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Vertical Distribution and Seasonal Dynamics of Fine Root Parameters for Apple Trees of Different Ages on the Loess Plateau of China

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Abstract

The vertical distribution pattern and seasonal dynamics of fine root parameters for the apple trees of different ages (3, 10, 15, and 20 years old) on the Loess Plateau of China were studied. Soil coring method was used to determine the vertical distribution and seasonal dynamics of fine roots at different root radial distances (1.0, 1.5, and 2.0 m from the main tree trunk). The fine root biomass density (FRD), fine root length density (RLD), and specific root length (SRL), as well as soil water content and soil temperature were also measured. The FRD and RLD for the 10, 15, and 20 years old trees reached peak values in the 20-30 cm soil layer. For the 3 years old tree, the highest FRD and RLD were observed in the 10-20 cm soil layer. The FRD and RLD decreased with increased soil depth from the 10-20 or 20-30 cm soil layer for all age apple trees. The SRL declined with the increase of tree age. The FRD at the 1.0 m radial distance from the main tree trunk was higher than that at other radial distances in the 3 and 10 years old orchard. However, in the 15 and 20 years old orchards, especially the 20 years old orchard, the FRD at the 2.0 m radial distance was nearly equal to or higher than that at the 1.0 and 1.5 m radial distances. For all the root radiuses or the tree ages, the FRD, RLD, and SRL were the highest in spring and the lowest in autumn. The age of an apple tree does not affect the vertical distribution pattern but the biomass of fine roots and the SRL. Radial distance affects the root horizontal distribution of 3 and 10 years old trees but the 15 and 20 years old trees. Additionally, effects of soil temperature and soil moisture on fine root distribution or seasonal dynamics are not significant.

Key words: fine root, vertical distribution, seasonal dynamics, apple tree, Loess Plateau

INTRODUCTION

Fine roots are the main component of a tree root system, as they are the main link between plant and soil. Growing roots turn over faster than growing shoot component and the rate of fine root decomposition is often higher than that of litter decomposition in forest systems (Vogt *et al*. 1996). The fine root turnover is a significant component of below-ground carbon budget (Eissenstat and Yanai 1997). Concerns about ongoing global change in atmosphere have focused scientific interest on the ecological role played by fine roots in carbon cycling and storage (Janssens *et al*. 2002). This resulted in several recent reviews on biomass and production (Gower *et al*. 2001; Nakane 2001; Roy and Saugier 2001). However, the accuracy of energy and nutrient budgets of forest ecosystems has been limited

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by the difficulty in obtaining reliable estimates of the production and turnover of fine roots (Eissenstat and Yanai 1997; Vogt *et al*. 1998).

The importance of fine roots for carbon cycling has been confirmed by the finding that fine root production contributes 33-67% of the annual NPP in forest ecosystems (Santantonio and Grace 1987). Fine roots can fluctuate considerably in biomass, production, and turnover throughout the season or between years, depending on different sites (Gill and Jackson 2000; Janssens *et al*. 2002; Wang and Guo 2008). Unfortunately, quantifying fine roots is more time consuming than other components of tree body and the methods are usually less precise. Thus, fine roots remain one of the most difficult but important areas of study in terrestrial ecosystems. Therefore, the studies of fine root dynamics and turnover rate are still essential at present.

There was an unconfirmed but popular opinion that fine roots were homogeneously distributed around tree trunk and were not related to the radial distance from the main tree trunk (Yang *et al*. 2008; Wang and Guo 2008). In previous studies of fine root vertical distribution and seasonal dynamics, fine root sample was usually collected in a special radial distance from the main tree trunk, or was randomly collected. However, in recent years, some researchers do not think that fine roots are always homogeneously distributed around tree trunk (Chen *et al*. 2005). Thus, the study of fine root distribution and seasonal dynamics through sampling at different radial distances is necessary.

In the arid and semiarid area on the Loess Plateau of China, apple trees are widely planted for raising the farmer's economic incoming and conserving soil and water because of the serious soil erosion in the area. With the Chinese government's policy of Converting Farmland to Forest or Grassland implemented, planting apple trees in the area is still increasing. Therefore, it is necessary to conduct a series of studies about fine root distribution and seasonal dynamics of apple trees on the Loess Plateau of China.

In this study, we determined the vertical distribution of fine root density (mass of roots per unit soil volume, kg m^{-3}, FRD), fine root length density (length of roots per unit soil volume, cm cm^{-3}, RLD), and specific root length (root length/root mass, m g^{-1}, SRL) at different radial distances. In addition, the vertical distribution of soil water content and soil temperature were measured to determine their possible relationships with fine root vertical distribution. The work may find the effect of radial distances on fine root distribution and the main factors which affect the fine root distribution pattern and seasonal dynamics in the arid and semiarid area on the Loess Plateau. Results may also help us to understand the regional carbon cycling and other ecological processes.

