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DEVELOPMENT OF ROOT SYSTEM IN ONE-YEAR OLD SEEDLINGS OF KUDZU VINE (*Pueraria lobata* Ohwi)

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Abstract

Kudzu seedlings were grown in polyvinyl chloride pipes of 1-m length and 32 cm inside diam., which were filled with air-dried sandy loam (78 kg) up to 10 cm below their upper ends, in the period from early June to early December, 1982. The soil core from each pipe was sampled at monthly intervals and the root system characteristics were examined in six vertical zones at 15 cm intervals. The main root elongated at the rate of about 3 cm per day until 30 days after sowing. It had vigorous thickening growth in the vicinity of the base until the 90 day and in the whole length thereafter. Dry weight-to-volume ratio of the main root increased rapidly between the 30th and 60th days and between the 120th and 150th days. Root branching proceeded from the base downward, and the quaternary branch roots occurred in all soil zones by the 120th day. The number of the primary branch roots reached a maximum level on the 60th or 90th day and then decreased in all zones. The thickness of the base of a few primary branch roots in each zone increased noticeably from the 90th day onward. Main root dry-weight increased rapidly from the 120th to 150th day in all zones. The main root dry-weight tended to be larger in the upper than in the lower zones until the 120th day but the reverse occurred thereafter. Differences in lateral root dry-weight among zones with advancing root maturity showed no consistent trend.

From the results of this study, it is considered that kudzu seedlings require several years to produce suitable roots for a crude drug.

Introduction

The root system of crop plants plays an important role, not only in anchoring the plants to the ground and supporting them, but also in imbibing nutrient and water, and in preserving photosynthetic products. Also, the root system is of special concern as an organ producing various kinds of useful substances.

Kudzu roots containing medical ingredients have been widely utilized as a crude drug from ancient times in East Asia. In recent years, the kudzu roots have been imported from Korea and China because they have been in short supply in Japan. However, recently it has been suggested that there is the possibility that the use of species of the genus *Pueraria* except *Pueraria lobata* (=*P. hirsuta* Matsum.=*P. thumbergiana* Benth) for Kakkon-to (a decoction of kudzu used as an antifebrile) would be prohibited in accordance with the amendments of the Drugs, Cosmetic and Medical Instrument Act. If it is materialized, the so-called Kakkon (kudzu root) of Korea and China growth cannot be used for a crude drug because it is feared that the Kakkon from Korea and China contains the roots of some species of *Pueraria* except *P. lobata*. From these reasons, studies on root production of kudzu vine have been intensely called for by drug manufacturers in order to promote a stabilized supply of the roots.

As to a study about the root system of kudzu vine there is nothing but the root system investigation in the potted seedlings by TSUGWA *et al.*[8] and in wild grown kudzu plants by YANO and

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TSUGAWA[9]. Though kudzu vine is thought to be a deep-rooted plant, presently very little is known about the developmental process of the root system in kudzu vine.

In this experiment, kudzu seedlings were grown in polyvinyl chloride pipes. Their root systems were sampled separately every 15 cm from the base of the roots at monthly intervals. The thickening growth and dry matter distribution of the main roots and branches, and the branching behavior were examined in order to understand the developmental course of the root systems.

Materials and Methods

Kudzu seedlings were grown in polyvinyl chloride pipes of 1-m length and 32 cm inside diam. in the 1.9 × 1.9 m rectangular lay out which was contained by concrete blocks, as shown in Fig. 1. The pipes were vertically cut in half to make it easier to take out the root systems. The 5-cm width polyvinyl tape was applied to both the inside and the outside of the pipes along the joints to prevent the roots from growing outside the pipes, and the pipes were bound around by a wire to keep the joints together. The pipes were set upright at the corners of a 48-cm grid and the space between the pipes was filled with sandy soil up to 10 cm below the upper end of the pipes to prevent abnormal temperature fluctuation.

