REGULAR ARTICLE

Effects of non-native tree plantations on the diversity of understory plants and soil macroinvertebrates in the Loess Plateau of China

Yan Zhu · Yafeng Wang · Liding Chen

Abstract

Aims Non-native trees are widely used to prevent soil erosion in the Loess Plateau. We aim to investigate the effects of non-native tree plantations on the communities of understory plants and soil macroinvertebrates.

Methods The soil, understory plants and soil macroinvertebrates were sampled in non-native *Robinia pseudoacacia* (RP) and *Populus × canadensis* (PC) stands, and native *Armeniaca sibirica* (AS) stands.

Results Abundance and richness of understory plants were significantly greatest in the RP stands. The macroinvertebrates collected belonged to 13 orders across all stands. At the community level, richness did not differ among the stand types, but the abundance was significantly greatest in the PC stands. At the functional group level, phytophages and detritivores preferred the PC stands, whereas predators preferred the RP stands. The generalist macroinvertebrate abundance was significantly greatest in the PC stands. Moreover, the community composition of understory plants clearly differed among the stand types; that of soil macroinvertebrates in the PC stands was separated from the other stand types, which was mediated by environmental variables, especially the soil temperature and soil organic carbon.

Conclusions Non-native tree plantations had positive effects on the overall abundance of understory plants and soil macroinvertebrates, but their effects on functional groups were inconsistent, associated with tree identity. The selection of non-native tree should be considered in term of multiple trophic levels, if afforestation has biodiversity objectives.

Keywords Afforestation · Soil arthropod · Non-native plant · *Robinia pseudoacacia* · Functional group

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Introduction

Ecosystem degradation may be induced by intensive human activities and climatic changes, and can result in ecosystem function decline and ecosystem service loss (Jackson and Hobbs 2009; Allan et al. 2015). Afforestation is one of the most common management approaches to enhance ecosystem characteristics and restore degraded environments (Pimentel and Kounang 1998). Due to their rapid growth rates, non-native tree species have been widely planted to restore ecosystems

worldwide (Zobel et al. 1987; Degomez and Wagner 2001).

Although non-native tree species can restore degraded ecosystems faster than native plants, they may have different effects on the physical environment when they are planted within local ecosystems (Qiu et al. 2010; Orozco-Aceves et al. 2015; Kou et al. 2016), resulting in changes to the composition, structure, and function of local ecosystems (Irwin et al. 2014; Horák et al. 2019). Plants are primary producers and provide consumers with both food and habitat. Plantations with different species may affect resource availability and habitat properties, and have cascading effects on local fauna (Bertheau et al. 2009; Sylvain and Buddle 2010; Salamon et al. 2011). Despite the well-documented impacts of non-native tree plantations (e.g., *Robinia pseudoacacia*, *Pinus radiate*, *P. contorta*) on the composition (Meers et al. 2010; Kasel et al. 2015), structure and cover of understory plants (Roberge and Stenbacka 2014; Huang et al. 2019) and the recognized links between aboveground and belowground biotic communities (Wardle et al. 2004; Kayler et al. 2010; Kivlin and Hawkes 2011), our understanding of the cascade effects of non-native tree plantations on soil fauna is poor (Sylvain and Buddle 2010; Roberge and Stenbacka 2014).

Soil arthropods are a common, abundant, and functionally important group of organisms in most ecosystems (Bardgett and van der Putten 2014; Wagg et al. 2014). Their activities have significant impacts on soil properties and ecosystem processes and functions (Wagg et al. 2014), such as decomposition and nutrient cycling (Bardgett and van der Putten 2014). Understanding the responses of soil arthropods to non-native tree plantations can inform efforts to conserve biodiversity and ecological processes. Some studies have examined the effects of non-native plants on the abundance, diversity, and composition of ground and belowground arthropods, and the reported effects appear to be idiosyncratic (e.g., Sax 2002; Brockerhoff et al. 2008; Quine and Humphrey 2010). Such differences reveal that the responses of arthropods are associated with non-native tree species identity, as well as the functional group to which they belong. To date, most studies only examined a single non-native species, and focused on a single or very few response variables within one ecosystem (Hulme et al. 2013). To better understand the consequences of non-native species plantation, studies are

needed that include a greater variety of non-native plant species and response variables—such as soil properties, understory plant communities, invertebrate predators, phytophages, detritivores, and omnivores—within one ecosystem. Such data are valuable as they provide a more comprehensive assessment of the impacts of non-native plants on the local ecosystems (Lazzaro et al. 2017).

