Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 1	pp. 79-84	2014

Original Research Paper

Relationship Between Litter Decomposition and Soil Properties Degradation in Six Typical Planted Pure Forests in Mu Us Desert, China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 29-7-2013
Accepted: 21-8-2013

Key Words:
Litter decomposition
Soil properties
Pure forests
Mu Us desert

ABSTRACT

In order to investigate the effect of litter decomposition on soil properties degradation of planted pure forests in southern fringe of Mu Us Desert, China, humus soil and litter (leaf litter and fine roots) were sampled in six typical forests; three treatments as "soil + leaf litter", "soil + roots" and CK were set for laboratory incubation experiment in this research. The results showed that soil properties in mixed-litter treatments increased at different extent in contrast to CK by litter decomposition. After analysing the increase ratios of soil properties by PCA (principal component analysis) method, as for the comprehensive effect, both leaf litter and roots decomposition showed negative effect in the *P. simonii* (S+L: -1.589; S+R: -1.671) and *C. microphylla* (S+L: -0.609; S+R: -1.081) forests soil. However, they showed positive effect of soil comprehensive properties in *R. pseudoacacia* (S+L: 0.392; S+R: 0.258), *S. matsudana* (S+L: 1.343; S+R: 0.956) and *A. fruticosa* (S+L: 0.914; S+R: 0.306) forests soil. As for the *H. rhamnoides* forest, leaf litter resulted in negative effect (-0.451) and roots resulted in positive effect (1.232). In general, litter decomposition of *P. simonii* and *C. microphylla* aggravate the soil degradation, and *R. pseudoacacia*, *S. matsudana* and *A. fruticosa* litter decomposition are more beneficial for soil properties than the other three plants after incubation.

INTRODUCTION

The southern fringe of Mu Us Desert is located in the transitional zone between Mu Us Desert and Loess Plateau of China. Desertification is severe in this region and results in a lot of environmental problems (Wu & Ci 2002). To curb desertification and alleviate its impact on environment and human life, the local governments have implemented a variety of measures to restore vegetation on sand land in this region (Li 2004). And large scale forests were planted due to their tolerance of the poor nutrient conditions and good adaptivity to windy and sandy environments. In addition, field experiments have revealed that the planted forests played a pivotal role in vegetation restoration and desertification prevention (Li et al. 2003, Ren et al. 2002). However, some of the forests have not developed in a good status, moreover, soil degradation occurred in the forests. We know that forest soil degradation is a very complex process in the sand region. In addition to unfavourable natural conditions, the internal factors of forest also can not be ignored.

The exactly internal factors which caused soil degradation are unknown by now. We just generally understand that soil properties degradation may be simultaneously affected by many variables such as litter decomposition, roots selective nutrient absorption, excretion and so on. In the forest ecosystem, decomposition of litter, by which organic matter and nutrients are returned to the forest soils, is a primary mechanism and has an important effect on the soil chemical and biological properties (Alhamd et al. 2004, Arunachalam et al. 1998, Lemma et al. 2007). Therefore, a better understanding of the relationship between litter decomposition and soil properties in the fragile ecological environments is critical for elucidating the principle of the soil degradation.

The objectives of this study were: (1) to investigate the effect of litter decomposition on soil properties of six typical planted pure forests in southern fringe of Mu Us Desert by lab incubation experiments; (2) to get the effect sequence of litter decomposition on six typical forests soil properties degradation. Valuable scientific information was provided to prevent soil degradation and continuous plantation obstacle.

MATERIALS AND METHODS

Study area: The study sites are located in Wanmu plantation forest region, Jingbian county, Shaanxi Province, China. This area belongs to a typical windblown sand region of northern Shaanxi. It has a warm temperate and semi-arid climate, showing obvious continental climatic characteristics. The mean annual temperature ranges from 7.8°C to 9.1°C, and the total annual precipitation is from 316 mm to 450 mm, of which 60-70 % is principally concentrated in July, August and September, mostly in a few heavy storms. The

annual evaporation is 1127-1546 mm, accumulated temperature above 10°C is 2600-3370°C, the annual solar radiation is 2700-3100 h, and the frost-free period is about 134-172 d. Local soil belongs to loessial sandy soil. Three typical planted pure broadleaved forests as *Populus simonii*, *Robinia pseudoacacia*, *Salix matsudana* and three typical planted pure shrub forests as *Amorpha fruticosa*, *Caragana microphylla* and *Hippophae rhamnoides* were selected for this study.

