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Roots of pioneer trees in the lower sub-tropical area of Dinghushan, Guangdong, China*

HAO Yan-ru[1], PENG Shao-lin[†‡1,2], MO Jiang-ming[1], LIU Xin-wei[1],
CHEN Zhuo-quan[1], ZHOU Kai[1], WU Jin-rong[1]
([1]*South China Botanical Garden, Chinese Academy of Science, Guangzhou 510650, China*)
([2]*School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China*)
[†]E-mail: lsspsl@zsu.edu.cn
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Abstract: Representative pioneer tree root systems in the subtropical area of South China were examined with regard to their structure, underground stratification and biomass distribution. Excavation of skeleton roots and observation of fine roots of seven species including the *Euphorbiaceae*, *Theaceae*, *Melastomataceae*, *Lauraceae* and *Fagaceae* families was carried out. The results showed that: (1) Pioneer tree roots in the first stage of natural succession were of two types, one characterized by taproot system with bulky plagiotropic branches; the other characterized by flat root system with several tabular roots. The late mesophilous tree roots were characterized by one obvious taproot and tactic braches roots up and down. Shrub species roots were characterized by heart fibrous root type featured both by horizontally and transversally growing branches. Root shapes varied in different dominant species at different stages of succession. (2) Roots of the different species varied in the external features—color, periderm and structure of freshly cut slash. (3) In a set of successional stages the biomass of tree roots increased linearly with the age of growth. During monsoon, the total root biomass amounted to 115.70 t/ha in the evergreen broad-leaved forest; 50.61 t/ha in needle and broad-leaved mixed forest dominated by coniferous forest; and 64.20 t/ha in broad-and needle-leaved mixed forest dominated by broad-leaved heliophytes, and are comparable to the underground biomass observed in similar tropical forests. This is the first report about roots characteristics of forest in the lower sub-tropical area of Dinghushan, Guangdong, China.

Key words: Pioneer tree, Tree roots, Lower subtropical forest, Dinghushan, China
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INTRODUCTION

The study of root biomass distribution provides good insight into the role of the root system, structure and function at the ecosystem level. So many studies of root distribution (Gale and Grigal, 1987; Jackson *et al*., 1996; Canadell *et al*., 1996; Schenk and Jackson, 2002; Cairns *et al*., 1997), root morphology (Misra and Gibbons, 1996; De Simone *et al*., 2003; Leuschner *et al*., 2004), root dynamics (Vogt *et al*., 1996; Gill and Jackson, 2000; Vercambre *et al*., 2003) and even root turnover (Norby and Jackson, 2000) have been carried out. Furthermore, there is increased interest in researching the roots of pioneer trees in succession of forests because of their role in the ecosystem dynamics (Cody, 1986; Pavlis and Jeník, 2000; Klinge, 1973a; 1973b; 1976; Cairns *et al*., 1997; Jordan and Escalante, 1980; Sanford and Cuevas, 1996). Schenk and Jackson (2002) carried out a literature analysis of 475 vertical root profiles from 209 geographical locations. However, study of root morphology and root biomass of forest vegetation in earth's low-subtropical region has not been conducted until now so that the pioneer trees root system remains unclear. This paper proposes to bridge this gap in the biogeography of roots.

Fieldwork for this study was carried out in

‡ Corresponding author
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Dinghushan, the national reserve, which became a part of the Network of World's Biosphere Reserve Organized by MAB, UNESCO in 1979. It is situated in the center part of Guangdong Province, South China, at 112°35′ E and 23°08′ N (Fig.1). The Reserve occupies 1155 ha and belongs to the Cathaysian Platform developed from the Sinian period. The altitude ranges from 14.1 m to 1000.3 m. The rocks are mainly made up of Devonian period sandstone and shale. The forest soil is lateritic red earth rich in humus with pH of 4.5~5.0. The annual mean temperature is 21.4 °C. The mean temperature of the coldest month is 12.0 °C. The area does not experience harsh cold winter or hot summer. It is warm throughout the year and the weather is suitable for the growth of organisms. Rainfall averages 1927.3 mm, although the precipitation in the year is not even. There are distinct wet (from April to September) and dry (from November to February) seasons. The mean relative humidity is 80%. He *et al.*(1982) extensively described the study area's 30 to 60 cm depth soil (Mo *et al.*, 2003; Fang *et al.*, 2004).