The Loess Plateau of China, one of the most severely eroded regions of the world, has received substantial research attention in China (Jiang et al. 2003; Deng et al. 2012; Kou et al. 2016; Yang et al. 2019). The destruction of vegetation cover, as a result of long-term human activities, has led to severe soil erosion (Chen et al. 2015). Afforestation has been widely implemented, especially under the Grain for Green program, which increased vegetation coverage on the Loess Plateau from 31.6% in 1999 to 59.6% in 2013 (Chen et al. 2015). Non-native *Robinia pseudoacacia* (RP) and *Populus ×canadensis* (PC) have been extensively planted because of their rapid growth rates (Yang et al. 2006). The impacts of plantations on soil properties (e.g., Qiu et al. 2010; Xu et al. 2014) and native plant communities (e.g., Jiang et al. 2003; Chen and Cao 2014) have been well-documented for the Loess Plateau. There is a lack of studies, however, on how soil macroinvertebrates—as a major component of many ecosystems—are affected by non-native tree plantations as well as associated understory plant communities and soil properties that may underlie macroinvertebrate responses. This knowledge gap may preclude us from determining whether or not non-native species should be widely planted in degraded ecosystems.

The aim of our work was to assess the impacts of two non-native plantations (RP and PC) on soil properties, diversity of understory plants, and soil macroinvertebrates and compare these with a native *Armeniaca sibirica* (AS) ecosystem. Specifically, we answer the following questions: (1) Do non-native tree plantations influence soil properties in comparison with the native tree plantation? (2) Do non-native plantations alter community composition and structure of understory plants and macroinvertebrates in comparison with the native tree plantation? (3) Are any differences in macroinvertebrate communities associated with plantation-induced changes in soil properties and understory plant communities?

Materials and methods

Study site

We selected the Yangjuangou Catchment (36°42′ N, 109°31′ E; Fig. S1), which is located in the middle region of the Loess Plateau near Yan'an, Shaanxi, China, as the study area. The region has a semi-arid continental climate with an average annual rainfall of 535 mm, and the rainfall is concentrated mainly between July and September and varies greatly from year to year (Wang et al. 2011). The soil is mainly derived from loess, with a texture that ranges from fine silt to silt, and is vulnerable to erosion (Fu et al. 2000). Long-term human activities (i.e., cultivation) have destroyed most natural vegetation, and after approximately 20 years of comprehensive management, soil erosion has been significantly mitigated. *Robinia pseudoacacia* (RP) is a broad-leaved and nitrogen fixing tree, *Populus ×canadensis* (PC) is a deciduous tree, and both of them are fast-growing tree. *Armeniaca sibirica* (AS) is one of the cash forest species in arid and semi-arid areas. All three tree species have been widely used in restoration projects at the study site, especially in "Grain for Green" projects by the Chinese government. This is a large-scale project that requires farmers to reserve a part of their sloping farmland for trees, shrubs, or grasses (Zhou et al. 2009).

Sampling design

We separately selected three stands (1–2 ha; >700 m apart) with similar topography and plantation ages (15 yr) for each tree species. The RP, PC and AS were planted on abandoned arable fields, where corn was planted previously. The soil in each stand was similar prior to planting and subsequent differences in soil properties reflect the effects of different tree species. Three plots (10 × 10 m) about 50 m apart were established in each stand, and the distance from the plots to the stand edge is more than 30 m. The understory plants diversity was investigated, and soil and macroinvertebrates were sampled in four 1 m × 1 m subplots of each plot from the 22 th June to 14 th July 2018 with similar weather conditions. There was no rainfall during this period.

Leaf litter (50 × 50 cm) was collected and one quadrat (50 × 50 × 30 cm depth) was excavated in each subplot; any organisms were recovered by hand sorting. The collected macroinvertebrates were preserved in a 70% alcohol solution in the field, and brought back to the laboratory for identification. In the laboratory, we counted the macroinvertebrates under a dissecting microscope. The order and family was identified for all taxa based on Yin (2001) and Zheng and Gui (2004).

Estimation of plants and soil parameters

We investigated the herbaceous vegetation to determine plant density (individuals/m^2), richness, and vegetation cover (%) in each subplot. Soil cores were taken at each subplot. We measured the soil bulk density, water content, soil organic carbon, total nitrogen, and soil pH. Soil bulk density and water content were determined gravimetrically by drying the soil samples at 105 °C for 48 h. Soil organic carbon (SOC) was measured using $K_2Cr_2O_7$–H_2SO_4 following the Walkley–Black oxidation method, and soil total N was determined using an elemental analyzer (vario EL III, Elementar Analysensysteme GmbH, Langenselbold, Germany). Soil pH was measured in a soil-water suspension (1:5 soil-water ratio) with pH analyzer (FE20, METTLER TOLEDO, Shanghai, China). Soil temperature was measured with a digital thermometer at the depth of 5, 10 and 20 cm in each subplot during soil macroinvertebrate sampling.