Sampling: In the typical sites of the six forests, set up standard plots (Table 1) of 20m×20m and measured the site factors and tree growth indexes. In the standard plots randomly selected 5 quadrats of 1m×1m, collected the humus layer of soil at 0-10 cm depth in each quadrat after clearing the litters above the ground, then bulked to one composite sample per stand and took to laboratory. Leaves, roots and gravel were removed from the soil samples by using 5 mm mesh sieves. Then samples were stored in sealed bags at room temperature until incubation.

Newly shed leaf litter was collected from the forest floor and dead fine roots ($\phi < 0.5$ cm) were dug up from the upper 50 cm of soil in the aforementioned forest sites. Thereafter, all litter samples were taken back to the laboratory, gently washed and oven-dried at 65°C for 24 hours to achieve constant weight. Then the dry litters samples were ground by using laboratory mill ($\phi = 1$ mm) for incubation.

Laboratory incubation: Three treatments including soil + leaf litter (S+L), soil + roots (S+R) and control soil (CK) were set for laboratory incubation experiment. Litter and soil were thoroughly mixed with the ratio 2:100 to final weight 2.5 kg. Placed mixed samples in the glass jar ($\phi = 18$ cm, H=16 cm) and each jar was equipped with a lid with 4 holes (1 cm diameter) to permit free gas exchange. During the incubation, soil moisture content was monitored and maintained at 50% of the water holding capacity by adding distilled water weekly. All the external conditions were kept consistent among the samples. The mixed soil samples were incubated at room temperature (20-25°C) for 120 days until the litter decomposed completely. All the experiments were done in triplicate.

Soil properties measurement: Fresh soil was picked up to test microbe quantities. The left soil samples were air-dried, and then grounded in a laboratory mill ($\phi = 1$mm) for biological and chemical properties measurements.

Among soil biological properties, microbe quantities were measured by dilution-plate method (Nanjing Institute of Soil Science 1985) (bacteria-beef extract peptone agar culture medium, fungi-potato dextrose agar culture medium, actinomyces-GAO 1th synthetic culture medium). Enzymes were measured by the methods of Guan (1986). Sucrase activity was measured by $Na_2S_2O_3$ titration method, protease activity by ninhydrin colorimetry method, polyphenoloxidase activity by iodine titrimetry method, phosphatase activity by disodium phenyl phosphate colorimetric method (in pH 8.5 borate buffer), urease activity by sodium phenate-sodium hypochlorite colorimetric method, catalase activity by $KMnO_4$ titrimetry method, and dehydrogenase activity by triphenyl tetrazolium chloride colorimetric method.

Soil chemical properties were measured by following methods of Lu (1999). Soil pH was measured by glass electrode method (the ratio of soil to water was 1:2.5), organic matter by oil bath-K_2CrO_7 titration method, CEC by NaOAc-NH_4OAc and blaze photometer method, available nitrogen by micro-diffusion technique after alkaline hydrolysis, available phosphorus by bicarbonate extraction method, and available potassium by NH_4OAc and blaze photometer method.

Data analysis: All data reported were mean values of three replications. Statistical procedures were carried out using the software packages SPSS version 17.0 for Windows. One-way ANOVA and least significant difference (LSD) test were used for determining whether differed significantly ($P < 0.05$) among the treatments.

The effect of litter decomposition on soil properties was analysed by comparing the variation of soil properties between soils mixed with litter and control soil after incubation. However, the variations were various after incubated with litter, so it is difficult to explain the comprehensive effect of the litter decomposition on soil properties by analysing one single soil property index. Hence, principal component analysis (PCA) was used in this study (Lin & Zhang 2005). Based on principal component model, the sum principal components were calculated. Then we analysed the comprehensive effect of the litter decomposition on soil properties by them.