Fig.1 Site of field work in Dinghushan, Guangdong Province of Southern China

Dinghushan forest communities can be described through some typical communities in different successional stages (Peng and Wang, 1995). The oldest community is over 400 years. The process of the successional mechanism of forest in the area is summarized in Fig.2 (Peng and Wang, 1985; Wang and Peng, 1985; 1986; Zhang *et al.*, 1955). Stage 1 is man-made forest with *Pinus massoniana* the infertile tolerant species, which provides better conditions for heliophytes than a wasteland. Therefore the pioneer species, such as *Castanopsis chinensi* and *Schima superba*, emerge from Stage 2 and Stage 3 and then the late mesophilous species, such as *Cryptocarya chinensis* and *Cryptocarya concinna*, grow by step in Stage 4 and Stage 5. The community tends to climax into evergreen broad-leaved forest dominated by mesophytes.

Succession stage:

Stage 1 Stage 2 Stage 3 Stage 4 Stage 5 Stage 6

Forest type:

A → B → C → D → E → F

A: Needle-leaved forest;
B: Needle and broad-leaved mixed forest dominated by coniferous trees;
C: Broad and needle-leaved mixed forest dominated by broad-leaved heliophytes;
D: Evergreen broad-leaved forest dominated by heliophytes;
E: Evergreen broad-leaved forest dominated by mesophytes;
F: Mesophytic forest (climax)

Fig.2 Successional process of forest of Dinghushan

Studies dealing with the structure of subtropical monsoon evergreen broad-leaved forest and coniferous and broad-leaf mixed forests (Peng and Wang, 1995; Peng and Zhang, 1995; Kong *et al.*, 1997) are hampered by the scarcity of data on tree roots, except for the few researches on the fine root biomass of separate species (Liao *et al.*, 1993; Wen *et al.*, 1999). Underground organs of sub-tropical trees, are little known and their structure and distribution in soil horizons remain rather obscure. Layering of underground biomass in humid sub-tropical forests is not well understood. The objectives of this study were to (1) predict root sizes and shapes for different species, (2) fill the information gap about roots retarding the adoption of rational silviculture and sustainable management of sub-tropical forests in South China. Little is known about the hidden structure and layering of the root systems of the woody r-strategists, such as *Castanopsis chinensis*, while the changes of visible aboveground structures in succession have been described (Peng, 1996; Peng *et al.*, 1998).

MATERIALS AND METHODS

Rhizological studies were conducted in two climatically distinct seasons April and November in the Dinghushan region as a follow-up project of earlier forest investigations in (Peng and Wang, 1995; Peng and Zhang, 1995). The following frequent and most dominant tree species of different sample trees were selected for detailed rhizological observations: *Schima superba*, *Castanopsis chinensi*, *Cryptocarya chinensis*, *Cryptocarya concinna*, *Aporosa Yunnanensis* and *Blastus cochinchensis*.

Harvest of standard sample trees

The standard sample trees were harvested according to diameter at breast height (*D*) and height (*H*) in every layer of every population (Table 1). The stems, branches and leaves of the samples were weighed. Some of the different parts of sample trees were taken back to laboratory and dried for calculating the ratio of dry to fresh weights.