MATERIALS AND METHODS

Site description

The study was carried out in apple tree orchards of four different ages (3, 10, 15, and 20 years old, respectively) in Changwu County of the south Loess Plateau (35°16´N, 107°40´E). The study sites were relatively flat with slope degree less than 5°. All the apple trees are planted with a tree spacing of approximate 4 m × 4 m. Sweet melons were intercropped in the 3 years old tree orchard and nothing was intercropped in the 10, 15, and 20 years old tree orchards. The annual mean air temperature was 9.1°C. The warmest and coldest months were July and January, respectively. The monthly soil temperatures at 10, 20, and 40 cm depths are showed in Fig.1. The frozen earth appears from December to February and the depth of the frozen earth reached the maximal (38±2) cm in

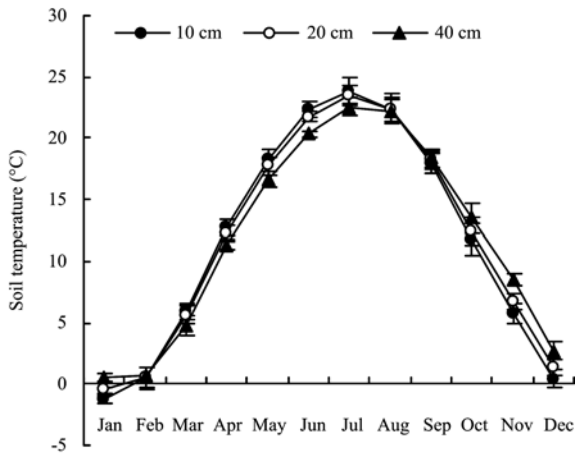

Fig. 1 Monthly soil temperature at 10, 20, and 40 cm depths in the study area (mean±SE, data from 1999 to 2007).

January. The annual mean precipitation was 584 mm and the monthly precipitation is showed in Fig.2. The soil is silty clay loam and the contents of sand, silt, and clay were 11, 66, and 23%, respectively.

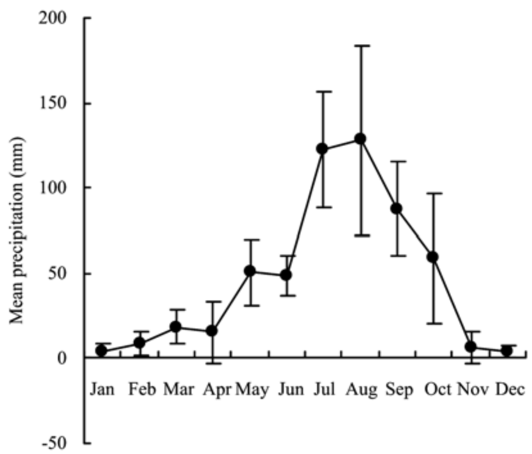

Fig. 2 The monthly precipitation variation in the study area (mean ± SE, data from 2002 to 2007).

Fine root sampling and measurements

Fine root distribution (<2 mm) was determined by sampling soil cores (soil core had a inside diameter of 90 mm) in 10 cm intervals to the depth of 100 cm in each age apple tree orchard. To repeat a seasonal sampling period, samples were collected on 5 April (spring), 10 July (summer), and 1 November (autumn) of 2007. Because of the frozen earth, none of samples were collected in winter. Fine root samples in three different aspects of the main tree trunk (0, 120, and 240°) were repeated at different distances (1.0, 1.5, and 2.0 m radial distance from the main tree trunk with 3 replications) in all age apple tree orchards. The samples from different depths were labeled and fine roots were manually removed from the samples and washed. All the fine roots were taken into laboratory and the segments of the fine roots were dried on absorbent filter paper and then spread on transparent rectangular plastic paper without overlapping and abutment to minimize possible deviations. A scanner was used to scan the roots on the plastic paper at 300 dpi. The images of the roots were recorded in Tiff format and the fine root length was measured using DELTA-T SCAN image analysis software (Delta-T Devices, UK). Before the roots were scanned, the scanner and software were calibrated by DELTA-T SCAN image standards for length. Then, all the roots were oven-dried at 70°C for 24 h and then weighed. The RLD and FRD were obtained by dividing root length and root mass by the inner volume of soil core, respectively. The SRL was obtained by dividing root length by root mass.