Among the selected soil properties, most of them are more beneficial to the tree growth when the values are higher except pH value. Therefore, the increased ratios (%) of soil properties except pH were chosen for extracting principal components whose characteristic values are above 1. The sum principal component is determined with the equation as follows:

$$F = \lambda_1/(\lambda_1+\lambda_2+.....+\lambda_n) \times F_1 + \lambda_2/(\lambda_1+\lambda_2+.....+\lambda_n) \times F_2 + ... + \lambda_n/(\lambda_1+\lambda_2+.....+\lambda_n) \times F_n$$

Where F_i is principal component whose characteristic value is above 1, λ_i is the characteristic value. If $F > 0$, it indicates that litter decomposition results in positive effect on soil properties, if $F < 0$, it results in negative effect.

RESULTS

Effect of leaf litter decomposition on soil properties: The

properties of soil samples (S+L, CK), which have been incubated for 120 days, are given in Table 2. From the Table 2 we can see that all the properties were significantly affected ($P < 0.05$) by leaf litter addition in contrast to control soil. Three enzymes (polyphenoloxidase, phosphatase, dehydrogenase) activities, organic matter and available N were higher than control treatment in the tested six forest soils by leaf litter addition. The tested microbial quantities, and sucrase, protease and catalase activities were higher in mixed-leaf litter treatment than CK in the *R. pseudoacacia*, *S. matsudana*, *A. fruticosa* and *C. microphylla* forest soils.

In the *P. simonii* forest soil, protease, urease and catalase activities were lower than those in CK at 15.81%, 9.09 % and 22.22%, respectively. Fungi quantity was lower than control at 10.00%, but bacteria quantity and actinomycetes quantity were higher than CK. CEC and available K were higher than CK at 12.01% and 153.89%, but available P was lower than CK at 31.20%. In the *R. pseudoacacia* forest soil, just CEC was slightly lower than CK at 2.15%. In the *S. matsudana* forest soil urease activity and available P were lower than CK. In the *A. fruticosa* forest soil, available P and K were lower than CK at 12.34% and 6.57%. In the *C. microphylla* forest soil, CEC and available P were slightly lower than CK. In the *H. rhamnoides* forest soil, 4 enzymes activities (sucrase, protease, urease, catalase) were lower than CK and ranged from 3.97% to 34.90%. Bacteria and actinomycetes quantities were lower than CK at 36.08% and 97.84%.

Effect of root decomposition on soil properties: From the Table 2, we can see that root decomposition did not show any significant effect on protease activity (*P. simonii* forest soil and *A. fruticosa* forest soil), pH (*A. fruticosa* forest soil), available P (*S. matsudana* forest soil and *H. rhamnoides* forest soil). However, phosphatase and dehydrogenase activities, fungi quantity, organic matter and available N were higher than control treatment after incubation with roots in the tested six species forest soil.

In the *P. simonii* forest soil, three enzymes activities (polyphenoloxidase, urease, catalase), actinomycetes quantity and available P were lower than those in CK. In the *R. pseudoacacia* forest soil, protease activity was significantly, but slightly lower than CK. Bacteria, actinomycetes quantity and CEC were lower than CK at 36.59%, 86.05% and 8.24% respectively. In the *S. matsudana* forest soil, protease activity was slightly lower than CK, and urease activity lower than CK at 19.23%. Three microbes quantities increase highly by root addition. And as for chemical properties available P was lower than CK. In the *A. fruticosa* forest soil, roots decomposition showed negative effect on urease activities and available P. In the *C. microphylla* forest soil, sucrase and urease were lower than CK. Bacterial quantity, and available P, K were lower than CK. In the *H. rhamnoides* forest soil, three enzymes activities (protease, urease, catalase) and two microbes quantities (fungi and actinomycetes) were lower than CK.

The comprehensive effect of litter decomposition on soil properties: We used principal component analysis to estimate the comprehensive effect of litter decomposition on soil properties. Based on analysing the increased ratios of mixed-leaf litter treatment soil properties, we thereby derived the principal component function:

$$F = 0.453F_1 + 0.284F_2 + 0.160F_3 + 0.103F_4 \quad ...(1)$$

Where F_1, F_2, F_3, F_4 indicated the first, second, third and fourth principal component with characteristic value above 1.

