum* is an annual plant with a short life cycle and should be seeded every year. The below-ground environment of roots and soil was disturbed because of ploughing and by seeding, which halted the formation process of WSA of big-particle diameters.

4.5 Correlation between WSA and fine roots (≤ 1 mm) and grass roots

There were significant or extremely significant positive correlations between live roots, dead fine roots (≤ 1 mm), total biomass of fine roots, water-stable aggregates (> 5 mm, 3 to 5 mm) and total water-stable aggregates but negative correlation with water-stable aggregate (1 to 2 mm) (Table 2). It indicates that live fine roots (≤ 1 mm) can enhance big-particle water-stable aggregates and reduce the water-stable aggregate (1 to 2 mm). Dead fine roots can enhance big-particle water-stable aggregates and reduce small-particles, but its function was smaller than live fine roots.

The correlation between grass roots and water-stable aggregates of different particle size was the same as for fine roots. Fine roots (≤ 1 mm) and water-stable aggregates (> 5 mm, 3 to 5 mm, 1 to 2 mm) were highly correlated with correlation coefficient respectively of 0.723, 0.552 and -0.51 , which implies that the function of grass roots cannot be neglected. If we take the unconverted steep slope farmland as control and assume that amount of water-stable aggregates remained constant, fine roots can enhance the amount of big-particle water-stable aggregates and reduce the amount of small-particle water-stable aggregates at the same time.

5 Conclusions

1) Both in the two models of TL and TN, the biomass of fine roots (including live and dead fine roots) in different layers was distributed as follows in a descending sequence:

Table 1 Water-stable aggregates of the three vegetation types (unit: %)

