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The abundance and community structure of soil arthropods in reclaimed coastal saline soil of managed poplar plantations

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ABSTRACT

Establishing poplar plantations is a common practice for improving the quality of reclaimed coastal saline soils in Eastern China. The abundance and diversity of arthropods can reflect changes in soil quality. However, the extent to which intensive forest management serves to alter soil arthropod communities remains elusive. In this study, we examined the effects of applying organic fertilizers (OF) and removing understory plants (UP) (two common practices to promote poplar growth) on the abundance and diversity of soil arthropods of poplar plantations in a reclaimed coastal area of Northern Jiangsu Province, China. We found that the OF addition significantly increased the total abundance of soil arthropods, and the abundance of Macrophytophages, Microphytophages and Omnivorous Acari, but decreased the total evenness. The removal of UP did not significantly influence the abundance and diversity of soil arthropods in the 0–20 cm soil layer. Our results suggested that the OF addition is a preferable management practice to UP removal in order to elevate the abundance of soil arthropods while promoting poplar plantation productivity.

1. Introduction

Soil arthropod is a critical element in the ecosystem processes of decomposition and nutrient cycling (De Deyn et al., 2003; Edwards, 2000; Wang et al., 2017). In forest ecosystems, soil arthropods facilitate soil fertility by accelerating litter and soil organic matter decomposition (Carrillo et al., 2011; Kampichler and Bruckner, 2009). Soil arthropods fracture plant litter, which increases the surface area available to the inoculation of microbes (Gonzalez et al., 2001; Lavelle et al., 1997), and consequently increases nutrient release via microbial decomposition (Eisenhauer et al., 2007).

The global land area of saline soil was estimated to be approximately 230 Mha, 15% of which is located in China (Li et al., 2014), mostly along the eastern coast between the Yellow and Yangzi Rivers. To ensure food security for growing populations, these soils are often reclaimed through the construction of dikes for agricultural use, in order to grow cotton, rice, and wheat (Sun et al., 2011). However, these newly reclaimed coastal saline soils are high in pH (8.8) and soil salinity (1.16 $g\,kg^{-1}$), thus they are not suited for immediate agricultural use (Sun et al., 2011). It often requires 30-yrs of natural vegetation succession (Shen et al., 2006) to reduce the soil pH to around 8.0 for agricultural use (Gale et al., 2001). One strategy for reducing soil pH is through biomass accumulation in tree plantations (Binkley et al., 1989). Wang et al. (2013) demonstrated that topsoil pH can be reduced from 8.62 to 7.83 within 19-yrs of poplar growth, which is about 10-yrs fewer than natural succession. Management practices including organic fertilizer (OF) application and the removal of understory plants (UP) are often employed to accelerate the growth of poplar plantations. The application of OF not only increases tree nutrition, but also raises the soil organic carbon content (Fan et al., 2016). The removal of UP may reduce plant competition, while promoting tree growth (Chang et al., 1996).

The abundance and diversity of soil arthropods may be impacted by changes in the quality and quantity of plant materials, as well as soil chemical and physical properties (Callaham, 2003; Gao et al., 2014; Haddad et al., 2009; Wardle et al., 2006). Plant production and soil properties can be altered by forest management practices. In the reclaimed coastal saline soils of Eastern China, OF application and UP removal are two common management practices to promote plantation growth. The addition of both farmyard manure and green manure were reported to promote the abundance and diversity of soil fauna communities in agricultural systems, as the abundant detritus input directly

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or indirectly increased the available nutritional resources (Birkhofer et al., 2008; Zhu and Zhu, 2015). The removal of UP changed the density and community structure of nematodes (Zhao et al., 2011) due to reduced or decreased soil moisture, soil temperature, and microbial biomass in Eucalyptus plantations (Zhao et al., 2013). However, little is known about the effects of OF application and UP removal on soil arthropod communities in poplar plantations.

The objective of this study was to explore the impacts of the OF addition and UP removal on soil arthropod communities in poplar plantations in a reclaimed coastal area of Eastern China. We anticipated that (1) the application of OF would increase the abundance of soil arthropods due to elevated resource availability, while decreasing the evenness of soil arthropods due to increased abundance of dominant groups, (2) the removal of UP would reduce arthropod abundance and diversity, and alter the distribution of arthropods along the surface soil profile.

2. Materials and methods

2.1. Site description

This study was conducted on a coastal plain at the Yellow Sea State Forest Park in a coastal area of Dongtai County, Northern Jiangsu Province, in Eastern China (32°33–57′N, 102°07′–53′E). This region is located in a warm temperate-subtropical transition zone, and is under the influence of a monsoon climate. The pH of the soil is 8.2, and remains alkaline at this stage of development, whereas the soil salinity is 1.1–2.1 g kg^{-1}. The mean annual temperature is approximately 15.4 °C, with 1494.0 mm of annual rainfall, and an annual average relative humidity of 76.0%. There is a 220 d frost-free period and 2169.6 h of sunlight exposure per year. Our study was conducted in a 10-yr-old pure poplar plantation. The dominant understory plants included graminoids (*Lophatherum gracile*, *Oplismentls undulatifolius* folius, *Miscanthus sinensis*), vines (*Cayratiatrifolia*, *Humulusscandens*, *Dioscorea opposita*), and herbs (*Erigeron annuus*, *Corchoropsis psilocarpa*). The canopy coverage of the plantation was 55% and the mean tree height was 21.3 m, with a mean diameter at breast height of 23.1 cm.