In general, eco-morphological comparative methods based on careful excavation and identification of root shapes (Sutton and Tinus, 1983; Oldeman, 1990) and methods for assessing root biomass in pertinent soil blocks (Böhm, 1979) were applied. Emphasis was laid on (1) assessment of morphological and histological traits of roots in selected tree species, (2) detection of characteristic root branching in trees of various ages, with regard to soil horizon and depth, and (3) estimation of level root biomass at various soil depths in trees of various ages. Individual roots and vertical structure of their systems were photographed and illustrated at the excavation spot. The horizontal arrangement of skeleton and fine roots was observed after successive removal of litter and humus soil. Drawings, photographs and samples (some stored in FAA solution) were subsequently analyzed and described.

To study the effects of different successional stages on the rhizosphere, below-ground biomass was examined in four typically differentiated stages (A, B, D, E in Fig.2). Soil blocks were withdrawn at five randomly situated points for each plot.

Root stratification was ascertained down to 50 cm through 15 cm×15 cm×10 cm rectangular blocks cut from the soil layers. The presence of fine and medium size roots (<5 mm) was found to be negligible below 40 cm depth. Deep and large roots were sampled to capture practically all the root bases on every tree root system. Separation of roots and further manipulation was carried out in the laboratory. Root biomass was quantified by dividing them into 3 size classes according to their diameter: <2 mm, 2~5 mm, >5 mm. Dead and live roots were not distinguished, since fine roots readily disintegrate and cause minor error. The dry biomass was assessed after 48 h of drying at 65 °C.

RESULTS AND DISCUSSION

Structure of roots and root systems of the pioneer species

Tree root systems were made up of large, permanent roots (which mainly provide anchorage and transport), many small, temporary feeder roots and root hairs. Tree root systems covered more area than one would expect, usually extending out in an irregular pattern 1.2 to 2 times larger than the crown area. Many fine roots mixed in with turf roots were located close to the soil surface. A large portion of the bigger roots was close to the soil surface as well. The type of roots formed initially was specific to a given species; with age, the initial root shape was often modified by the growing environment. Factors such as soil hardpans, water tables, texture, structure, and degree of compaction all influenced the mature root shape. In the study area, there were essential differences between

Table 1 Distribution of sample species in succession series

Species	Succession stage					
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Schima superba		a b c	d	e	√	√
Castanopsis chinensis		a b	c	d	√	√
Cryptocarya concinna, *Cryptocarya chinensis*				a b	c d	e
Aporosa yunnanensis		a b c d	e	f	√	√
Blastus cochinchensis		a b c d e	f h i	j	√	√
Psychotria rubra		a	√	√	√	√

Note: √ is no samples but in existence in forest; a to j means the number of samples in Figs.3~8 the root structure of pioneer species and other species. Main horizontal roots of pioneer heliophytes in early successional stage were found to be growing more or less straight from the trunk as shown in Fig.3 and Fig.4. They typically grew close to the soil surface and divided or branched into smaller roots within four feet of the trunk. However, obvious taproot and rich branches characterized roots of mesophyte in late successional stage.

1. *Castanopsis chinensis*

The root system of this pioneer species was generally rich in branching and was characterized by the flat root system with several tabular roots, a few plagiotropic skeleton roots dominated the system, with 3~5 roots reaching 15~22 m in length (Fig.3). In the seedling stage of this species we found stretched roots in a radial pattern, but in older specimens a few plagiotropic skeleton roots dominated the system by both horizontally and transversally growing branches. Juvenile taproots hardly penetrated below a depth of 0.4 m, but in mature trees they reached down to 0.7 m. At the soil surface, the same skeleton roots developed numerous thin lateral branches bearing the system of slender brachyrhizas. There were clusters of fine roots in the long lateral branching root. In excavated trees, maximum root concentration was in the upper 0.3 m. Fine roots occupied the upper 0.2 m layer and clusters of terminal roots appeared far beyond the crown projection.

