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Root System Formation in Clonal Tea Plants

Masataka YAMASHITA
Kurume Branch, National Research Institute of Vegetables, Ornamental Plants and Tea (Makurazaki, Kagoshima, 898 Japan)

Abstract
The formation of the root system and annual root growth of tea plants exhibit a peculiar regularity. Several adventitious roots produced when the plants are young from the skeleton of the future root system. As the root system of clonal plants is generally shallow unlike that of seedling plants, careful management is necessary especially when plants are young for subsequent vigorous growth and for achieving a high yield. The white roots play an important role in nutrient uptake and always account for the largest amount of all aged roots. The white roots in mature plants undergo a cycle of degeneration and regeneration every year and grow most actively in the autumn season when shoot growth is reduced. The white roots produced in the season are considered to be most useful because they display the longest longevity. The lignified thick roots act as reserve organs and are closely related to the tolerance to various stresses. The environmental conditions and the practices peculiar to tea production, including soil hardness, fertilizer application, plucking, pruning and shading, markedly affect shoot growth and also root growth. Emphasis should be placed on studies on the effect of these factors on root growth to increase the yield and improve the quality of tea plants.

Discipline: Crop production
Additional key words: growth periodicity, plucking, shading, soil hardness

Introduction

Plant root systems play various important roles, such as support of a plant body, water and nutrition uptake, storage of nitrogen components and carbohydrates, biosynthesis of hormones, etc. Therefore, the growth and functions of roots are essential to the maintenance of vigorous growth of plants and to the increase of yield and improvement of quality.

Especially, harvesting of young leaves in tea plants to promote photosynthesis affects considerably root growth as well as shoot growth. Although the importance of the root system has been emphasized from the viewpoint of plant vigor, there are few studies on the formation of the root system due to the labor and time required and to the fact that it was considered that these studies may not be directly related to the improvement of yield and quality. Actually, however, root growth in young plants and the regeneration of inactive plants largely depend on root management.

The current report deals with the process of formation of the root system, the mechanism of root reproduction and the physiological functions of roots in tea plants on the basis of the results of former studies.

Shape and structure of root system

1) Distribution

The distribution of the root system differs between seedlings and clones. Seedlings are deep-rooted[1)] and have a thick taper root which extends to a depth of 1 m or more and the amount of roots is smaller. On the other hand, clones which are currently popular in Japan are shallow-rooted (Plate 1). They lack a taper root but display several thick adventitious roots that grow diagonally down. These roots produce numerous fine roots. As a whole, the root system is distributed within a depth of about 40 cm in soil. These differences in the root system are considered to affect the tolerance to various environmental stresses.

2) Classification of roots

The structure of the root system of the tea plant which is a perennial plant is extremely complex. Generally, the roots composing the root system can be classified into brown thick

Plate 1. Root system of a 5-year old tea plant
The configuration of the root system is peculiar to plants grown from rooted cuttings and is characterized by a relatively shallow and wide distribution.

roots (lignified roots) and white fine roots (feeder roots or rootlets). To analyze the structure and functions of roots, it is necessary to classify roots on the basis of physiological or morphological standards. Classification based on the root age was examined as one of the new methods (Fig. 1). As a result, it was shown that the annual ring was a useful index for determining the root age (Fig. 2). Age I roots and age II or older roots identified by this method corresponded to the white roots and brown thick roots, respectively. Roots of all ages contained different amounts of several chemical components (Fig. 3). It is considered that this method is effective for the analysis of the composition, physiological functions and structure of the root system.

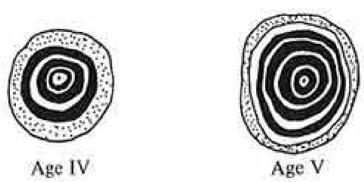


Fig. 1. Annual rings of roots

Development of root system with plant age

Total root weight increased only slightly for 2 years after transplanting but thereafter the increase was linear (Fig. 4). The lignified roots exhibited the most rapid increase. The duration of rapid growth in white roots was short and thereafter the roots grew steadily. The weight of the roots formed within 3 years after