Prescribed fire is commonly used to decrease understory competition and to maintain forest biodiversity in the US and Europe (Davies et al., 2014). In China, understory vegetation is typically removed by manual labor due to a relatively cost-effective labor force. The byproducts of soybean oil are widely employed by farmers as organic fertilizers to improve soil quality in poplar plantations (Wang et al., 2015).

2.2. Experimental design

This study was conducted from September 2013 to 2014, and followed a randomized block design, with three treatments in three replicate blocks (at least 500 m apart), for a total of nine 4 m × 4 m plots. The treatments were: (1) control (CK), (2) OF addition with the byproduct of soybean oil (3750 kg/ha, organic content: 75%; $N = 7\%$; $P = 1.12\%$; K = 2.13%) and (3) UP removal: manual removal of all understory vegetation with a machete. OF addition and UP removal were applied in September and December 2013 and March and June 2014, respectively, coinciding with the growing demand of poplar plantations. The OF was applied to a depth of 0–20 cm soil by trenching. Two trenches were also created in the center of the CK and UP plots to create a comparable trenching effect. The fertilizer dose matched that of what has commonly been used in local fertilization practice.

2.3. Field sampling and laboratory processing

We collected soil fauna from 0 to 10 and 10–20 cm depth intervals. The soil samples were extracted from each plot in December 2013, March, June, and September 2014 with soil cores (4 cm in diameter). At each sampling date, we also dug pits measured (25 × 25 × 20 cm) to sample macroarthropods (e.g., Polydesmida, Scolopendromorpha, Coleoptera, Araneida and Hymenoptera) (Decaëns et al., 1998). Macroarthropods encountered in the field at the time of sampling were hand collected and placed in a plastic bottle with ethanol. All samples were immediately placed in plastic bags, sealed, and transported to the laboratory for further processing.

Soil arthropods were extracted from each soil core using the modified Tullgren extractors (Tullgren Funnel Unit, BURKARD, UK). All extracted faunal samples were preserved in 75% ethanol and subsequently sorted under a dissecting microscope (Eclipse E200, Nikon, Japan). The biodiversity of soil fauna communities were estimated using taxonomic Orders (e.g., Trombidiformes, Sarcoptiformes, Hymenoptera, Collembola, Siphonaptera, Mesostigmata, Scolopendromorpha, Diptera (larva), Coleoptera (larva, mature), Thysanoptera, Homoptera, Polydesmida, Araneae and Psocoptera (Krantz and Walter, 2009; Yin, 1998). The feeding structure of Acari was grouped by macrophytophages, microphytophages, panphytophages and Omnivorous guilds (Cao et al., 2011; Moore et al., 1988). We analyzed soil arthropod abundance (individual numbers per square meter), Order richness, Order evenness, and Shannon's index in both 0–10 cm and 10–20 cm depth mineral soil layers, and considered them as a whole, spanning the 0–20 cm soil depth. We calculated Order richness as the number of Orders, Order evenness using J' index (Pielou, 1966), and the Shannon-Wiener index (Whittaker, 1972).

We also extracted soil samples at four random locations from 0 to 10 and 10–20 cm depth soil layer with soil cores (2.5 cm in diameter) in each plot to determine soil properties. Two random soil cores from the four locations were composited into one, and passed through 2 mm sieves for soil moisture determination. The other two cores were air-dried and passed through 2.00 and 0.25 mm sieves for chemical analyses. Soil moisture was calculated as [(wet weight of soil-dry weight of soil) × 100] / dry weight of soil. The dry weight of the soil was determined following oven drying at 105 °C for 24 h. Soil pH was determined using a glass electrode in a 1:2.5 soil: water solution (w/v). Total nitrogen (TN) concentrations in the soil were measured using an elemental analyzer (Elementar, Vario ELIII, Elementar Analysen Systeme GmbH, Hanau, Germany). Available phosphorus (AP) was extracted using a NaHCO3 solution, and was measured using the Mo-Sb colorimetric method. Available potassium (AK) was extracted with neutral ammonium acetate and was determined using flame photometry. Loss-on-ignition and organic carbon were used to estimate organic matter content (OM) of the soil (Howard and Howard, 1990).

