Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 14	No. 2	pp. 325-330	2015

Original Research Paper

Effect of Litter Decomposition on Soil Polarization in Two Typical Planted Pure Broadleaved Forests in the Gully Region of Loess Plateau, China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 2-12-2013
Accepted: 16-1-2014

Key Words:
Litter decomposition
Soil polarization
Broadleaved forests
Loess plateau
Robinia pseudoacia
Betula platyphylla

ABSTRACT

Soil polarization is a new concept which describes the deviation of soil properties of planted pure forest from its original equilibrium status towards an extreme condition due to long-term growth or continuous planting of single tree species. It is thought to be one obstacle of forest. In order to investigate the effect of litter decomposition on soil polarization of planted forests in the gully region of Loess Plateau, China, humus soil and litter were sampled in two typical broadleaved forests, and 4 treatments as "soil + leaf litter", "soil + roots", "soil + leaf litter + roots", and CK were set for laboratory incubation experiment in this research. The results showed that polarizations of different properties were variable, in both direction and degree, after the incubation with litters. Based on analyzing the polarization ratios by PCA (principal component analysis) method, the results of comprehensive soil properties were showed as follows: in the *Robinia pseudoacia* forest soil, both of leaf litter and roots resulted in negative polarization, and leaf litter showed greater effect than roots; in the *Betula platyphylla* forest soil both of leaf litter and roots resulted in negative polarization, and also leaf litter showed greater effect than roots. When leaf litter and roots mixed-together with the soil, the interaction sequence is *R. pseudoacia* (0.497) > *B. platyphylla* (-0.466). The result indicated that leaf litter and roots when mix-incubated with forest soil showed promoting effect on soil properties in the *R. pseudoacia* forest soil, and showed inhibitory effect on soil properties in *B. platyphylla* forest soil. In general, litter decomposition in *R. pseudoacia* forest soil was more beneficial for soil properties than *B. platyphylla*.

INTRODUCTION

The gully region of Loess Plateau in China is well known for its serious soil erosion in the world. Since the late 1990s, the Chinese Central Government has enacted a policy "Shift from Cropland to Forest or Grassland" for the restoration of vegetation, with the aim of controlling soil and water losses and improving the ecological environment of the area (Du et al. 2007, Wang et al. 2011). Due to this policy, a lot of planted pure forests such as *Betula platyphylla* and *Robinia pseudoacia* were planted in the local place. In addition, there are some studies which proved that the planted forest has played an important role in water and soil conservation in the gully region (Jiao et al. 2007). However, recently some researchers discovered that the planted pure forests did not develop in good status, and some problems occurred in the planted pure forests along with trees continuously planting for long term, such as soil fertility declines, slow tree growth, and natural regeneration ceases (Li et al. 2008, Liu et al. 1998). If the problems become more serious, the ability of planted pure forests for water and soil conservation will be decreased, and the ecosystem will be destroyed again. In order to deeply analyze the reason of soil degradation of the planted pure forest, a new concept of soil polarization (Liu et al. 2007) was presented. Each tree species has unique biological and ecological characteristics, and the presence of single tree species in planted pure forest will result in selective nutrient absorption and special environmental effects (Liu et al. 1998, Liu & Qiang 2002), which will cause the soil to deviate from its original equilibrium status and gradually develop toward an unbalanced or extreme status. For example, some nutrients content may increase in the soil while others may decrease; some soils become more acidic while others become more alkaline; some biological properties are improved while others may be worsened. These changes describe the effect which is called "soil polarization", which was thought to be the fundamental obstacle to continuous growth of planted pure forest. Based on this principle, models were established to evaluate the soil properties of planted pure forests in the gully area of the Loess Plateau and the results showed that there was tendency of polarization in the local forests soil (Liu et al. 2009).

However, the exact reason of soil polarization is unknown by now. We just generally understand that soil polarization is a complicated ecological process which may be simultaneously affected by many variables, such as litter decomposition, roots selective nutrient absorption, excretion and so on. In the forest ecosystem plant litter decomposition plays a critical role in the processes of nutrient cycling and organic matter turnover within ecosystem (Gallardo & Merino 1993, Gholz et al. 1986, Giai & Boerner 2007), and these processes are important determinants of soil properties. Therefore, a better understanding of the relationship between litter decomposition and soil properties is helpful to analyze the principle of the soil polarization.