Soil moisture

Soil water content was monitored using neutron probe. In each sampling plot, 3 PVC neutron probe access tubes were installed to the depth of 2.0 m. Measurements were made from August, 2006 to November, 2007.

Data analysis

In this study, we took the average of all the seasonal sampling data as the mean fine root distribution parameter for studying the fine root vertical distribution pattern. In addition, we took the average of the fine root data from the 10 cm intervals as the mean fine root parameter for analyzing the fine root seasonal dynamics pattern. One-way ANOVAs were carried out with the SAS statistical software package (SAS Institute, Cary, USA) to test the differences in the vertical distribution and seasonal dynamics of the FRD, RLD, and SRL for different soil depth intervals and seasons at the error probability of $P=0.05$.

RESULTS

Soil water content

The mean soil water contents in the 0-100 and 100-200 cm soil layers for the apple orchards of different ages are shown in Fig.3-A. In general, the mean soil water content in the 0-100 cm soil layer was higher than that in the 100-200 cm soil layer for the orchards of all ages. The mean soil water content over the two layers for the 3 years old orchard was the highest among the four different age orchards. The difference in the mean soil water content in the 0-100 cm layer was not significant among the orchards of different ages. However, the mean soil water content in the 100-200 cm layer was significantly different between the 3 years old and other years old orchards. Among all age apple tree orchards, the mean soil water content in the 0-200 cm soil layer was the highest in November and the lowest in July (Fig.3-B). For all age apple tree orchards, the variation of the mean soil water content from July 7 to November 7 was the greatest, which was 1.96, 2.14, 2.15, and 3.08% for 3, 10, 15, and 20 years old orchards, respectively.

Fine root biomass density

For the same depth intervals, the FRD of the 3 years old apple trees was significantly lower than that of other age trees. There was also no significant difference in the FRD among 10, 15, and 20 years old trees (Fig.4). Except for the 3 years old orchard, the fine roots of apple trees had a similar vertical distribution pattern. Among all of the radial distances from the main tree trunk, most of the FRDs were observed in the 20-30 cm intervals and the FRD decreased with increased soil depth below 20 cm. However, for the 3 years old orchard, the highest FRDs at the 1.0 and 1.5 m radial distances from the main tree trunk were observed in 10-20 and 0-10 cm intervals, respectively. This may be due to pooling of the roots in the upper soil layers during the infant stage of the 3 years old trees. With the increase in tree age, its roots expanded to deeper soil layers.

In addition, the FRD at the 1.0 m radial distance from the main tree trunk was higher than that at other radial distances in the 3 and 10 years old orchards. However, in the 15 and 20 years old orchards, especially the 20 years old orchard, the FRD at the 2.0 m radial distance from the main tree trunk was nearly equal to or higher than that at the 1.0 and 1.5 m radial distances. This phenomenon may be explained by the facts that the root systems expanded in the radial direction with the increase in tree age and different tree roots occupied within the 2.0 m radius, which results in the FRD being higher than that at the 1.0 or 1.5 m radial distances.

Among the three sampling seasons (spring, summer, and autumn), the mean FRD was the highest in spring and the lowest in autumn. However, for the same radial distance from stem, the seasonal effect on FRD dynamics was not significant. In addition, the seasonal effect on different age trees was different. For the 3 and 10 years old trees, the variation of the FRD was higher than that for 15 and 20 years old trees (Fig.5).

Fine root length

The RLD decreased with increased depth in 3 and 10 years old trees. However, in 15 and 20 years old trees, the RLD decreased with increased depth with the exception of the upper two intervals of 0-10 and 10-20 cm.

