Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 1	pp. 317-324	2016

Original Research Paper

Allelopathic Effects of Humus Soil of *Platycladus orientalis* Forests on Understory Plants in the Loess Plateau, China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 19-01-2015
Accepted: 15-03-2015

Key Words:
Allelopathy
Humus soil
Platycladus orientalis
Understory plants

ABSTRACT

Allelopathic effect of humus soil of mono-species-community on the understory plants was a critical problem in the mixed reformation of planted pure forests. In order to investigate the practical allelopathic effect of humus soil of *Platycladus orientalis* forest on understory plants in the Loess Plateau of China and provide a scientific basis for its future management, humus soils of *P. orientalis* forests in the hilly (north) and gullied (south) areas of the Loess Plateau were sampled separately for pot experiment of 10 common species of shrubs and grasses, and seed germination, seedling growth and physiological indexes were measured during the whole test. According to the comprehensive analysis, humus soil of *P. orientalis* forest in the hilly area showed obvious allelopathic inhibition on *Medicago sativa, Melilotus officinalis, Vicia villosa* and *Astragalus adsurgens*; while in the gully area, it showed obvious allelopathic inhibition on *M. officinalis*, *V. villosa* and *Coronilla varia*. Species which are inhibited by allelopathic effects should be avoided choosing, to form mixed vegetation with *P. orientalis*.

INTRODUCTION

Soil and water losses are serious in the Loess Plateau of China for its broken topography and degradation of vegetation. The remained natural forests or artificial pure forests play important role in eco-environment protection and soil and water conservation. However, because of the mono-species composition, single property of litter, and special environment of mono-dominant community, pure forests usually cause soil degradation, sparse understory plants and significant decrease of biodiversity (Zhang et al. 2013). Accordingly, introducing other plants to form mixed forests is an essential way to solve this problem (Liu et al. 2007, Liu et al. 2008). When choosing suitable species for mixed afforestation, allelopathic effects between trees and undergrowth species are inconvenient interspecific relationships besides their competition for solar, water and nutrients and mechanical actions of aerial part and roots (Li et al. 2010).

Platycladus orientalis is one of the most commonly planted tree species in the Loess Plateau for its extensive adaptability and strong resistance to environmental stress. Many previous studies have indicated the existence of allelopathic effects of *P. orientalis*, such as the water extracts of several organs of it, could accelerate the germination and seedling growth of *Pinus tabulaeformis* (Wang et al. 2012) and water extract of its foliar litter could promote the growth of *Medicago sativa* (Li et al. 2013). However, most of these studies usually treated seeds or seedlings of receptor plants using the water extracts of organs or litters, which were difficult to simulate the actual state of allelopathic effects. Because, only a few kinds of allelochemicals can affect receptor plants directly via released volatilization or rain leaching, whereas, most of them are transformed under the effects of soil biological and chemical factors after being leached, or released from roots or decomposed litters (Hu et al. 2002). In the soil processes, the components and concentration of allelochemicals will be significantly altered (Tamura et al. 1969). For example, phenolic allelochemicals can be decomposed by soil microbes, and cannot reach the active concentration (Yenish et al. 1995). Ceratiolin, a non-allelopatic active substance can be transformed into poisonous chemical, hypnone (Blum 1998, Walker et al. 2003). Therefore, cultivating receptor plants with the humus soil, which was affected by forest trees and its litters, may be the most suitable way to investigate the allelopathic effects. For this purpose, humus soils of typical *P. orientalis* pure forests of the hilly (north) and gullied (south) areas in the Loess Plateau were gathered as a culture medium for pot experi-

ment of 10 common shrub and grass species, the allelopathic effects of humus soils on undergrown plants were investigated, and we hope to provide a scientific basis for artificial pure forests reformation and the tree-shrub-grass complex vegetation formation.