Each pipe was filled up to 10 cm below its upper end with air-dried sandy loam (78 kg soil weight), which had been screend through a 5-mm sieve and then mixed with fertilizers. The fertilizers were applied at the rates of 2.8 g N, 11.9 g P_2O_5 and 7.0 g K_2O per pipe. The maximum capillary capacity and the field capacity of soil used in this study were 47.1 % and 34.8 %, respectively.

After being scarified with conc. H_2SO_4[7] on 8 June 1982, the seeds of kudzu vine were placed in the dark at 25°C on a moistened blotter in a closed Petri dish. Five apparently uniform seeds that had germinated were planted in each polyvinyl chloride pipe on June 10, 1982. At the 2nd leaf stage, seedlings were thinned to one plant per pipe. Five plants were harvested at 30 day intervals after sowing up to early December and they were used for measurement of the root system characteristics.

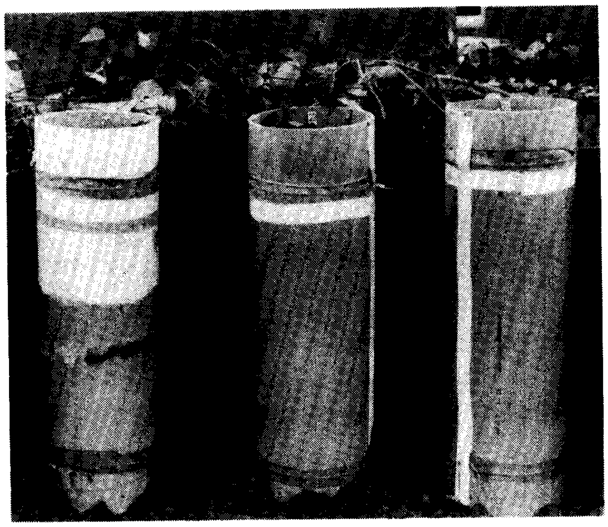

Fig. 1. Polyvinyl chloride pipes dug out from a concrete block enclosure.

The soil cores from each pipe were divided into six vertical zones at 15 cm intervals below the soil surface. The root systems in each 15-cm soil zone were washed free from soil using a 1-mm screen to collect root material. The main root diameter at 1-cm intervals from the base, and dry weight and dry weight-to-volume ratio (g/cm^3) of the main root were determined in each soil zone. The dry weight-to-volume ratio of the main root in each soil zone was calculated from the values of the dry weight and the volume in horizontal slices of the main root, 1 cm thick. The diameters of the bases of the primary branch root* from the first to the fifth thickest root and the number of the primary branch roots were measured in each soil zone. Also, the branching behavior of the roots was examined and the dry weights of the lateral roots were measured in this study. While kudzu roots reached the ground lying beneath the pipe by 60 days after sowing (Aug. 9), the parts of roots penetrating to the underlying ground were not collected.

Moisture for growth was provided from natural precipitation and hand watering. Plants were watered once every two days to the end of June and every five days until July 20, and

*Branch root arising from the main root was designated as the primary branch root.

Table 1. Weather conditions during the growing season of kudzu vine in 1982.

Time	Temperature (°C)	Rainfall (mm)	Sunshine hours
Mid to late Jun.	21.6 (−0.7)	23.0(−140.9)	136.4(+39.3)
Jul.	23.8 (−2.1)	230.0(+ 39.6)	152.7(−40.8)
Aug.	26.1 (−1.1)	232.0(+124.2)	175.8(−43.5)
Sept.	22.2 (−1.3)	84.5(− 92.1)	143.1(−20.1)
Oct.	17.9 (+0.1)	32.5(− 73.3)	199.8(+29.4)
Nov.	14.0 (+1.4)	151.0(+ 81.9)	127.3(−32.8)
Early Dec.	9.7 (+0.9)	6.5(− 8.6)	68.7(+16.1)

The weather data were cited from the observations of Kobe Marine Meteorological Observatory situated about 8 km west of Kobe University. Figures in parentheses show the difference from the normal year.

no water was provided thereafter except for the 21st of October. Soil moisture content in each 15 cm zone was determined from 3 replications using gypsum blocks and the soil moisture meter of Kett Electric Laboratory (model J-3). Insecticide was applied several times during the growing period.