Data analysis

The macroinvertebrate data from the litter and soil were combined, and the results were converted into individuals per square meter (ind. m^{-2}). We used linear mixed effects models (function *lme* in the package *nlme* of R software; Bates et al. 2015) to examine the effects of stand type (*Robinia pseudoacacia*, *Populus ×canadensis* and *Armeniaca sibirica*) on the soil properties, understory plants, and soil macroinvertebrates (including the overall macroinvertebrates, main taxonomic groups, functional groups, and the groups of forest generalist and specialist species). The stand type was fitted as a fixed effect, and nested within plots, which were modelled as random effects. Each response variable (soil properties, understory plants, and soil macroinvertebrates) was log-transformed where necessary to meet the assumptions of parametric tests. If significant effects were detected, we used post hoc Tukey tests (*multcomp* package of R software;

Hothorn et al. 2008) to evaluate significant differences between stand types. All the statistical tests were evaluated using $\alpha = 5\%$.

Ordination of multidimensional data on community composition is an important multivariate statistical method widely used in the biodiversity research. Principal component analysis (PCA) and detrended correspondence analysis (DCA) are unconstrained ordination method, and canonical correspondence analysis (CCA) is a constrained ordination method. PCA was used to evaluate the effects of stand type on community composition of macroinvertebrates and understory plants. DCA was conducted to estimate the length of the gradient on the log-transformed macroinvertebrate abundance data. Due to the long gradient length (> 4 SD), CCA was chosen to determine the relative contributions of measured environmental parameters (soil and understory plant) to the community composition of macroinvertebrates with a Monte Carlo test, and stand was included as a covariate. All statistical analyses were performed in R 3.5.1 and CANOCO v5 (ter Braak and Šmilauer 2012).

Results

Soil properties

Soil properties differed among the non-native and native plantations (Table 1). The water content, soil temperature, and soil pH significantly differed among the stand types, with the highest values being observed in the PC stands; no differences were observed for bulk density, SOC, and TN (Table 1).

Macroinvertebrates

Abundance, richness, and community composition

The macroinvertebrate abundance within specific taxonomic groups significantly differed among the non-native and native plantations (Table 2; Fig. 1). The macroinvertebrates collected belonged to 13 orders (i.e., Tubificida, Araneae, Polydesmida, Scutigeromorpha, Scolopendromorpha, Geophilomorpha, Protura, Dermaptera, Hemiptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera) and 25 families (Table S1). Coleoptera (33.33%), Araneae (13.33%), Polydesmida (12.73%), Geophilomorpha

(9.70%), and Hemiptera (7.27%) were the five most abundant orders. Of them, three groups significantly differed among the stand types (Table 2; Fig. 1). The abundances of Geophilomorpha and Coleoptera were greatest in the PC stands, whereas that of Araneae was greatest in the RP stands (Table 2; Fig. 1).

At the community level, macroinvertebrate abundance was significantly greater in the PC stands than in the RP and AS stands (Table 2; Fig. 2), whereas the richness did not differ among the stand types (Table 2; Fig. 2). The PCA results showed that community composition varied among the stand types (Fig. 3), and the first and second axes explained 28.9% and 43.3% of the total variation, respectively. Paradoxosomatidae and larval Scarabaeidae were the main groups associated with the separation of PC1 axis; Liocranidae, Scolopendridae and Geophilidae were the main groups associated with the separation of PC2 axis. Larval Scarabaeidae was most associated with the PC stands, and Tingidae was most associated with the RP and AS stands.

Functional groups and forest generalist and specialist groups

The macroinvertebrate abundance and richness within specific functional groups significantly differed among the non-native and native plantations (Fig. 4). The abundance of predators and omnivores did not significantly differ among the stand types (Table 2; Fig. 4a, d), whereas that of phytophages was significantly more abundant in the PC stands than in the RP and AS stands (Table 2; Fig. 4b), and detritivores were significantly more abundant in the PC stands than in the RP stands (Table 2; Fig. 4c). Predator richness in the RP stands was significantly greater than in the PC stands (Table 2; Fig. 4e), and the detritivore richness in the PC stands was significantly greater than in the RP and AS stands (Table 2; Fig. 4g); the richness of phytophages and omnivores did not significantly differ among the stand types (Table 2; Fig. 4f, h).

The abundance of forest generalist species significantly differed among stand types, with their abundance in the PC stands being greater than in the AS stands, whereas the forest specialist abundance, and the generalist and specialist richness did not differ among stand types (Table 2).

Table 1 Soil properties (mean ± SE) in *Robinia pseudoacacia* (RP), *Populus × canadensis* (PC), and *Armeniaca sibirica* (AS) stands. Different lowercase letters in the same row indicate significant differences at the $P < 0.05$ level. Significant results are in bold

Level	RP	PC	AS	F	P
Bulk density (g cm^{-3})	1.12 ± 0.02	1.20 ± 0.03	1.16 ± 0.03	2.05	0.15
Water content (%)	19.01 ± 0.65 b	21.63 ± 0.44 a	13.95 ± 1.03 c	27.87	**< 0.001**
Temperature (°C)	15.39 ± 0.39 b	17.52 ± 0.26 a	16.78 ± 0.32 a	11.09	**< 0.001**
SOC (g kg^{-1})	4.78 ± 0.49	5.64 ± 0.61	4.11 ± 0.48	2.21	0.13
TN (g kg^{-1})	0.65 ± 0.03	0.56 ± 0.03	0.57 ± 0.03	2.47	0.11
pH	8.71 ± 0.27 a	8.72 ± 0.01 a	8.59 ± 0.05 b	6.15	**0.007**