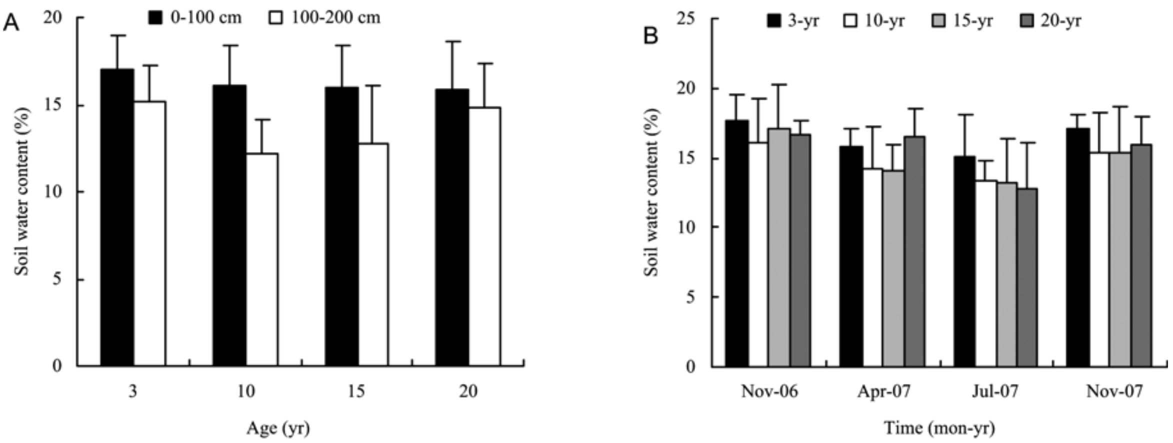

Fig. 3 Mean soil water content (%) in 0-100 and 100-200 cm soil depth intervals in the different age apple tree orchards (A); seasonal variation of the mean soil water content (%) in 0-200 cm depth intervals from November, 2006 to November, 2007 (B). The 3-, 10-, 15-, and 20-yr represent 3, 10, 15, and 20 years old, respectively, the same as below.

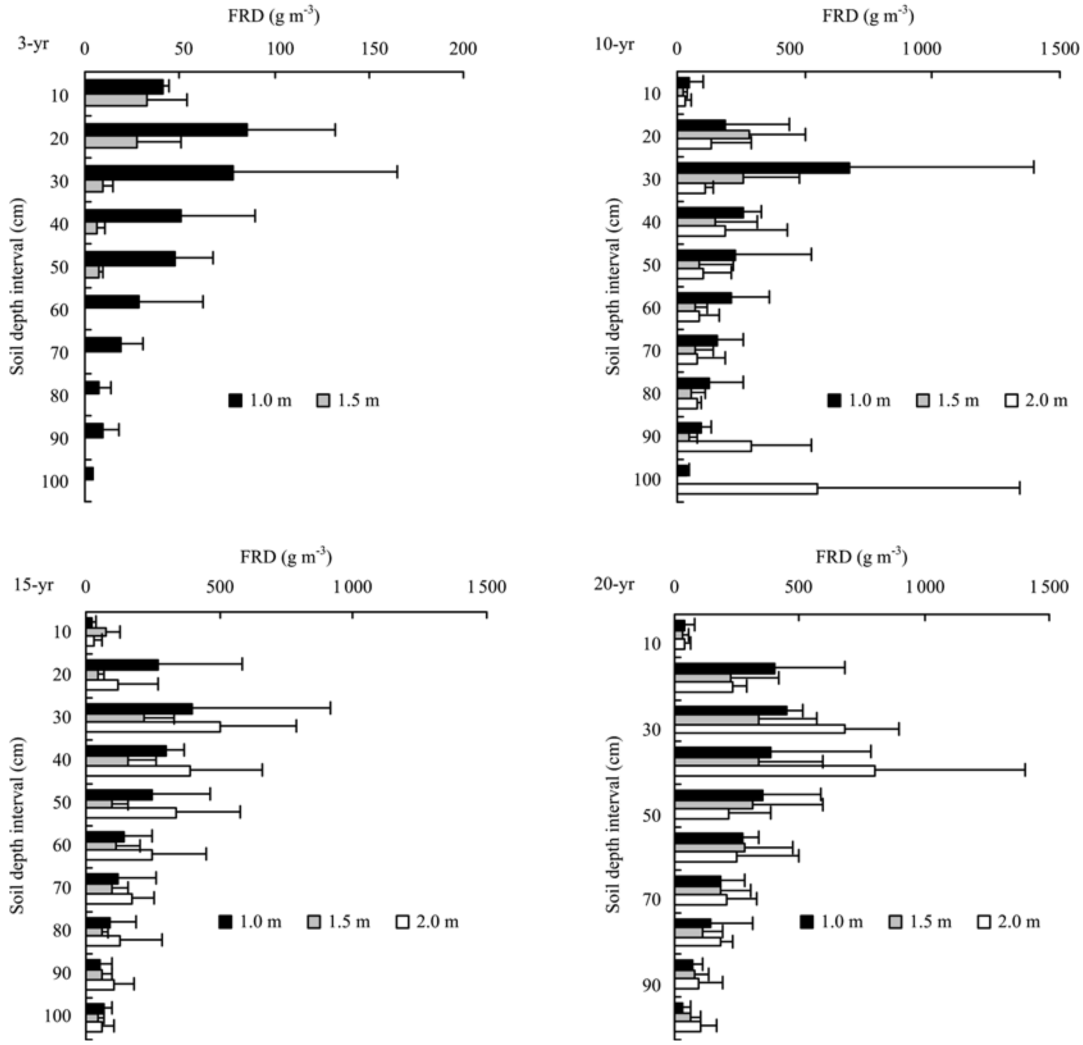

Fig. 4 Vertical distribution of the annual mean FRD in different radial distances from stem. The 1.0, 1.5, and 2.0 m represent the different radial distances from stem, the same as below.