The textures of old specimen of *Castanopsis chinensis* species were hard and close-grained. Underground root skeletons were characterized by periderm of red-purple color and their brown-red color slash. Their vertical structure lacked positively geotropic roots. Even the main skeleton root was not developed into the depth, and remained either dwarfed or curved in a plagiotropic direction. However, roots of this pioneer species was characterized by some buttress-like roots in older specimen. *Castanopsis chinensis* has over 400 years of history in the study area, rooting depths and lateral root spreads were generally increased in tree growth forms as their size and life span increased (Fig.3).

2. *Schima superba*

This intolerant pioneer tree species was characterized by a developed taproot and several bulky plagiotropic branches. Skeleton of this pioneer species generally have a periderm with gray-brown color

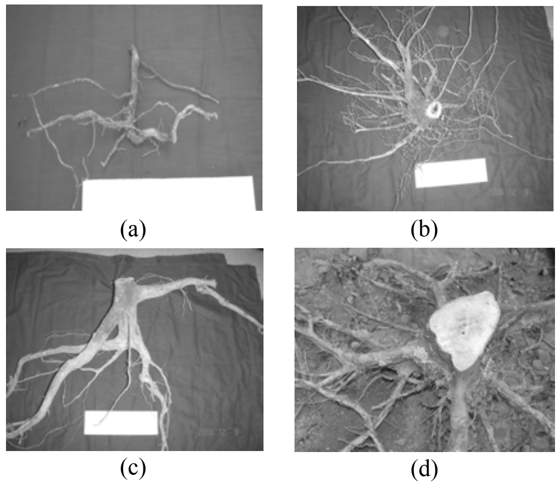

Fig.3 Scheme of root system development in *C. chinensis* from early development stage to the oldest specimen. (a) *H* is 0.94 m; (b) *D* is 2.0 cm, *H* is 3.2 m; (c) *D* is 3.5 cm, *H* is 5.25 m; (d) *D* is 20 cm, *H* is 21 m

(Fig.4) and bole with an aroma. From the early seedling stage the root system develops clear taproot type featured by positively geotropic roots, but with age, the roots system develops a great number of transversal and vertical skeleton roots creating a complicated root system. Several oblique roots were also visible, growing down at an angle. Six or more typical coarse plagiotropic skeleton roots horizontally radiated from the stem and were distributed in the top 50 cm in a mature specimen. In this soil layer, trees concentrate most of their absorbing roots in the top

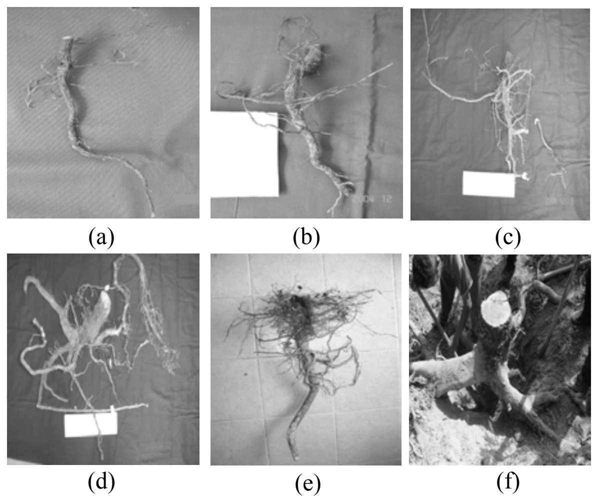

Fig.4 Scheme of root system development in *S. superba* from early development stage to the oldest specimen. (a) *H* is 0.45 m; (b) *H* is 0.74 m; (c) *D* is 2.87 cm, *H* is 5.25 m; (d) *D* is 2.80 cm, *H* is 3.40 m; (e) *D* is 7.64 cm, *H* is 6.60 m; (f) *D* is 22 cm, *H* is 25 m

10~45 cm of soil. Plagiotropic roots spread far beyond the crown projection and the largest diameter roots were found to be the main lateral roots close to the soil surface.

