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Full Length Research Paper

Distribution difference of peanut root between walnut-peanut intercropping and peanut monoculture in the Loess Plateau of China

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Growing walnut (*Juglans regia*) in farmland may lead to the changes of crop root distribution in the Loess Plateau of China, because walnut trees would dominantly exploit the shortage of water. In order to provide scientific guidance for efficient management of agroforestry, spatial distribution and morphological variation of peanut (*Arachis hypogaea*) root under walnut-based intercropping were examined by stratified excavation method. The results indicated that root length density (RLD) of peanut in all intercropping sections were less than that in monoculture section. The RLD of intercropped peanut mainly distributed in the first soil layer (0-10 cm), while the soil layer 10-20 cm in the peanut monoculture had the maximum RLD in the vertical profile. Though root vertical barycenter of intercropped peanut showed a tendency of depth increase with increasing distance and had a significant boundary at 2.0 m from the tree row, it was always shallower than the barycenter of sole peanut. Meanwhile, compared with the peanut monoculture, walnut-peanut intercropping had a negative soil moisture effect. Contrasting the two types of peanut plantation, we concluded that the presence of walnut reduced the available water for peanut and compelled peanut root to concentrate in the soil layer 0-10 cm, especially within the range of 1.0-2.0 m from the tree row, but the negative influences would be weaken with increasing distance from the tree row.

Keywords: stratified excavation method, root length density, root vertical barycenter, morphological variation, soil moisture effect.

INTRODUCTION

Crop planting is the traditional model of agricultural land use and the main source of income to farmers in the Loess Plateau, but which was limited badly by the water resources shortage and the past unsound management (Zhu and Zhu, 2003). These directly resulted in farmers replaced the crops on their farmland with walnut (*Juglans regia*) because it offers higher economic benefits, has stronger drought resistance, adapts broken terrace ridge planting and utilizes effectively the natural resource (land, water, nutrient, light). But the walnut trees can't provide any income for farmers until the fruit tree has yield of profitability, so farmers selectively plant some cash and oil crops in inter-row area of walnut trees to obtain the economic income and improve the land use efficiency. This also will buffer the effect of food insecurity in the region (Adisa and Balogun, 2013). During intercropping, if the economic incomes of intercrops, which is more valuable to farmers compared to the fruit tree before the returns of the fruit tree is greater than the crops and regarded as the major management object, is less than the investment, such intercropping will result in the failure of agroforestry systems and it will not be adopted by farmers.

A disadvantage of the walnut trees and crops intercropping system, however, is that the trees and crops may compete for resources, in particularly where the availability of resources are limited (Gao et al., 2013; Jose et al., 2006; van Noordwijk et al., 1996). Competition between trees and crops may affect distribution and morphological characteristics of crops root when trees exploited resources (Xu et al., 2013), further reduce its ability to acquire the soil moisture and nutrients that limit growth and productivity of the crops (Anderson and Sinclair, 1993; Grime, 1979). Smith et al. (1999) also found that the dominant root system of the trees and the high density of their roots at the top of the profile meant the growth of maize roots was suppressed and constrained to the upper region of the soil profile because of the low soil water availability. However, Meng et al. (2002) found that the amount of crop root was less in zones influenced by trees but there is no significant difference of vertical and temporal roots distribution trend between the intercropping and the monoculture. Schroth and Zech (1995) concluded even that at high root length density, the *Gliricidia sepium* hedgerows affected root development mainly by improving crop root growth. Therefore, systematic methods are required to quantify the competitive effects of trees on crops root in tree-crops intercropping systems.

Knowledge of rooting patterns of crop is necessary for better understanding the influence mechanism of trees on crop root, taking further steps to control it (Ong and Leakey 1999; Schenk 2006). Although many aspects of crop root in intercropping systems have been identified, not all studies adequately quantify morphological characteristics of crops root, especially for that crop is regarded as the major management object in agroforestry systems. Considering the growing importance of walnut and crops intercropping systems in Loess Plateau in economic development and ecological environment restoration, the study was conducted to analyze the vertical and horizontal distribution and morphological variation of peanut root in the walnut-peanut intercropping system and peanut monoculture system and the corresponding soil moisture effect.