Results

1. Weather condition and soil moisture

Table 1 shows monthly averages of temperature, precipitation and sunshine hours during the growing period of 1982. As seen in these weather records, monthly mean temperatures were lower than normal by 1.1 to 2.1°C and sunshine hours were 12 to 21% shorter during the months from July to September in which kudzu vine grew vigorously. After October, monthly mean temperatures were higher than normal. High rainfall occurred during mid July and early August.

Soil moisture contents in each soil zone are given in Fig. 2. While soil moisture content was highest in mid June at each depth, as water was sufficiently provided to the pipes just before the beginning of this experiment, it decreased gradually until early July in all zones because of low rainfall. The relatively high values of soil moisture were obtained in all zones, except for the 75–90 cm zone, in late July and early August because of the continuous rainfall. Soil moisture content within the pipe was low as a whole between late August and early October because of low rainfall and lack of watering.

The soil moisture profile tended to decrease with depth except the 75–90 cm zone. The differences in soil moisture content among soil zones ranged from 1.2 % in early October to 6 % in late July.

2. Thickening growth of the main root

Fig. 3 shows the change with time in the diameter of the main root between the base and the soil depth of 90 cm. The main root elongated up to the 90 cm depth by 30 days after sowing (July 10). It exceeded the length of the pipe and penetrated into the underlying ground on the 60th day (August 9). The main root diameter increased markedly in the vicinity of the base throughout the 90 days following planting (September 8) and it began to increase between 15 cm and 75 cm in depth on the 120th day (October 7). The diameter of the main root increased by 1.2 times at the base between 90 days and 120 days after sowing, whereas the increase was as much as 2.6 times in the two zones from 15 cm to 45 cm in depth. The diameter of the main root increased vigorously over all the zones, between the 120th day and the 150th day (November 8), particularly in a 30 to 75 cm depth. There seemed to be no increment

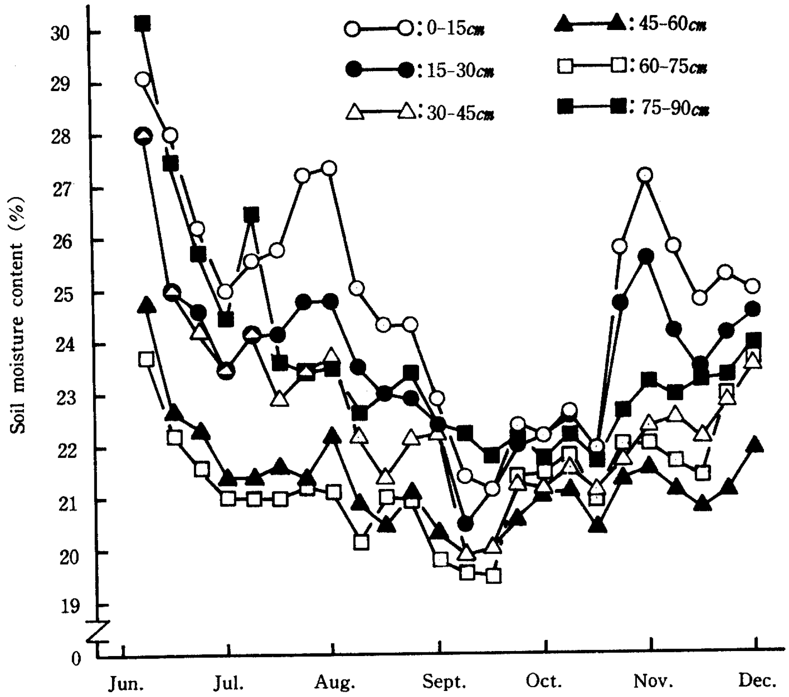

Fig. 2. Change in soil moisture content of each soil zone.