And at the same time, we also analysed the mixed-roots treatment soil properties of six species forest soil, and the principal component model was expressed as follows:

$$F = 0.359F_1 + 0.290F_2 + 0.202F_3 + 0.148F_4 \quad ...(2)$$

The result are shown in Fig. 1, which showed that, both leaf litter and roots decomposition, have positive effect of soil comprehensive properties in *R. pseudoacacia* (S+L: 0.392; S+R: 0.258), in *S. matsudana* (S+L: 1.343; S+R: 0.956) and in *A. fruticosa* (S+L: 0.914; S+R: 0.306) forest soil. However, in the *P. simonii* (S+L: -1.589; S+R: -1.671) and *C. microphylla* (S+L: -0.609; S+R: -1.081) forest soil, the two kinds of litter showed negative effect of the soil comprehensive properties. As for the *H. rhamnoides* forest, leaf litter resulted in negative effect (-0.451) and roots resulted in positive effect (1.232).

Table 1: Standard plots of planted pure forests.

Forest type	Age (a)	Elevation (m)	Aspect	Slope (º)	BHD (cm)	Height (m)	Density (individul·hm^{-2})
P. simonii	20	1350	NE90°	10°	12.07	6.1	1667
R. pseudoacacia	20	1350	NW10°	5°	15.59	6.3	1667
S. matsudana	55	1210	SW65°	6°	58.18	10.5	494
A. fruticosa	8	1350	0°	0°	-	-	-
C. microphylla	20	1350	NW15°	5°	-	-	-
H. rhamnoides	15	1350	NW15°	5°	-	-	-

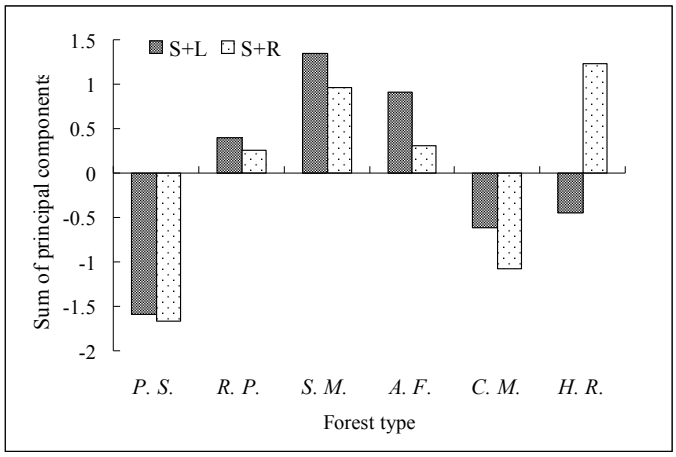

Fig. 1: The comprehensive effect of litter decomposition on soil properties.
Note: *P.S.-P. simonii*; *R.P.-R. pseudoacacia*; *S.M.-S. matsudana*; *A.F.-A. fruticosa; C.M.-C. microphylla*; *H.R.-H. rhamnoides*
S+L = Soil + Leaf litter; S+R = Soil + Roots

DISCUSSION

Due to the special physiological traits and drought resistance, forests were established on a large scale in the Mu Us Desert, as pure stands consisting of single dominating species. This kind of silvicultural practice is convenient for forest management, but may result in soil degradation particularly after two or more rotations under continuous cropping. As for the pure forests, most of the researches focus on its function in windbreaks and sand fixation (Dong & Zhang 2001, He & Zhang. 2003), however, little information concerning the internal mechanism by which soil degradation occurs and tree growth is reduced under continuous cropping. In order to deeply analyse the internal reason, which caused forest soil degradation, we collected leaf litter and fine roots in six typical forests in the Mu Us Desert for the lab incubation experiment.

Based on the results of the mixed-litter incubation experiment, it is clearly showed that most of the soil properties changed significantly by litter decomposition. Especially, some of the soil properties were lower than CK after incubation. It indicated that litter decomposition is inhibiting effect on some soil properties.

