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Full Length Article

Distribution and Morphological Variation of Fine Root in a Walnut-Soybean Intercropping System in the Loess Plateau of China

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Abstract

In order to provide scientific and technological guide for efficient and sustainable agroforestry management, spatial distribution and morphological variation of fine root in a walnut-soybean intercropping system were examined using stratified excavation method in the Loess Plateau of western Shanxi Province, China. Fine root dry weight (FRDW) of walnut concentrated in the soil layer 0-40 cm, while soybean (FRDW) mainly distributed in the soil layer 0-20 cm. 57.4% of the FRDW of walnut allocated within the section 1.0-1.5 m and the section1.5-2.0 m from the tree row, and soybean (FRDW) showed an increasing trend with the distance from the tree row. Fine root vertical barycenter (FRVB) of both walnut and soybean showed a tendency to deep soil, but the depths of the FRVB of walnut were always deeper than soybean's in all sections. Abundant fine roots of both walnut and soybean in the soil layer 0-20 cm and the smaller relative distance of the depth of FRVB between walnut and soybean in the section 1.0-1.5 m and the section 1.5-2.0 m, indicate that the major area of interspecific competition for soil water and nutrients appear in the surface soil layer (0-20 cm) within the range of 1.0-2.0 m from the tree row in walnut-soybean intercropping system. © 2013 Friends Science Publishers

Key words: Fine root dry weight; Fine root vertical barycenter; Fruit tree-crop intercropping system; Stratified digging method; Underground interspecific competition

Introduction

Agroforestry management practices aim at to improve and optimize productivity of agroforestry systems. The productivity is mostly resulted from promotion of mutual benefits and elimination of competitions of aboveground and underground components (Guenni *et al*., 2002; Liu and Zeng, 2007). Therefore, the key issue in agroforestry management is how to maximize such benefits and to minimize those competitions for efficient utilization of natural resources allowing the agroforestry systems achieve high efficiency and sustainable development (Rao *et al.*, 1998; Thevathasan and Gordon, 2004; Carvalho *et al.*, 2008). The competitive role of the underground component is likely more important than that of aboveground component in the aspects of competitive balance, competitive intensity and resources utilization (Monteith *et al*., 1991; Ong *et al.*, 1991; Wang and Zhang, 2000).

Spatial structure and distribution of roots in the underground portion of an agroforestry system reflect not only the utilization of soil resources and land productivity, but also determine individual competitive ability among plants to soil water and nutrients (Bowen, 1984; Schroth, 1995; Kumar *et al.*, 1999; Smith *et al.*, 1999). The root of trees and crops exploit different resource space is the key way to increase the productive utilization of resources in agroforestry system (Ong *et al.*, 1996). Further, when roots of different components in an agroforestry system jointly exploit resources from the same soil layer, it is most likely that the underground components of the agroforestry system compete for soil moisture and nutrients, in particularly at times when the availability of resources are potentially limited (Jose *et al.*, 2006; Yang *et al.*, 2011).

The walnut-crops intercropping system is one of major regional agro-forestry systems in the Loess Plateau, because of its high economic returns. However, due to past unsound management and overexploitation of soil water and nutrients, some walnut-crops intercropping systems result in low economic benefits overall. Therefore, studying spatial distribution of fine root of both walnut and soybean is important for better understanding on the competitive mechanisms between those two components in the system and for taking further steps to minimize competitions in such agro-forestry system. Yun *et al.* (2011) studied the characteristics of agro-forestry root systems in the Loess Plateau of Shanxi Province. However, they only characterized root distribution of trees. To our knowledge, no study has been reported on root distribution

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of crop. This study was therefore conducted to compare fine root spatial distribution and quantify fine root morphological variation of walnut and soybean in a walnut-soybean intercropping system.