month	sample		WSA size/mm						
			>0.25	0.25-0.5	0.5-1	1-2	2-3	3-5	>5
January	upper layer	L	65.08 (3.25)	6.23 (0.31)	13.77 (0.68)	8.33 (0.41)	4.67 (0.23)	6.51 (0.32)	25.57 (1.28)
		N	63.55 (3.17)	4.36 (0.21)	13.24 (0.66)	5.37 (0.26)	1.53 (0.07)	6.73 (0.33)	32.32 (1.61)
		P	64.80 (3.24)	5.70 (0.28)	14.16 (0.70)	8.67 (0.43)	3.93 (0.19)	8.33 (0.41)	24.01 (1.20)
	middle layer	L	59.43 (2.97)	8.60 (0.43)	14.71 (0.73)	4.81 (0.24)	3.42 (0.17)	6.48 (0.32)	21.41 (1.07)
		N	58.88 (2.94)	4.28 (0.21)	12.15 (0.60)	11.29 (0.56)	1.31 (0.06)	5.54 (0.27)	24.31 (1.21)
		P	65.68 (3.28)	7.05 (0.35)	18.08 (0.90)	10.14 (0.50)	4.47 (0.22)	9.93 (0.49)	16.01 (0.80)
	lower layer	L	53.04 (2.65)	5.83 (0.29)	10.25 (0.51)	6.94 (0.34)	4.89 (0.24)	6.01 (0.30)	19.12 (0.95)
		N	54.86 (2.74)	5.77 (0.28)	9.88 (0.49)	11.19 (0.55)	1.75 (0.08)	6.74 (0.33)	19.53 (0.97)
		P	59.01 (2.95)	7.61 (0.38)	17.55 (0.87)	10.98 (0.54)	4.98 (0.24)	7.69 (0.38)	10.20 (0.51)
May	upper layer	L	67.66 (3.38)	6.58 (0.32)	12.93 (0.64)	7.74 (0.38)	2.79 (0.13)	8.08 (0.40)	29.54 (1.47)
		N	70.01 (3.50)	6.69 (0.33)	10.87 (0.54)	5.46 (0.27)	1.49 (0.07)	6.92 (0.34)	38.58 (1.92)
		P	66.14 (3.30)	6.28 (0.31)	16.21 (0.81)	9.29 (0.46)	4.40 (0.22)	10.22 (0.51)	19.74 (0.98)
	middle layer	L	64.93 (3.24)	6.85 (0.34)	14.08 (0.70)	6.01 (0.30)	3.06 (0.15)	6.97 (0.34)	27.96 (1.39)
		N	64.22 (3.21)	5.23 (0.26)	12.01 (0.60)	9.88 (0.49)	2.56 (0.12)	5.74 (0.28)	28.80 (1.44)
		P	63.88 (3.19)	7.33 (0.36)	19.96 (0.36)	10.29 (0.51)	6.23 (0.31)	8.86 (0.44)	11.21 (0.56)
	lower layer	L	55.87 (2.79)	7.76 (0.38)	10.16 (0.50)	8.95 (0.44)	3.88 (0.19)	5.27 (0.26)	19.85 (0.99)
		N	56.50 (2.82)	5.98 (0.29)	13.82 (0.69)	10.54 (0.52)	1.92 (0.09)	5.06 (0.25)	19.18 (0.95)
		P	58.40 (2.92)	5.78 (0.28)	14.99 (0.74)	8.93 (0.44)	4.56 (0.22)	7.94 (0.39)	16.20 (0.81)
July	upper layer	L	66.10 (3.30)	5.23 (0.26)	9.77 (0.48)	4.33 (0.21)	1.67 (0.08)	9.53 (0.47)	35.57 (1.77)
		N	71.40 (3.57)	5.70 (0.28)	11.82 (0.59)	6.07 (0.30)	1.33 (0.06)	8.68 (0.43)	37.80 (1.89)
		P	60.74 (3.03)	6.72 (0.33)	12.02 (0.60)	7.99 (0.39)	2.06 (0.10)	6.74 (0.33)	25.21 (1.26)
	middle layer	L	63.99 (3.19)	3.31 (0.16)	12.14 (0.60)	3.58 (0.17)	4.94 (0.24)	7.63 (0.38)	32.39 (1.61)
		N	65.35 (3.26)	6.21 (0.31)	13.57 (0.67)	6.15 (0.30)	2.98 (0.14)	7.17 (0.35)	29.27 (1.46)
		P	58.13 (2.90)	4.45 (0.22)	16.50 (0.82)	8.72 (0.43)	2.14 (0.10)	9.18 (0.45)	17.14 (0.85)
	lower layer	L	56.37 (2.81)	6.37 (0.31)	12.50 (0.62)	8.47 (0.42)	1.14 (0.05)	6.91 (0.34)	20.98 (1.04)
		N	60.98 (3.04)	7.76 (0.38)	17.44 (0.87)	6.91 (0.34)	3.01 (0.15)	6.39 (0.31)	19.47 (0.97)
		P	63.50 (3.17)	5.89 (0.29)	13.62 (0.68)	12.96 (0.64)	2.48 (0.12)	7.72 (0.38)	20.83 (1.04)
September	upper layer	L	73.69 (3.68)	3.97 (0.19)	9.01 (0.45)	6.52 (0.32)	1.80 (0.09)	9.87 (0.49)	42.52 (2.12)
		N	73.53 (3.67)	4.20 (0.21)	8.12 (0.40)	5.23 (0.26)	1.67 (0.08)	10.21 (0.51)	44.10 (2.20)
		P	67.51 (3.37)	5.84 (0.29)	10.93 (0.54)	8.85 (0.44)	2.26 (0.11)	10.77 (0.53)	28.86 (1.44)
	middle layer	L	68.14 (3.40)	3.03 (0.15)	7.53 (0.37)	6.96 (0.34)	1.49 (0.07)	8.26 (0.41)	40.87 (2.04)
		N	67.45 (3.37)	4.16 (0.20)	7.23 (0.36)	5.16 (0.25)	2.17 (0.10)	9.60 (0.48)	39.13 (1.95)
		P	59.94 (2.99)	4.56 (0.22)	14.41 (0.72)	9.29 (0.46)	2.11 (0.10)	10.77 (0.53)	18.80 (0.94)
	lower layer	L	63.23 (3.16)	5.66 (0.28)	8.08 (0.40)	10.70 (0.53)	2.10 (0.10)	8.26 (0.41)	28.52 (1.42)
		N	65.56 (3.27)	6.35 (0.31)	15.01 (0.75)	5.41 (0.27)	1.25 (0.06)	8.80 (0.44)	28.74 (1.43)
		P	68.93 (3.44)	7.03 (0.35)	13.58 (0.67)	11.69 (0.58)	3.66 (0.18)	8.88 (0.44)	24.09 (1.20)
December	upper layer	L	65.49 (3.27)	5.63 (0.28)	13.64 (0.68)	6.95 (0.34)	3.43 (0.17)	7.15 (0.35)	28.69 (1.43)
		N	62.76 (3.13)	4.10 (0.20)	7.38 (0.36)	5.19 (0.25)	3.07 (0.15)	9.78 (0.48)	33.24 (1.66)
		P	62.85 (3.14)	5.97 (0.29)	12.94 (0.64)	8.35 (0.41)	3.28 (0.16)	9.62 (0.48)	22.69 (1.13)
	middle layer	L	60.67 (3.03)	3.34 (0.31)	12.61 (0.63)	9.96 (0.49)	1.82 (0.09)	5.62 (0.28)	24.32 (1.21)
		N	64.09 (3.20)	4.89 (0.24)	12.34 (0.61)	8.37 (0.41)	1.89 (0.09)	6.97 (0.34)	29.63 (1.48)
		P	63.05 (3.15)	6.32 (0.31)	13.05 (0.65)	10.53 (0.52)	4.35 (0.21)	8.97 (0.44)	19.83 (0.99)
	lower layer	L	56.64 (2.83)	5.92 (0.29)	9.84 (0.49)	9.83 (0.49)	2.04 (0.10)	6.03 (0.30)	22.98 (1.14)
		N	60.76 (3.03)	5.31 (0.26)	13.24 (0.66)	9.68 (0.48)	2.03 (0.10)	6.83 (0.34)	23.67 (1.18)
		P	67.84 (3.39)	7.63 (0.38)	17.79 (0.88)	12.35 (0.61)	5.64 (0.28)	8.81 (0.44)	15.62 (0.78)

Note : L is *P. tomentosa* + *L. multiflorum*; N is *P. tomentosa* + natural grass; P is farmland. Data out of bracket is mean and in bracket is the standard error.