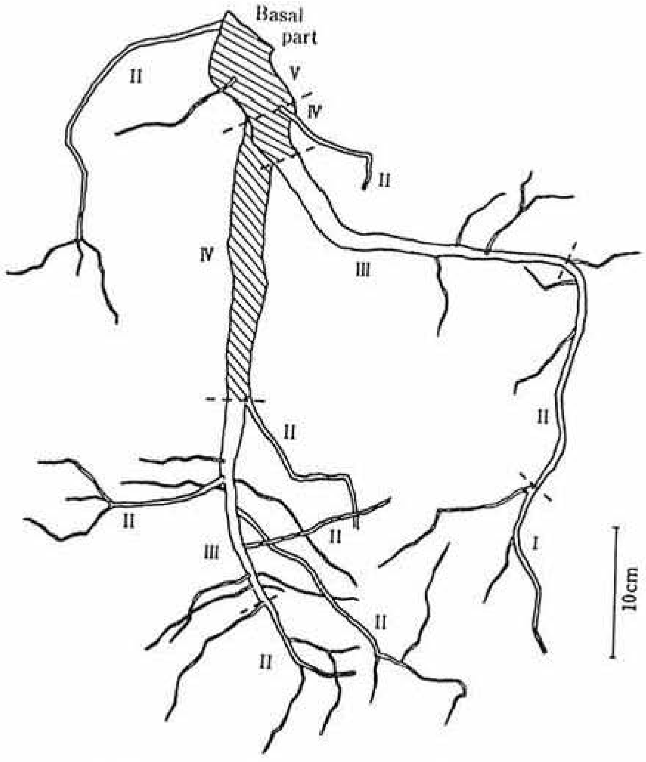


Fig. 2. Classification of typical tea roots

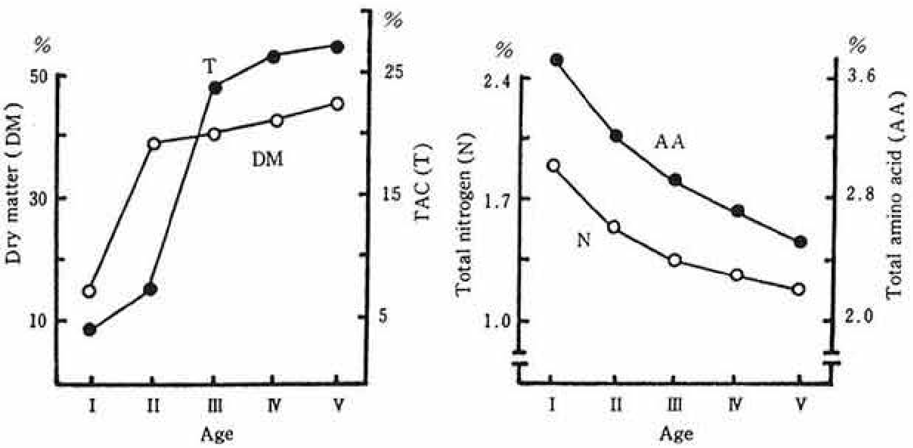


Fig. 3. Changes in contents of chemical components of roots with aging
TAC: Total available carbohydrates.

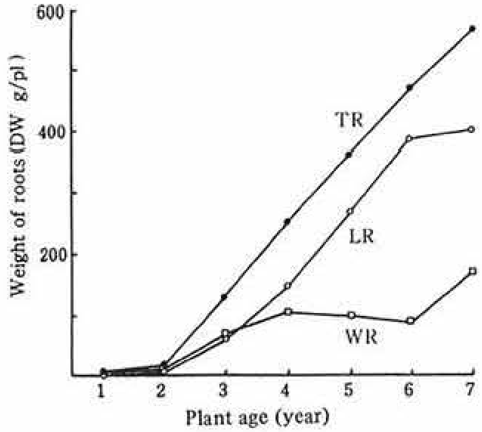


Fig. 4. Growth of roots with plant age
TR: Total roots,
LR: Lignified roots,
WR: White roots.