Understory plants

For all stands, the most represented plant families were Asteraceae, Rosaceae, and Rubiaceae (Table S2). Most of the understory plants (except *Parthenium hysterophorus*) were native to the Loess Plateau. Plant abundance ($F = 15.43$, $P < 0.001$, LMMs; Fig. 2) and coverage ($F = 31.82$, $P < 0.001$, LMMs) were significantly greater in the RP stands than in the PC and AS stands. The plant richness in the RP and PC stands was twice as high as in the AS stands ($F = 14.49$, $P < 0.001$, LMMs; Fig. 2). The PCA results showed that plant community composition varied among the stand types (Fig. 5), and the first and second axes explained 27.7% and 48.0% of the total variation, respectively. *Rubia* sp., *Artemisia annua* and *Agropyron cristatum* were the main species associated with the separation of PC1 axis; *Rubus coreanus*, *Saussurea* sp., *Viola betonicifolia* and *Parthenium hysterophorus* were the main species associated with the separation of PC2 axis. *Viola betonicifolia* and *P. hysterophorus* were most associated with the RP stands; *A. annua* and *Rubia* sp. were most associated with the PC and AS stands, respectively.

Contributions of environmental variables to community composition of macroinvertebrates

CCA showed that first and second axes explained 13.45% and 24.53% of the data, respectively (Fig. 6).

Table 2 The effects of stand type on the abundance and/or richness of macroinvertebrates at different taxonomic levels and functional groups. For the post hoc comparisons ">" denotes significant differences between stand types. Significant results are showed in bold

|	Abundance			Richness		
	F	P	Post hoc comparisons	F	P	Post hoc comparisons
All species	7.50	**0.003**	PC > RP, AS	0.62	0.55	
Taxonomic group						
Araneae	3.64	**0.04**	RP > PC			
Polydesmida	0.09	0.91				
Geophilomorpha	3.84	**0.03**	PC > RP, AS			
Hemiptera	6.64	0.42				
Coleoptera	7.46	**0.003**	PC > RP, AS			
Functional group						
Predator	0.62	0.55		4.00	**0.03**	RP > PC
Phytophage	4.70	**0.02**	PC > RP, AS	0.06	0.94	
Detritivore	3.45	**0.04**	PC > RP	7.79	**0.003**	PC > RP, AS
Omnivore	0.09	0.92		0.11	0.89	
Generalist-specialist						
Generalist species	5.13	**0.015**	PC > AS	0.85	0.44	
Specialist species	1.06	0.36		1.04	0.37	
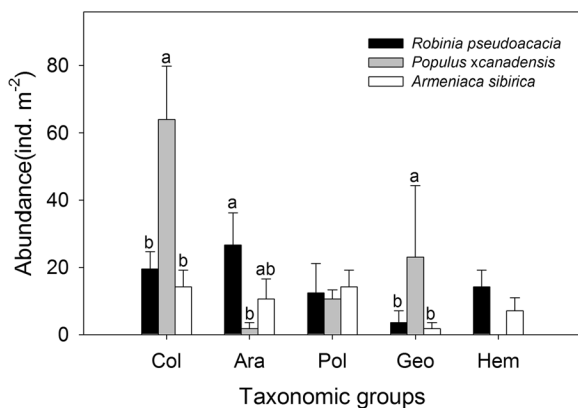
Fig. 1 The abundance of the main taxonomic groups in three stand types (mean + SE). Col: Coleoptera, Ara: Araneae, Pol: Polydesmida, Geo: Geophilomorpha, Hem: Hemiptera. Different lowercase letters denote significant differences between stand types

CCA also showed that different environmental variables had different influences on macroinvertebrate community composition (Fig. 6). The effects of soil temperature ($F = 2.3$; $P = 0.014$) and SOC ($F = 2.2$; $P = 0.016$) on macroinvertebrate communities were significant as

shown under the Monte Carlo permutation test, whereas the remaining variables were not shown to be significant with the same test (plant coverage, $P = 0.124$; TN, $P = 0.36$; pH, $P = 0.386$; plant density, $P = 0.69$; bulk density, $P = 0.84$; plant richness, $P = 0.864$; water content, $P = 0.7$).