MATERIALS AND METHODS

Sampling of humus soil of *P. orientalis* pure forests and preparation of seeds of receptor plants: Humus soils of *P. orientalis* pure forests were gathered from 2 biogeocl-imatic zones in the Loess Plateau, respectively. Humus soil of Loess hilly area was gathered from the Shuanglong forest farm in Huangling County which locates in the centre of Northern Shaanxi area, China. The average annual precipitation here is 630.9 mm, average annual temperature is 9.4°C, and the frost-free season is 150 d. The soil here is classified as Taupe forest soil. Forest age is 25 a, density of trees is 1500 plants/ hm^2, average BHD is 10.31 cm and average height is 6.4 m.

Humus soil of gullied area was gathered from the Yinglie forest farm in Chunhua County which locates in the Weibei area of Shaanxi, China. The average annual precipitation is 600.6 mm, average annual temperature is 10.5°C, and the frost-free season is 190 d. The soil here is classified as Baishan soil. Forest age is 24 a, density of trees is 1941 plants/ hm^2, average BHD is 9.62 cm and average height is 6.31 m.

In each *P. orientalis* pure forest, 5 quadrats with a size of 1 × 1 m were established uniformly, and humus soil from the 0~10 cm layer under the intermediate decomposed organic horizon, was collected and mixed together. Simultaneously, humus soil from tree-free waste land which was close to forest and had the same site conditions was collected as a control sample (CK) using the same method. Soil samples were placed in plastic bags and brought back to the lab, and the roots, stones and other sundries were removed. Fresh soil samples were sieved and passed through a 5 mm soil sieve to reserve. Fertility indicators of soil from forests and waste land (CK) are represented in Table 1, and the data demonstrated that the fertility of soil from *P. orientalis* forests was significantly higher than that from waste land (CK).

Current-year quality seeds of common under grown plants in the Loess Plateau were selected, including *Medicago sativa*, *Melilotus officinalis*, *Astragalus adsurgens*, *Coronil lavaria*, *Vicia villosa*, *Leapedeza bicolor*, *Hippophae rhamnoides*, *Caragana korshinskii*, *Amorpha fraticosa*, *Robinia pseudoacacia*. Plump seeds without moth attack were disinfected using 1 ‰ corrosive sublimate and then washed by germfree distilled water for 3 times, and steeped in distilled water for 2~4 h. The prepared seeds were used for germination testing.

Seed germination and pot cultivation testing: Fresh soils from *P. orientalis* forests and waste land were divided into subsamples with a weight of 2.5 kg (converted into dried weight according to the moisture measured before). Soil subsamples were placed into plastic cultivation pots (the diameter of them is 18 cm, and the height is 16cm). Soil was appropriately compacted (the soil surface was 5 cm under the upper border of pots, uniformly). Prepared seeds were sowed uniformly with equal distance from each other in the core area of the soil. According to the sizes of seeds, 50 seeds from *R. pseudoacacia*, *C. korshinskii* and *V. villosa*, and 100 seeds from other species were sowed respectively. Buried depth of seeds was 2 cm. Every combination of soil and species was regarded as a treatment, and replicated 3 times. After seeding, distilled water was added into the soil to adjust the soil moisture to 50% of the saturation moisture capacity. Plastic film with 2 air holes was covered on the pots to keep moisture, and then the pots were placed in vinyl house for germination and cultivation testing. During the testing period, water was added every 3 days. Environmental conditions such as soil moisture, illumination and temperature was kept the same among pots. Indicators were measured along with germination and further periods.

Indicators Measurement: *Soil nutrients*: Organic matter was determined using potassium dichromate titrimetric method. Alkaline-N was measured with the micro-diffusion technique. Available P was measured by $NaHCO_3$ extraction-molybdenum blue colori-metric method. Available K was measured using NH_4OAc extraction-flame photometric method. Cation exchange capacity (CEC) was measured using NaOAc extraction-flame photometric method. Soil pH was measured by a glass electrode method using PHS-2 acidimeter (soil: water = 1: 2.5) (Bao 2000).