Similar to the FRD, the RLD of 3 years old trees was significantly lower than that of older trees in the same intervals. For 10, 15 and 20 years old trees, there was no significant difference between different root radiuses in the same intervals (Fig.6). In most root radiuses and old years, the higher values of the RLD were found in spring and the lowest were recorded in autumn (Fig.7), although the seasonal effect on the RLD was not significant.

Specific root length

The value of the SRL decreased with the increased tree age. The highest and lowest SRLs were found in 3 and 20 years old trees in the same season and root radius, respectively (Fig.8). From spring to autumn, the value of the SRL decreased slowly but did not show significant difference between seasons for the same age trees at the same root radial distance. In addition, the effect of root radius on the value of the SRL was also insignificant.

DISCUSSION

Fine root density parameters (FRD, RLD) of different age apple trees measured in the study area peaked in the 20-30 cm soil layer. However, in most forest ecosystems, fine roots are the most abundant in the

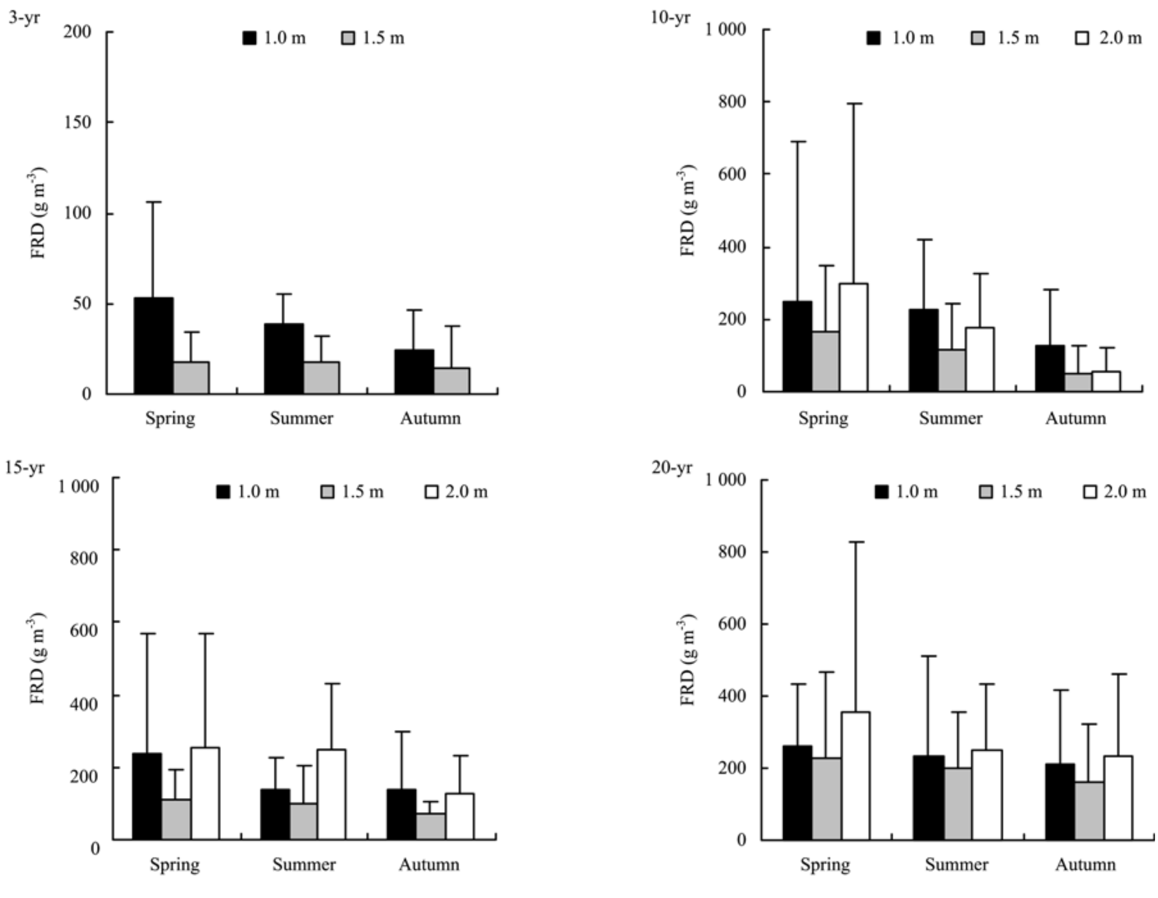

Fig. 5 Seasonal dynamics of the mean FRD of 0-100 cm soil depth intervals in different age apple tree orchards.

uppermost soil layer (Burke and Raynal 1994; Hendrick *et al*. 1996; Steele *et al*. 1997). Usually, fine root biomass and length density decrease with increased soil depth (Xiao *et al*. 2003; Konôpka *et al*. 2005; Zhou and Shangguan 2007). In this study, the vertical distribution pattern of fine root biomass and length for all age trees decreased with increased soil depth from the second or the third soil layer. More than 60% of the fine root biomass or length was retrieved in the upper 40 cm soil layers.