Materials and Methods

Experimental Site

The experimental site located in Jixian County (35°53′-36°21′ N, 110°27′-111°07′ E), Shanxi Province, China. Jixian County is a typical broken and gully area in the Loess Plateau. Climate in this area is of temperate continental monsoon nature with four distinct seasons, rainfall and heat in the same period, adequate illumination. The average annual precipitation is 571 mm and unevenly distributed throughout the year. The average annual temperature is 9.9°C. The average annual accumulative temperature above 10°C is 3357.9°C, sunshine hours are 2563.8 h, and frostless period is 172 days. During the growing season from April to October, the accumulative temperature above 10°C is 3050°C, sunshine hours are 1498 h, and rainfall is 521 mm accounting for more than 90% of the total annual precipitation. The soil is loess parent material, thick soil layer, and the soil properties are uniform. The bulk density, organic C, total N, available P and available K, pH, cation exchange capacity, and Ca of the 0-100 cm soil layer is 1.32 $g{\cdot}cm^{-3}$, 12.3 $g{\cdot}kg^{-1}$, 0.79 $g{\cdot}kg^{-1}$, 19.2 $mg{\cdot}kg^{-1}$ and 225.7 $mg{\cdot}kg^{-1}$, 7.92, 18.43 $cmol{\cdot}kg^{-1}$, 9.2 $mg{\cdot}kg^{-1}$, respectively. The major species of fruit trees planted for agroforestry are walnut (*Juglans regia*), apple (*Malus pumila*), apricot (*Prunus armeniaca*). The major crops planted in the agroforestry systems are soybean (*Glycine max*), peanut (*Arachis hypogaea*), maize (*Zea mays*). No irrigation took place on any of the experimental area, so the trees and the crops mostly depend on the rainfall received in the area.

Materials and Experimental Design

The experiment was carried out in a provincial demonstration zone of walnut-crop intercropping system from August 2009. Walnut trees were planted at a spacing of 7.0 m × 6.5 m in 2000, and the average tree crown width was 2.1 m and tree height was 4.2 m in August 2009. Soybean was planted at a spacing of 0.45 m×0.5 m and 100 cm away from the tree row.

The area within a distance of 1.0 m to 3.5 m from the tree row was used as experimental area. In this area, we designed three plots (2.5 m in length perpendicular to the tree row, 0.5 m in width parallel to the tree row) as three replications, and we divided each plot into five equal size sections (parallel to the tree row) according to the distance from the tree row, which were denoted as section 1-1.5 m, section 1.5-2 m, section 2-2.5 m, section 2.5-3 m, section 3-3.5 m, respectively (Fig. 1). In each section, we excavated and collected walnut and soybean roots hierarchically in vertical soil profile, which was divided into five soil layers (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm).

Root samples were individually collected and put into mesh bags (0.15 mm pores) and soaked in water for 24 h before being washed with tap water to remove soil particles adhering to the roots. The diameter class levels of roots were separated into fine (≤2 mm) and coarse (>2 mm) by aid of a vernier caliper. For both walnut and crop roots, only fine roots were retained for the purpose of this study. Dead roots of dark color, partly decomposed and brittle were removed with charcoal and other extraneous materials. Walnut roots were identified by their black-brown, while soybean roots were gray. All root samples were weighted immediately, after drying in the oven at 70°C for 48 h. Data were expressed as fine root dry weight (FRDW).

Quantification of Fine Root Morphological Variation

For comparing and quantifying fine root morphological variation, the depths of the fine root vertical barycenter (FRVB) of both walnut and soybean were determined for each section respectively. The depths of the FRVB in each section were calculated as follows:

$$D_{FRVB} = \sum_{i=1}^{n} D_i P_i$$

Where, D_{FRVB} represents the depth of the fine root vertical barycenter, i ($i \leq 5$) represents soil layer, D_i is the depth of the middle of ith soil layer and P_i is the proportion that the FRDW of ith soil layer accounted for the total FRDW of the soil layer 0-100 cm.