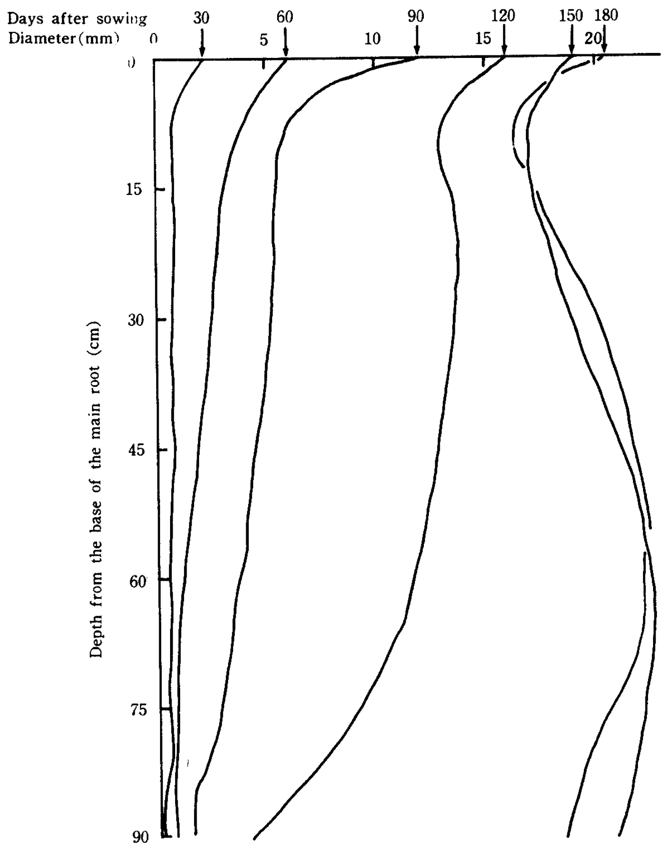

Fig. 3. Transition in the diameter of main root ranging from the base to the 90 cm depth.
Root diameter was measured at 1 cm intervals from the base.

Table 2. Transition in dry weight-to-volume ratio (g/cm^3) of the main root.

Soil zone (cm)	Days after sowing					
	30	60	90	120	150	180
0—15	0.11	0.15	0.14	0.16	0.30	0.32
15—30	0.06	0.15	0.17	0.19	0.28	0.36
30—45	0.05	0.15	0.16	0.17	0.33	0.38
45—60	0.04	0.15	0.13	0.16	0.30	0.36
60—75	0.04	0.16	0.13	0.16	0.31	0.34
75—90	0.03	0.20	0.21	0.22	0.30	0.44

in the diameter of the main root thereafter.

Judging from the data in Fig. 3, the main root of kudzu vine was shaped like a burdock root, having a maximum diameter at the base and a progressively diminishing diameter towards the root tip by 90 days after sowing. However, after 90 days it showed that the shape was slightly larger in diameter in the portion midway between the base and the tip rather than just in the base.

3. Dry weight-to-volume ratio of the main root

As shown in Table 2, there was a downward trend in the dry weight-to-volume ratio from the base toward the tip of the main root 30 days after sowing, with this ratio in the lowermost zone being only a third of that in the uppermost zone. This ratio showed only a slight increment in a 0–15 cm zone between 30 days and 60 days after sowing, whereas it increased to almost two times to a little less than 7 times in the remaining zones. This ratio remained relatively constant in all zones between the 60th and 120th days. However, all zones had fairly remarkable increases in this ratio between the 120th and 150th days.

4. Progress of root branching

Table 3 shows how high order of lateral roots emerged in each soil zone at each harvesting time. All plants examined produced the secondary branch root in two zones above 30 cm depth by the 30th day. Some plants had the secondary branch roots in a 30–45 cm zone, however no secondary branch root was observed in the subsequent zones. Only the main root existed

Table 3. Degree of root-branching in each soil zone.

Soil zone (cm)	Days after sowing					
	30	60	90	120	150	180
0—15	2.0	3.8	4.0	4.0	4.0	4.0
15—30	2.0	3.0	3.6	4.0	4.0	4.0
30—45	1.3	3.0	3.0	4.0	4.0	4.0
45—60	1.0	3.0	3.0	4.0	4.0	4.0
60—75	0.7	3.0	3.2	4.0	4.0	4.0
75—90	0	2.6	3.2	4.0	4.0	4.0

The values of 1.0, 2.0, 3.0 and 4.0 show the presence of the primary, secondary, tertiary and quarternary branch roots in all five plants examined, respectively.