***Seed germination indicators*:** The start day of germination testing was defined as the first day. The number of gemmiparous seeds were counted daily from the second day, until the numbers were constant for 3 continuous days. Based on these data, the germination rate and the germination index (*GI*, obtained by equation 1) were calculated.

$$GI = \Sigma(Gt/Dt) \quad ...(1)$$

Where, *Dt* was lasting time of germination (day), and *Gt* was gemmiparous seeds (number) in that time.

***Plant physiological indicators*:** In the fast growth period of plants (middle of June), several plants were selected randomly from seedlings in every pot with different treatments. 2~3 pieces of fully expanded new leaves were sampled from the upper part of plants. Leaf samples were used for the measurements of physiological indicators by following methods: malonaldehyde (MDA) content was determined by glucosinolates barbituric acid chromogenic method; chlo-

rophyll content was determined by ultraviolet-visible spectrophotometry; catalase activity was determined by titrimetric method (Guan 1986).

***Plant growth indicators*:** Plants were harvested completely at the end of the growth period (according to the growth periodicity of testing plants, about 90~120 d after germination), and the shoot height, ground diameter, root length, and dry weight of shoot, root and total plant per pot were determined.

Data analysis: IBM SPSS 19.0 software and Microsoft Office Excel 2010 were employed for data processing. Significance of differences between indicators of treatments and control values was tested by one-way variance analysis (ANOVA) method, and LSD method was used for *post hoc* analysis (α=0.05). Response Index (RI) was calculated as following:

$$RI=T/C-1 \quad ...(2)$$

Where, T is the indicator value of treatment, and C was that of control testing. RI>0 indicated promotional effects, while RI<0 indicated inhibitory effects, and the absolute value indicated the strength of allelopathic effects.

Furthermore, RI values of different indicators of every treatment were submitted to SPSS 19.0 for the integrated principal component (IPC) analysis.

RESULTS

Impacts of humus soil from *P. orientalis* pure forests on seed germination: Soil from *P. orientalis* pure forests of the hilly area of the Loess Plateau (HA soil for short) significantly improved the seed germination rates of *C. korshinskii* and *H. rhamnoides* by 38 and 11% (compared with CK value, the same below), respectively (P<0.05) (Table 2); while it significantly decreased that of *M. sativa*, *M. officinalis*, *V. villosa* and *A. adsurgens* by 24, 22, 46 and 31% respectively. Soil from *P. orientalis* pure forests of the gullied area (GA soil for short) significantly improved the seed germination rates of *H. rhamnoides* (P<0.05), while it significantly decreased that of *R. pseudoacacia*, *L. bicolor*, *C. varia*, *M. sativa* and *M. officinalis* by 10, 22, 11, 17 and 19% respectively (P<0.05).

HA soil significantly improved the germination indexes of *C. korshinskii* and *C. varia* by 107 and 14%, respectively (P<0.05); while it significantly decreased that of *M. sativa*, *M. officinalis*, *V. villosa* and *A. adsurgens* by 16, 27, 32 and 37% respectively. GA soil significantly improved the germination indexes of *H. rhamnoides* and *A. adsurgens* by 34 and 13%, respectively (P<0.05), while it significantly decreased that of *R. pseudoacacia*, *L. bicolor*, *C. varia*, *M. sativa*, *M. officinalis* and *V. villosa* by 24, 26, 26, 16, 21 and 31% respectively (P<0.05).

Impacts of humus soil from *P. orientalis* pure forests on plant growth: *Impacts on ground diameter, shoot height and root length*: Humus soil from different areas showed variable effects on the ground diameter of 10 species (Table 3). HA soil significantly decreased the ground diameters of *R. pseudoacacia*, *A. fraticosa*, *L. bicolor*, *H. rhamnoides*, *C. varia*, *M. sativa*, *M. officinalis* and *A. adsurgens* by 24~41% (P<0.05), whereas GA soil only significantly decreased that of *A. fraticosa* and *H. rhamnoides* by 28 and 26% (P<0.05), respectively.