In this research we chose two typical planted pure broadleaved forests, *Betula platyphylla* and *Robinia pseudoacia,* as the study forests. The objectives of this study were, (1) to investigate the effect of litter decomposition on soil polarization the two forests in gully region of Loess Plateau by lab incubation experiments; and (2) to get the sequence of soil polarization of forests soil after litter decomposition. Valuable scientific information was provided to prevent soil degradation and continuous plantation obstacle.

MATERIALS AND METHODS

Study area: The study sites are located in Yehe plantation forest region, Chunhua county, Shaanxi Province, China. This area belongs to a typical gully region of Loess Plateau. It has a warm temperate and semi-humid climate with an average annual temperature 10.5C°. The average annual precipitation is 600.6 mm, average frost-free period is approximately 190 days.

Sampling: In the typical sites of the three forests, standard plots of 20m × 20m were set up and the site factors measured (Table 1). In the standard plots, after removal of the litter of each plot, the humus layer soil (0-10cm) of 5 quadrats plots was collected and mixed completely, and then the portion of soil was randomly selected and taken to the laboratory. After the visible litter, roots and organic residues in soil sample were removed, the fresh soil sample was sieved through 5-mm mesh and stored in plastic bags for mixing with the litter.

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 65C° for 24 hours to achieve constant weight. Then the dry litter samples were grinded by using laboratory mill ($\Phi = 1$ mm) for incubation.

Laboratory incubation: Four treatments including soil + leaf litter (S+L), soil + roots (S+R), soil + leaf litter + roots (S+L+R, leaf litter and roots with ratio 1:1) 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. Mixed samples were placed 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 (20-25C°) for 120 days until the litter decomposed completely. All the samples have been done in triplicate.

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

Among the soil biological properties, microbial quantities were measured by dilution-plate method (bacteria-beef extract peptone agar culture medium; fungi-potato dextrose agar (PDA) culture medium; actinomyces-GAO 1th synthetic culture medium) (Nanjing Institute of Soil Science 1985). Enzymes were measured by the methods as follows (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 (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 the 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 data differed significantly ($P< 0.05$) among the treatments.

We fixed the properties of control soil as the equilibrium status. The effect of litter decomposition on soil properties was analyzed 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 analyzing single soil property index. Hence, principle component analysis (PCA) was used to analyze the comprehensive effect of different litter decomposition on soil properties polarization. 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 are chosen for extracting principal components. Based on principal component model, the sum principal components (F) were calculated. Then we analyzed the comprehensive effect of the litter decomposition on soil polarization by them. If $F > 0$, it indicates that litter decomposition results in positive polarization on soil properties, and if $F < 0$ it results in negative polarization.

The interaction between leaf litter and roots is estimated by the principle as followed. Presume that there is no interaction between leaf litter and roots on soil properties during incubation, then the soil properties values can be expressed as the formula:

$$T_{LR} = aP_L + bP_R$$

Where, T_{LR} is the theoretical values of soil properties after the leaf litter and roots mixed incubation; P_L and P_R represent practical values after leaf litter and roots separated incubation; a, b express the percents of leaf litter and roots in the mixed sample (the values of a, b are 50%). If theoretical value (T_{LR}) and the practical value (P_{LR}) are not equal, this indicates that there is interaction between leaf litter and roots. If $P_{LR} > T_{LR}$, this indicates that interaction is positive, and if $P_{LR} < T_{LR}$, this indicates that interaction is negative.

RESULTS

Effect of leaf litter and roots separated-decomposition on soil polarization: The properties of soil samples (S+L, S+R, CK), which have incubated for 120 days, are given in Table 2. We can see that in the *B. platyphylla* forest soil, protease activity in mixed-leaf litter soil, catalase activity and available N in mixed-roots soil did not have significant differences in contrast to control soil. Also the pH value did not change significantly by litter addition. This result showed that the soil properties above do not have extreme development after decomposition with litter. However, sucrase, urease and dehydrogenase activities, bacteria and fungi quantities, organic matter, and CEC were higher than those in the CK at 5.18%~71.72% by litter addition. Catalase activity, available N in mixed-leaf litter treatment and polyphenoloxidase, phosphatase in mixed-roots treatment were higher than CK at different extent. The results indicated that leaf litter decomposition resulted in positive polarization of catalase activity and available N content. Actinomycetes quantity, available P and available K in the two mixed litter treatment were lower than those in CK. Polyphenoloxidase and phosphatase activities in mixed-leaf litter treatment and protease in mixed-root treatment are also lower than CK. The results showed that leaf litter decomposition resulted in negative polarization of soil properties above.

