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Effects of Understory Liana *Trachelospermum jasminoides* on Distributions of Litterfall and Soil Organic Carbon in an Oak Forest in Central China

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Received: 4 April 2017; Accepted: 9 June 2017; Published: 14 June 2017

Abstract: Liana constitutes an important structural and functional component in many forest ecosystems and has profound impacts on forest carbon (C) cycling. However, whether and how liana regulates spatial distributions of litterfall and soil organic C are still poorly understood. To address this critical knowledge gap, we investigated litterfall composition and soil physicochemical characteristics in stands with different densities of liana (*Trachelospermum jasminoides* (Lindl.) Lem.). Both fresh and decomposed leaf litters were greater in the stands with high density of the liana species *T. jasminoides*. More liana covered stands also had higher soil respiration rate, soil organic C, and total nitrogen than those with less liana. The findings demonstrate that understory liana can regulate litterfall distribution and thus soil organic C, suggesting that the influences of understory liana on belowground ecological processes should be considered while assessing the role of liana in forest ecosystems.

Keywords: soil organic carbon; litter biomass; liana biomass; soil respiration; oak forest

1. Introduction

Lianas are woody climbers that not only germinate and root in soils, but also remain rooted in the soil during its entire life [1–3]. Lianas are a conspicuous and important component of most tropical forests [2,4–6]. In tropical forests, there are approximately 9216 liana species, representing 97 families of vascular plants [7]. A study in a tropical forest showed that more than 40% of trees > 10 cm diameter at breast height had lianas in their crowns, and juvenile lianas comprised approximately 20% of the biomass of the upright plants in the forest understory [8].

Lianas are prominent growth forms in tropical forests and studies indicate that its abundance is increasing in most forest ecosystems over the 20-year period [9,10]. The increases in lianas abundance and expansion have potential influences on forest community structure and nutrient cycling [10,11]. For example, host trees of lianas were reported to have lower growth rate, smaller size in diameter, and higher mortality compared to non-hosts [8], as a result of the destruction of bark and buds of trees by lianas [2,11,12]. It has been well reported that the differences in lianas abundance could induce spatial variations in aboveground biomass, mainly due to strong influences on the growth of their structural hosts [8]. For example, increased lianas abundance has been found to decrease aboveground C storage by as much as 18% in the tropical forest [13]. Despite the ubiquity of lianas in most forest ecosystems, and their impacts on forest structure and aboveground C stock have been well studied, their effects on belowground ecological processes have not been well studied [14].

Compared with tree species, lianas depend on other plants as trellises to reach the canopy, and thus invest proportionally less C into woody stem but more C toward roots and leaves [5,15]. Well-developed root systems of lianas [16] could impact soil physicochemical property, such as soil texture and C substrate availability during root growth and turnover [17,18]. For example, it has been found that soil organic C (SOC) and total nitrogen (TN) content were increased because of root turnover and rhizodeposition in an agricultural vineyard [19]. Additionally, lianas contribute more than 30% of total annual leaf litterfall in the tropical forest [16], thus can regulate soil C availability through changing litter quality and quantity. Moreover, soil nutrient availability also showed spatial variation due to the effects of creeping stems of lianas on litter distribution and decomposition rate [19]. The potential influence of lianas on soil ecological process should be considered in studies that attempt to determine the roles of lianas in regulating forest structure and function. However, research that focused on the direct effects of lianas on soil process is scarce, especially in temperate forests, where lianas have increased in size and abundance over the past 20 years as a consequence of forest fragmentation [20,21]. To date, it remains unclear whether and to what extent lianas affect litter distribution and soil C cycling in temperate forests.

In China, there are approximately 2175 liana species (woody climbers), representing 85 families of vascular plants [22]. Lianas account for 11.3% of the total species number of the spermatophyte flora of China [22]. The liana species *Trachelospermum jasminoides* (Lindl.) Lem. (belong to *Apocynaceae*) is an evergreen woody creeping plant, widely distributed in central and southern China. In natural forests, most of *T. jasminoides* are distributed on the forest floors, but few can climb trees and reach the top of the forest canopy through its adventitious root. This study addressed the following research questions: (1) Does the variation in understory liana affect the spatial distribution patterns of forest litter and soil physicochemical property? (2) Do stands with higher density of liana species show greater contents of SOC, TN, and rates of soil respiration?