Impacts of humus soil from two areas on receptor plants' root length were not significant, except for HA soil decreased root length of *V. villosa*, and GA soil decreased that of *H. rhamnoides*, *C. varia* and *V. villosa* significantly.

Humus soil of *P. orientalis* forests always inhibited shoot growth of receptor plants. Shoot heights of 9 plants except for *C. korshinskii* in HA soil were significantly shorter than that in control testing, especially that of *A. fraticosa* and *R. pseudoacacia*. In GA soil, shoot heights of *C. varia*, *L. bicolor*, *M. officinalis*, *V. villosa*, *C. korshinskii* and *A. adsurgens* were significantly decreased by 45, 35, 25, 19, 16% and 11% respectively (P<0.05).

Impacts on dry weights of shoot, root and total plant: Soil from different areas mainly showed inhibitory effects on the root dry weight of 10 species (Table 3). In HA soil, root dry weights of 8 receptor plants expect for *C. korshinskii* and *L. bicolor* were significantly lower than that of control testing, especially *V. villosa* and *M. sativa*, and the decrease rates reached 56~75%. In GA soil, root dry weights of 7 receptor plants expect for *R. pseudoacacia*, *H. rhamnoides* and *A. adsurgens* were significantly lower than that of control testing, especially *V. villosa*, and the decrease rates reached 21~74%.

In HA soil, shoot dry weight of *C. korshinskii* and *L. bicolor* significantly increased by 21 and 39%, while that of other 8 species were significantly decreased by 26~76%. In GA soil, shoot dry weights of 8 species except for *H. rhamnoides* and *A. adsurgens* were significantly decreased by 22~38%.

In HA soil, total dry weights of *C. korshinskii* and *L. bicolor* was significantly increased by 17 and 26%, while that of the other 8 species were significantly decreased by 24~76%. In GA soil, total dry weights of 8 species except for *H. rhamnoides* and *A. adsurgens* were significantly decreased by 15~54%.

Table 1: Soil fertility of forestlands and wasteland.

Sources of soil		Organic matter ($g.kg^{-1}$)	Available N ($mg.kg^{-1}$)	Available P ($mg.kg^{-1}$)	Available K ($mg.kg^{-1}$)	CEC ($cmol.kg^{-1}$)	pH
Loess hilly area (HA):	*P. orientalis* forest	45.96*	338.3**	11.05 **	327.48*	41.42**	7.40
	Wasteland (CK):	38.17	216.50	7.70	301.14	20.85	7.74
Gullied area (GA):	*P. orientalis* forest	34.91**	347.55**	12.46 **	265.11**	32.28*	7.34
	Wasteland (CK):	24.87	257.70	8.21	144.93	27.50	7.86

Note: *, ** indicates significant or very significant difference between practical and theoretical value, respectively.

Table 2: Seed germination indexes of understory plants cultured with humus soil from *P. orientalis* forest.

Test Species	Seed germination rate (%)				Seed germination index			
	Hilly area (HA)		Gullied area (GA)		Hilly area (HA)		Gullied area (GA)	
	T	C	T	C	T	C	T	C
C. korshinskii	55.0*	40.0	56.0	53.0	15.25*	7.36	10.33	11.13
R. pseudoacacia	43.0	43.0	45.0*	50.0	8.46	8.49	5.69*	7.46
A. fraticosa	80.0	84.5	79.0	81.0	13.84	13.63	12.48	12.37
L. bicolor	14.0	14.0	14.0*	18.0	3.21	3.40	2.52*	3.40
H. rhamnoides	25.0*	22.5	28.0*	22.5	2.77*	2.78	3.10*	2.31
C. varia	28.5	27.0	33.5*	37.5	5.80*	5.09	6.39*	5.09
M. sativa	55.5*	73.5	62.5*	75.0	34.37*	41.07	33.25*	39.79
M. officinalis	43.5*	55.5	38.5*	47.5	20.97*	28.67	18.64*	23.63
V. villosa	6.5*	12.0	10.0	12.0	1.66*	2.45	1.79*	2.59
A. adsurgens	35.0*	50.5	45.5	44.0	10.27*	16.25	17.52*	15.52

T: Treatment; C: Control; * express significant difference of the same tree between different concentrations at the 0.05 level. The same below.