Data Analysis

Analysis of variance (ANOVA) test was performed using the SPSS software 20.0 (SPSS Inc., Chicago, USA). One-way ANOVA was applied to assess differences of the FRDW at different distances or depths, and significant differences of their mean values were compared by the least significant difference (LSD). Paired samples t-test was applied to examine differences of the FRDW between walnut and soybean. Statistical results were showed with error bars and significance level (P), and differences at the $P \leq 0.05$ were considered statistically significant.

Results

Vertical Distribution of Fine Root Dry Weight

The FRDW of walnut decreased with soil depths in the profile (Fig. 2), and mostly concentrated in the soil layer 0-40 cm, which contained 64.1% of the total FRDW of walnut. And 13.7%, 12.2%, 10.0% of the total FRDW of walnut was allocated in soil layer 40-60 cm, 60-80 cm, 80-100 cm, respectively. Below 40 cm, differences in FRDW of walnut among the soil layers were un-significant ($P > 0.05$).

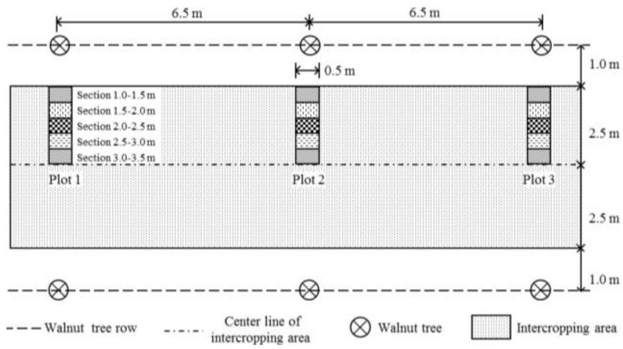

Fig. 1: Location of sampling sections in walnut-soybean intercropping system. Sampling plots located in the intercropping area (width is 5.0 m), three plots represented three replications. Every plot was divided into five equal size sections, which were denoted as section 1.0-1.5 m, section 1.5-2.0 m, section 2.0-2.5 m, section 2.5-3.0 m, section 3.0-3.5 m, respectively

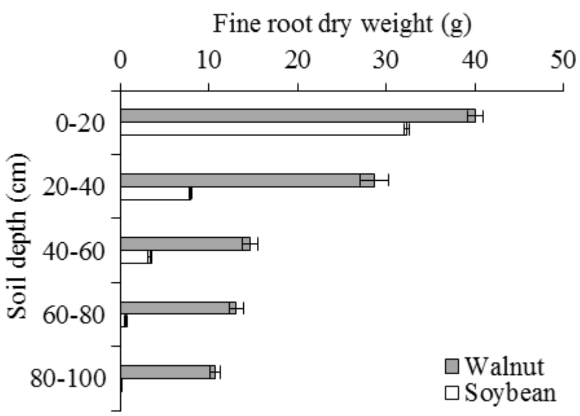

Fig. 2: Distribution of the fine root dry weight (FRDW) of walnut and soybean in different soil layers in walnut-soybean intercropping system. Each bar (±S.D) is the mean of three areas, with five samples per sampling soil layer. Standard Deviation bars are not shown for soybean to improve the clarity of the figure

The FRDW of soybean was high in the soil layer 0-20 cm that contained 72.8% of the total FRDW of soybean, and decreased sharply with soil depths (Fig. 2). Statistical results showed that the FRDW of soybean in the soil 0-20 cm layer was significantly different from that of other soil layers ($P < 0.05$). The FRDW of soybean in the soil layer 40-60 cm was ten times lower than that in the soil layer 0-20 cm. In the soil layer 80-100 cm, the FRDW of soybean only accounted for 0.3% of the total FRDW of soybean, and just randomly occurred in the soil layer 80-100 cm through root digging investigation.

Horizontal Distribution of Fine Root Dry Weight

The FRDW was related to the distance from the tree row, for both walnut and soybean (Fig. 3). The closer the section was to the tree row, the higher the FRDW of walnut. Walnut fine roots largely concentrated in the section 1.0-1.5 m (dry weight is 40.4 g, or 37.7% of total) and the section 1.5-2.0 m (dry weight is 21.1 g, or 19.7% of total). The FRDW of walnut in the section 2.0-2.5 m, the section 2.5-3.0 m and the section 3.0-3.5 m decreased slightly with the distance from the tree row, and differences were not detected among these sections ($P > 0.05$).