2. Materials and Methods

2.1. Site Description

This study was conducted at Lijiazhai Forest Protection Station in the Jigong Mountain National Natural Reserve (31°51'58" N, 114°04'47" E, 185 m *a.s.l.*), Henan Province in central China. Mean annual temperature is 15.3 °C, ranging from 1.9 °C in January to 27.5 °C in July. Mean annual precipitation is 1098 mm, most of which (66%) occurs during May–September period (average values from 1951 to 2012). The soil type is a Haplic Luvisols (FAO) (pH = 4.0–5.5) developed from Sandshale bedrock. Soil depth varies between 20 and 50 cm [23]. The typical forest in this region is warm-temperate deciduous forest. The dominant tree species consist of *Quercus* spp., *Pinus tabulaeformis* Carr., *Acer truncatum* Bunge., *P. massoniana* Lamb., *Cunninghamia lanceolata* (Lamb.) Hook., and *Camellia oleifera* Abel. [24].

2.2. Experimental Design

The experiment was conducted in an oak forest (dominated by *Quercus* spp.), where the liana species *T. jasminoides* distributed widely on the surface (area of the watershed is ~2 ha). Mean diameter at breast height (DBH) of the forest is 26.6 ± 4.8 cm with an average age of 65 years. Stand density is 1033.9 individuals·ha⁻¹, and basal area is 29.8 m²·ha⁻¹. The average bulk density and SOC content at 10 cm surface layer of the study site are 0.64 ± 0.06 g·cm⁻³ and 43.80 ± 0.89 g·kg⁻¹, respectively.

Twenty 2 m × 2 m plots were randomly established on the stand with high density of *T. jasminoides* covered the surface (liana density > 2×10^6 individuals·ha⁻¹) (hereafter named plots with high density of liana (PHL)) (Figure 1). Another twenty 2 m × 2 m plots were randomly established on the stand with low density of *T. jasminoides* covered the surface (liana density < 1×10^6 individuals·ha⁻¹) (hereafter named plots with low density of liana (PLL)). The distance between plots (m) was determined by random numbers. Stands with two different liana densities showed no significant differences in tree

density and tree size. All plots were located at interspace between trees with similar topography (location, slope, aspect, size, and landform).



Figure 1. Forest floor characteristics of plots with different densities of lianas. (a) PHL, plots with high density of liana; (b) PLL, plots with low density of liana.

2.3. Liana Survey

We conducted a survey of lianas in each of the 40 plots on 14 May 2014. Lianas located within each plot were investigated, including basal diameter, height, density, and leaf number. After the investigation, all *T. jasminoides* individuals were entirely collected from each plot including root system. The plant samples were washed to remove attached soil particles and other materials adhering to them. Cleaned *T. jasminoides* were oven-dried at 70 °C for 72 h; classified as leaf, stem (erect part of *T. jasminoides*), and root (belowground part of *T. jasminoides*); and then weighed.

2.4. Litter Survey

The oak litterfall within each plot (2 m × 2 m) was collected carefully from the surface during the harvest of *T. jasminoides* on 14 May 2014. Litterfall was subjectively classified into four types: fresh leaf litter, and decomposed leaf litter (Oi and Oe sub-horizon in O horizon according to FAO), branch, and fruit. Different litter types were oven-dried at 70 °C for 72 h and weighed.

2.5. Soil Microclimate and Respiration

Soil temperature was measured at a depth of 5 cm and 10 cm by thermocouples at three random points in each plot. Soil volumetric water contents (% V) at a depth of 5 cm and 10 cm were measured with a portable Time Domain Reflectometer (TDR) equipment (Soil moisture equipment Corp., Santa Barbara, CA, USA) at three random points in each plot. One 100 mm diameter polyvinyl chloride collar was installed to a soil depth of 50 mm in the center of each plot on 1 April 2014. Soil respiration was measured at 5 days intervals using a portable soil respiration system (Li-8100, LI-COR, USA) over a 30-day period beginning on 10 April 2014. All measurements were made in the afternoon (12:30–15:30 p.m.) and executed in 2 min intervals with a 20 s deadband. Soil temperature and moisture were investigated at the same intervals with soil respiration measurement. All these measurements were conducted before the collection of *T. jasminoides* and litterfall. The average value of six measurements of soil temperature, moisture, and soil respiration within each plot was used in the statistical analysis.