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. During the growing season of vegetation from April to October, the accumulative temperature above 10°C is 3050°C, sunshine hours are 1498 hours, 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 major species of fruit trees planted for agroforestry are walnut, apple (*Malus pumila*) and apricot (*Prunus armeniaca*). The major crops planted in the agroforestry systems are peanut (*Arachis hypogaea*), soybean (*Glycine max*) and 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.

Experimental materials and design

The experiment was conducted in a family farm of walnut-crops intercropping systems from August 2013. Walnut trees were planted in 2007, at a spacing of 7 m both within rows and between rows. The average crown width of walnut trees was 2.2 m and the tree height was 4.3 m in August 2013. Intercropped peanut and mono-cropped peanut were grew at a spacing of 0.45 m within rows and 0.5 m between rows.

The area within a distance of 1.0 m to 3.5 m from the tree row was used as experimental area in the walnut-peanut intercropping system. 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, treated as intercropping sections) according to the distance from the tree row, which were denoted as section 1-1.5 m (S1), section 1.5-2 m (S2), section 2-2.5 m (S3), section 2.5-3 m (S4) and section 3-3.5 m (S5), respectively (Figure 1). We randomly selected three sections (0.5 m in length and 0.5 m in width) as contrast sections (CK) in peanut monoculture system. In the intercropping sections and the contrast sections.

Root processing and measurement

We excavated and collected peanut roots hierarchically in vertical soil profile which was divided into four soil layers (0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm). Root samples were individually collected and put into mesh bags (0.28 mm pores) and soaked in water for 24 hours before being washed with tap water to remove soil particles adhering to the roots. Dead roots of dark color, partly decomposed and brittle were removed with charcoal and other extraneous materials. Clean root samples were placed in 100 ml of 30% (v/v) methanol solution for storage at 4°C. Data were expressed as root length density (RLD, cm·dm^{-3}). We identified root length of peanut root samples by WinRHIZO (Regent Instruments. Inc., Quebec, Canada) image analysis system, then the root length density of peanut was calculated as the ratio of the root length (*L*, cm) to the sample volume (*V*, dm^3).

$$RLD = \frac{L}{V} \quad \text{..............................1}$$

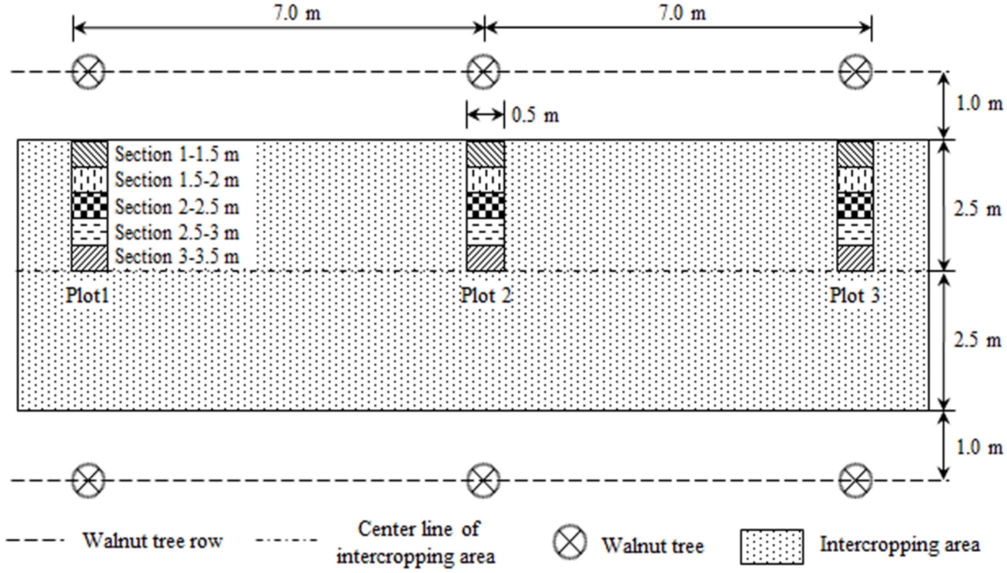

Figure 1. Location of sampling sections in walnut-peanut intercropping system. Sampling plots located in the intercropping area (width is 5.0 m), three plots represented three replications. Every plot was divided into five equal size sections, which were denoted as section 1-1.5 m, section 1.5-2 m, section 2-2.5 m, section 2.5-3 m and section 3-3.5 m, respectively.