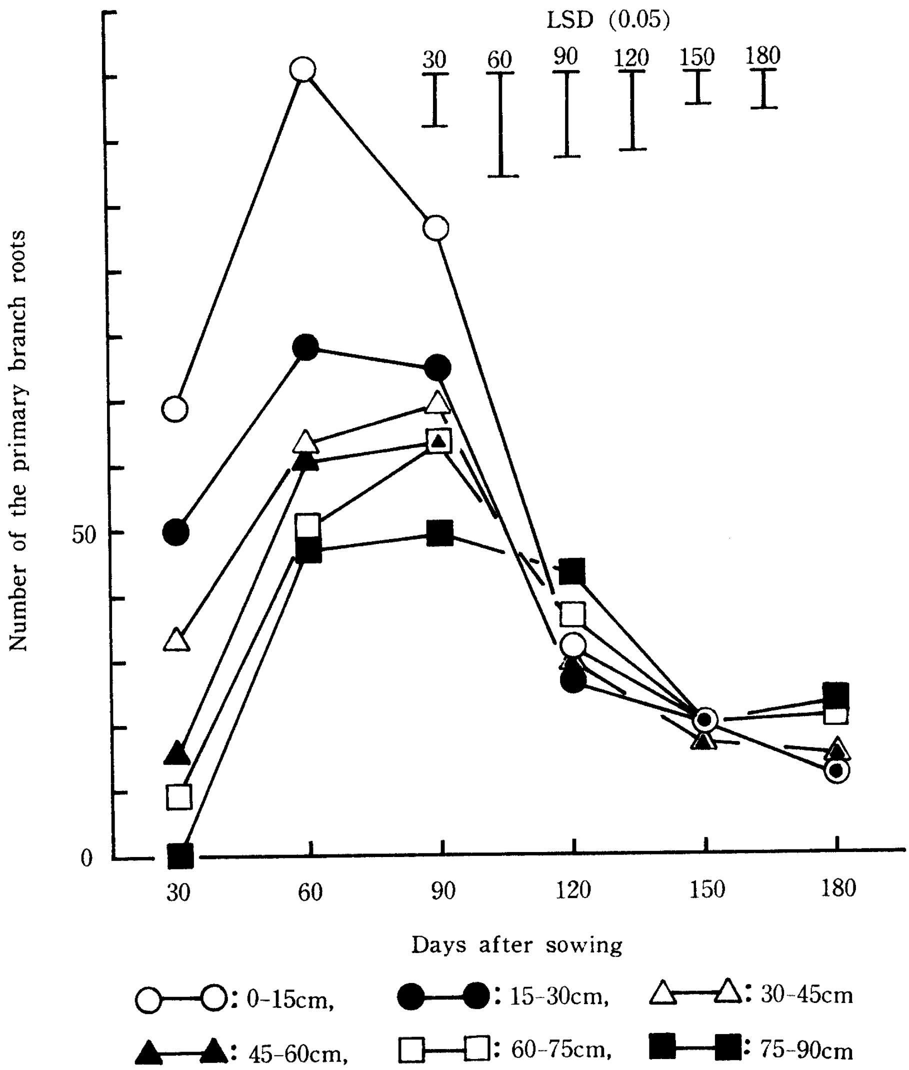

Fig. 4. Transition in the number of the primary branch roots in each soil zone.

at the lowermost zone. The root branching proceeded considerably by the 60th day, and the quarternary and tertiary branch roots appeared in the uppermost zone and the remaining zones, respectively. There were two plants without the tertiary branch roots in the lowermost zone. The quarternary branch root appeared in all zones on the 120th day after sowing.