2.6. Soil Organic Carbon and Total Nitrogen Content

Four soil cores (5 cm in diameter and 10 cm in depth) were collected from four corners within each plot after the *T. jasminoides* and litterfall was harvested. After removing plants and stones with 2 mm mesh sieve, soil samples were air dried at room temperature (25 °C) and then passed through a 0.25 mm mesh sieve for further chemical analysis. SOC was measured by dichromate oxidation method [25], and TN content was analyzed using the Kjeldahl method [26].

2.7. Data Analysis

Paired Student's *T*-test was used to examine the differences in liana characteristic (height, number of leaf, density, leaf biomass, stem biomass, root biomass, and total biomass), litter types (fresh leaf litter, decomposed leaf litter, branch, and fruit), and soil variables (soil temperature and moisture, soil respiration, SOC, and TN) between PHL and PLL. Linear regression was used to assess the relationships between leaf litter (fresh and decomposed leaf litters) and liana density and height in PHL and PLL. In addition, linear regression was also used to determine if liana density and height have the potential to affect SOC and TN in PHL and PLL. All statistical analyses were conducted using SPSS 16.0 for windows (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. *T. jasminoides* Characteristics and Biomass Distribution

The density of *T. jasminoides* in PHL was 232.4×10^4 individuals·ha⁻¹, significantly higher than that in PLL (40×10^4 individuals·ha⁻¹, $p < 0.05$, Table 1). In PHL, the biomass of *T. jasminoides* allocated to leaf, stem, and root was 0.19 t·ha⁻¹, 0.33 t·ha⁻¹, and 1.64 t·ha⁻¹, respectively, which was significantly higher than that in PLL (all $p < 0.05$, Table 1). Root biomass of *T. jasminoides* accounted for more than 75% of total biomass in both PHL and PLL (Table 1).

Table 1. The liana species *Trachelospermum jasminoides* characteristics and biomass distribution patterns among plots with different liana densities. Numbers in parentheses are the proportions of each organ accounted for in total biomass. Means \pm S.E., $n = 20$.

Types	Height (cm)	Number of Leaf	Density (10 ⁴ Individuals·ha ⁻¹)	Biomass (t·ha ⁻¹)			
				Leaf	Stem	Root	Total
PHL	21.89 \pm 5.58 a	4.3 \pm 2.0 a	232.4 \pm 19.3 a	0.19 \pm 0.06 (8.8%) a	0.33 \pm 0.13 (15.3%) a	1.64 \pm 0.31 (75.9%) a	2.16 \pm 0.55 a
PLL	26.37 \pm 5.31 b	5.9 \pm 1.5 b	40.2 \pm 31.4 b	0.05 \pm 0.01 (10.5%) b	0.07 \pm 0.01 (14.6%) b	0.36 \pm 0.04 (75.0%) b	0.48 \pm 0.02 b

PHL and PLL represent plots with high and low density of liana, respectively. In each column, mean values with different letters (a and b) are significantly different at 0.05 level.

3.2. Effect of Liana on Litter Distribution

Biomass of fresh leaf litter in PHL (2.86 t·ha⁻¹) was significantly greater than that in PLL (1.72 t·ha⁻¹; $p < 0.05$, Figure 2). In addition, PHL also had a substantial higher biomass of decomposed leaf litter (13.54 t·ha⁻¹) than that in PLL (7.22 t·ha⁻¹, $p < 0.05$, Figure 2). There were no differences in branch and fruit biomass between PHL and PLL ($p > 0.05$, Figure 2). Overall, total litter biomass in PHL was substantially greater (16.38 t·ha⁻¹) than that in PLL (13.88 t·ha⁻¹, $p < 0.05$, Figure 2).

Linear regression analysis illustrates the effects of liana density and height on fresh and decomposed leaf litters. Across the 20 plots in PHL, fresh leaf litter was positively related to liana density ($R^2 = 0.15$, $p = 0.05$) but not to liana height ($p = 0.28$; Figure 3a,b). The decomposed leaf litter showed strong positive correlations with both liana density ($R^2 = 0.26$, $p < 0.05$) and height ($R^2 = 0.23$, $p < 0.05$; Figure 3c,d). For PLL, fresh leaf litter showed positive correlation with liana height ($R^2 = 0.24$, $p < 0.05$), but not with liana density ($p > 0.05$, Figure 3a,b). Neither liana density nor height displayed significant effects on decomposed leaf litter in PLL (Figure 3c,d).

