DYNAMICS OF ROOT DEVELOPMENT OF HERBACEOUS VEGETATION ON ABANDONED LAND ON A LOESS PLATEAU IN CHINA

Tantai Zhan[A] *Peng Li*[B,C] *Zhanbin Li*[A,B,C]
[A] Institute of Soil and Water Conservation, Yangling Shaan Xi, 712100.
[B] Xi'an University of Technology, Xi'an Shaanxi, 710048.
[C] Northwest Sci-technological University of Agriculture and Forestry, Yangling Shaanxi, 712100.

Abstract
Currently, returning farmlands to forest and grassland is the main measures for ecological construction in West China. In this study, vertical root distribution characters of vegetation at different succession stages were investigated by soil drilling methods. Results indicated that root distribution patterns of main root indexes changed with abandonment times. At the earlier stages, more roots were distributed in the deeper soil layer. With increased abandonment time, more roots concentrated in the surface soil layer. By comparing the root extinction coefficient, results indicated that the value of β at earlier succession stages was bigger than that at later stages.

Keywords: root length, root biomass, vertical distribution, root distinction coefficient

Introduction
The root system is the main organ for water and nutrient absorption in vegetation. Its form and distribution directly reflect the adaptation of vegetations to local site conditions. Formal studies of root distributions have occurred for more than 250 years (Hales 1727). With the development of science and technology, advanced techniques, such as tracer techniques (Hall *et al*., 1953; Dansgaard 1964), video recording and image processing (Taylor 1987), have been applied in root investigations. Although there are great improvements in the techniques of root excavation and studies, the most commonly used technique for root investigation remains soil coring or excavation and subsequent separation of roots. Böhm (1979) provides an excellent historical review of the methods for root studies. In spite of the long history of root study, our understanding of root distributions, and the below ground processes in general, remains inadequate. Gaps in our knowledge include root attribute, the scaling of soil processes, and their role in ecosystem processes.

To study the vertical root distribution characters, Gale and Grigal (1987) presented a model of vertical root distribution based on the following asymptotic equation: $Y=1-\beta^{d}$. In this equation, β is the only parameter estimated in the model and provides a simple numerical index of rooting distribution. High β values correspond to a greater proportion of roots at depth and lower β values imply a greater proportion of roots near the soil surface (Stone and Kalisz, 1991; Jackson *et al*., 1996; Gale and Grigal, 1987). Jackson *et al.* compiled a database of 250 root studies, and fitted the depth coefficient β to the data for each biome. In addition, soil physical and chemical properties have important effects on root distribution characters (Sainju and Good, 1993; Pu Mou *et al*., 1997; Hendrick and Pregitzer, 1993; Troyn, 1983). Also, vertical root distribution characters have close affinities to forest productivity, and productivity of species with a deep root system was higher than one with shallow roots (Peng Li, 2002; Stone, 1991; Jackson, 1996; Gale, 1987; Bartsch, 1987).

In China, with the progress of returning farmlands to forest and grasslands, returning farmlands have become important land types in West China. However, little efforts were carried out to investigate the dynamics of vertical vegetation root distribution characters. In this research, root investigations were carried out to compare the differences in vertical root distribution patterns of vegetation at different rehabilitating times, and provided scientific support for local ecological construction.

Materials and methods
Site description
Experimental sites were located in Wangdong Watershed of ISWC (Institute of Soil and Water Conservation) Changwu Field Experimental Station of CAS (Chinese Academy of Sciences). Local elevation was ranged from 950–1225 m. Its climate belonged to warm temperate continental seasonal climate, with its average annual temperature 9.1℃, average annual rainfall 584.1mm, most of which was concentrated in Jul--Sept. Main soil types on most sites were loess, its clay (<0.01mm) content was 25%, with >0.25mm water stable aggregate content 8.12%, and organic content 0.746%.

Root sampling and analysis
Based on the investigation of the vegetation development patterns, 5 root investigation sites of different abandoned years were determined. Vegetation composition is listed in Table 1. As the natural grassland was the main type on most slopes, three sites were selected for root investigation.