Soil enzymes play a key role in soil nutrient cycling. Study has been published indicating that enzyme activity can be used as index of soil productivity or microbial activity (Alef et al. 1995), so soil enzymes are identified as the most important parameters in evaluating soil quality. Some enzymes activities in mixed-litter treatment were higher than CK after incubation. May be litters have released various enzymes or metabolites into the soil to enhance the enzymes activity (Guan 1986). At the same time different litter types released different metabolites which may have inhibited effect of some enzymes activities. For this reason some enzyme activities were lower in mixed-litter treatment than CK.

As for the soil chemical properties, the different values of mixed-litter treatment and CK may be caused by two reasons. First, some litter released sufficient chemicals directly into soil to increase the nutrient, but some have not released enough, which depleted some nutrients during the decomposition process; second, the microbes and enzymes activities affect the chemical properties indirectly (Alhamd et al. 2004, Arunachalam et al. 1998, Lemma et al. 2007).

The single tree is the main dominating species in the planted pure forest. This phenomenon results in the litter of the dominating tree making the main constituent in the pure forest. As a long term consequence the single litter decomposition may release or absorb the special chemical materials to the soil, which may alter the original balance of the soil properties. This problem will be exacerbated in the second rotation under continuous planting. Some soil properties may be increased and some be decreased. As the soil properties decreased, it will cause the continuous planting obstacle, resulted in soil degradation and decline in tree growth. The study of Liu Shirong showed that decrease in soil nutrients and decline in tree growth occurred in pure larch plantation after the continuous planting (Liu et al. 1998). In 2007, Nèble et al. (2007) had reported that soil microbes and enzymes activity showed declining trend as the effect of litter decomposition in the planted pure forest.

The conditions of lab incubation experiment are very difficult to consistent with the outdoor forest environment. However, this research controlled all soil samples in the same incubation condition and accelerated the litter decomposition rate. Even if the results can not reflect the true outdoor

Table 2: The variation of soil properties after decomposition with leaf litter and roots.