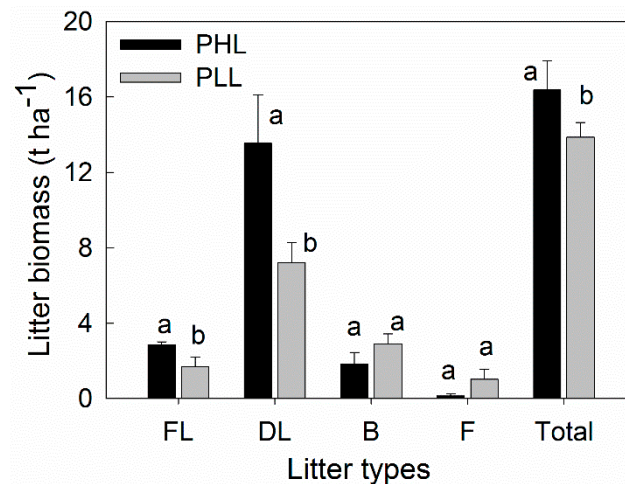


Figure 2. Differences in litter biomass between plots with high density of liana (PHL) and those with low density of liana (PLL; mean \pm S.E., $n = 20$). FL, fresh leaf litter; DL, decomposed leaf litter; B, branch; F, fruit. Values followed by different lowercase letters between different plots are significantly different at 0.05 level.

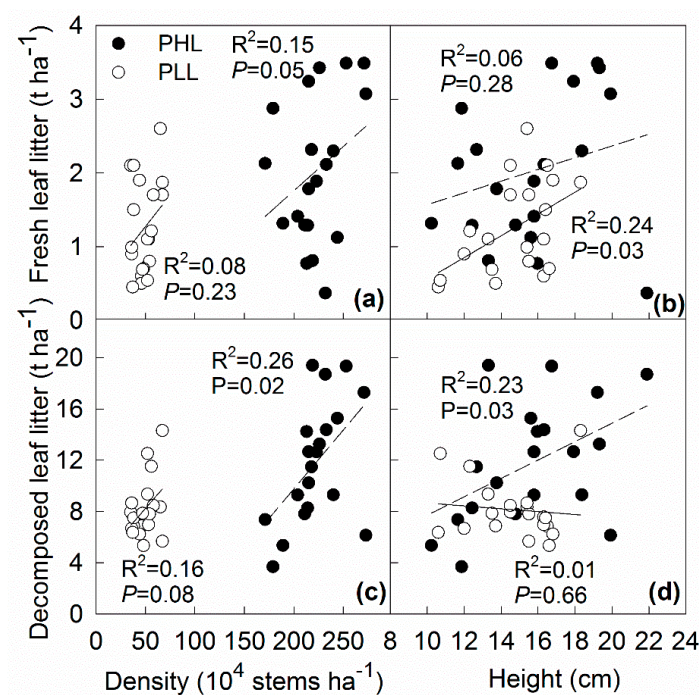


Figure 3. Dependences of different leaf litter types, (a,b) fresh leaf litter and (c,d) decomposed leaf litter, on liana density and height in the plots with high density of liana (PHL, $n = 20$) and those with low density of liana (PLL, $n = 20$).

3.3. Effects of Liana on Soil Temperature and Moisture

Soil temperature in PHL was marginally lower than that in PLL (both $0.05 < p < 0.10$; Figure 4a). Soil moisture at a depth of 10 cm in PHL was 1.01% lower (absolute difference, $p < 0.05$) than that in PLL, but showed no differences between PHL and PLL at a depth of 5 cm ($p > 0.05$, Figure 4b).