2.4. Statistical analysis

To examine the effects of treatment, sampling date and soil layer on measured soil arthropod variables, we used linear mixed effect models with sample plot as a random effect to account for temporal autocorrelation associated with sampling date and spatial autocorrelation associated with soil layer (i.e., layer nested within plot). We used package "*lme4*" with restricted maximum estimation (Bates et al., 2017). To better understand the response at the entire soil profile sampled at 0–20 cm depth, we also used linear mixed effect models to test the effects of treatment and sampling date on abundance and diversity of soil arthropods. Spearman's rank correlation was performed to test for relationships between soil physicochemical characteristics and the abundance of soil arthropod major groups, which were defined as an individual group abundance > 1% of the total across all treatments and sampling dates. When appropriate, data were natural log (x + 1) transformed to meet the ANOVA parametric assumption of normality and homogeneity. We used redundancy analysis (RDA) to examine the associations between soil arthropod community composition and soil physicochemical characteristics (Borcard et al., 2011), implemented with package "*vegan*" (Oksanen et al., 2017). In order to

Table 1
The effects (*P* values) of treatment (T), sampling date (D), and soil layer (L) on soil arthropod total abundance (ind m^{-2}) and diversity indices, and dominant groups abundance (ind m^{-2}) to in coastal saline region of northern Jiangsu.

Factor	T	D	L	T × D	T × L	D × L	T × D × L
Total abundance	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Trombidiformes	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Sarcoptiformes	0.09	0.69	0.02	0.09	0.05	< 0.001	< 0.001
Richness	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.39	0.004
Shannon's index	0.04	< 0.001	0.68	< 0.001	0.18	0.11	0.002
Evenness	< 0.001	< 0.001	0.002	< 0.001	0.04	< 0.001	< 0.001

simplify the analysis, we used eight groups (Trombidiformes, Sarcoptiformes, Hymenoptera, Collembola, Siphonaptera, Mesostigmata, Scolopendromorpha, and Diptera that together consisted of 96% of the total number of arthropods across treatments and sampling dates) in the analysis (Wu et al., 2014). All analyses were performed in R Version 3.3.2 (R Development Core Team, 2017).

3. Results

3.1. Total arthropod abundance

The total abundance of soil arthropods varied among treatments, sampling dates, soil layers, and their interactions (Table 1, Fig. 1A). The addition of OF increased soil arthropod abundance in the 0–10 cm layer, but did not alter arthropod abundance in the 10–20 cm layer. The removal of UP decreased arthropod abundance in the 0–10 cm layer, while it had no significant effect in the 10–20 cm layer. When soil layers were combined at the 0–20 cm depth, the total abundance of soil arthropods varied with OF addition and UP removal with a significant interaction effect of treatment and sampling date (Table 2, Fig. 1B). Compared with the CK, the addition of OF on averagely increased arthropod abundance ($P = 0.004$), whereas the removal of UP had no significant effect ($P = 0.56$).

3.2. Order abundance rank

In the 0–10 cm layer of the CK plot (Fig. 2), Trombidiformes and Sarcoptiformes comprised the most abundant orders, which accounted for 75.7% of the total individuals, followed by Hymenoptera, Collembola, Siphonaptera, Mesostigmata, Scolopendromorpha and Diptera