Discussion

Effects of stand type on soil macroinvertebrates and understory plants

There has been considerable debate regarding the impact of non-native plantations on soil macroinvertebrates (Bonham et al. 2002; Robson et al. 2009; Quine and Humphrey 2010). In general, non-native plantations are popularly regarded as "biological deserts" (Allen et al., 1995a), and seen to have negative effects on invertebrate communities compared with native plantations (Brockerhoff et al. 2008). However, some studies showed that non-native plantations have similar (Sax
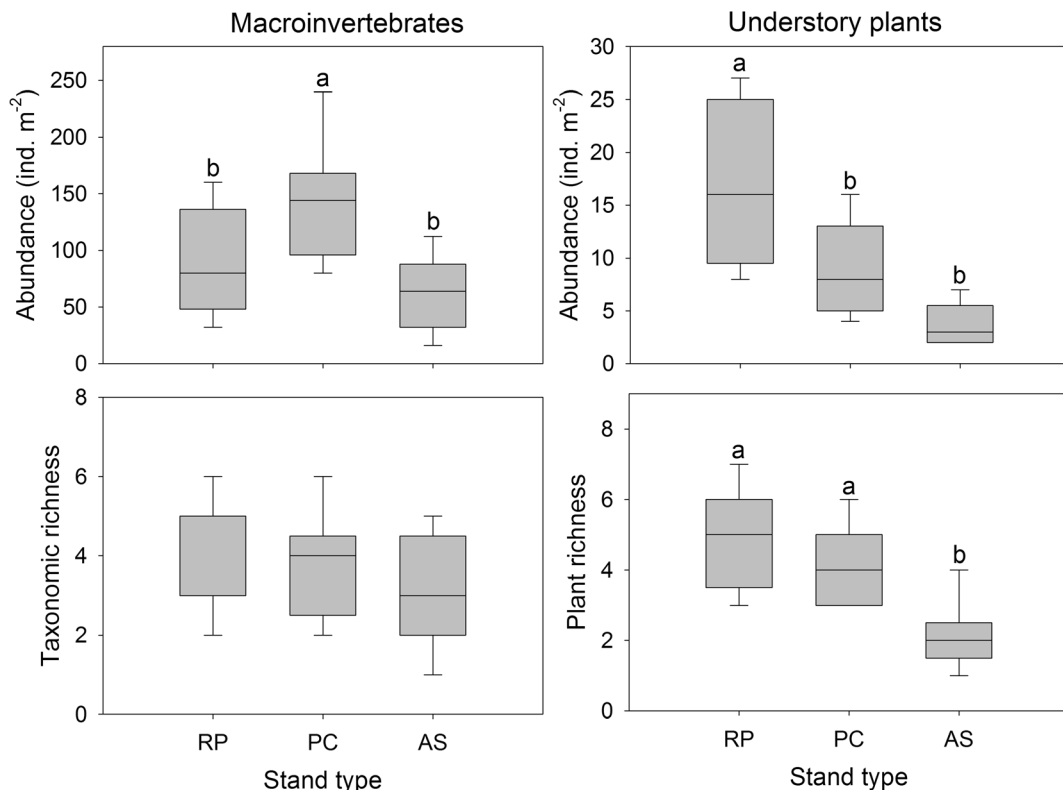

Fig. 2 The abundance and richness of macroinvertebrates and understory plants (mean + SE) in *Robinia pseudoacacia* (RP), *Populus ×canadensis* (RC) and *Armeniaca sibirica* (AS) stands. Different lowercase letters denote significant differences between stand types
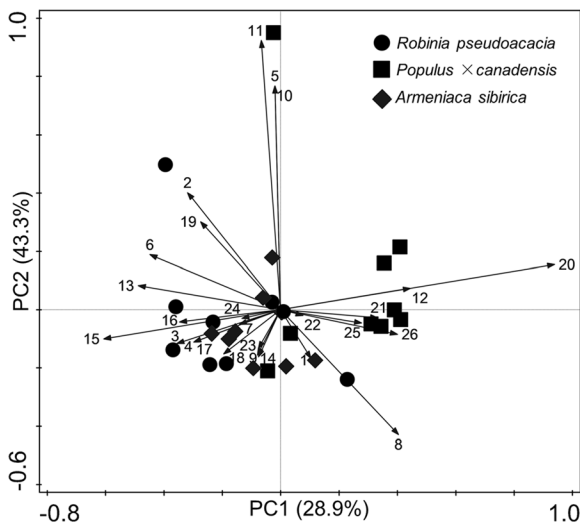
Fig. 3 Principal component analysis (PCA) graph of soil macro-invertebrate communities in three stand types. 1: Enchytraeidae, 2: Oxyopidae, 3: Ctenidae, 4: Zodariidae, 5: Liocranidae, 6: Gnaphosidae, 7: Zoropsidae, 8: Paradoxosomatidae, 9: Scutigeridae, 10: Scolopendridae, 11: Geophilidae, 12: Eosentomidae, 13: Anisolabididae, 14: Forficulidae, 15: Tingidae, 16: Carabidae, 17: Lucanidae, 18: Scarabaeidae, 19: Larval Elateridae, 20: Larval Scarabaeidae, 21: Noctuidae, 22: Therevidae, 23: Tabaniadae, 24: Asilidae, 25: Phoridae, 26: Formicidae