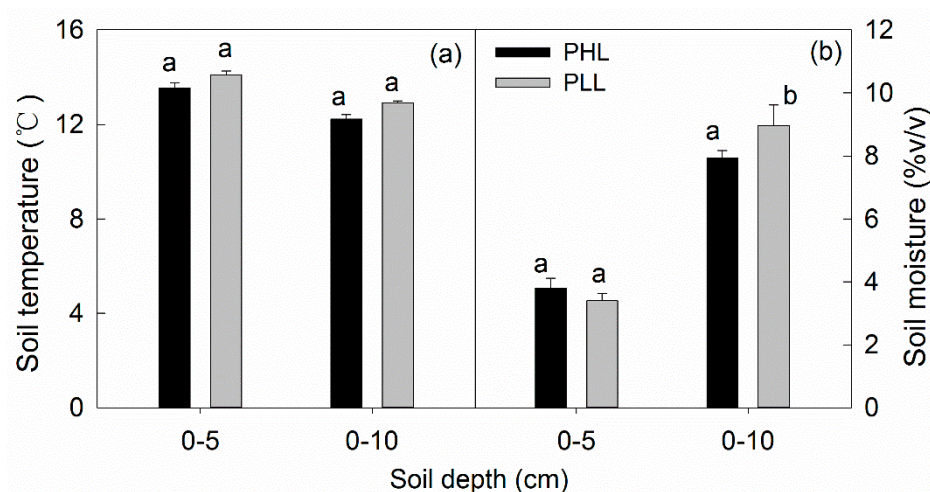


Figure 4. Differences in (a) soil temperature and (b) moisture between plots with high density of liana (PHL) and those with low density of liana (PLL) (mean \pm S.E., $n = 20$). Values followed by different lowercase letters between different plots are significantly different at 0.05 level.

3.4. Effects of Liana on Soil Respiration, SOC, and TN

Soil respiration in PHL and PLL was 2.39 and 1.82 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively (Figure 5). Significant differences in SOC and TN were found between PHL and PLL (both $p < 0.05$, Figure 6). The SOC and TN concentrations of 0–5 cm soil layer in PHL were significantly greater than those in PLL (both $p < 0.05$, Figure 6).

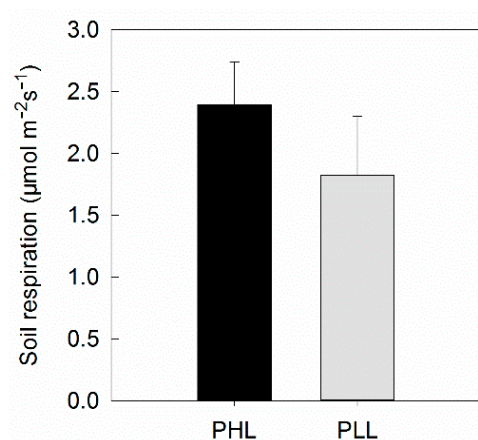


Figure 5. Differences in soil respiration between plots with high density of lianas (PHL) and that with low density of lianas (PLL; mean \pm S.E., $n = 20$).

Across the 20 plots, liana density showed significant positive effect on SOC ($R^2 = 0.22$, $p < 0.05$) and marginal effect on TN ($p = 0.08$) in PHL (Figure 7a,c). However, liana height displayed no influences on both SOC and TN ($p > 0.05$, Figure 7b,d). In addition, liana density displayed positive effects on SOC and TN in PLL ($p < 0.05$, Figure 7a,c). Nevertheless, liana height showed no effects on SOC and TN ($p > 0.05$, Figure 7b,d).