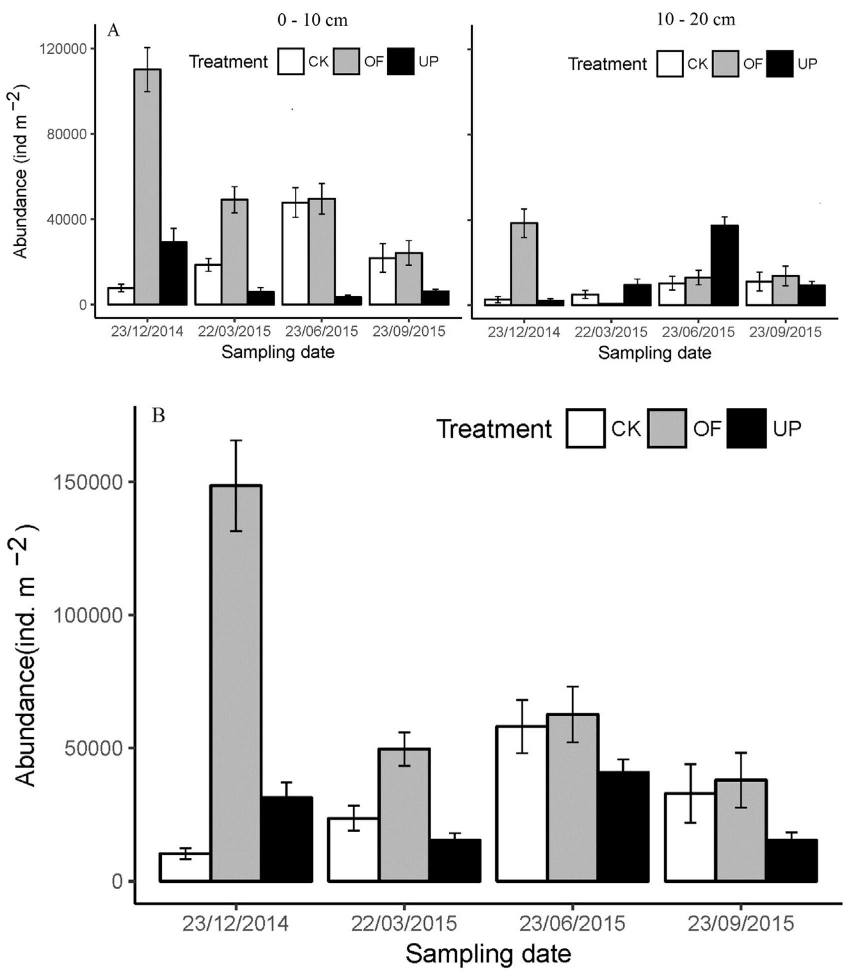

Fig. 1. The response of total soil arthropod abundance (ind. m^{-2}) to OF addition and UP removal with four sampling dates at 0–10 cm and 10–20 cm soil depth (A), and at 0–20 cm soil depth (B) in reclaimed coastal saline soil of managed poplar plantations (bars indicate SE). CK: control; OF: organic fertilizer; UP: understory plant removal.

Table 2
The responses of soil arthropod total abundance (ind m^{-2}) and diversity indices, and dominant groups abundance (ind m^{-2}) to treatments (T) along sampling dates (D) at 0–20 cm soil depth in coastal saline region of northern Jiangsu.

Trait		Source	Sum Square	df	F. value	P
Abundance	Total	D	3.17	3, 24	9.19	< 0.001
		T	7.58	2, 24	32.96	< 0.001
		D × T	7.18	6, 24	10.40	< 0.001
	Sarcoptiformes	D	5.45	3, 18	8.68	< 0.001
		T	1.68	2, 6	4.00	0.08
		D × T	5.46	6, 18	4.35	0.007
	Trombidiformes	D	6.01	3, 24	7.64	< 0.001
		T	17.02	2, 24	32.45	< 0.001
		D × T	18.87	6, 24	11.99	< 0.001
Richness		D	94.89	3, 18	42.70	< 0.001
		T	24.31	2, 6	16.41	0.004
		D × T	9.28	6, 18	2.09	0.11
Shannon's index		D	3.56	3, 24	37.55	< 0.001
		T	0.08	2, 24	1.21	0.31
		D × T	0.32	6, 24	1.68	0.17
Evenness		D	0.19	3, 24	8.13	< 0.001
		T	0.40	2, 24	25.15	< 0.001
		D × T	0.15	6, 24	3.16	0.02

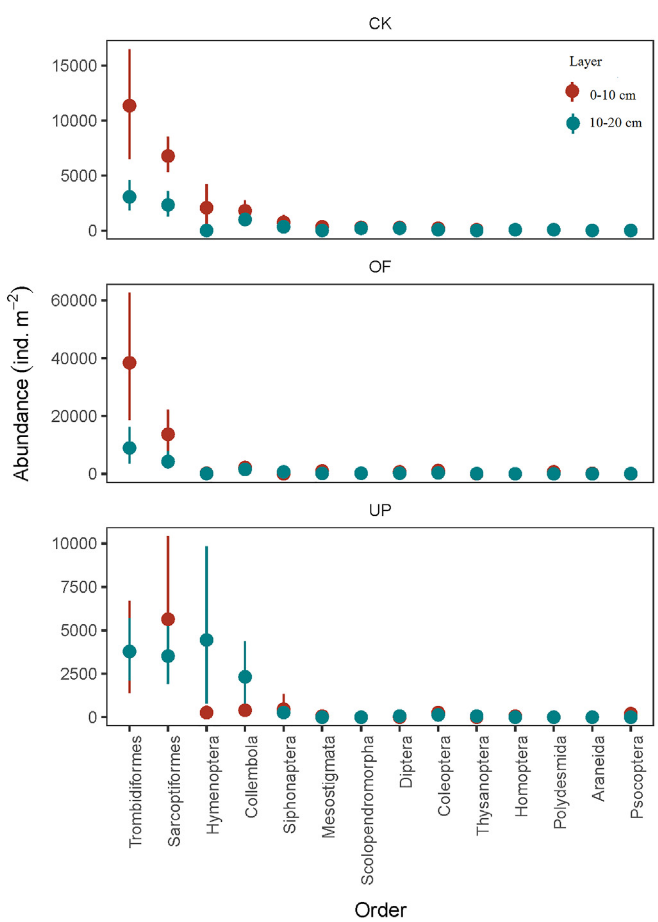

Fig. 2. Order abundance rank. CK: control; OF: organic fertilizer; UP: understory plant removal.

together accounting for 23.1% of the total individuals. Rare orders included, with a decreasing order of abundance, Coleoptera, Thysanoptera, Homoptera, Polydesmida, Araneae and Psocoptera. In the 10–20 cm of the CK treatment, the Order rank remained the same, except that Hymenoptera and Mesostigmata were absent.

In the 0–10 cm layer in the OF plot (Fig. 2), the relative abundance of Trombidiformes and Sarcoptiformes (proportion of total arthropod numbers) was increased by 13.7% compared to the CK. The addition of OF had a positive effect on the abundance of Macrophytophages, Microphytophages and Omnivorous Acari (Table 3). At the 10–20 cm soil depth, the addition of OF tripled the abundance of Trombidiformes mites as compared with the CK, and significantly increased the amount of Microphytophages and Omnivorous Acari. When combined at the 0–20 soil layer, the OF addition positively impact the abundance of Sarcoptiformes ($P = 0.01$) and Trombidiformes ($P < 0.001$). OF addition also changed the functional traits of Acari, significantly increased the number of Macrophytophages mites ($P < 0.001$), Microphytophages mites ($P = 0.003$), and Omnivorous mites ($P = 0.004$).