5. Number of the primary branch roots

Fig. 4 shows the transition of the number of primary branch roots in each soil zone. The primary branch root had a maximum number of 70 in the uppermost zone, and the number of the primary branch roots was progressively less at the lower zone on the 30th day after sowing. At that time, no primary branch root was produced in the lowermost zone. All soil zones had more primary branch roots on the 60th day than on the 30th day. The number of the primary roots tended to decrease in two zones above the 30 cm depth and to increase slightly or level off in other zones between the 60th day and the 90th day, but the upper soil zones were superior to the lower zones in the number of the primary roots until the 90th day. A large reduction occurred in the number of the primary roots between the 90th day and the 120th day, and the number of the primary roots in the lower zones tended to exceed that of the upper zones from the 120th day onward.

The kudzu seedlings had about 170 primary branch roots per plant on the 30th day after sowing and about 420 primary roots during the

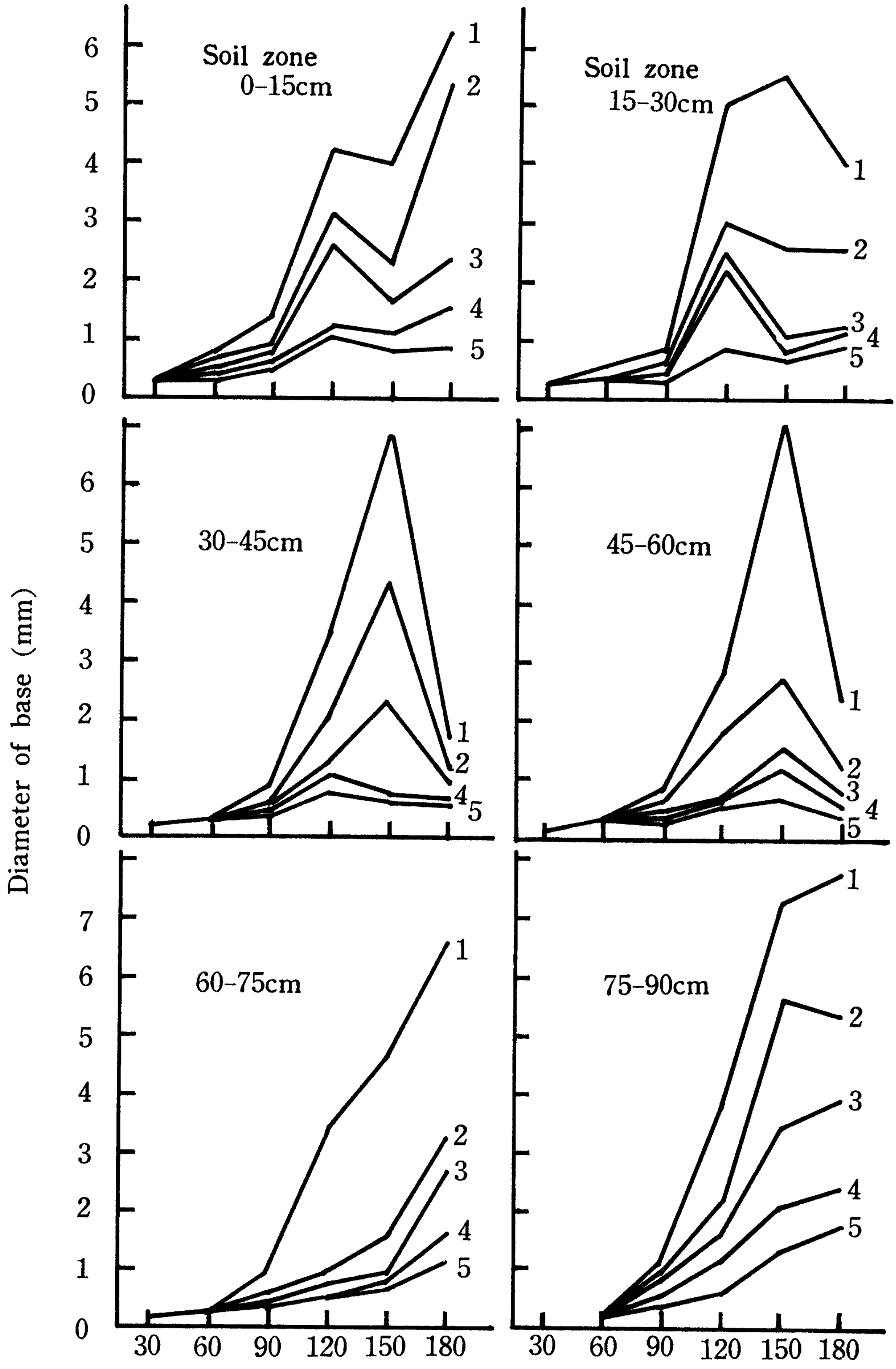

Fig. 5. Transition in the diameters of five thickest primary branch roots at their base in each soil zone.