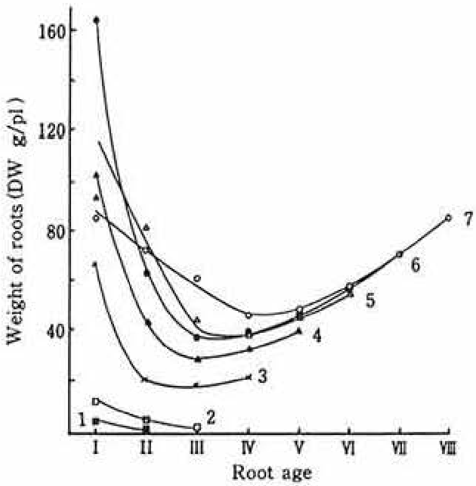


Fig. 5. Changes in age structure of roots with plant age
The numerals in the figure indicate the plant age (year).

transplanting increased with age but after the plants reached the age of 4 years the weight decreased with aging. These facts suggest that roots produced in young plants form the skeleton of the root system and that most of the white roots in mature plants undergo a cycle of degeneration and regeneration every year. Although the ratio of the white roots or Age I roots to the total roots declined annually, they accounted for the largest amount of roots among all the age groups, including old plants (Fig. 5). These findings suggest that white roots play a major role in plant growth.

Growth period of roots

Annual growth of roots showed a distinct periodicity and alternated with active shoot growth. In unplucked plants, new roots grew most vigorously during the 3-month period from October to December (Fig. 6), suggesting that the time of active growth of roots occurs from early to late autumn while the shoot growth becomes inactive. Although the pluckings did not modify these characteristics, the period of active growth was shortened somehow and root growth was reduced (Fig. 6). The reduction in the root growth after December was considered to be due to the low temperature.

Longevity of white roots

As mentioned previously, most of the white roots in mature plants undergo a cycle of degeneration and degeneration in 1-year period. However, the longevity of the roots was different depending on the time when they were produced (Table 1). The life of the roots produced in June and August under high temperature conditions was short due to the low

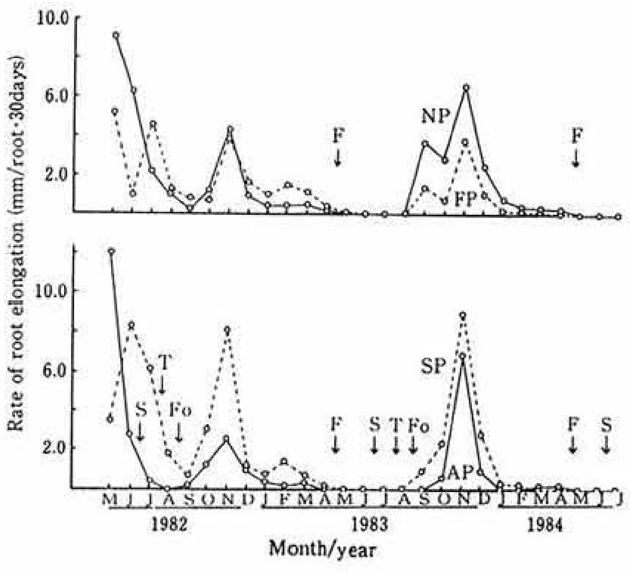


Fig. 6. Seasonal variation in growth of white roots
NP: No plucking, FP: Only the 1st plucking,
SP: 2nd–4th pluckings, AP: 1st–4th pluckings,
F: First plucking time, S: Second plucking time,
T: Third plucking time, Fo: Fourth plucking time.

Table 1. Relationship between the time of formation of roots and growth period of new roots

Time of formation	Days after formation								
	5	10	20	30	60	90	120	150	180
Late June	0.5	0.5	7.7	8.1	12.8	25.5	26.8	26.8	28.1
Early August	0.0	0.0	4.5	4.5	12.1	13.6	15.1	16.7	37.9
Late October	—	0.0	2.0	2.0	3.4	9.1	9.1	9.1	11.4
Mid November	—	0.0	0.0	0.0	0.0	2.0	3.9	5.2	5.9

Percentage of necrotic roots to the total number of roots investigated (%).