To quantifying the morphological variation of peanut root , root vertical barycenter (RVB) of every section was determined. The depth of RVB in each section was calculated as follows:

$$D_{\mathrm{RVB}} = \sum_{i=1}^{n} D_i P_i \quad \text{.......................... 2}$$

Where, D_{RVB} represents the depth of the root vertical barycenter, i ($i \leq 5$) represents soil layer, D_i is depth of the middle of ith soil layer and P_i is the proportion that RLD of ith soil layer accounted for total RLD of the soil layer 0-60 cm.

Soil moisture processing and measurement

The samples of soil moisture were taken in each section (including intercropping and monoculture). A drill was used to remove the soil from 0-60 cm as four soil layers (0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm). The soil moisture content was determined gravimetrically.
To quantify the difference of walnut-peanut intercropping and peanut monoculture, the soil moisture effect in every intercropping section was calculated by the following equation:

$$E = [(M - M_{\mathrm{CK}})/M_{\mathrm{CK}}] \quad \text{.....................3}$$

Where, E was soil moisture effect, M was average soil moisture content of walnut-peanut intercropping in 0-60 cm, M_{CK} was average soil moisture content of peanut monoculture in 0-60 cm.

Statistical analysis

Analysis of variance (ANOVA) test was performed using the SPSS software 20.0 (IBM Inc., Armonk, USA). Two-way ANOVAs were applied to assess differences of the RLD (dependent variable) at different distances and depths (independent variables) for peanut, and the significance of difference of their mean values (n=3) were compared by the least significant difference (LSD). We examined differences of the RVB at different distances from the tree row using two-way ANOVAs for peanut. Paired-samples T tests were conducted on root length density of peanut to test the difference of root distribution of first two soil layers. Statistical results were showed with error bars and significance level (P), and differences at the $P \leq 0.05$ were considered statistically significant.

RESULTS

The RLDs along the horizontal distance from the tree row were significantly increased in walnut-peanut intercropping (Figure 2). But the multiple comparisons showed that there was no significant difference between S1 and S2 ($P > 0.05$), and S1 and S2 had significant differences with the S3, S4 and S5, respectively.

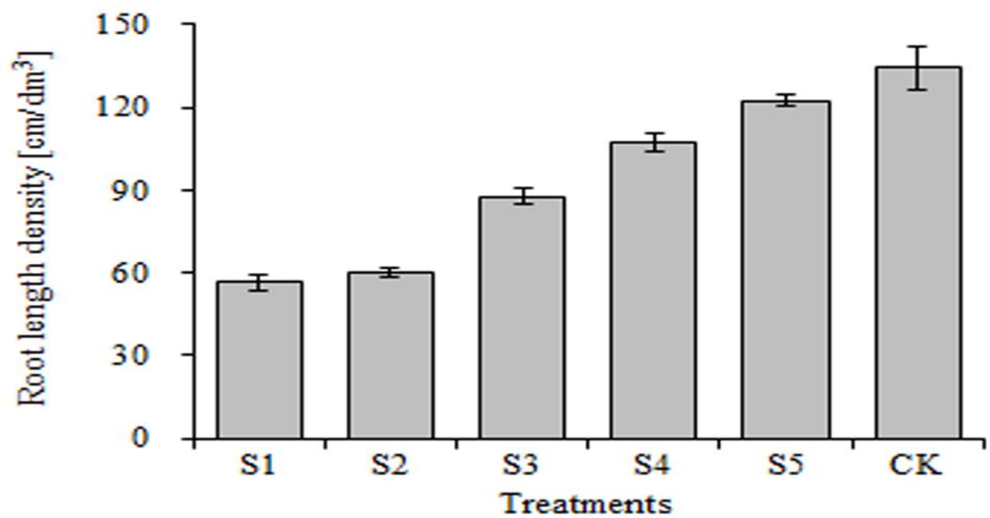

Figure 2. Distribution of the root length density of peanut measured in different sections from the tree row and the contrast sections. Each bar (±S.D) represented the average of three samples of every treatment.