Table 3: Growth indexes of understory plants cultured with humus soil from *P. orientalis*forest.

		Ground diameter (mm)		Shoot height (cm)		Root length (cm)		Root DW ($g.pot^{-1}$)		Shoot DW ($g.pot^{-1}$)		Total DW ($g.pot^{-1}$)	
		LH	GA	LH	GA	LH	GA	LH	GA	LH	GA	LH	GA
C. korshinskii	T	2.12	1.82	31.78	18.56*	18.60	14.10	5.04	3.06*	10.99*	4.10*	16.03*	7.16*
	C	2.47	1.87	27.40	22.17	19.25	17.50	4.58	3.87	9.08	5.28	13.66	9.15
R. pseudoacacia	T	2.68*	2.14	17.46*	13.37	18.88	15.51	4.81*	3.21	5.32*	3.07*	10.13*	6.62*
	C	3.54	2.37	27.23	15.23	18.21	17.05	11.01	3.38	15.38	4.00	26.39	7.38
A. fraticosa	T	2.00*	1.77*	18.23*	14.46	10.89	10.96	6.11*	4.86*	8.11*	6.18*	14.22*	11.04*
	C	2.75	2.46	33.54	18.73	12.05	10.59	14.23	6.73	22.30	9.96	36.53	16.69
L. bicolor	T	1.48*	1.43	30.12*	20.17	17.49	16.49	4.52*	4.24*	16.84*	5.00*	21.36*	9.24*
	C	2.20	1.43	41.42	31.02	16.82	17.53	4.75	5.43	12.09	6.45	16.84	11.88
H. rhamnoides	T	1.96*	1.55*	27.72*	22.85	14.29	11.82*	2.41*	1.63	7.97*	5.69	10.38*	7.31
	C	2.62	2.09	39.71	29.80	14.22	15.12	2.80	1.72	10.82	6.02	13.61	7.73
C. varia	T	1.46*	1.47	15.64*	9.46*	14.59	8.71*	5.77*	3.13*	3.82*	2.52*	9.59*	5.64*
	C	2.48	1.36	20.88	17.19	15.78	15.12	13.16	4.62	10.26	3.21	23.42	7.83
M. sativa	T	1.72*	1.54	19.71*	20.38*	11.54	9.98	4.46*	3.58*	2.55*	2.13*	7.01*	5.71*
	C	3.02	1.64	27.94	21.51	12.47	9.79	15.72	4.74	13.06	3.12	28.77	7.86
M. officinalis	T	1.93*	1.52	20.91*	31.55*	10.39	9.84	6.84*	4.42*	4.65*	2.32*	11.48*	3.37*
	C	2.74	1.66	31.36	22.73	11.77	10.24	19.36	6.05	15.19	3.04	34.54	9.08
V. villosa	T	1.75	1.82	32.38*	28.97*	7.25*	7.08*	0.40*	0.43*	1.13*	1.19*	1.53*	1.62*
	C	1.78	1.78	42.11	35.87	13.38	13.38	1.62	1.67	4.21	1.83	5.83	3.50
A. adsurgens	T	1.90*	1.51	27.57*	18.55*	15.36	13.68	4.25*	3.44	10.55*	6.54	14.80*	9.98
	C	2.88	1.49	36.94	20.87	14.79	16.74	9.78	3.61	33.99	6.75	43.77	10.36

Table 4: Physiological indicators of understory plants cultured with humus soil of *P. orientalis.*