3. *Cryptocarya concinna* and *Cryptocarya chinensis*

Cryptocarya concinna and *Cryptocarya chinensis* were mesophilous tree species in late succession. In the study area, there was no essential difference in the root structure of these two species (Fig.5). Their root system clearly had taproots and tactic lateral roots, which were stouter and growing straight towards horizontal and vertical direction. The lateral roots were more regularly branched along their length and longer than those of *Schima superba*. Skeleton roots of this late species had smooth ashy bark and slash, which became rust yellow after a while. At the early seedling stage the root system displayed a well-developed and extended lateral root system. However, the older specimens had many lateral roots spreading in the upper of part of the taproot.

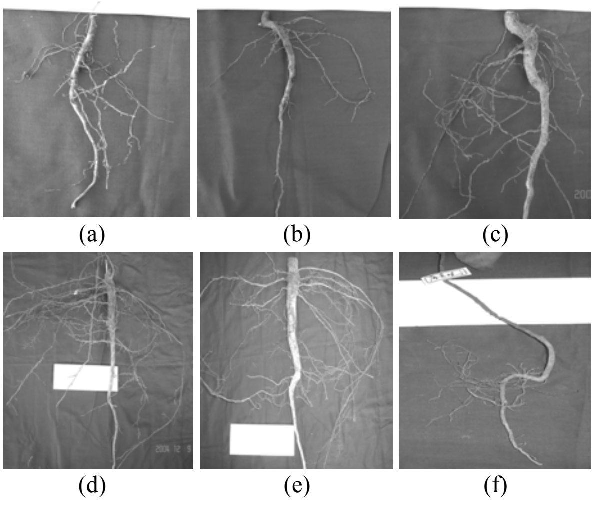

Fig.5 Root system development of *C. concinna* ((a) *H* is 0.60 m; (b) *H* is 0.47 m; (c) *H* is 83 cm; (d) *D* is 1.30 cm, *H* is 2.08 m; (e) *D* is 2.07 cm, *H* is 3.60 m) and *C. chinensis* (f)

In addition, the fine roots of these species were less than those of heliophytes pioneer trees in upper soil layers. The poor root system of these species may be responsible for their low resistance to various hazards, such as drought and insect pest in later part of succession.

4. *Aporosa yunnanensis*

Aporosa yunnanensis is the dominant species in the third layer in evergreen broad-leaved forest. The root system was characterized by well-developed deep taproot from which protruded the least and shortest lateral roots in its middle section (Fig.6). The taproot developed into the depth and was not dwarfed or curved in the plagiotropic direction. Deeply penetrating taproot dominated the root system of young saplings. With increasing age, a dominant taproot prevailed and became thickened. This species had rapidly growing taproot systems to rapidly reach deeper resource. However fine roots were lacking in the whole root system. In addition, *Aporosa yunnanensis* root was characterized by a gray colored periderm and ecru colored slash. Skeleton roots generally had smooth yellow-ashy bark.

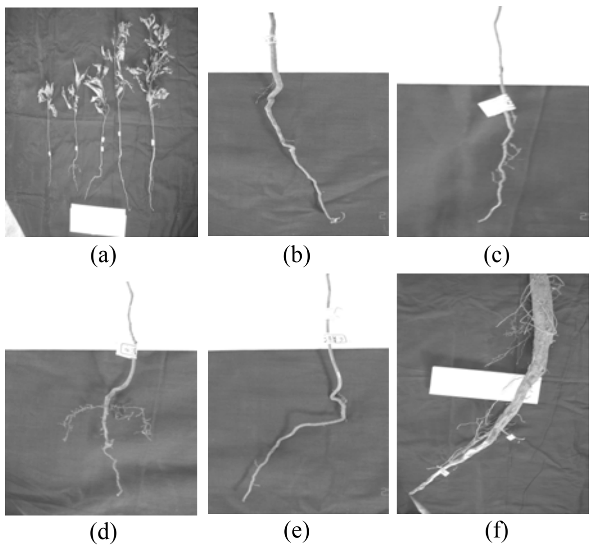

Fig.6 Root system development of *A. yunnanensis* in seedling stage. (a) *H* is less than 0.20 m; (b) *H* is 0.25 m; (c) *H* is 0.30 m; (d) *H* is 0.36 m; (e) *H* is 0.40 m; (f) *D* is 21 cm, *H* is 2.50 m