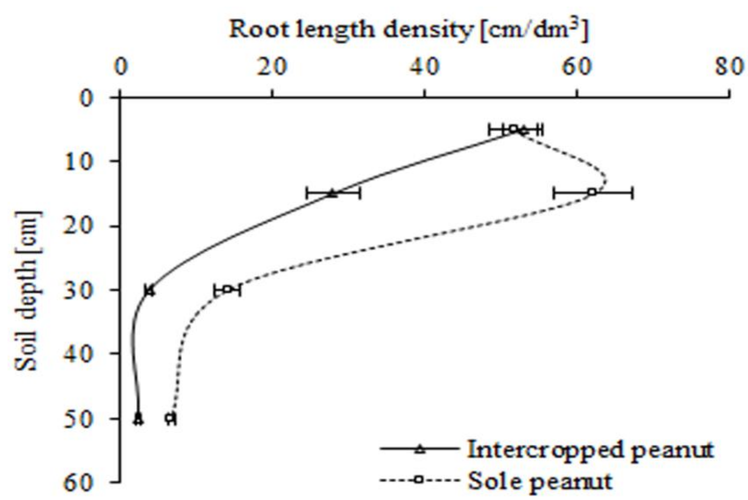

Figure 3. Vertical distribution of the root length density of peanut in different sections under two different planting types: intercropping and monoculture. Each error bar (±S.D) was the mean of three replications.

($P < 0.05$). And obviously, any treatments in the walnut-peanut intercropping had less RLD than the peanut monoculture (Figure 2). Intercropped peanut in the S1 and S2 showed a decrease of over 55% RLD compared with sole peanut. And a decrease of only 8.9% RLD was measured between intercropped peanut in the S5 and sole peanut.

The RLD of intercropped peanut significantly decreased with increasing soil depth ($P < 0.05$) (Figure 3). 62.2% of peanut root concentrated in the first soil layer (0-10 cm depth). Intercropped peanut root in the 10-20 cm soil layer was 49.3% less abundant than in the surface soil layer ($P < 0.05$). And only 6.6% RLD existed in the soil layer 20-60 cm. Surprisingly, the maximum RLD of solo peanut (the RLD was 62.1 cm·dm^{-3} and accounted for 46.2% of the total RLD) was found at the 10-20 cm soil layer, but decreased with increasing soil depth below 20 cm (Figure 3). However, there was still 15.4% of total RLD in the 20-60 cm soil layer for solo-cropped peanut (Figure 3) which was significantly greater than that of intercropped peanut ($P < 0.05$).

We found a significant interaction between distance and depth for peanut ($P < 0.05$), so that a significant increase in RVB value with increasing distance from the tree row was observed for intercrops (considering only the roots of the first 60 cm of soil) (Figure 4). The horizontal

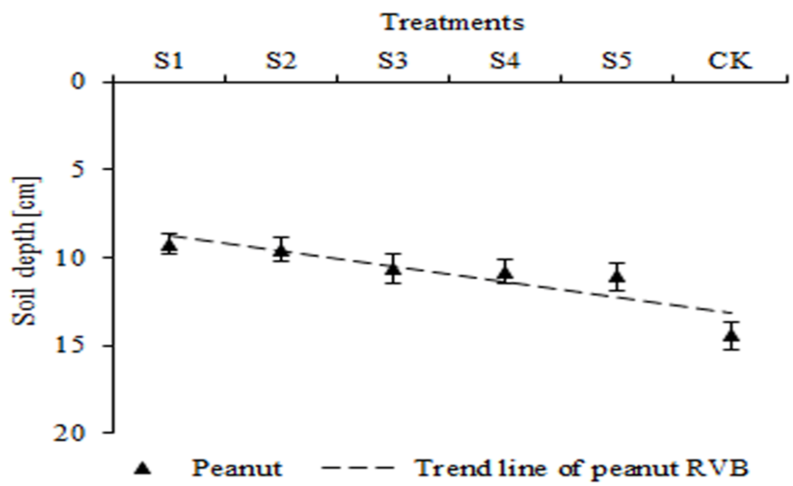

Figure 4. Variation of root vertical barycenter (RVB) for intercropped peanut with the distance from the tree row, and the RVB of sole peanut. Each point was the mean of three replications of every sampling section. Bars represent standard deviations.