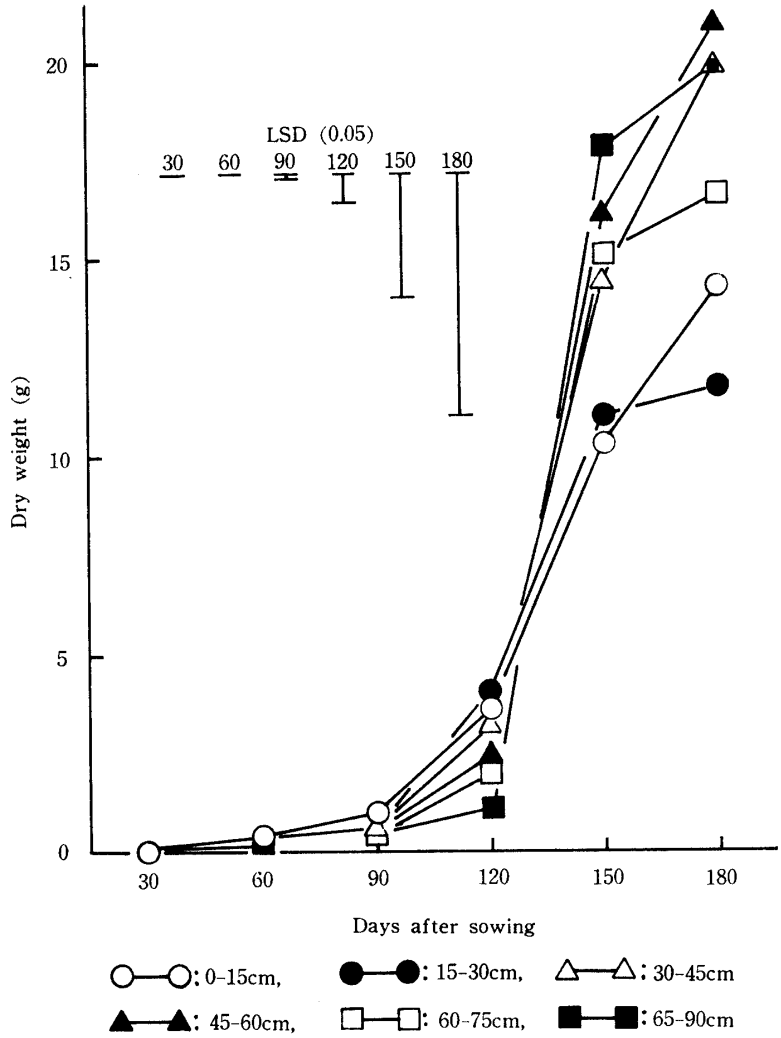

Fig. 6 Transition in dry weight of the main root in each soil zone.

60th to the 90th day, which are a little less than 3 times as much as those on the 30th day. After the 90th day, the number of the primary roots decreased sharply to the number equivalent to that of the 30th day.

6. Base diameters of the primary branch roots

The transition of the diameter of the primary branch roots, from the first to the fifth places in thickness in each soil zone, is given in Fig. 5. On the 30th day, the primary branch roots were produced in all zones except for the lowermost zone. The diameter of the primary roots at the bases increased slowly until the 90th day when they increased sharply and the increasing differences in diameter among the lateral roots began to appear. On the 180th day, the base diameter of the thickest primary branch roots fell within the range between 1.7 mm in a 30-45 cm zone and 7.5 mm in the lowermost zone, whereas the diameters of the least thickest of the five primary roots reached 1.5 mm in a 75-90 cm zone but were less than 1 mm in most of the soil zones. As seen in Fig. 5, the diameter of thicker lateral roots decreased sharply in two zones ranging from 30 to 60 cm in depth between the 150th and the 180th days. However, in these zones the roots with a large base diameter were not observed to die.