5. *Blastus cochinchensis*

Blastus cochinchensis belongs to typical species of shrub in the studied forest. *Blastus cochinchensis* root system was characterized by the presence of fibrous root systems and an evident heart shallow root system, consisting of several main roots that branch to form a dense mat of roots. Most functioning roots were in the upper 40 cm of soil but branched roots extended well beyond the expansion of overhead branches (Fig.7). Their vertical structure lacked positively geotropic roots. At the early seedling stage the root system developed about three main seminal roots just above radicle, these roots later branched and formed a fibrous root system. Older specimens often had seven or eight coarse roots which were well branched. Underground root skeletons were characterized by ashen-yellow colored periderm and ivory-white colored slash.

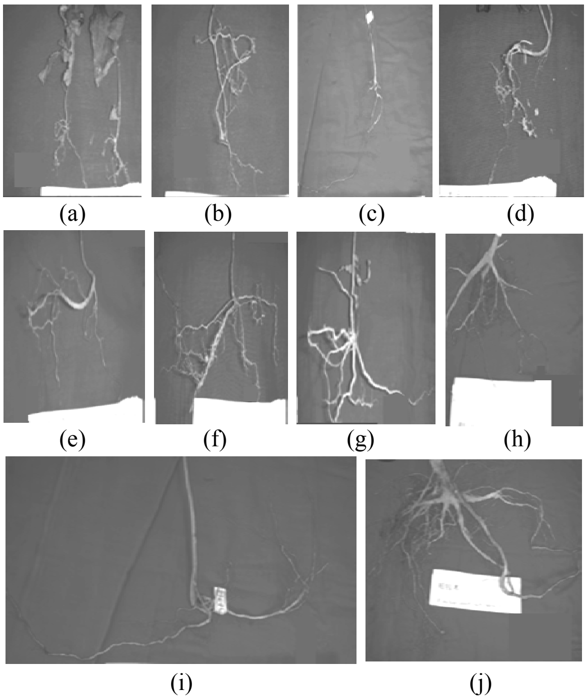

Fig.7 **Root system development of *B. cochinchensis* in early years. (a) *H* is less than 0.10 m; (b) *H* is 0.13 m; (c) *H* is 0.15 m; (d) *H* is 0.30 m; (e) *H* is 0.36 m; (f) *H* is 0.60 m; (g) *H* is 0.63 m; (h) *H* is 0.65 m; (i) *D* is 0.90 cm, *H* is 2.34 m; (j) *D* is 0.20 cm, *H* is 3.60 m**

6. *Psychotria rubra*

Psychotria rubra had fibrous root system, whose skeleton roots were clear with long branches. Plagiotropic roots were found to be spreading far away from the stem (Fig.8).

In a nutshell, the success of pioneer species arises from their capacity for vigorous growth and deep rooting low fertility sites. However, strong competition for water and other resources may limit subsequent success in establishing indigenous trees and under story species. In sub-tropical area were many species in zonal communities (Huang *et al*., 1998), roots of trees development were obviously restricted by inter-species competition (Martínez Sánchez *et al*., 2003). Moreover, root grow status was important to seedling growth and development (Romero *et al*., 1986). In this study, *Castanopsis chinensis* and *Schima superba* were sun species early coming forth in succession, their roots have strong penetrability and flourishing branches. *C. concinna* was mesophyte species that distributed in deeper soil layer with developed branch roots and fibrous roots. *Aporosa yunnanensis* was a dominant species in the third tree layers, with a rapid growth taproot. *B. cochinchensis* and *P. rubra* were shade-tolerant shrub in underlayer, and fibrous roots were one important character.