In the 0–10 cm layer of the UP removal plot (Fig. 2), the abundance of Collembola decreased to one-fourth that of the CK, but its Order rank did not change. At the 10–20 cm soil depth, Hymenoptera emerged and ranked first with the UP removal treatment. When combined at the 0–20 soil layer, the rank of Trombidiformes was altered, from the top in the CK to the second position and the rank of Collembola accordingly switched to the forth from the third.

3.3. Order diversity

Response of diversity indices of soil arthropods differed to treatments, sampling dates, soil layers (Table 1, Fig. 3A). The addition of OF decreased evenness at two soil layers, and did not affect richness, Shannon's index and evenness. UP removal decreased Order richness ($P = 0.02$) in 0–10 cm layer. When the soil layers were combined to reflect a 0–20 cm depth, the arthropod richness and evenness varied during sampling dates from 2014 to 2015 under different treatments (Table 2, Fig. 3B). Compared with the CK, the OF addition decreased evenness.

3.4. Changes in soil properties and their correlation to soil arthropods

The soil properties were influenced by the treatments (Table 4), where the addition of OF significantly increased soil organic matter (OM), total nitrogen (TN), available phosphorus (AP), and decreased soil pH at both 0–10 cm and 10–20 cm depth. Available potassium (AK) at 10–20 cm soil did not change. The removal of UP did not alter soil chemical properties, but significantly decreased soil moisture content.

In a correlation analysis (Table 5), the abundance of Trombidiformes and Mesostigmata correlated positively to OM, TN, AK, AP and soil moisture, and negatively correlated to pH. Sarcoptiformes abundance positively correlated to OM and TN. Scolopendromorpha abundance positively correlated to OM and moisture. Diptera abundance correlated positively with OM, TN and AP, and negatively correlated to pH. The results of the redundancy analysis (RDA: Cumulative percentage variance of species data for both axes: 42.7%) showed that OF addition plots were separated from the other treatments on the right, while UP removal plots were on the top and left, respectively by soil layers (Fig. 4). Trombidiformes abundance was positively associated with OF application and increasing TN, AP, and OM, but negatively with soil pH. Sarcoptiformes abundance was positively associated with UP removal and negatively associated with soil moisture at the 0–10 cm depth. Mesostigmata abundance was associated with UP removal at 10–20 cm depth and negatively with TN, AP, AK, and OM.

4. Discussion

Resource quality and quantity are critical factors in determining the abundance and community structure of soil fauna (Lenoir et al., 2006). As we anticipated, we found that soil arthropod abundance was increased with the addition of OF. This aligned with other studies that used both farmyard manure (Birkhofer et al., 2008) and green manure (Wang et al., 2016). The addition of OF can elevate the abundance of

Table 3
The abundance (ind m^{-2}) of Acari functional groups as influenced by the different treatments at the study site. CK: control; OF: organic fertilizer addition; UP: understory plant removal.

Treatment	Saprophage	Microphytophages	Panphytophages	Omnivorous
0–10 cm				
CK	1260.6 ± 239.2^{b}	$10{,}682.1 \pm 1593.7^{b}$	4246.3 ± 518.2^{a}	2123.1 ± 239.2^{b}
OF	2919.3 ± 289.2^{a}	$35{,}230.9 \pm 1493.9^{a}$	3848.2 ± 464.4^{a}	$11{,}013.8 \pm 928.9^{a}$
UP	995.2 ± 304.0^{c}	5042.5 ± 1004.0^{b}	2853.0 ± 747.7^{a}	597.1 ± 114.9^{b}
10–20 cm				
CK	265.4 ± 175.5^{a}	3052.0 ± 1042.7^{b}	1393.3 ± 500.9^{a}	663.4 ± 298.2^{b}
OF	597.1 ± 289.2^{a}	9620.5 ± 1650.7^{a}	1592.4 ± 689.5^{a}	1459.7 ± 403.6^{a}
UP	398.1 ± 199.0^{a}	4710.7 ± 632.9^{ab}	1592.4 ± 414.3^{a}	597.1 ± 114.9^{b}

Different letters indicate a significant difference between treatments at $\alpha = 0.05$.

detritus feeders through increased resource availability (Birkhofer et al., 2008), and the abundance of microbe predators through increased microbial biomass (Bardgetta and Cookb, 1998; Birkhofer et al., 2008; Rotheray et al., 2009). Another possible rationale is that OF improved soil properties, and the abundance, diversity and composition of soil fauna are altered in response to the changes of soil environment (Fu et al., 2009; Wang et al., 2015).