As for the *R. pseudoacia* forest soil, with exceptions of urease activity, pH value and CEC in mixed-leaf litter soil, other properties were significantly affected by litter addition in contrast to CK. Protease activities were lower than CK at 5.34% and 12.01% after decomposition with leaf litter and roots separately. Polyphenoloxidase activities were lower than CK at 13.64% and 11.69%. And available P contents were also lower than CK at 38.64% and 42.27% after decomposition with the two kinds of litter. The result showed that, both leaf litter and roots decomposition resulted in negative polarization of soil protease activity, polyphenoloxidase activity and available P contents. Organic matter was higher than CK at 12.44% and 12.11% after decomposition with leaf litter and roots separately. Available N contents were higher than CK at 33.50 % and 37.93 %. And available K contents were also higher than CK at 91.88 % and 15.61 % after decomposition with the two kinds of litter. The result showed that both leaf litter and roots decomposition resulted in positive polarization of soil organic matter, available N and available P content.

We used principal component analysis to estimate the comprehensive effect of litter decomposition on soil polarization. We get three principal components as 10.545, 2.990 and 1.465. From Fig. 1, we can see that the first principal component can reflect the main information of soil properties including sucrase, polyphenoloxidase, phosphatase, catalase, dehydrogenase activities, bacteria, fungi, actinomycetes quantities, CEC, and available N, P, K content. The second principal component can reflect the main information of soil protease, urease activities, and organic matter contents.

We thereby derived the principal component function as follows:

$$F = 0.703F_1 + 0.199F_2 + 0.098F_3 \quad ...(1)$$

Where F_1, F_2, F_3 indicated the first, second and third principal component which characteristic value was above 1.

Based on the sum of principal component values (F), which reflect the total effect of litter decomposition on soil properties polarization, the species can be ordered as follows: *R. pseudoacia* leaf litter (3.046) > *R. pseudoacia* roots (1.085) > *B. platyphylla* leaf litter (-1.430) > *B. platyphylla* roots (-2.701). This result showed that according to the comprehensive soil properties, in the *R. pseudoacia* forest soil, both of leaf litter and roots resulted in negative polariza-

Table 1: Standard plots of planted pure forests in the loess gully region.

Forest type	Age (a)	Elevation (m)	Aspect	Slope (°)	BHD (cm)	Height (m)	Density (individul·hm^{-2})
Betula platyphylla	35	1180	NE20°	25°	11.41	9.8	4400
Robinia pseudoacia	22	1210	SW60°	25°	11.91	7.95	2364

Table 2: Effect of leaf litter and roots separated-decomposition on soil properties polarization in pure planted broadleaved forests.

Soil properties	*B. platyphylla*			*R. pseudoacia*		
	S+L	S+R	CK	S+L	S+R	CK
Biological properties						
Sucrase (mL·g^{-1}·d^{-1})	1.286 a	1.378 b	1.161 c	1.298 a	1.296 a	1.297 a
Protease (μg·g^{-1}·d^{-1})	1.254 a	1.120 b	1.249 a	0.922 a	0.857 b	0.974 c
Polyphenoloxidase (mL·g^{-1})	0.240 a	0.273 b	0.252 c	0.133 a	0.136 b	0.154 c
Phosphatase (mg·kg^{-1})	6.710 a	10.096 b	9.730 c	16.955 a	22.007 b	5.546 c
Urease (mg·g^{-1}·d^{-1})	0.079 a	0.060 b	0.057 c	7.195 a	5.992 b	4.947 c
Catalase (mL·g^{-1})	1.200 a	1.050 b	1.050 b	1.250 a	1.090 b	0.835 c
Dehydrogenase (mL·g^{-1}·d^{-1})	0.636 a	0.687 b	0.522 c	0.841 a	0.390 b	0.179 c
Bacteria (×10^{5}·g^{-1})	6.80 a	6.63 b	3.96 c	10.05 a	8.80 b	1.50 c
Fungi (×10^{2}·g^{-1})	4.70 a	4.00 b	3.00 c	13.00 a	10.50 b	5.50 c
Actinomycetes (×10^{5}·g^{-1})	16.30 a	14.55 b	17.80 c	17.60 a	9.65 b	8.30 c
Chemical properties						
pH	7.91 a	7.75 a	7.83 a	7.62 a	7.37 b	7.60 a
Org. matter (g·kg^{-1})	64.66 a	58.67 b	51.06 c	43.83 a	43.70 b	38.98 c
CEC (cmol·kg^{-1})	16.91 a	15.19 b	14.11 c	16.39 a	17.79 b	16.64 a
Available N (mg·kg^{-1})	103.25 a	86.10 b	85.75 b	94.85 a	98.00 b	71.05 c
Available P (mg·kg^{-1})	11.95 a	11.39 b	12.37 c	8.09 a	7.09 b	13.19 c
Available K (mg·kg^{-1})	125.3 a	156.2 b	166.7 c	212.6 a	128.1 b	110.8 c

Table 3: Practical (P_{LR}) values of soil properties after mix-incubated forest soil with leaf litter and roots.