Fig.8 Root system of *P. rubra* in seedling

Total root biomass in different successional stages

Results of the fresh and dry biomass dynamics (Fig.9) suggested the difference in the totals of all size categories of roots.

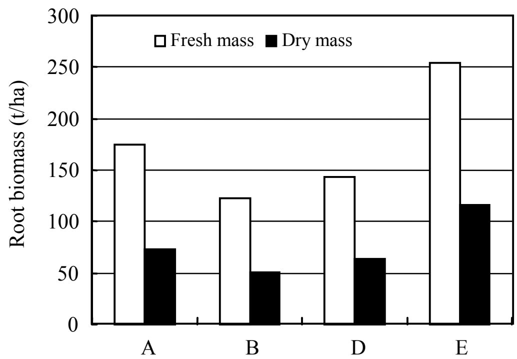

Fig.9 Tree root biomass in various development stages of the subtropical monsoon evergreen broad-leaved forest in South China

Comparing the total root dry biomass of 115.70 t in the monsoon evergreen broad-leaved forest, we found 50.61~115.70 t/ha in the studied forest appeared comparable to the 33~171.8 t/ha in other areas, (Table 2). Chen (1991) referred to the 72.344 t/ha in subtropical evergreen broad-leaved forest in Heishiding. Liao *et al.*(1993) reported 35.43 t/ha for *Cryptocarya concinna*, *Lindera chunii* community in Dinghushan Biosphere Reserve. Vogt *et al.*(1996) estimated 113 t/ha for needle leaf evergreen forest. Lin *et al.*(1990) reported 171.8 t/ha for the mangrove forest in the estuary area of Dongzhai Harbour of Hainan island.

Table 2 Comparison of root biomass with other area

Root biomass (t/ha)	Ecosystem/region	Source/authors
33.00	Thailand	Ogawa *et al.*(1961)
40.00	Panama	Golley *et al.*(1975)
45.00	Manaos	Klinge (1976)
61.00	Venezuela	Sanford (1989)
51.55	Changbai Mountains	Yang and Li (2003)
54.23	Changbai Mountains	Du *et al.*(1998)
72.34	Heishiding	Chen (1991)
35.43	Dinghushan	Liao *et al.*(1993)
171.80	Hainan island	Lin *et al.*(1990)
113.00	Needle leaf evergreen forest	Vogt *et al.*(1996)

On low fluvial terraces of the Caqueta River, Araracuara region, the available data of Pavlis and Jeník (2000) refer to fresh weight. Taking into account the differences in various soil types and climate, the fresh weight in our sampling amounted to about double the dry weight biomass, this value (2.2~2.4) is comparable with these results.

Understandably stratification of the below-ground biomass of roots of various size categories can better reflect the differences in different succession stages. This vertical arrangement is affected also by the structure of root systems of particular species (Figs.3~8), but quantitative assessment of the biomass could not be readily identified—in spite of the fact that root surface tissue might enable us to distinguish between various species. Stratification and decline of root biomass in relation to depth are summarized in Fig.10.