By contrast, the FRDW of soybean was significantly lower in the section 1.0-1.5 m (dry weight is 6.4 g, or 14.5% of total) and in the section 1.5-2.0 m (dry weight is 7.6 g, or 17.1% of total) than that of other sections ($P < 0.05$), and showed an increasing tend with the distance from the tree row. However, the further away from the tree row, the lower the intensive degree of soybean fine roots in the surface soil layer (0-20 cm), the proportion that the FRDW in the soil layer 0-20 cm accounted for the total FRDW of soybean in soil layer 0-100 cm decreased from 81.0% at the section 1.0-1.5 m to 67.9% at the section 3.0-3.5 m (Fig. 4).

Morphological Variation of Fine Root

The depths of the FRVB of walnut (except for the section 1.5-2.0 m) tended to deep with the distance from the tree row (Fig. 5), up to 54.8 cm in the section 3.0-3.5 m, and exhibited significant differences among all sections ($P < 0.05$). The depths of FRVB of soybean moved down to deep soil layer with the distance from the tree row, reduced significantly from 15.2 cm in the section 1.0-1.5 m to 18.2 cm in the section 2.0-2.5 m ($P < 0.05$). The relative distance of the depth of FRVB between walnut and soybean was least in the section 1.5-2.0 m and the maximum of the relative distance occurred in the section 3.0-3.5 m (Fig. 5). The depths of FRVB indicated significant difference between walnut and soybean ($P < 0.05$).

Discussion

In the underground root component of a walnut-soybean intercropping system, 37.3% (dry weight is 40.0 g) of the total FRDW of walnut distributed in the soil layer 0-20 cm, and 72.8% (dry weight is 32.3 g) of the total FRDW of soybean also concentrated in the soil layer 0-20 cm (Fig. 2). Thus, the spatial overlap of the rooting zones of walnut and soybean inevitable occurs in the surface layer. Under no-irrigated conditions in the arid and semi-arid Loess Plateau, water that limits plant growth is the primary limiting factor as, and the soil nutrients of farmland is insufficient (Zhu and Zhu, 2003), so competition for soil water and nutrients caused by niche overlap and resources deficiency is unavoidable and high in the surface soil layer (0-20 cm). Nevertheless, the fact that the FRDW of soybean decreases rapidly with depth below 20 cm and 62.7% (dry weight is 67.1 g) of the total FRDW of walnut tree still distributed in

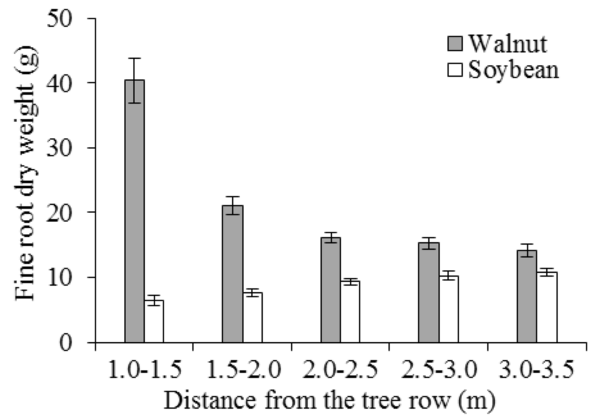

Fig. 3: Distribution of the fine root dry weight (FRDW) of walnut and soybean in different sections from the tree row in walnut-soybean intercropping system. Each bar (FRDW) is the mean of three areas, with five samples per sampling section. Each bar (±S.D) represents the average of three sampling areas for walnut and soybean