Fig. 5 Principal component analysis (PCA) graph of understory plant communities in PR, PC and AS stands. Pat: *Patrinia rupestris*, Par: *Parthenium hysterophorus*, Bid: *Bidens biternata*, Sau: *Saussurea* sp., Art: *Artemisia annua*, Rubc: *Rubus coreanus*, Pot: *Potentilla chinensis*, Viob: *Viola betonicifolia*, Vioy: *Viola yedoensis*, Reh: *Rehmannia glutinosa*, Rub: *Rubia* sp., Fes: *Festuca* sp., Agr: *Agropyron cristatum*, Pol: *Polygonum criopolitanum*

2002) or higher (Quine and Humphrey 2010) diversity of invertebrates than native plantations. For example, Quine and Humphrey (2010) reported that the richness of all sampled invertebrate groups was higher in non-native Norway spruce (*Picea abies*) stands compared to native oak (*Quercus robur*) stands. In this study, the
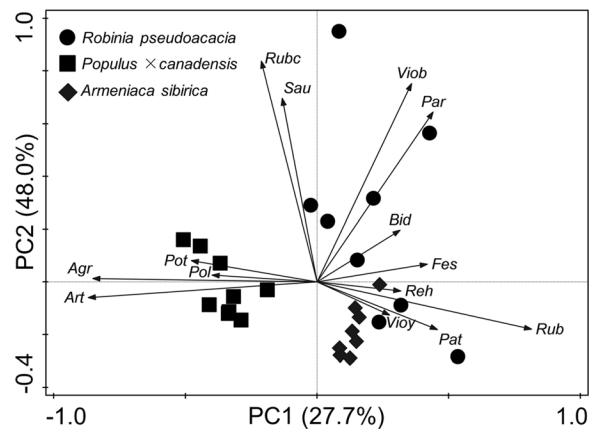
stand type had no significant effect on macroinvertebrate richness, but did affect their overall abundance. The two non-native tree plantations had different effects on the macroinvertebrate abundance than the native trees. Overall macroinvertebrate abundance was significantly greater in the non-native PC stands than in the native AS stands, but no significant difference was observed between the non-native RP and AS stands. The result implied that the impacts of non-native plantations on soil macroinvertebrates depend on species
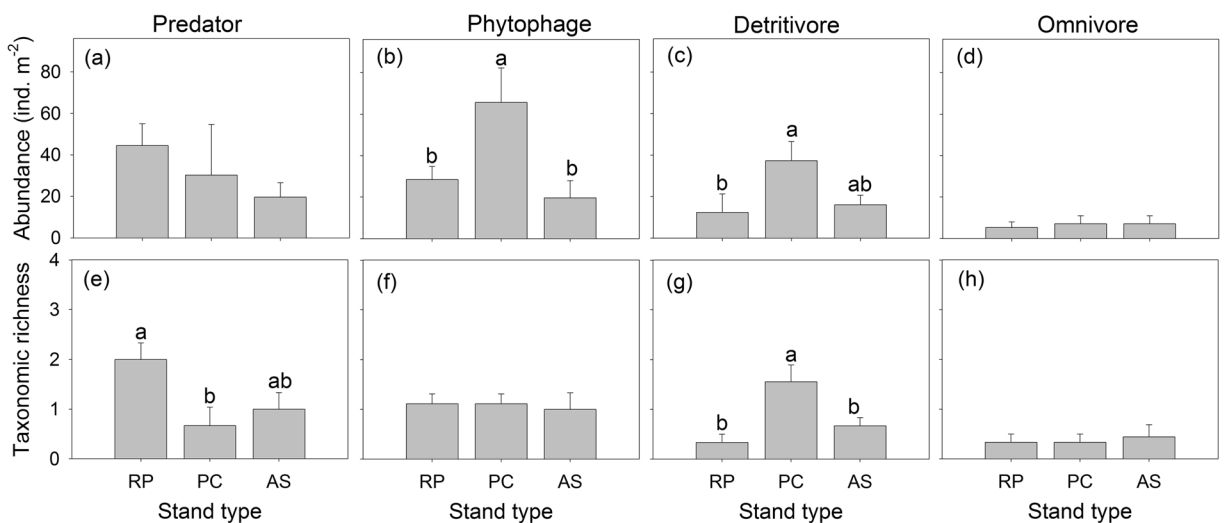