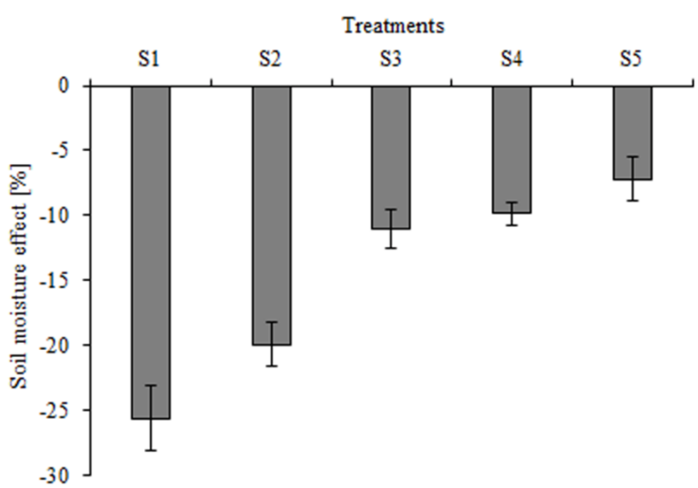

Figure 5. Effects of soil moisture in different sections from the tree row in walnut-peanut intercropping system compared with the contrast sections. Each bar (±S.D) represented the average of three samples of every treatment.

distribution of RVB in both S1 and S2 were significantly lower than the others ($P<0.05$). And the RVBs of all section in walnut-peanut intercropping were also significantly lower than that of peanut monoculture ($P<0.05$).

The horizontal distribution of soil moisture effect as well as the RLD in the walnut-peanut intercropping, soil moisture of all intercropping sections showed negative effects compared with the peanut monoculture (Figure 5). Among them, the negative effects of soil moisture of S1 and S2 were most obvious ($P<0.05$), but soil moisture had not significantly decrease in other intercropping sections ($P>0.05$).

DISCUSSION

The results leads us to realize that peanut had a more intense coverage in the uppermost 10 cm of the soil depth in the walnut-peanut intercropping compared with the monoculture. Meanwhile, the rapid decline of RLD in vertical profile and the shallower position of RVB in Walnut-peanut intercropping indicated a more asymmetrical vertical root distribution than in the peanut monoculture. All of those presented that peanut roots had a variety of plasticity and change their vertical distribution and morphological characteristics in a certain degree when concurrent grown with a competitive root system (Mou et al., 1997; Farooq et al., 2009). But we should not ignore the relatively low fraction of RLD of intercrops in the subsoil. Because it implies that crops are lack of the capacity to grow deeper and only occupy a smaller soil volume in the intercropping systems, which is not avail for exploiting more soil resources to sustain crop growth.

The root of intercropped peanut adapted to a certain shifting-down with the increasing distance from the tree row, which can be regarded as a response to the decrease of competitive pressure by walnut trees in horizontal direction, thus and it allows intercropped peanut to capture more soil moisture and win survival advantages with the distance. There was an obvious boundary of the intercrops root and soil moisture between significant area (1-2 m) and not significant area (2-3.5 m from the tree row) in the walnut intercropping, which illustrated that the great competition on soil moisture for intercropped peanut were distributed closer to the tree row than beyond the canopy edge (2-3.5 m from the tree row). But because the lateral root spread of walnut tree can influence beyond 4 m (Liu, 2004), the RLD of crops in every section of the walnut-peanut intercropping was less than that of the sole peanut, and the RVBs of crops in the intercropping sections had a more shallow distribution than in the contrast section.

Our results confirmed that the negative effect on soil moisture exist in the intercropping, due to competition for the limited soil moisture accessed by tree and crop. The soil moisture in intercropping sections showed a negative effect of 14.7% in comparison to the monoculture. But greater resource availability had a positive effect on root length density (Coleman, 2007). The degree of reduction for intercropped peanut, similar with the distribution of soil moisture, depended on the distance of peanut from the tree row, since root of walnut tree gradually lost the ability to gain soil moisture with increasing distance from the row of tree (Yun et al., 2012). Therefore, some practices must be taken to minimize the negative effect. When updating the intercropping systems with adult walnut tree we should plant peanut in areas outside the range of 2.0 m from the tree row, or set root barrier (e.g. digging furrow along with two sides of walnut tree row) at the 2.0 m from the tree row to ensure peanut roots have enough growth space and adequate soil moisture.

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