Table 1. Vegetation composition on the sites of root investigation

Sites	Vegetation composition	Land history
1year	*Artemisia annua* L, L. *berystarchys* Bge	Abandoned land
5 year	*Artemisia annua* L and *Stipa bungeana, Bothriochlon ischaemum*	Abandoned land
10 year	*Stipa bungeana, Bothriochlon ischaemum,* L. *berystarchys* Bge	Abandoned land
20 year	*Stipa bungeana, Bothriochlon ischaemum,* L. *berystarchys* Bge, *Artemisia annua* L.	Abandoned land
HBY	*Stipa bungeana, Bothriochlon ischaemum, Lespedeza bicolor, Dendranthema indicum, Ziziphus jujuba*	Natural grassland

Note: In the table, 1~2, 7~9, 15~17 and 23~25 was the years of the lands after abandoned;
HBY was the abbreviation of the natural grassland site name of Huang Baiwa,
which was of the same meaning in the following.

Soil drilling was applied for the root investigation of the herbaceous vegetation. At certain stages, 15 points (5×3) distributed evenly across the slope was chosen for drilling 100cm, and the root from every 10 cm layer was selected as sample by coring. Roots selected from each layer was taken back to the laboratory in plastic bag after numbering. In the lab, morphological index of all root samples were analysed by using root scanner and root analysis system (WinRHIZO). The root biomass was determined after drying to constant weight at 85 □

Results

Root morphological index distribution characters
From Figure 1, on the abandoned land of 1 year, with the increase of diameter classes, root length density decreased, roots with diameter less than 1mm accounted for the most proportions of the root length density, and variations of root distribution. That means fine root was the most significant character of vegetation on the abandoned land of 1 year. Also, with the increase of soil depth, root length density decreased gently. On the abandoned land of 5 years, root length density also decreased with the increase of root diameter classes, and its root density increased compared to that on the abandoned land of 1 year. Fine roots still accounted for the majority of the root. On the abandoned land of 10 years, root length density still decreased with the increase of root diameter classes. And its root density increased compared to that on the abandoned land of 5 year. Fine roots still accounted for the majority of the root.

On the abandoned land of 20 years, root length density decreased with the increase of root diameter classes, and root density increased compared to that on the abandoned land of 10 year. Fine root was still accounted for the most parts of the root. There was a significant change in vertical root distribution patterns. Compared to the root distribution of the earlier stages (1a, 5a, 10a), more roots was concentrated in the surface soil layer of 0~40cm. On the natural grasslands, the root length density decreased with the increase of root diameter classes, and root density increased compared to that on the abandoned land. Fine root still accounted for the majority of the root.

Most of the roots were concentrated in the surface layer of 0~40cm, similar to that of the vegetation abandoned of 10 years. It was clear that significant changes occurred in root distribution characters when the abandoned time was over 10 years, which tended to be similar to that of natural grassland. Judging from the vegetation composition of the communities, dominant species was also similar too between the two stages. Thus it can be concluded that the vegetation on the abandoned lands will reach its stable stage after 10 years restoration.

Vertical root biomass distribution characters
As root biomass classification by hand was difficult, and the diameter of most herbaceous roots was less than 3mm, only total root biomass was determined in this study. From Figure 2, it was clear that the root biomass on all sites decreased with the increase of soil depth. Comparing the root biomass on the abandoned lands, root biomass in the surface layer on the natural grassland was bigger, but its root biomass in deeper soil was smaller, which was in accordance with the root length distribution patterns. On the abandoned lands, with the increase of abandoned years, root biomass in the surface layer increased too, which indicated there would be more root returning to soil and increase soil organic content by root turnover.