Acari is often the most abundant and includes diverse species in grasslands (Menta et al., 2011), forests (Lindberg and Bengtsson, 2005) and agricultural land (Zhu and Zhu, 2015). In this study, the Trombidiformes and Sarcoptiformes were the most abundant Orders in poplar plantations instead. The abundance of Macrophytophages, Microphytophages and Omnivorous Acari were increased by OF addition. Furthermore, the OF addition resulted in a lower soil pH and higher amount of soil OM, TN, AK and AP, which is beneficial for the improvement of reclaimed coastal saline soils. Soil arthropods are sensitive to change in soil pH and soil enrichment with nutrients (Laiho et al., 2001; Wang et al., 2016). Decreasing soil pH can result in elevated populations of soil arthropod through the application of organic fertilizer (McCormack et al., 2013; Wang et al., 2015). The number of dominant and common groups was found negatively correlated with soil pH and positively related with soil organic matter in this study, indicating reduced soil pH and improved soil nutrient could influence their abundance. Thus whether the OF addition had the direct (resources availability) or indirect (soil pH change) effect on soil arthropods abundance remained to be elucidated in the future.

The increased abundance Order Trombidiformes and Sarcoptiformes under the addition of OF treatment resulted in a high

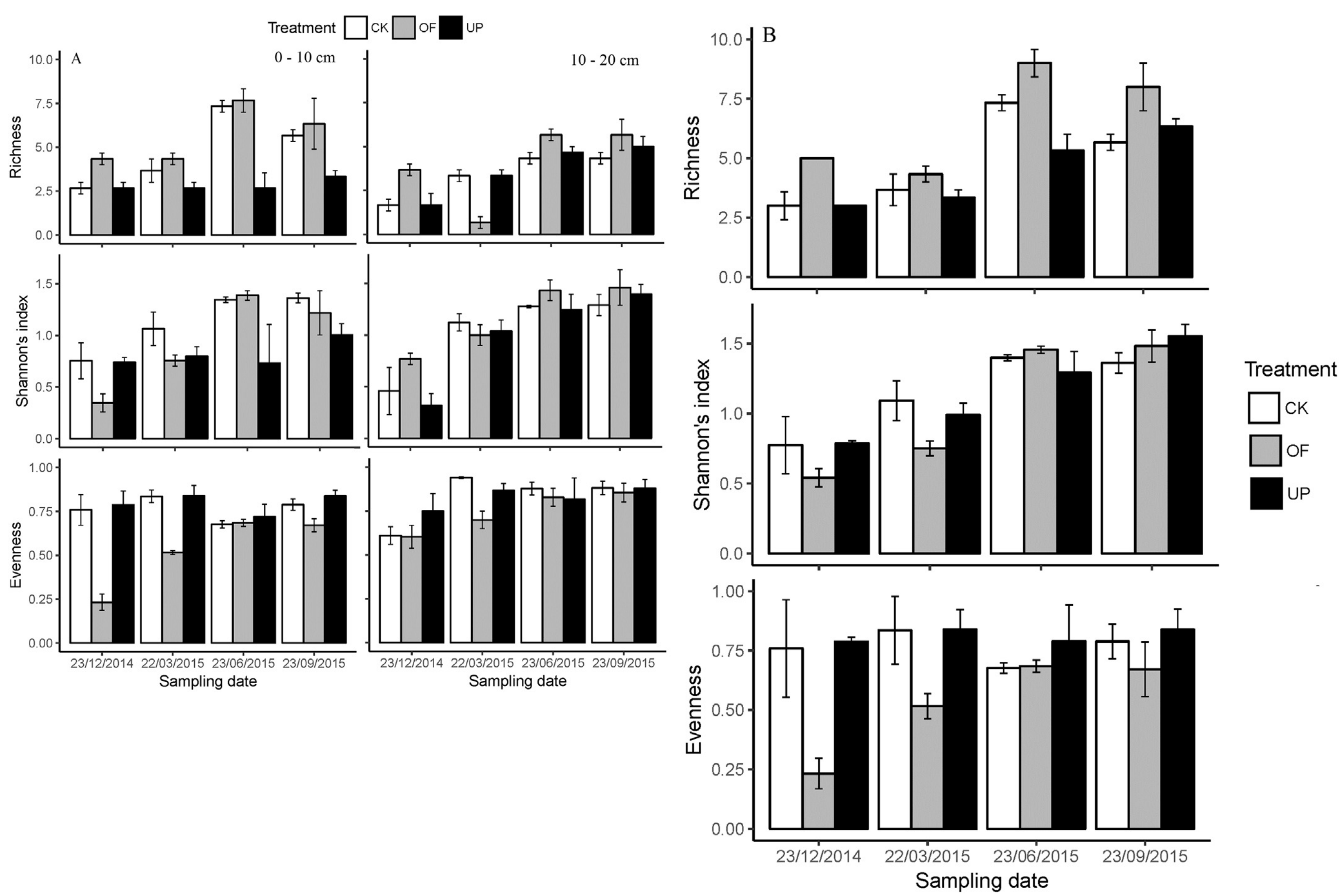

Fig. 3. The response of soil arthropod diversity indices to OF addition and UP removal with four sampling dates at 0–10 cm and 10–20 cm soil depth (A), and at 0–20 cm soil depth (B) in reclaimed coastal saline soil of managed poplar plantations (bars indicate SE).CK: control; OF: organic fertilizer; UP: understory plant removal.