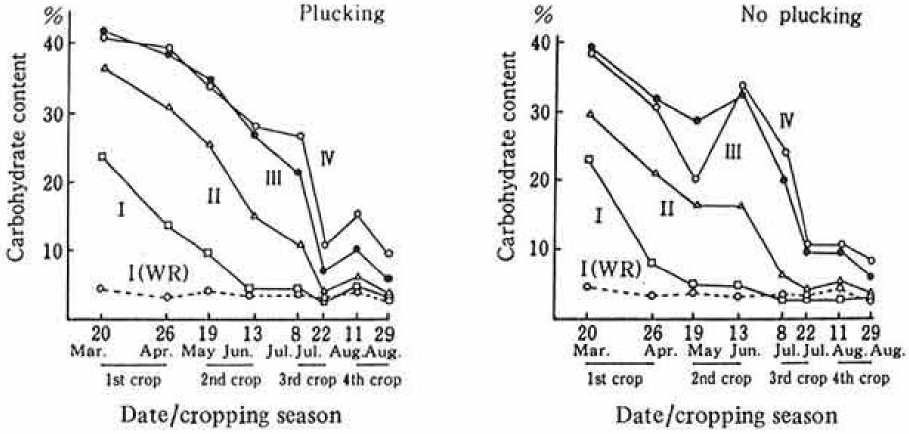
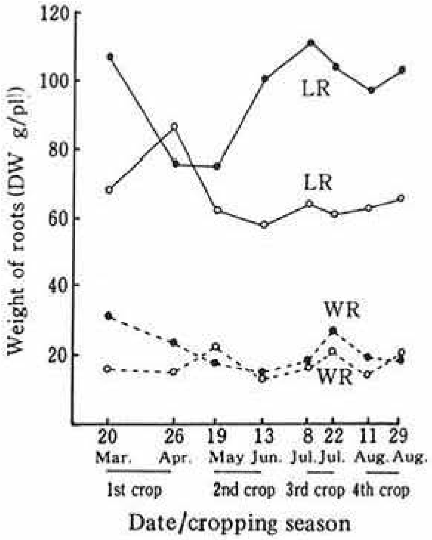


Fig. 7. Changes in carbohydrate content of roots with plucking
IV: Age IV roots, III: Age III roots, II: Age II roots,
I: Age I roots (lignified roots), I (WR): Age I roots (white roots).



LR: Lignified roots. WR: White roots.
● No plucking. ○ Plucking.

Fig. 8. Effect of plucking on root growth

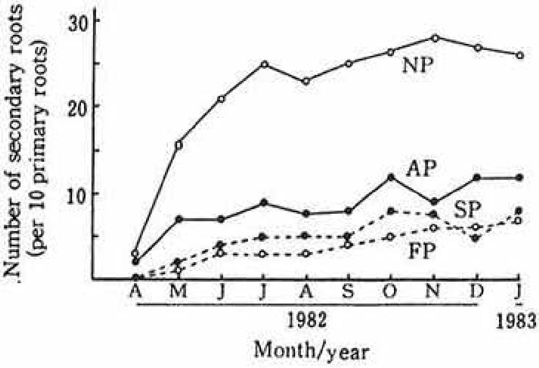


Fig. 9. Effect of annual plucking frequency on branching of roots
Secondary roots refer to new roots directly formed on primary roots that had regenerated after root pruning.
NP, AP, SP, FP: See the legend of Fig.6.

level of reserves and competition with shoot growth. Some ceased to grow within only a few days after initiation. In October and November the roots were relatively thick, grew vigorously and most of them remained active for more than half of a year. It is considered that the white roots produced in the autumn season play an important role in nutrient and water uptake in the next year, although their longevity depends on the temperature, soil moisture, nutrient availability, etc.

Factors related to root growth

1) Effects of plucking and pruning on root growth

Plucking preferentially removes young leaves

Table 2. Effect of plucking and skiffing on horizontal distribution of root systems

Kinds of roots	Distance from the base (cm)	Annual plucking frequency				
		0	1	3	4	4*
Lignified roots	0-15	111.3	101.8	106.4	113.2	87.8
		(100)	(92)	(96)	(102)	(79)
	15-30	39.0	38.0	38.4	38.2	35.4
		(100)	(97)	(99)	(98)	(91)
	30-45	13.7	12.8	10.4	8.8	14.7
		(100)	(93)	(76)	(64)	(107)
	45-60	5.9	4.8	2.4	3.4	4.7
		(100)	(81)	(41)	(58)	(79)
White roots	0-15	13.7	10.0	12.8	10.5	8.3
		(100)	(73)	(94)	(77)	(61)
	15-30	21.5	17.3	15.7	13.9	13.9
		(100)	(80)	(73)	(65)	(65)
	30-45	13.5	13.2	9.4	10.9	9.0
		(100)	(98)	(69)	(81)	(66)
	45-60	8.8	6.4	4.4	6.1	5.7
		(100)	(72)	(50)	(70)	(65)

Dry matter weight g/plant. Figures in parentheses show indices.
* Including top pruning immediately after the 1st crop.