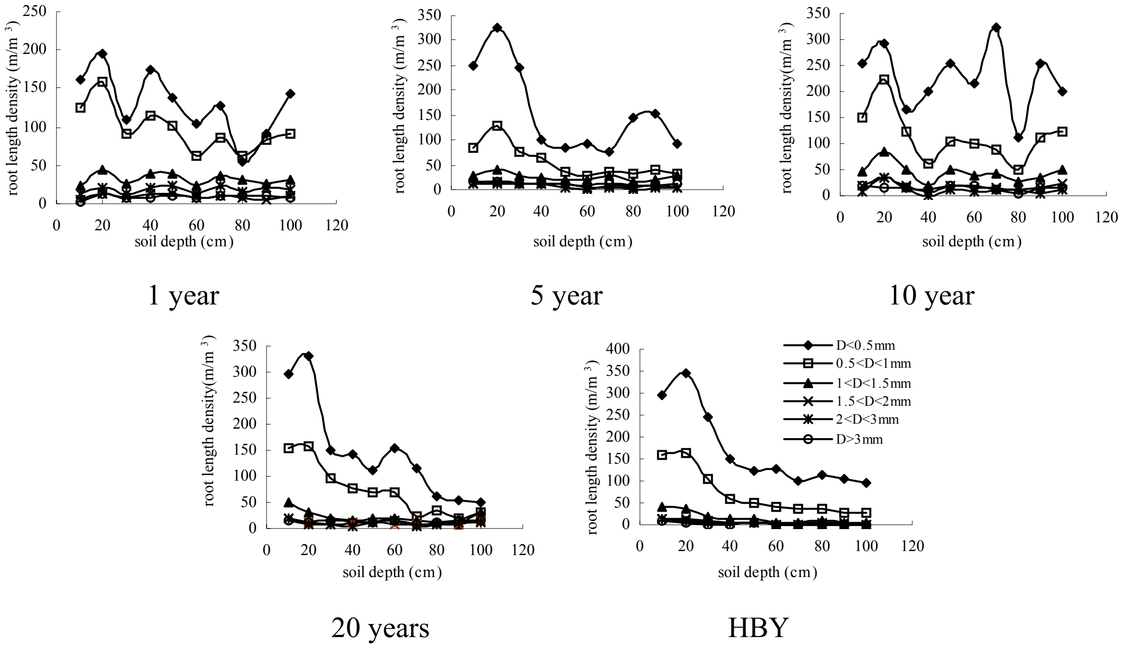

Figure 1. vertical root distribution characters of root length density on the site of different rehabilitating year
Note: significance of all legend in each figure was the same to that in HBY

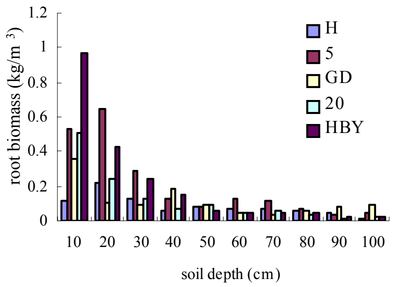

Figure 2. Root biomass distribution natural grassland and abandoned lands of different years

Root extinction coefficient of β

Based on the equation (1), root extinction coefficient of different root indexes was calculated by curve fitting method (Table 2). According to the definition of root extinction coefficient of β, it can be concluded that the value of β of annual vegetation was bigger than that of perennial vegetation, which indicated that there was more root distributed in deeper soil layer; while to perennial vegetation, its β value was relative small, which indicated that there were more root concentrated in surface layer. Other root indexes (root surface area and root volume etc) of the vegetation at different succession stages showed similar trends. At the earlier succession stages, more roots distributed in the deeper soil layer helped to increased soil organic matter, improved both soil physical and chemical properties, and created favourable conditions for new species, which in turn helped the vegetation succession development.

Table 2. root extinction coefficient of *β* of vegetation at different rehabilitating years

	1~2 yr	7~9 yr	15~17 yr	23~25 yr	HBY
Root biomass	0.975	0.965	0.975	0.96	0.95
Root length	0.98	0.978	0.979	0.975	0.97
Root surface area	0.98	0.978	0.98	0.975	0.969
Root volume	0.982	0.98	0.978	0.979	0.966

Conclusions

Based on the investigation of root development patterns on the abandoned lands and natural grassland, the following conclusions can be reached: A larger proportion of the roots were distributed in deeper soil at earlier vegetation development stages, with more roots were concentrated in the surface layer at later stages. When the abandoned time was over 10 years, both community composition and root distribution was similar to that on natural grassland. Root extinction coefficient decreased with the increase of abandoned years, which helped to interpret quantitatively the difference in vertical root distribution.

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