Table 4
Soil chemical parameters (mean ± standard error) as influenced by the different treatments at the study site. CK: control; OF: organic fertilizer addition; UP: understory plant removal; OM: soil organic matter; TN: total nitrogen; AP: available phosphorus; AK: available potassium.

Dimension	Parameter	CK	OF	UP
0–10 cm soil	OM ($g\,kg^{-1}$)	24.78 ± 1.48^b	29.17 ± 0.78^a	21.3 ± 0.9^b
	TN ($g\,kg^{-1}$)	1.06 ± 0.08^b	1.35 ± 0.03^a	1.07 ± 0.09^b
	AP ($mg\,kg^{-1}$)	2.76 ± 0.23^b	3.97 ± 0.33^a	2.63 ± 0.24^b
	AK ($mg\,kg^{-1}$)	136.74 ± 11.01^b	185.44 ± 6.58^a	135.04 ± 11.39^b
	pH	8.1 ± 0.12^a	7.43 ± 0.07^b	8.16 ± 0.29^a
	Moisture (%)	24.88 ± 0.36^a	25.6 ± 0.44^a	20.44 ± 0.36^b
10–20 cm soil	OM ($g\,kg^{-1}$)	22.93 ± 0.44^b	26.96 ± 0.34^a	19.97 ± 1.84^b
	TN ($g\,kg^{-1}$)	0.98 ± 0.08^b	1.21 ± 0.05^a	0.93 ± 0.03^b
	AP ($mg\,kg^{-1}$)	2.67 ± 0.15^b	3.13 ± 0.20^a	2.13 ± 0.24^b
	AK ($mg\,kg^{-1}$)	131.58 ± 6.37^a	147.95 ± 7.29^a	128.81 ± 4.32^a
	pH	8.22 ± 0.05^a	7.76 ± 0.12^b	8.15 ± 0.16^a
	Moisture (%)	24.6 ± 0.27^a	25.03 ± 0.27^a	23.94 ± 1.09^b

Different letters indicate a significant difference between treatments at $\alpha = 0.05$.

Table 5
Correlation between major (dominant and common) groups of soil arthropods and soil chemical characteristics under three treatments. Values are Spearman correlation coefficients. Dominant (> 10%) and common groups (1%–10%).

Variables	OM	TN	AP	AK	pH	Moisture
Trombidiformes	0.77***	0.74***	0.59**	0.61**	−0.48*	0.50*
Sarcoptiformes	0.51*	0.65**	0.46	0.32	−0.30	0.16
Collembola	0.28	0.25	−0.04	0.11	−0.02	0.19
Hymenoptera	−0.42	−0.41	−0.19	−0.36	0.16	−0.02
Siphonaptera	−0.24	−0.41	−0.01	−0.19	−0.03	0.01
Mesostigmata	0.63**	0.55*	0.60**	0.55*	−0.55*	0.50*
Scolopendromorpha	0.52*	0.29	0.32	−0.06	−0.11	0.47*
Diptera	0.63**	0.54*	0.67**	0.2	−0.51*	0.36

Statistical significance: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

dominance of their relative abundance (accounted for 90% of the total number of arthropod individuals). Trombidiformes increased almost four fold with the OF addition compared with CK. This increase in the dominance of Trombidiformes and Sarcoptiformes led to a decrease in the arthropod evenness calculated based on the Order level. The lack of responses in richness and Shannon's diversity index to OF treatment could partially due to the low resolution level of data at the Order level. Thus an increase in the resolution level of the taxonomic identification is recommended for future studies examining treatment effect on soil biodiversity with a low number of replicates (e.g. $n < 15$).

Our data only partially supported our second anticipation that the removal of UP would reduce soil arthropod abundance and diversity. In this study, the effects of UP treatment on soil arthropod abundance differed between soil depth layers, where the strongest variations were observed at the 0–10 cm depth level, and the removal of UP decreased the total abundance and richness. First, the removal of UP can reduce live roots, thus suppressing herbivore fauna (Zhao et al., 2011). Second, the removal of UP may decrease rhizosphere microbial populations along with mycorrhizal fungal biomass, thereby suppressing microbial feeders (Siddiqui and Pichtel, 2008). Third, the removal of UP can reduce root litter input, thus suppress detritus feeders. Forth, the removal