Table 2 Correlation coefficients of WSAs and fine roots (≤ 1 mm) and grass roots

water-stable aggregate/mm	≤ 1 mm live fine root	≤ 1 mm dead fine root	≤ 1 mm fine root	grass root	≤ 1 mm root
>0.25	0.609**	0.417*	0.606*	0.608*	0.759**
0.25-0.5	-0.163	-0.208	-0.179	-0.116	-0.170
0.5-1	-0.202	-0.094	-0.193	-0.159	-0.212
1-2	-0.393*	-0.462*	-0.425*	-0.402*	-0.512*
2-3	0.070	0.094	0.078	-0.279	-0.205
3-5	0.504**	0.414*	0.513**	0.409*	0.552**
>5	0.545**	0.412*	0.549**	0.594**	0.723**

Note: * means $P < 0.05$; ** means $P < 0.01$.

upper layer, middle layer and lower layer, approximately in ratios of 50:30:20. The biomass of fine root in the TL model was twice that in the TN model. The grass roots were distributed only in the upper and middle layer in the TL model while it occurred in all three layers in the TN model. The roots of grass were found largely in the upper layer both in the two models. The biomass of the grass roots in the TN model was 4.4 times greater than that in the TL model. Because of the harvests, fertilization and fallow ploughing every year, the biomass of grass root was relatively smaller and the biomass of fine roots increased in the TL model. Actually, grass roots and fine roots grow and die at the same time, which is not a simple cumulative process in the mixed grass-forest model (Li et al., 2005) so that the below ground litter provided available nutrition for the triploid *Populus tomentosa*. Because of fewer anthropogenic effects in the TN model, the natural death of grass and fine roots supplied abundant litters for the growth of grass. As a result, the grass roots were quite abundant and well distributed in the upper layer.

2) After four years of converting farmland to forest (grass), water-stable aggregates of upper, middle and lower layers and of unconverted lands did not show any significant difference, whereas water-stable aggregates of big particles in the upper and middle layers were much larger than those of unconverted lands. Water-stable aggregates in the TN model were larger than those in the TL model, which reflects the effects for ameliorating and improving the soil anti-erosion capability. The amount of water-stable big particle aggregates was related to the amount of organic soil matter. The organic carbon mineralized more easily in macro aggregates than in micro aggregates and there is also organic carbon of more recent origin in macro-aggregates (Zhao et al., 2006). That resulted in more effective and decomposable organic matter in forest land, which provided more available nutrition for plant growth. On the other hand, as Elliott (1990) pointed out, organic carbon in micro-aggregates could transfer into macro aggregates, while the organic carbon in macro aggregates is decomposable and involved in the carbon cycle of plants-atmosphere-soil directly.

3) At the initial stages of mixed forest-herbal patterns in the process of converting farmland to forests (grass), the effect of roots (≤ 1 mm) was remarkable in the increase of amount of water-stable aggregates of big-particle (>5 mm, 3 to 5 mm) and decrease of amount of water-stable small particle aggregates (1 to 2 mm), which is consistent with the results of Wu et al. (1997) and Liu and Li (2003). Cheng et al. (2006) thought the roots of herbal layers have a high density with more fibrous roots, they also thought that the value of anti-shearing strength of the density of the unit fibrous root was 2–3 times the roots of trees and regarded as root's "reinforcement". The roots (≤ 1 mm) provided more bonding mineral to the soil by excretion and death, which enhanced the netted structure of the roots on the earth surface, activated the organic

structure of the soil and formed a virtual cycle of matter, energy and information between the roots and soil.

4) The seeded and natural grass in young forests of the triploid *Populus tomentosa* can enhance soil anti-erosion capacity and improve its function of conservation of soil and water. This is the result from fertilization during the course of management that increased the amount of water-stable aggregates, especially that of water-stable aggregates of big-particles (Whalen et al., 2003). Therefore, more attention should be paid to the impact of fertilization (from both organic and inorganic fertilizers) on fine roots and water-stable aggregates, on their amounts and the relation between the water-stable aggregates and soil microbial biomass carbon and nitrogen, soil enzyme, soil microorganism and mycorrhiza. At present, studies abroad mainly involved interactions of aggregate and crops (Martin, 2002; Six et al., 2002; Sainju et al., 2003; Wrisat and Frank, 2004), while Chinese studies have been extended to aggregates related to the restoration of vegetation (Wang and Liu, 2002; Peng et al., 2003; Ning et al., 2005; Yang et al., 2006).

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