Soil properties	*B. platyphylla*	*R. pseudoacia*	Soil properties	*B. platyphylla*	*R. pseudoacia*
Sucrase(mL·g^{-1}·d^{-1})	1.309	1.325	Fungi (×10^{2}·g^{-1})	8.30	11.00
Protease (μg·g^{-1}·d^{-1})	1.276	0.865	Actinomycetes (×10^{5}·g^{-1})	15.00	18.50
Polyphenoloxidase (mL·g^{-1})	0.261	0.136	pH	7.92	7.27
Phosphatase (mg·kg^{-1})	10.074	24.097	Organic matter (g·kg^{-1})	61.39	38.85
Urease(mg·g^{-1}·d^{-1})	0.065	9.514	CEC (cmol·kg^{-1})	15.28	17.88
Catalase (mL·g^{-1})	1.205	1.125	Available N (mg·kg^{-1})	86.45	101.15
Dehydrogenase (mL·g^{-1}·d^{-1})	0.973	0.566	Available P (mg·kg^{-1})	10.080	5.942
Bacteria (×10^{5}·g^{-1})	6.38	11.40	Available K (mg·kg^{-1})	203.4	225.0

tion, and leaf litter showed greater effect than roots. In the *B. platyphylla* forest soil both of leaf litter and roots resulted in negative polarization, and also leaf litter showed greater effect than roots.

Interaction between leaf litter and roots in affecting the soil properties: Leaf litter and roots can not affect the soil properties separately in the forest ecosystem, when they together mixed with soil, does the effect equal to the separate effects which add together, or new promoted or inhibitory effect will appear. The values of S+L treatment which are the practical (P_{LR}) values are given in Table 3. The comparisons between practical (P_{LR}) and theoretical (T_{LR}) values of soil properties after mix-incubated forest soil with leaf litter and roots are shown in Fig. 2. We can see that, in the *B. platyphylla* forest soil, the together decomposition of leaf litter and roots has promoting effect on soil protease, phosphatase catalase, dehydrogenase activities, fungi quantity and available K content. However it showed the inhibitory effect on soil urease, bacteria quantity, CEC, available N, and available P compared to separated decomposition. In the *R. pseudoacia,* the together decomposition of leaf litter and roots showed promoting effect on soil phosphatase urease, fungi, actinomycetes, CEC, available N, and available K, however it showed inhibitory effect on soil catalase, dehydrogenase activities, fungi quantity, organic matter, and available P.

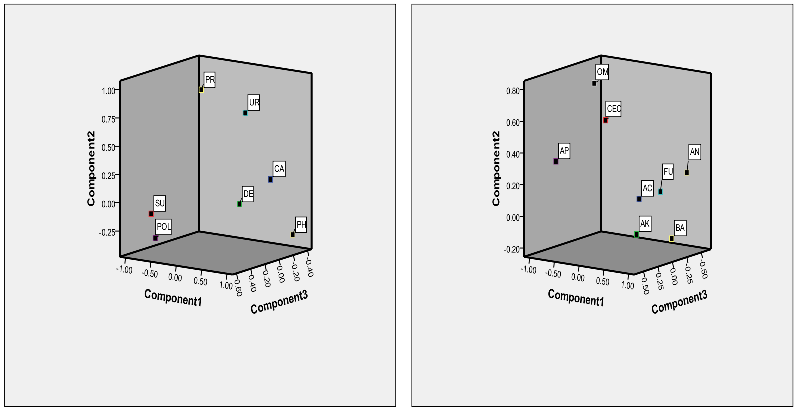

Fig. 1: Component plot in rotated space about soil properties.
Note: SU: Sucrase, PR: Protease, POL: Polyphenoloxidase, PF: Phosphatase, UR: Urease, CA: Catalase, DE: Dehydrogenase, BA: Bacteria, FU: Fungi, AC: Actinomycetes, OM: Organic matter, AN: Available N, AP: Available P, AK: Available K.