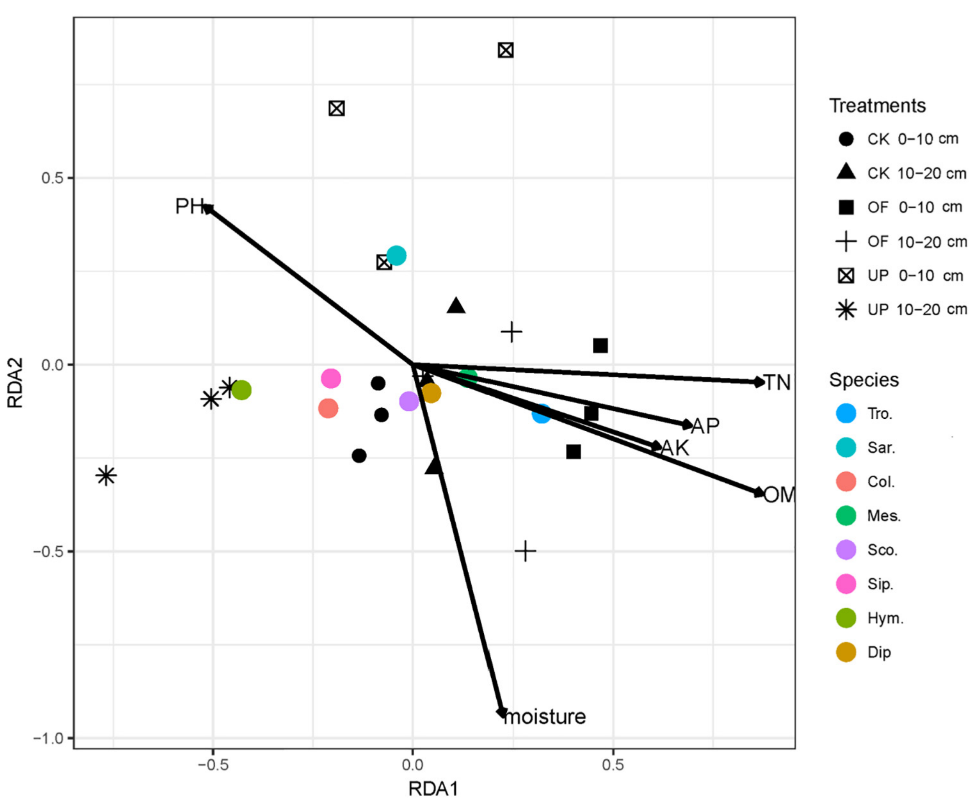

Fig. 4. Redundancy analysis (RDA) ordination plot for soil arthropod communities and correlated soil chemical characteristics (arrows). Data Hellinger transformed. Eigenvalues: first axis (horizontal = 0.03), second axis (vertical) = 0.01. Cumulative percentage variance of species data for both axes: 42.7%. RDA test $P = 0.02$. Trombidiformes: Tro; Sarcoptiformes: Sar; Scolopendromorpha: Sco; Collembola: Col; Mesostigmata: Mes; Hymenoptera:Hy; Siphonaptera: Si; Diptera: Di.

of UP may alter the structure of arthropod communities due to physical changes in soil conditions (Xiong et al., 2008).

Collembola are among the most abundant and diverse arthropods in the soils of many ecosystems (Behanpelletier, 2003; Zhu and Zhu, 2015). In this study, Collembola are also the most abundant species except Acari. UP removal negatively impacted the number of Collembola which was consistent with the previous study that the number of Collembola decreased with the removal of UP in plantations (Zhao et al., 2011). Published studies demonstrated Collembola feed predominantly on plant detritus and fungi, and exhibit preferences for various fungi (Rotheray et al., 2009). The removal of UP reduces the root litter input, decreases fungal biomass and the fungal:bacterial ratio, as well as soil organic carbon in forest plantations (Zhao et al., 2011), which may consequently decrease fungivores and detritus feeders such as Collembola (Jonas et al., 2007; Rotheray et al., 2009). Furthermore, Scolopendromorpha, Diptera and Coleoptera disappeared under UP removal may be another reason leads to the decrease of soil arthropod abundance and richness at 0–10 cm soil depth.

The reduction in soil moisture at the surface layer may trigger the vertical migration of soil fauna to deeper soil layers (Briones et al., 1998). Soil moisture was reduced by 17% in the 0–10 cm soil layer compared with the 10–20 cm soil under UP removal in this study. Species devoid of pigmentation, such as Collembola often migrate to deep soil layers to avoid harmful UVB radiation, or to locate an optimal substrate (Krab et al., 2010). Increased UVB radiation due to the removal of UP might be another incentive that drives the vertical migration of arthropods into deeper soil layers. Furthermore, soil properties were not significantly altered due to the removal of UP, which might explain why UP removal did not affect the abundance of arthropod communities in the 0–20 cm soil depth layer, as shown in our study.

The effects of OF addition and UP removal on the abundance, diversity and composition of soil arthropod community were investigated in reclaimed coastal saline soils. OF addition could directly (resource availability) and indirectly (soil environment) influence soil arthropod abundance through the modification on the feeding structure of dominant groups. UP removal had no significant effect on the overall (0–20 cm) abundance and diversity of soil arthropod activities. While both OF and UP promote plantation productivity, neither of the treatment have a negative effect on the abundance nor diversity of soil arthropods, and OF can substantially promote the abundance of soil arthropods. Thus, we conclude that OF is a preferable management practice, compared with UP removal, in promoting the abundance of soil arthropods for the restoration of coastal saline soils.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2018.05.004.

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