Fine root turnover is a critical component of ecosystem nutrient dynamics and carbon sequestration, and is also an important sink for plant primary productivity (Gill and Jackson 2000). Seasonal dynamics of fine root biomass and length are affected by tree age and species, as well as environmental conditions (Makkonen and Helmisaari1998). Konôpka *et al*. (2005) reported that fine root biomass increased until late summer (August) and then declined. In this study, the FRD and RLD were the largest in the spring (April) and then declined as season progressed.

The fine root parameter was also significantly different between different growth stages of trees (i.e., the infancy stage 3 years old vs. maturity stage 10-20 years old). In this study, the FRD and RLD of 3 years old trees were significantly lower than those of older trees. In addition, the SRL decreased with tree age increasing. This is also supported by the result from de Silva *et al*. (1999).

Fine root production is variable, depending on environmental conditions (Cheng *et al*. 2005), and is extremely difficult to estimate accurately (Helmisaari *et al*. 2002). Schenk (2005) summarized the impacts of a large number of variables affecting root growth and root vertical distribution such as soil environment factor, soil resource availability, and other biotic variables. Soil temperature data were not differentiated between different age orchards. The fine root parameters seemed to be ambiguous in our study. We were unable to exclude the role of temperature in restricting root

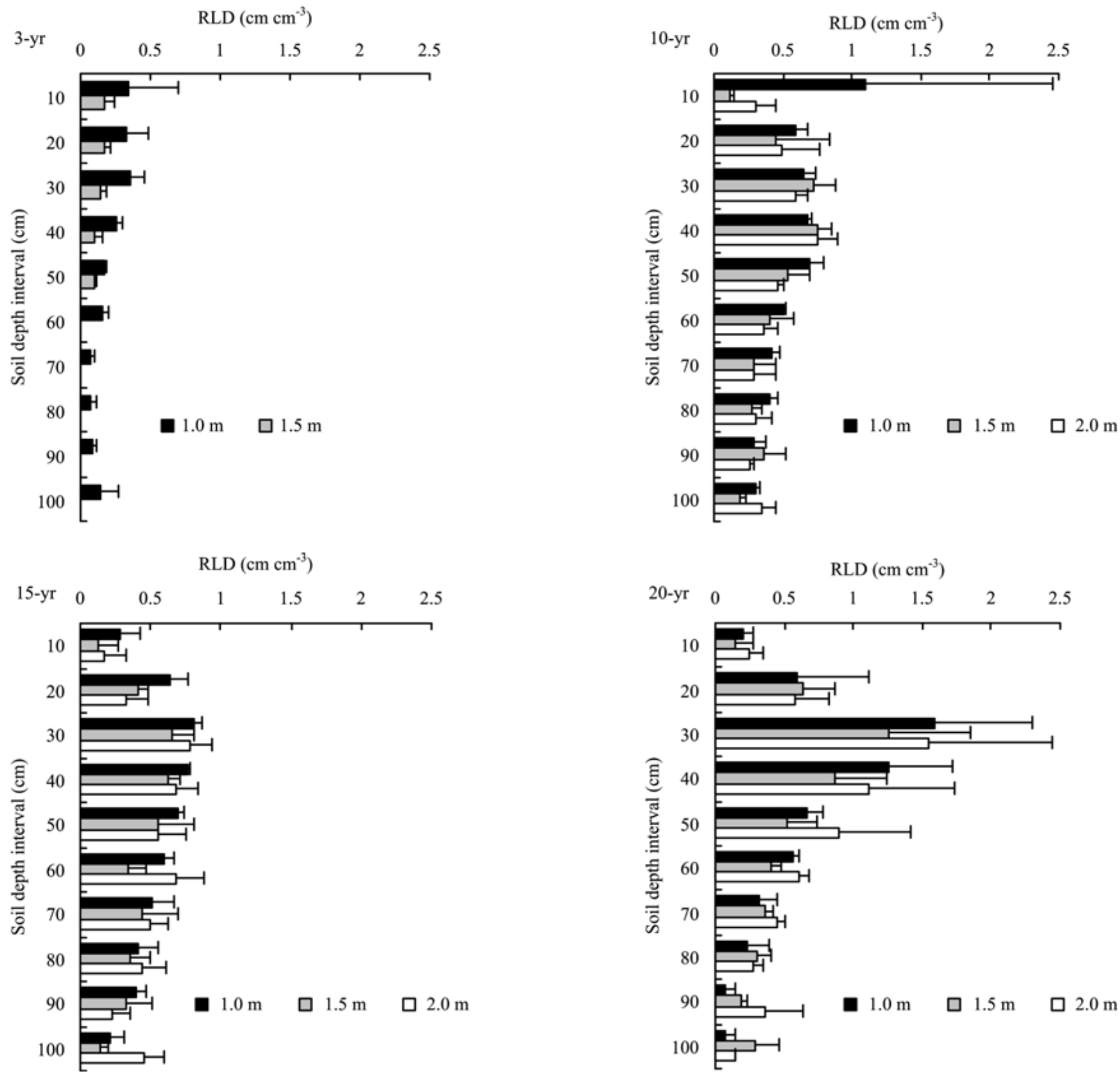