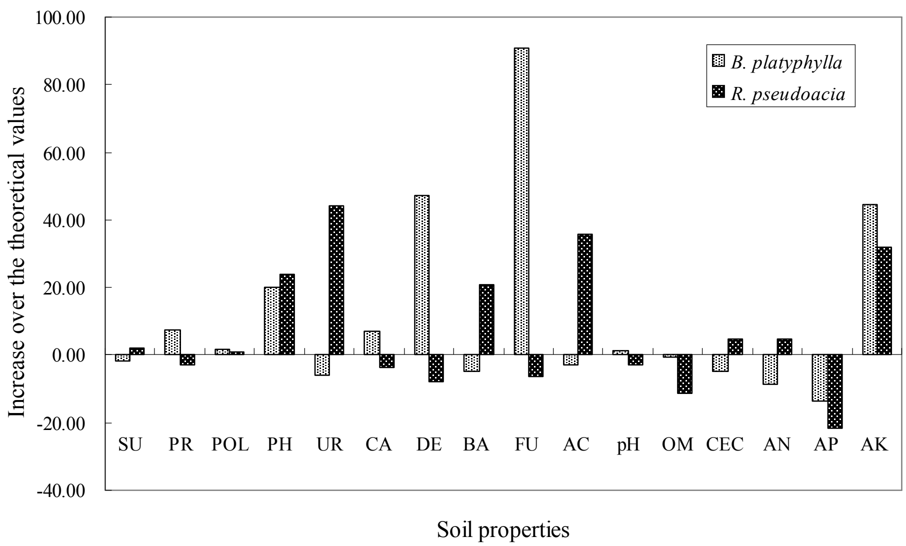

Fig. 2: Comparison of practical (P_{LR}) and theoretical (T_{LR}) values of soil properties after together -incubated soil with leaf litter and roots (%). Abbreviations as in Fig. 1.

In order to explain the comprehensive interaction between leaf litter and roots in affecting the soil properties, the increment ratios (%) of practical (P_{LR}) values in contrast to theoretical (T_{LR}) values, were used for principal component analysis. The principal component model was expressed as follows:

$$F = 0.534F_1 + 0.243F_2 + 0.222F_3 \quad ...(2)$$

Based on the sum of principal component values (F), the species can be ordered as follows: *R. pseudoacia* (0.497) > *B. platyphylla* (-0.466). The result indicated that leaf litter and roots when mix-incubated with forest soil have promoting effect on soil properties in the *R. pseudoacia* forest soil, and inhibitory effect on soil properties in *B. platyphylla* forest soil.

DISCUSSION

In order to deeply analyze the reasons of soil degradation of the planted pure forest, we proposed a new concept called "soil polarization" which means non-equilibrium or polarizing tendency of soil development in pure forests due to its single tree species. The negative polarization of soil is thought to be one fundamental obstacle to the forest development. And in this research, we investigated the relationship between litter decomposition and soil properties polarization in two typical planted pure broadleaved forests in the gully region of Loess Plateau. Our research results clearly indicated that most of the soil properties deviated from its original status of equilibrium (CK) due to the effect of litter decomposition.

The community structure in the planted pure forest is very simple. And this results in that the litter is also not diverse. As a long term consequence the single litter decomposition may release the special chemical material 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 will develop to the positive direction and others negative direction. The negative polarization will cause the continuous planting obstacle, resulted in soil degradation and decline in tree growth. Some researchers discovered that soil microbes and enzymes activity showed decline trend as the effect of litter decomposition in the planted pure forest (Nèble et al. 2007). Also some Chinese researchers discovered that soil nutrients decreased in tree growth in pure larch plantation after the continuous planting (Liu et al. 1998).

Based on the PCA method, we get the results as follows. In the *B. platyphylla* forest soil both of leaf litter and roots resulted in negative polarization, and also leaf litter showed greater effect than roots. When leaf litter and roots mixed-together with the soil, the interaction sequence is *R. pseudoacia* (0.497) > *B. platyphylla* (-0.466). The result indicated that the leaf litter and roots when mix-incubated with forest soil have promoting effect on soil properties in the *R. pseudoacia* forest soil, and inhibitory effect on soil properties in *B. platyphylla* forest soil. In general, litter decomposition in *R. pseudoacia* forest soil was more beneficial for soil properties than *B. platyphylla*. A low-cost and effective way to prevent soil polarization in pure forest is to develop mixed stand in future afforestation. Plant rotation with different tree species should be adopted instead of continuous pure *B. platyphylla* planting in order to maintain long term stability of soil fertility and forest productivity of plantations.

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