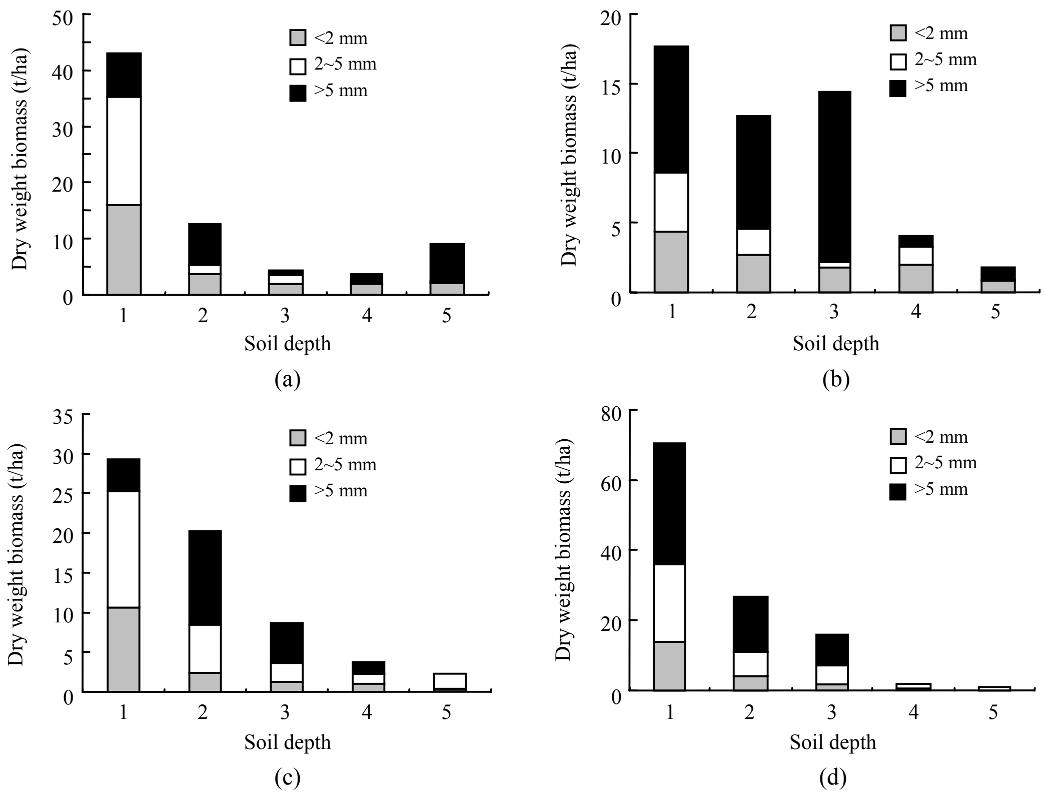

Fig.10 Dry weight biomass (t/ha) of roots of different size categories (diameter<2 mm, 2~5 mm, >5 mm), according to their diameter, in the soil profile (soil horizons by 10 cm) in Dinghushan. (a) Needle-leaved forest; (b) Needle and broad-leaved mixed forest dominated by coniferous forest; (c) Evergreen broad-leaved forest dominated by heliophytes; (d) Evergreen broad-leaved forest dominated by mesophytes. 1, 2, 3, 4, 5 represent 0~10 cm, 10~20 cm, 20~30 cm, 30~40 cm, 40~50 cm soil depth respectively

CONCLUSION

Roots of trees are opportunistic organs and their maximum penetration depends both on hereditary features of the species and soil properties (see above). Availability of nutrients and aeration in the soil essentially control the depth of taproots. Maximum vertical root penetration observed in the loam soil reached 1.65 m, but occasionally deeper roots could be expected.

While pioneer roots can extend hundreds of feet from the stem, the constraints of soil exploration and photosynthate supply tend to limit the extent of most roots to one stand spacing. Successful selection of pioneer tree species is clearly of critical importance to the forest succession. In South China, the adopted species including several species in our study have ecological value as pioneer species (Yu, 1994; 1995; Midgley and Pinyopusarerk, 1996) and functional significance for theoretical research on succession.

This initial attempt has been to describe morphology of the tree roots and their stratification in the lower subtropical region. There remain many questions needing answers through further studies. For example, we found a superficial layer of fine roots and slender plagiotropic skeleton roots which interweave extensively forming a reinforcing root mat in mixed forest and monsoon evergreen broad-leaved forest in South China. The importance of superficial root mats inside the studied forest floor for the nutrition and the function of a root mat adherent to decomposing organic material was not been investigated in this study.

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