Table 3. Effect of shading on growth and activity of roots

Shading intensity		Rate of shading	Dry matter weight (g/plant)		Branching dimension[c]	Activity[d]
			Lignified roots	White roots		
No shading		0.0%	1.66	3.04	4.7	3.7
Single	white[a]	38.5	1.64	2.44	5.2	3.5
Single	black[b]	53.8	1.57	2.46	4.9	2.9
Double	black	73.8	1.07	1.98	5.0	2.8
Triple	black	90.8	1.11	1.94	4.8	2.6
Fourfold	black	92.3	0.88	1.78	4.4	1.2

a): White cheesecloth, b): Black cheesecloth, c): Maximum dimension based on the primary white root, d): Activity of the apices of white roots; 0 (low)-5 (high).

which, with a higher capacity for photosynthetic functions, should otherwise replace the old leaves with a declined capacity. This practice exerts a pronounced effect on the carbohydrate metabolism and controls root growth as well as shoot growth. When plucking was carried out three times a year, the content of the root reserves (carbohydrates and amino acids) decreased more sharply compared with the absence of plucking (Fig. 7). Furthermore, both the amount of white and lignified roots hardly increased (Fig. 8) and the branching and activity of the white roots decreased during the cropping season (Figs. 9, 10). Shoot growth was reduced in proportion to the annual plucking frequency, while root growth was markedly inhibited by only one plucking and more severely by additional prunings. Besides, the expansion of the root system in the soil layers was restricted (Tables 2, 3).

2) Effect of shading on root growth

Shading technique is used to produce 'Gyokuro' (high grade green tea), to improve the quality of the summer crop and to protect tea plants from winter cold and late frost in Japan. Shading also affects markedly the carbohydrate metabolism as in the case of plucking and pruning. Especially, long term shading inhibited not only shoot growth but also the growth and activity of the white and lignified roots (Fig. 11). Under shading conditions, the growth of the white roots was markedly reduced and multiple branching occurred (Fig. 12). The activity of the white roots was remarkably reduced through shading for only 3 days. After the 3-day period of shading, the white roots required about 20 days to recover their activity. As for the shading intensity, shoot growth was not appreciably affected up to a 60% shading intensity, while the root growth and activity

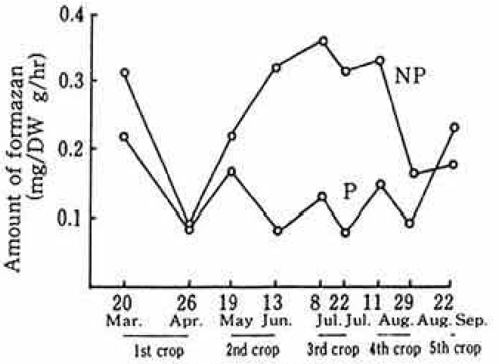


Fig. 10. Changes in activity of white roots with plucking
NP: No plucking, P: Plucking.

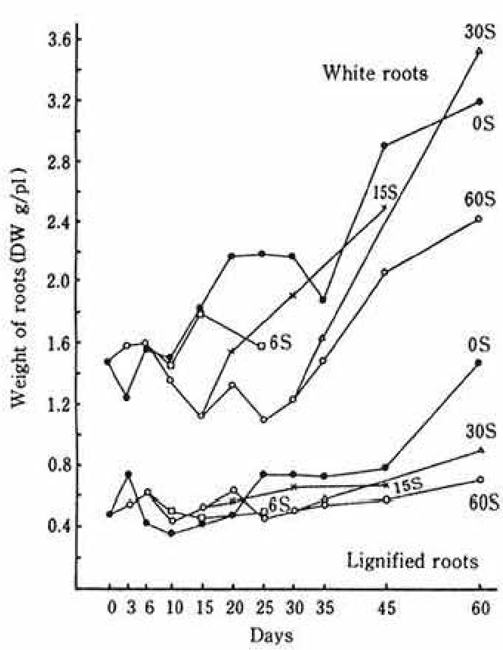


Fig. 11. Effect of shading on growth of lignified and white roots
0S: No shading (Control), 6S: 6-day shading, 60S: 60-day shading.