Soil properties	*P. simonii*			*R. pseudoacacia*			*S. matsudana*			*A. fruticosa*			*C. microphylla*			*H. rhamnoides*		
	S+L	S+R	CK	S+L	S+R	CK	S+L	S+R	CK	S+L	S+R	CK	S+L	S+R	CK	S+L	S+R	CK
Biological properties																		
Sucrase ($mL \cdot g^{-1} \cdot d^{-1}$)	1.333a	1.102b	0.977c	1.284a	1.273b	1.106c	1.146a	1.036b	0.743c	1.273a	1.246b	0.906c	1.279a	1.194b	1.249c	0.895a	1.064b	0.932c
Protease ($\mu g \cdot g^{-1} \cdot d^{-1}$)	0.900a	1.069b	1.069b	1.412a	1.359b	1.382c	1.159a	1.056b	1.082c	1.226a	1.165b	1.153b	1.156a	1.024b	0.997c	1.141a	0.974b	1.263c
Polypheno-loxidase ($mL \cdot g^{-1}$)	0.841a	0.624b	0.638c	1.053a	1.085b	0.777c	1.090a	1.006b	0.655c	0.777a	0.592b	0.493c	0.899a	0.792b	0.644c	1.209a	0.986b	0.832c
Phosphatase ($mg \cdot kg^{-1}$)	6.438a	5.843b	5.226c	8.495a	11.010b	5.477c	7.672a	6.309b	3.740c	10.233a	9.227b	4.174c	11.490a	12.588b	6.780c	9.958a	10.393b	6.186c
Urease ($mg \cdot g^{-1} \cdot d^{-1}$)	0.020a	0.016b	0.022c	0.052a	0.051a	0.044b	0.024a	0.021b	0.026c	0.046a	0.028b	0.042c	0.049a	0.039b	0.047c	0.035a	0.030b	0.038c
Catalase ($mL \cdot g^{-1}$)	0.945a	0.780b	1.215c	1.635a	1.550b	1.375c	1.310a	1.194b	0.995c	2.065a	2.090b	1.260c	1.465a	1.495b	1.360c	1.455a	1.335b	2.235c
Dehydrogenase ($mL \cdot g^{-1} \cdot d^{-1}$)	0.366a	0.354b	0.164c	0.517a	0.399b	0.179c	0.386a	0.272b	0.120c	0.523a	0.385b	0.199c	0.503a	0.586b	0.284c	0.372a	0.227b	0.182c
Bacteria ($10^5 \cdot g^{-1}$)	8.55a	2.55b	1.50c	38.00a	13.95b	22.00c	19.00a	12.40b	1.35c	8.75a	7.95b	4.30c	324.50a	111.00b	210.00c	3.10a	4.65b	4.85c
Fungi ($10^2 \cdot g^{-1}$)	9.00a	17.50b	10.00c	48.00a	38.00b	25.50c	25.50a	19.00b	3.50c	47.50a	36.50b	4.50c	24.50a	20.50b	10.00c	148.50a	134.00b	40.50c
Actinom-ycetes ($10^5 \cdot g^{-1}$)	39.50a	10.50b	19.00c	200.00a	18.00b	129.00c	116.50a	85.40b	16.50c	156.50a	131.50b	29.00c	24.50a	28.40b	9.45c	0.27a	0.10b	12.50c
Chemical properties																		
pH	8.04a	8.31b	8.17c	7.73a	7.96b	8.20c	8.15a	8.29b	8.18a	7.70a	8.05b	7.98b	7.34a	7.71b	7.87c	7.81a	8.23b	8.05c
Org-M ($g \cdot kg^{-1}$)	21.66a	15.60b	13.60c	24.94a	22.90b	16.74c	16.45a	18.40b	9.22c	29.10a	24.93b	21.14c	24.99a	23.12b	20.02c	24.35a	24.76b	15.05c
CEC ($cmol \cdot kg^{-1}$)	5.13a	5.12a	4.58b	5.46a	5.12b	5.58c	4.37a	4.27b	3.87c	10.53a	10.78b	10.35c	4.80a	5.24b	5.02c	5.47a	5.48b	4.27c
Available N ($mg \cdot kg^{-1}$)	38.15a	26.95b	23.80c	56.00a	56.70a	46.20b	37.80a	30.63b	23.63c	60.60a	49.00b	35.00c	60.20a	61.30b	48.70c	50.10a	48.30b	33.60c
Available P ($mg \cdot kg^{-1}$)	6.77a	8.88b	9.84c	11.78a	11.00b	9.46c	10.03a	10.81b	10.60b	10.94a	11.03a	12.48b	8.51a	7.35b	9.28c	8.51a	7.74b	7.73b
Available K ($mg \cdot kg^{-1}$)	411.3a	177.1b	162.0c	229.0a	85.7b	67.8c	194.9a	104.5b	121.3c	216.1a	243.4b	231.3c	118.8a	74.2b	92.0c	88.9a	162.5b	56.6c

condition, they still have valuable scientific basis for prevention of soil degradation and continuous plantation obstacle.

The result indicated that, from the view of sustainable development of the local forests, *R. pseudoacacia*, *S. matsudana* and *A. fruticosa* were suitable for successive planting in this area during a certain time than the other three plants. A low-cost and effective way to prevent soil properties degradation in pure forest is to develop mixed stand in future afforestation. Plant rotation with different tree species should be adopted instead of continuous pure *P. simonii* and *C. microphylla* plantation in order to maintain long term stability of soil fertility and forest productivity of plantations.

As the previous studies showed, not only the chemical components of leaf litter and roots are different (Lemma et al. 2007), but also the way to release chemical material to soil is not the same (Zhang et al. 2009). Leaf litter and roots play different roles in the forest ecosystem. This research showed that some of the soil properties changed at different direction after incubating with leaf litter and roots. It proved that although leaf litter and roots are homologous litter of the tree, when they are mixed with soil, the effects are not consistent. Incongruities in litter scale between above ground and below ground have impeded our understanding. It is very difficult to calculate the ratio of the upper and under ground litter. In this research we just have the effect of leaf litter and roots separated-decomposition on soil properties. We will focus on measuring the exact ratio of leaf litter and roots, to find the effect on soil properties in the future research.

ACKNOWLEDGMENTS

This research was supported by National Natural Science Foundation of China (No. 31070630).

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