Receptor Species	Chlorophyll content(mg.g^{-1})				Catalase activity(mg.g^{-1}.min^{-1})				Malonaldehyde content (mg.g^{-1})			
	HA		GA		HA		GA		HA		GA	
	T	C	T	C	T	C	T	C	T	C	T	C
C. korshinskii	2.11*	1.71	2.26	1.93	81.84*	70.74	54.12*	67.91	2.31*	1.91	2.78*	1.65
R. pseudoacacia	1.69	1.77	1.22*	1.60	8.92*	18.14	15.98	14.18	3.37	2.97	2.93*	3.94
A. fraticosa	2.46	2.79	1.14	1.35	29.95*	41.03	30.75	34.34	1.41*	1.80	1.93*	1.53
L. bicolor	2.09*	1.71	1.69	1.89	19.36	24.00	25.49	21.85	4.25*	3.14	3.01*	2.87
H. rhamnoides	2.04	1.99	1.77	1.97	36.88	34.22	21.25*	28.85	0.83*	1.15	1.29	1.34
C. varia	0.93	1.11	1.33	1.53	22.15	18.21	13.94	13.69	1.38*	0.76	1.40*	0.89
M. sativa	2.04	1.93	1.66	1.81	44.97*	34.80	39.81	37.55	9.95	10.05	8.44*	13.22
M. officinalis	1.87*	2.31	1.53*	2.11	7.06*	20.82	9.36*	16.65	7.51	6.23	6.04	7.16
V. villosa	0.46*	0.65	0.65	0.70	56.57*	40.12	51.37	52.45	0.52*	0.27	3.15*	2.51
A. adsurgens	1.65	1.92	1.34	1.40	39.84*	30.47	27.87*	34.55	4.33*	3.25	4.60	4.84

Impacts on physiological activity: Humus soil of *P. orientalis* forests only showed significant impacts on chlorophyll (Chl) content of a few species in 10 receptor species: HA soil treatments increased the Chl contents of *C. korshinskii* and *L. bicolor* by 24 and 22%, but decreased that of *M. officinalis* and *V. villosa* by 19 and 30% (P <0.05). GA soil treatments increased the Chl contents of *C. korshinskii* by 17%, but decreased that of *R. pseudoacacia* and *M. officinalis* by 24 and 27% (P <0.05).

Malonaldehyde (MDA) is one of the final products in membrane lipid peroxidation process, and its content can indicate the degree of plant oxidative damage (Zhou et al. 2005). In HA soil, MDA contents of *C. korshinskii*, *L. bicolor*, *C. varia*, *V. villosa* and *A. adsurgens* were significantly increased, but that of *A. fraticosa* and *H. rhamnoides* were significantly reduced by 22 and 28% respectively. In GA soil, MDA contents of *C. korshinskii*, *A. fraticosa*, *C. varia* and *V. villosa* were significantly increased, while that of *R. pseudoacacia* and *M. sativa* were significantly reduced by 26 and 36% respectively.

Catalase (CAT) commonly exists in plant tissue. As it can remove the H_2O_2 produced by metabolic activity and protect cells from oxidative damage, its activity can indicate the ability of stress resistance of plants (Chen & Ma 2010). Humus soil from different areas showed variable impacts on leaf catalase activity of 10 receptor species (Table 4). HA soil treatment significantly accelerated the CAT activity of *C. korshinskii*, *C. varia*, *M. sativa*, *V. villosa* and *A. adsurgens* by 17~41%, while it inhibited that of *R. pseudoacacia*, *A. fraticosa* and *M. officinalis*. GA soil treatment significantly inhibited the CAT activity of *C. korshinskii*, *H. rhamnoides* and *M. officinalis*.