Fig. 4 The abundance and richness of each functional group (mean ± SE) in RP, RC AS stands. Different lowercase letters denote significant differences between stand types
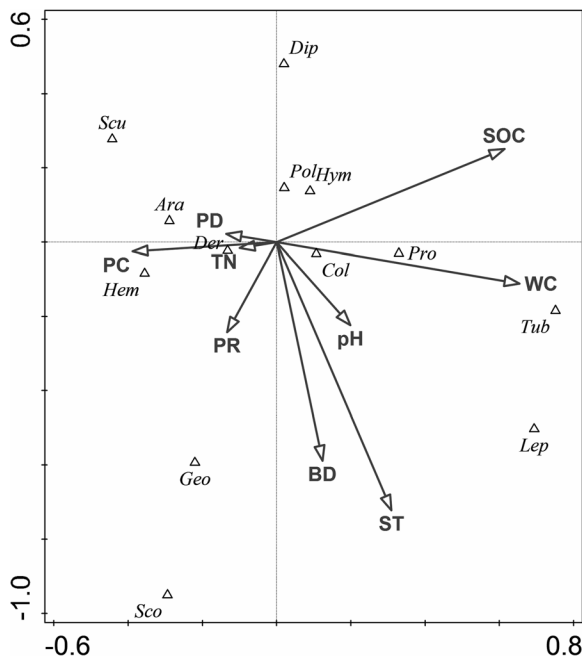
Fig. 6 Canonical correspondence analysis (CCA) showing the relationship between macroinvertebrate composition and environmental factors. PR: plant richness, PD: plant density, PC: plant coverage, ST: soil temperature, WC: water content, BD: bulk density, SOC: soil organic carbon, TN: total nitrogen. Tub: Tubificida; Ara: Araneae, Pol: Polydesmida, Scu: Scutigeromopha, Sco: Scolopendromorpha, Geo: Geophilomorpha, Pro: Protura, Der: Dermaptera, Hem: Hemiptera, Col: Coleoptera, Lep: Lepidoptera, Dip: Diptera, Hym: Hymenoptera

identity. Therefore, studies on the impacts of non-native plantations on the soil macroinvertebrates should focus on various non-native species rather than one, which could contribute to more in-depth understanding of the consequences of non-native plantations within an ecosystem.

Native and non-native plantations may have different effects on specific macroinvertebrate taxa. Our results showed that different orders had contrasting responses to stand type; Polydesmida and Hemiptera abundances showed no significant responses to stand type; Geophilomorpha and Coleoptera abundances were greatest in the PC stands, whereas Araneae abundances were greatest in the RP stands. This result is in line with several studies (Gerber et al. 2008; Gallé et al. 2015), which suggested that non-native plantations can have different effects on local macroinvertebrate assemblages. Such differences may be related to the microhabitat preferences of different taxa. For example, the higher abundance of Geophilomorpha and Coleoptera in

PC stands may be related to the higher water content, as it is known that Geophilomorpha (Dong et al. 2014) and Coleoptera (Liu et al. 2013) prefer sites with these conditions.

The effects of non-native and native plantations on understory plant diversity are under debate (Brockerhoff et al. 2008; Bremer and Farley 2010; Thijs et al. 2014; Horák et al. 2019). While some researches showed that native plantations perform better for the biodiversity restoration than the non-native plantations (Hartley 2002; Brockerhoff et al. 2008), others studies suggested that non-native plantations are not always negative (Brockerhoff et al. 2008; Bremer and Farley 2010; Horák et al. 2019). Peloquin and Hiebert (1999) reported that RP significantly reduced the natural diversity of herbaceous plants in *Quercus velutina* savannas and woodland dune communities in northern Indiana. Likewise, Boothroyd-Roberts et al. (2013) reported that hybrid poplar plantations contributed to the understory plant richness in comparison with adjacent abandoned fields. However, Sitzia et al. (2012) did not record a significant difference in the richness and diversity of the understory plant community between 32 RP stands and paired native stands in the Eastern Alps. In this study, we found that understory plant richness was significantly greater in the RP and PC stands than in the AS stands, and the understory plant abundance was significantly greater in the RP stands than in the PC and AS stands. This indicated that non-native plantations had positive effects on the understory plant diversity in our study site. In addition, we also found that most of the understory plants in all plantations were native to Loess Plateau, despite the fact that non-native plantations often favored exotic plant species (Allen et al. 1995b; Ito et al. 2004; Paritsis and Aizen 2008). In combination with previous studies, the results indicate that the effects of non-native plantations on the diversity of understory plants are ambiguous.

Effects of stand type on macroinvertebrate functional groups

While there is a growing body of evidence that non-native plants can influence soil fauna, their impact on different invertebrate feeding guilds has received relatively less attention (Gratton and Denno 2005;