Fig. 6 Vertical distribution of the annual mean RLD in the 0-100 cm soil layer (10 × 10 cm intervals) in different age apple tree orchards in different radial distances from stem (1.0, 1.5, and 2.0 m).

development.

There was an unconfirmed but popular opinion that fine roots were homogeneously distributed around tree trunk and not related to the radial distance form main tree trunk (Yang *et al*. 2008; Wang and Guo 2008). However, Yang *et al*. (2008) studied the horizontal distribution of 28 years old *Larix principis-rupprechtii* fine root biomass. Their results showed that most of fine root biomass was concentrated in 100 cm root radius and little was found in 20 cm root radius. In our study, the FRD at the 1.0 m radial distance from the main tree trunk was higher than other radial distances in the 3 and 10 years old orchards. However, in the 15 and 20 years old orchards, especially the 20 years old orchard, the FRD at 2.0 m radial distance from the main tree trunk was nearly equal to or higher than that at 1.0 and 1.5 m radial distances. For 10, 15, and 20 years old trees, there was no significant difference between different root radiuses in the same soil depth intervals. The effect of root radius on the value of the SRL was also insignificant.

Several studies have indicated that fine root growth and distribution in soil profile are positively correlated with change in soil water content (West *et al*. 2004; Cheng *et al*. 2005; Powers *et al*. 2005; Zhou *et al*. 2007). In this study, fine root parameter distribution pattern was not correlated with change in soil water content except for the vertical root distribution at 2.0 m