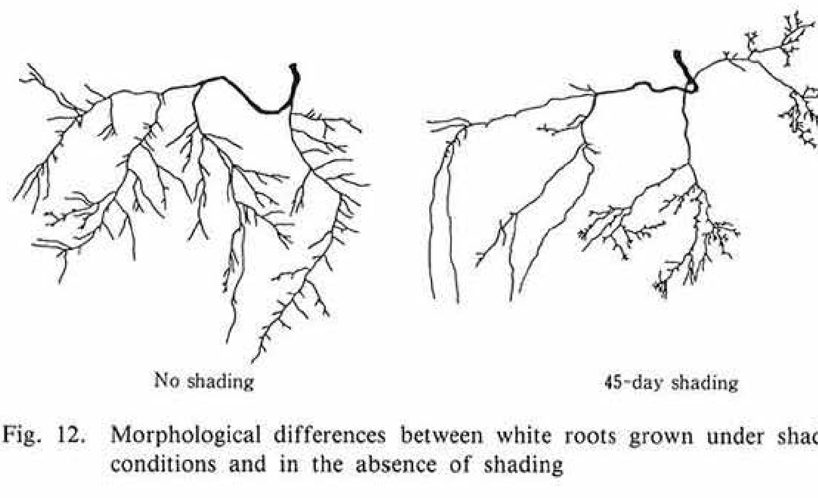


Fig. 12. Morphological differences between white roots grown under shading conditions and in the absence of shading