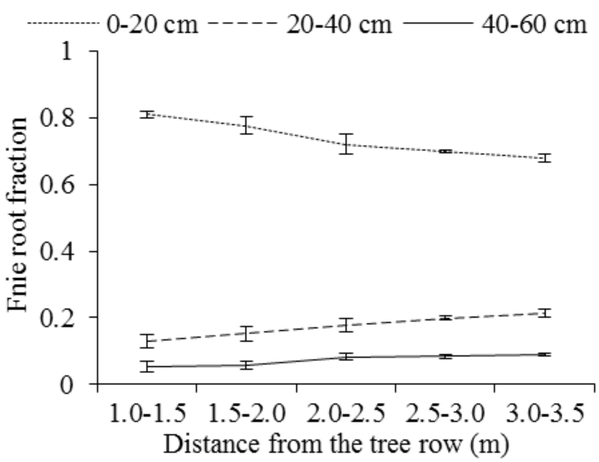

Fig. 4: Horizontal distribution of the proportion that the fine root dry weight (FRDW) of soybean in different soil layers accounted for the total FRDW of the soil layer 0-100 cm in walnut-soybean intercropping system. Each point is the mean of three areas, with five samples per sampling section. Bars represent Standard Deviations

the soil layer 20-100 cm (Fig. 2), indicated that walnut was capable of capturing more soil resources in the soil layer 20-100 cm, and that underground interspecific competition in the soil layer 20-100 cm is not that strong even though water and nutrient are scarce in the Loess Plateau.

To obtain adequate soil water and nutrients, plant roots can produce a variety of plasticity and change their morphological characteristics and spatial distribution characteristics in a certain degree to response of spatial heterogenous soil water and nutrients during their growth (Gross *et al.*, 1993; Mou *et al.*, 1997; Farooq *et al.*, 2009). Our study showed that both walnut and soybean, their roots

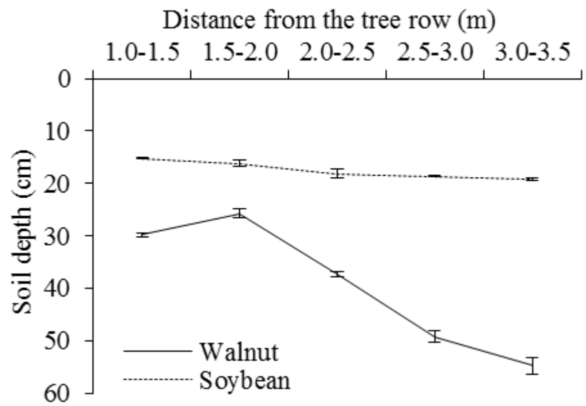

Fig. 5: Variation of the depths of the fine root vertical barycenter (FRVB) for walnut and soybean with the distance from the tree row. Each point is the mean of three areas, with five samples per sampling section. Bars represent Standard Deviations

adapted to a certain shifting-down to avoid fierce competition in the surface soil layer and fulfill their resource requirements. However, such shifting-down degree are different for different sections away from the tree row (Fig. 5). The relative distance of the depth of FRVB between walnut and soybean was smaller in the section 1.5-2.0 m than that in other sections. The result indicated that utilization for soil water and nutrients of walnut and soybean largely concentrated in the section 1.5-2.0 m, where the interspecific competition is mostly intense. The next interspecific competition region is section 1.0-1.5 m (Fig. 5).

In conclusion, this study provides further evidence that particularly in the Loess Plateau, the spatial separation of the root systems of trees and annual crops in agroforestry may be unobtainable. Competition for soil water and nutrients stored largely concentrated in the surface soil layer (0-20 cm) in vertical direction and the area under canopy in horizontal direction (within 2.0 m from the tree row). The dominance of the walnut root system ensured that walnut had a much higher capacity to capture soil resources than crops, and competition for soil resources resulted in severe suppression of crops roots growth. Thus, to minimize the underground interspecific competition, when managing or implementing agroforestry systems, farmers should be fertilize more fertilizer in the surface soil layer (0-20 cm), intercrops should be planted in the area outside the range of 2.0 m from the tree row and the root barrier should be disposed at the 2.0 m from the tree row.

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