Integrated analysis of allelopathic effects of humus soil of *P. orientalis* forests on undergrowth plants: Humus soil of *P. orientalis* forest showed quite different impacts on indicators of seed germination, plant growth and physiological properties. The strength, even the impact trend (acceleration or inhibition) was variable. Hence, it is difficult to assess the integrated allelopathic impacts on receptor species as a whole. In this study, RI values of different indicators of every treatment were submitted to SPSS 19.0 for integrated principal component (IPC) analysis. Because, high MDA content indicates disadvantageous physiological properties, thus in IPC analysis, the RI values of it were translated into negative values. After the analysis, an equation was obtained for calculating the IPC value F, and a positive F indicated humus soil of *P. orientalis* forest had promotional effects on receptor plants, while a negative F indicated inhibitory allelopathic effects.

$$F = 0.524\,F_1 + 0.216\,F_2 + 0.147\,F_3 + 0.113\,F_4 \quad ...(3)$$

Where, F_i was principal component extracted by SPSS 19.0, the values before them were their loading coefficients.

According to equation 3, the IPC values F of the allelopathic effects of *P. orientalis* forests soil on 10 receptor species were calculated (Fig. 1). The results showed that: HA soil had obvious allelopathic inhibitory effects on *M. sativa*, *M. officinalis*, *V. villosa* and *A. adsurgens*, while it had obvious promotional effects on *C. korshinskii*, *L. bicolor* and *H. rhamnoides*. GA soil had obvious allelopathic inhibitory effects on *M. officinalis*, *V. villosa* and *C. varia*, while it had obvious promotional effects on *C. korshinskii*, *R. pseudoacacia*, *H. rhamnoides*, *M. sativa* and *A. adsurgens*.

The inhibitory effects of *P. orientalis* forest soil on grasses were generally more obvious than on woody plants. Both of the two kinds of humus soil showed promotional effects on *C. korshinskii* and *H. rhamnoides*, while inhibitory effects on *C. varia*, *M. officinalis* and *V. villosa*. The impacts of the two kinds of humus soil acted differently in

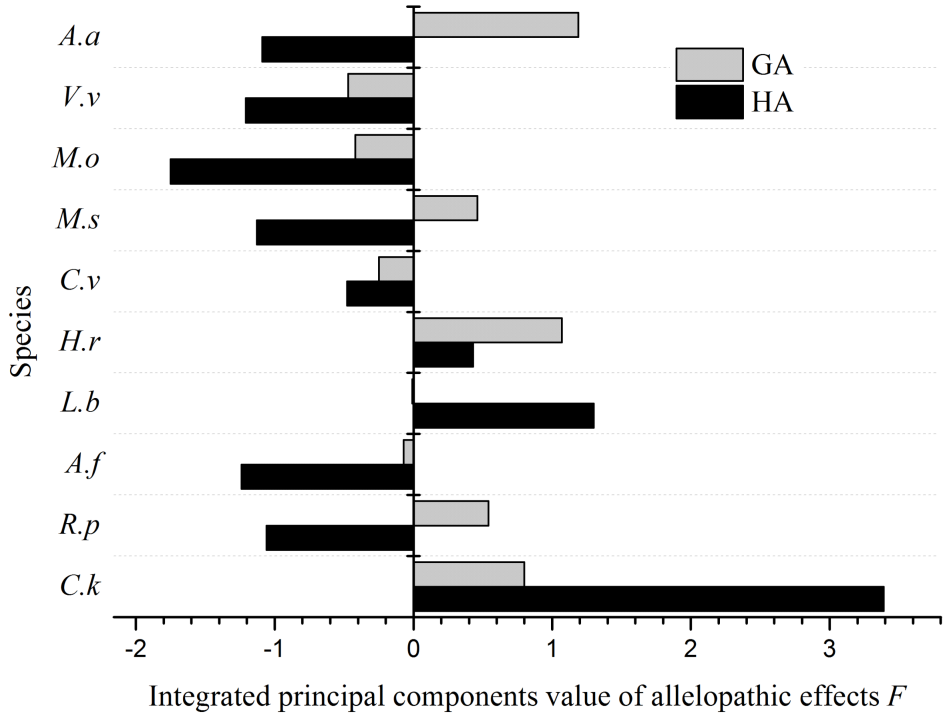

Fig. 1: Comprehensive principal components value of allelopathic effects of humus soil from *P. orientalis* forest on understory plants in the hilly area (HA) and gullied area (GA) of Loess Plateau.

impacts on *R. pseudoacacia*, *M. sativa* and *A. adsurgens*, HA soil showed obvious allelopathic inhibition, while GA soil showed promotion.