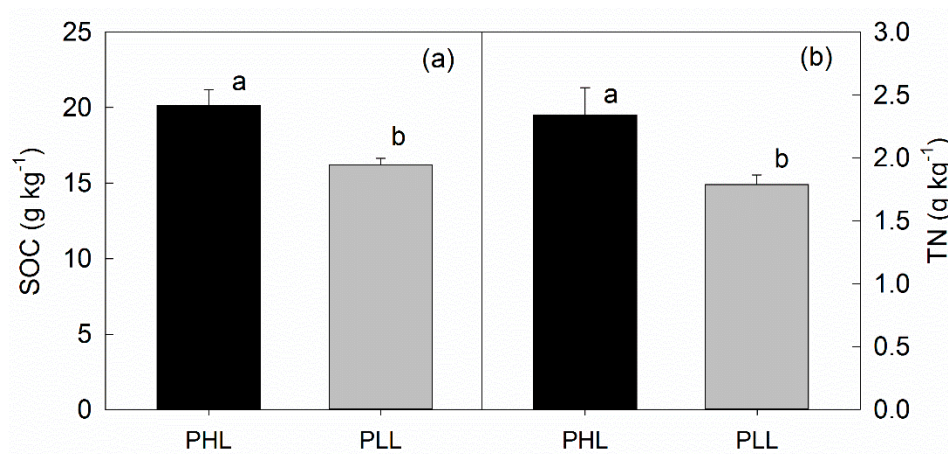


Figure 6. Differences in (a) SOC and (b) TN for 0–10 cm soil layer between plots with high density of liana (PHL) and that with low density of liana (PLL; mean \pm S.E., $n = 20$). Values followed by different lowercase letters between different plots are significantly different at 0.05 level.

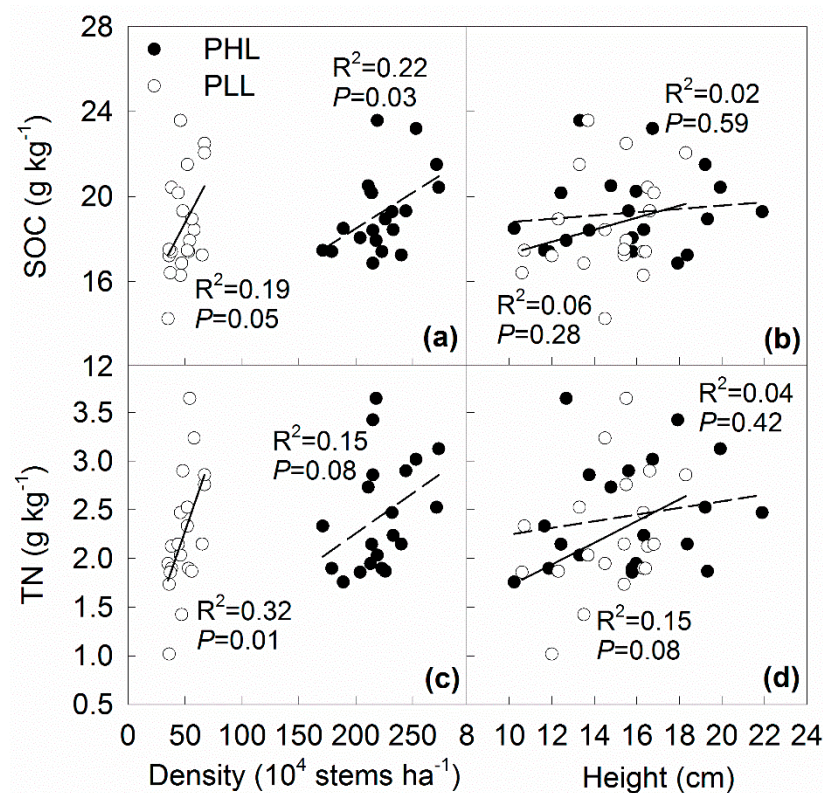


Figure 7. Dependences of (a,b) SOC and (c,d) TN for 0–10 cm soil layer on liana density and height in the plots with higher density of liana (PHL, $n = 20$) and those with low density of liana (PLL, $n = 20$).

4. Discussion

4.1. Effect of Liana on Litter Distribution

The finding that liana strongly affected the distribution pattern and decomposition degree of surface litter supports the conclusion that the spatial heterogeneity of forest floor litter is regulated by the distribution of trees as well as the understory plants [27,28]. The differences in litter components between stands with different densities of liana were attributed to the physical and biological characteristics of the liana plant [14,29]. According to the decomposition equation reported by