Gerber et al. 2008). Gerber et al. (2008) pointed out that studies addressing multiple trophic levels, e.g., predators, phytophages, detritivores, and omnivores, may yield additional insight into how non-native species alter ecosystem patterns and processes. They reported that the abundances of predators, phytophages, and detritivores were all significantly greater in non-native *Fallopia* stands than in native grassland and bush stands (Gerber et al. 2008). In this study, we found that the distribution patterns of each functional group were different among the stand types. Firstly, the abundance and richness of phytophages and detritivores were greatest in the PC stands, albeit only significantly for phytophage abundance. The PC stands had more ground litter and decaying vegetation (Zhu, pers. obs.), which may provide alternative food resources and preferred microclimate conditions for detritivores (Litt et al. 2014). Indeed, in the review by Litt et al. (2014), the authors also showed that detritivores were most likely to benefit from non-native plants. Secondly, predator abundance and richness were greatest in the RP stands. This pattern may be associated with the greater understory plant abundance (Dassou and Tixier 2016) and coverage in the RP stands than in the other two stands; the greater plant abundance and coverage may provide alternative food and suitable microhabitat for the insects on herbaceous plants, and therefore have a positive effect on the predators through bottom-up effects. Finally, omnivore abundance and richness did not significantly vary among the three stand types. This finding is consistent with the work of Oxbrough et al. (2016), who reported that the species richness of omnivores was similar between the stands of non-native Norway spruce (*Picea abies*) and native ash (*Fraxinus excelsior*). This result suggests that omnivores may be well represented in all stands because they can feed on a greater diversity of food types than other functional groups.

Effects of environmental variables on soil macroinvertebrates

Bardgett and van der Putten (2014) showed that spatial patterns in soil biota at local scales were often explained by variation in the physical and chemical properties of the soil. Soil fauna have low migration ability and small home ranges and,

therefore, any changes in their microenvironment, such as soil properties or understory plant communities, could have a significant effect on their communities. The characteristics of plant communities (such as species richness and cover) and soil properties (such as soil temperature, water content, bulk density, organic matter, and pH) are often correlated with soil fauna composition (Cole et al. 2008; Huerta and Wal 2012; Wu et al. 2015). In this study, we also found that observed differences in community structure among the three stand types were mediated by environmental variables; soil temperature was the most important factor determining macroinvertebrate composition, as it explained the greatest proportion of the total variation. It is generally accepted that soil temperature is closely associated with macroinvertebrate community composition (Perner and Malt 2003; Liu et al. 2015), and has a positive effect on their abundance (Liu et al. 2015; Robinson et al. 2018), because soil temperature can affect feeding activity (Gongalsky et al. 2008) and egg laying of soil fauna (Willis et al. 2008).

Beside the soil temperature, the water content and soil pH also significantly differed among the stand type, with both of them being greater in the RP and PC stands than in the AS stands. These differences may be potential reasons which lead to the relatively higher macroinvertebrate abundance in the RP and PC stands, because the water content (Wu et al. 2015) and soil pH (Oxbrough et al. 2010) have positive effects on the invertebrate abundance. At the functional group level, the greater abundance and richness of phytophages and detritivores in the PC stands may also be associated with the higher water content, because Scarabaeidae larvae and Oligochaeta, which are the dominant phytophages and detritivores, respectively, prefer soil with higher water content. Additionally, RP is a nitrogen fixing and therefore may be expected to impact soil nitrogen. However, despite TN being greatest in the RP stands, there were no significant differences among stands. This may be attributed to the young age of the RP forests (i.e., 15 yr) in this study, because the TN may increase along the chronosequence of 10, 20, 30, and 40 yr RP plantations in the Loess Plateau (Kou et al. 2016).

It has been proposed that the variation in plant communities seen following the introduction of non-native plants may alter resource availability and habitat properties and may, therefore, have

cascading effects on local fauna (Robson et al. 2009; Litt et al. 2014). For example, the higher species richness of invertebrates in the eucalypt woodland than pine plantations was attributed to the richness and abundance of native understory plants (Robson et al. 2009). In the study of Lazzaro et al. (2017), they reported that the abundance and richness of microarthropods, and the richness and diversity of plant communities were significantly lower in the RP stands than these in the native oak stands, which also implies the association between understory plants and invertebrates. In this study, the RP and PC stands were characterized by greater abundance and richness of understory plants, and greater macroinvertebrate abundance in comparison to the AS stands. In combination with previous studies, the results indicate that there are positive associations between understory plants and soil macroinvertebrates. One possible reason is that the greater richness and abundance of understory plants can provide a greater array of potential habitats (Robson et al. 2009), diverse leaf-litter (Parris and Lindenmayer 2004), and alternative food resources (Salamon et al. 2011) for macroinvertebrates.

Conclusions

Our study showed that plantations of non-native *Robinia pseudoacacia* and *Populus ×canadensis* positively affected the diversity of understory plants and soil macroinvertebrates in comparison with native *Armeniaca sibirica* plantations. We also found that the two non-native tree plantations had inconsistent effects on specific functional groups. The results provide strong evidence that non-native plantations can affect biodiversity at different trophic levels and highlight that these levels should be considered when assessing the effects of non-native plantations on ecosystems. Given the fact that the diversity of understory plants and soil macroinvertebrates may vary among different seasons, further studies should pay attention to the seasonal variations of plantation type effects on biodiversity in the Loess Plateau.

Compliance with ethical standards

Declarations of interest The authors declare that they have no conflict of interest.

Statement of human and animal right All applicable international and/or national guidelines for the care and use of animals were followed.

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