DISCUSSION

Our test demonstrated that the fertility of *P. orientalis* forest soil was much higher than that of wasteland (Table 1), but *M. sativa*, *M. officinalis*, *V. villosa* and *A. adsurgens* in HA soil and *C. varia*, *M. officinalis* and *V. villosa* in GA soil were obvious inhibited compared with control testing (Tables 2, 3 & 4). Based on these results, we can state that *P. orientalis* forest soil contains allelochemicals and their concentration reached the threshold values to perform inhibitory effects. Because previous studies stated that the allelochemicals usually showed promotional effects at low concentration but inhibitory effects at high concentration (Du et al. 2003, Yang et al. 2009, Tian et al. 2013, Li et al. 2012). When the chemical concentrations were above the threshold values, the plant physiological properties, such as water and fertilizer absorbing capacity (Turk 2003, Yu & Zhang 2003, Baziramakenga et al. 1997) and key enzymes controlling germination (Li et al. 2012, Song et al. 2006), were affected. Furthermore, in this condition, the organelle biological membrane system would be damaged as well, and these damages consequently would influence the germination and growth.

Our results showed that the formation of allelochemicals and strength of allelopathy were affected not only by donor plant species themselves, but also by climate and soil environmental factors. For example, *P. orientalis* forest soil from hilly area of the Loess Plateau showed promotional integrated effects on *R. pseudoacacia*, *M. sativa* and *A. adsurgens*, while that from gullied area showed inhibitory integrated effects on the mentioned 3 species. There were 2 possible reasons causing these phenomena. The first, different climates lead to differences in allelochemicals production (kinds and quantity) in the *P. orientalis* forests (Wanget al. 2007, Li et al. 2007). The second, different soil environments altered the chemicals, cause after entering soil, allelochemicals might be diffused or transferred (Li et al. 2013, Cheng 1992), decomposed by microbes and enzymes (Cayuela et al. 2008), and complex reaction with soil chemicals or interaction between allelochemicals (Liu et al. 2012) would also influence the activity and concentration of them. Besides, the differences in pH and nutrients would influence the allelopathic effects, according to the previous studies (Li et al. 2007, Timsina et al. 2011, Shann & Blum 1987).

HA soil treatment showed promotional integrated effects on *C. korshinskii* and *L. bicolor*, while GA soil treatment showed promotional integrated effects on *R. pseudoacacia* and *H. rhamnoides*. That might be caused by the promotional effects of allelochemicals at low concentration or nutrients which were not measured in this study. Because humus soil contains numerous chemicals that affect plants growth, including nutrients that in favour of plants growth, and allelochemicals that with harmful impacts. The whole impact of *P. orientalis* forest soil on plants was simultaneously controlled by these two kinds of chemicals.

Besides, our results showed that the inhibitory allolopathic effects on grasses were stronger than that on woody plants, which indicated the resistant ability to environmental stress of grasses were weaker than that of woody species. This can explain why the decrease of species number and biomass of grasses was much more obvious than that of woody species in continuous planted pure forests (Yang et al. 2011).

CONCLUSION

According to the measurement of the impact of humus soil from *P. orientalis* forest on seed germination, plant growth and physiological properties, HA soil showed obvious inhibitory allolopathic effects on *M. sativa*, *M. officinalis*, *V. villosa* and *A. adsurgens*. GA soil showed obvious inhibitory allolopathic effects on *M. officinalis*, *V. villosa* and *C. varia*. These species should be avoided choosing to form mixed vegetation with *P. orientalis.*

ACKNOWLEDGMENTS

The authors thank Dr. Luc NhuTrung for the help in experiments.

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