Harmon et al. [30], a greater litter mass could result from greater production of litter and/or smaller decomposition rate. Greater rate of soil respiration and greater contents of SOC and TN could indicate that decomposition rate would be greater in the plots with greater liana density. However, litter biomass was also greater in the plots with greater liana. The higher total litter biomass in the stand with high density of liana could be explained by the physical interception effect of the *T. jasminoides* on leaf litters, mainly as a result of its developed and upright stems [31]. As a creeping plant, most of *T. jasminoides* individuals grow along the soil surface, and thus, can elevate wind resistance of surface leaf litters attributed to its upright stems. The quantity of decomposed leaf litter in the stand with high density of liana was higher than that with low density of liana, which can be explained by the following two processes. First, one of the main processes leading to the leaf decomposition is comminution. The dense stems and accumulated leaf litters in the stand with high density of liana provide better habitat and food for invertebrates. The stronger activity of the invertebrates in the stand with greater liana can largely break the fresh organic material into tiny pieces. Second, leaf litters could be degraded, to some extent, by the well-developed adventitious roots of the *T. jasminoides* [16] while it grows and prostrates on the surface, this can also be supported by the positive relationship between decomposition and liana density (Figure 3). The finding that plots with more liana not only had greater decomposed litters, but also total litter biomass seems contradictory. We attributed this to the different magnitudes of increase in litter accumulation and invertebrate activity. However, understory liana showed no influences on the spatial distributions of the fallen branch and fruit litters. The finding suggests that the distribution patterns of branch and fruit litters may largely depend on the tree size and location.

4.2. Effects of Liana on SOC and TN

The SOC and TN in PHL were higher than those in PLL indicates that understory *T. jasminoides* is helpful for the improvement of soil C and N availability. Consistent with our results, a significant positive effect of vines on total organic C and N content was reported in a vineyard ecosystem [19]. Several reasons may explain this phenomenon. First, the elevated SOC in PHL was due in part to the elevated litter accumulation (Figure 2), which may increase the substrate availability for microbes and soil fauna [32], and elevated potential dissolved organic C. Second, PHL showed higher soil temperature and moisture (Figure 4), which may benefit the activity and metabolism of soil microbial community. Third, more invertebrates tend to inhabit in the stand with high density of the liana species *T. jasminoides* due to better food supply [33]. The gathered invertebrates could directly improve the soil nutrient condition through its feces, and indirectly elevated the decomposition of litters by its feeding.

4.3. Implications for Forest C Storage and Ecological Restoration

Given the direct competitive relationships between lianas and trees, it has been reported that the increase in lianas could influence the composition and dynamics of forest communities [2,34]. Liana thus has the potential to alter forest C storage, by reducing tree growth and survival [18]. It has been widely reported that tree aboveground biomass is negatively correlated with liana abundance [10,18,35], which indicates the increase in liana under climate change [36,37] may reduce C storage of forest by the inhibition of growth. However, the positive effects of liana on litter accumulation and SOC found in this study may temper the negative influence of liana on forest C storage at the ecosystem level. One of the main drawbacks is that we only collected soil samples once in May, early growing season, which may over- or underestimate the effect of liana due the failure to capture the seasonal soil and plant variabilities. Nevertheless, at least the spatial variation of soil C storage induced by liana should be taken into consideration while estimating liana effects on forest C cycling.

Although vines can compete with trees for resources such as water, nutrient and light, vine also plays an important role in ecosystem processes and ecological restoration. In this study, most of *T. jasminoides* individuals cover the surface soil, their dense population can mitigate soil erosion and

maintain the soil nutrients which can be easily leached by exposed topsoil without ground cover. The improved soil nutrient by lianas in forest is surely helpful for the long term restoration and population succession.

5. Conclusions

In summary, we investigated the effects of the liana (*T. jasminoides*) on forest floor litter distribution and soil basic characteristic in a deciduous broadleaf forest. Greater leaf litter, SOC and TN were found in the stand with high density of the liana species *T. jasminoides*. The differences in litter patterns and soil basic characteristic between stands with high/low density of liana indicates that liana influence belowground ecological processes, such as C input and N availability, which may affect forest C cycling. This study provides baseline data on the effect of liana on belowground soil property, and further research is needed for better understanding of the belowground ecological processes affected by lianas.

Acknowledgments: We thank the two anonymous reviewers for their constructive suggestions. We thank Renhui Miao for his comments in the manuscript. This study was jointly supported by the China National Science Foundation (No. 31600379), Key Research Project of Colleges and Universities in Henan Province (No. 17A180001), Chinese Postdoctoral Science Foundation (2017M612389), and Scientific Research Fund Project of Henan University (2015YBZR035).

Author Contributions: All the authors contributed to this manuscript. Yanchun Liu proposed the research and designed the experiments; Qing Shang and Kesheng Zhang performed the experiments; Yanchun Liu wrote the paper; and Bo Zhang, Junwei Luan edited the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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