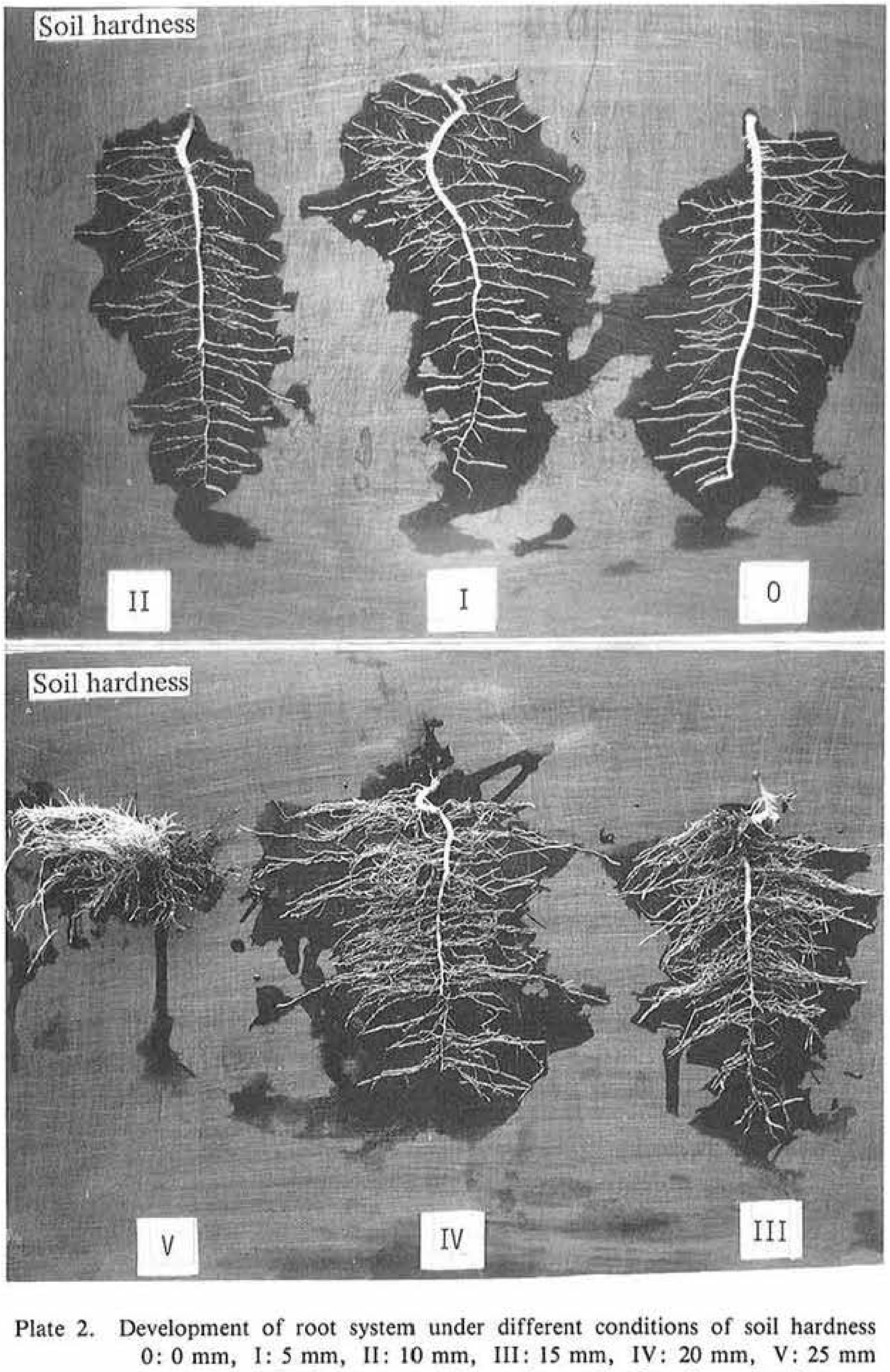


Plate 2. Development of root system under different conditions of soil hardness 0: 0 mm, I: 5 mm, II: 10 mm, III: 15 mm, IV: 20 mm, V: 25 mm (Use of soil hardness meter, Yamanaka type). Prominent development of branched roots was observed at soil hardness levels of 15 and 20 mm.

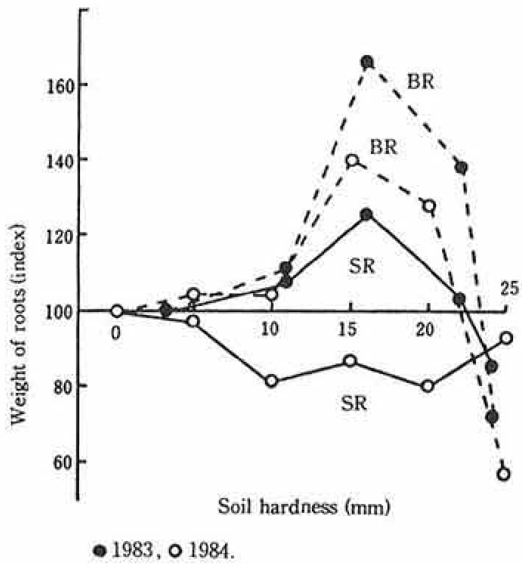


Fig. 13. Effect of soil hardness on root growth Root weight under 0 mm = 100, SR: Seminal root, BR: Branched roots.

were markedly restricted by 40% shading (Table 3), suggesting that the roots are more sensitive to low intensity light conditions than shoots.

3) Effect of soil hardness on root growth

Soil hardness is one of the important factors controlling root growth. When the seedlings were grown at a low level of soil hardness, the development of the root system was impaired because the growth of individual roots was active but branching was not vigorous (Fig. 13 & Plate 2). However, at a high level of soil hardness the seedlings could develop large root systems because the roots bended and branching was extremely vigorous (Plate 2). This response of the roots to soil hardness is similar to that of other crops.

4) Effect of fertilizer application on root growth

In young tea plants, both the activity and amount of roots decreased when nitrogen fertilizer was applied at a rate above 30 kg/10 a/year. In mature plants, excessive application of nitrogen fertilizer resulted in the reduction of the root amount as in the case of young plants.

Conclusion

The roots of tea plants exhibit several peculiar growth patterns depending on the environmental conditions and management. It is important to consider the root growth patterns to enhance the tolerance to stress and efficiency of nutrient uptake as well as to maintain vigorous growth of the plant and achieve high yield and quality. Studies on roots should be promoted in spite of the difficulties encountered.

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