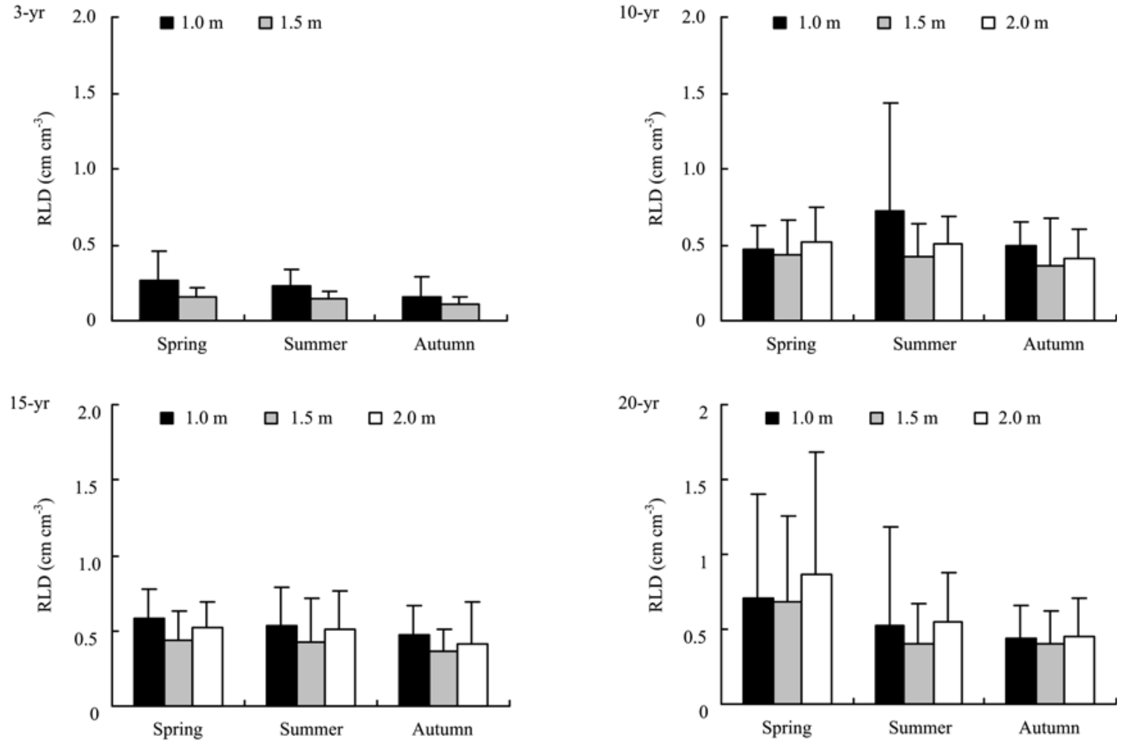

Fig. 7 Seasonal dynamics of the mean RLD in the 0-100 cm soil layer in different age apple tree orchards.

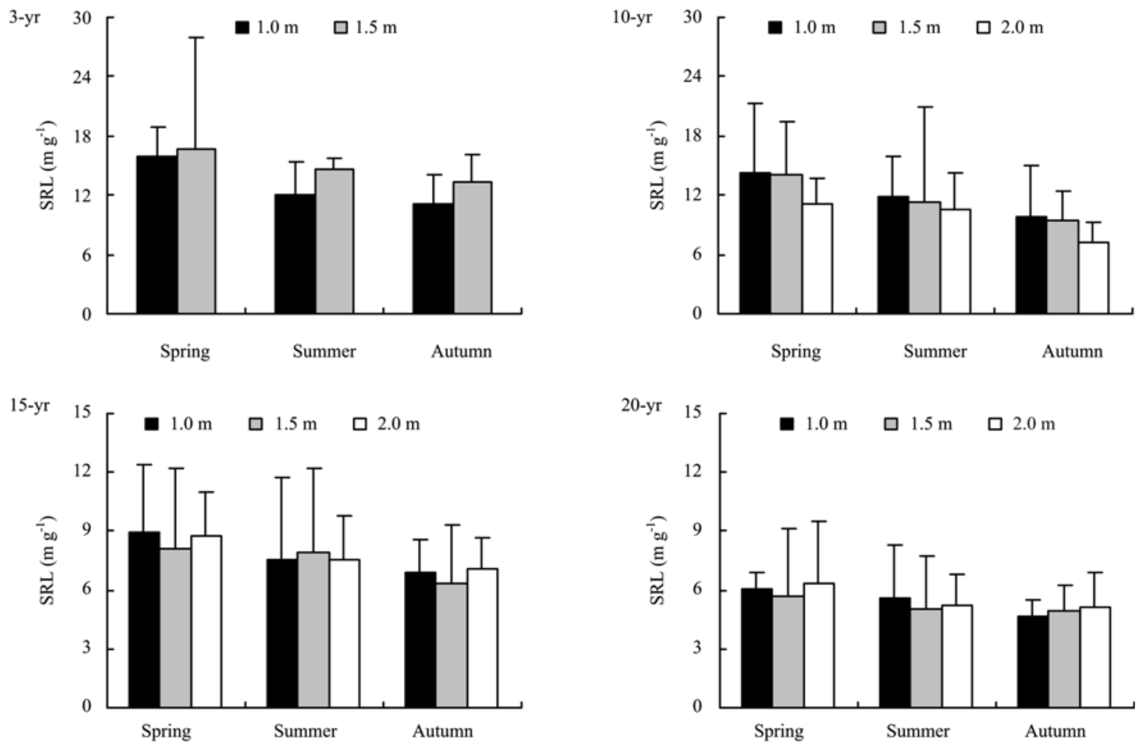

Fig. 8 Seasonal dynamics of the mean SRL of 0-100 cm soil depth intervals in different age apple tree orchards.

radial distance for 20 years old tress. Therefore, we can not exclude the soil moisture effect on fine root distribution pattern. Additionally, for the seasonal dynamics of fine root development, the seasonal mean soil water content in the 0-100 or 0-200 cm soil layer could not explain its variation for different age trees. Also change in mean soil water content can not explain the difference in fine root biomass or length density. There possibly exists a seasonal and age effect on fine root distribution and turnover.

CONCLUSION

Our results show the vertical distribution patterns and seasonal dynamics of the FRD and RLD of different age apple trees at different radial root distances. The age of apple tree does not affect the vertical distribution pattern but the production of fine root and the SRL. Additionally, due to the effects of season and tree age, changes in soil temperature and soil moisture in fine root distribution or seasonal dynamics can not be explained.

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