7. Dry weights of the main and lateral roots

The transition in dry weight of the main root is shown in Fig. 6. Even though it is not possible to judge from this Figure, the dry weight of

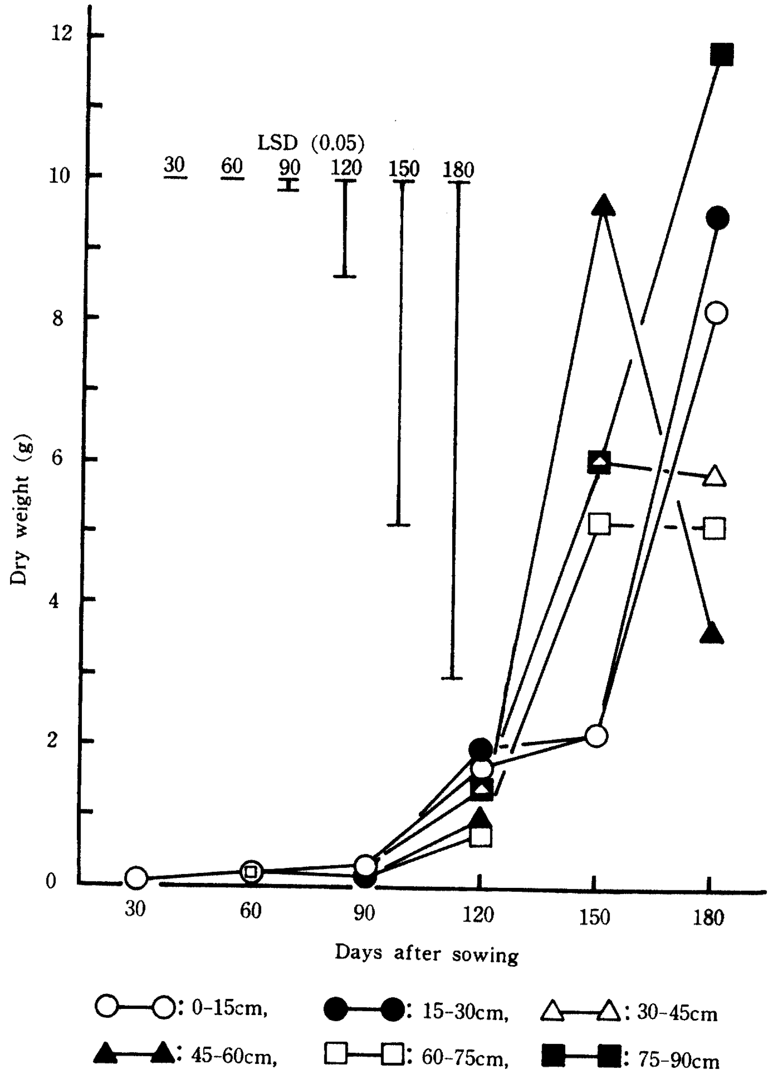

Fig. 7. Transition in dry weight of the lateral root in each soil zone.

the main roots was significantly lower at lower soil zones until the 90th day ($P<0.05$). The dry weight increased markedly from the 90th day onward. There were no differences in the dry weights among the top three zones, which had larger dry weights compared to the other three zones below 45 cm in depth. The main roots in all zones showed the fastest rate in dry weight increase between the 120th and the 150th days after sowing. At the 150th day and similarly at the 180th day, the dry weights in four zones below the 30 cm depth were larger than that of the top two zones.

Fig. 7 shows the transition of the lateral root dry weight in each soil zone. On the 30th day, no lateral root was produced in the lowermost zone, and even though it is not possible to judge from this Figure, the lateral root had significantly smaller dry weights at the lower zones ($P<0.05$). No consistent differences in the lateral root dry weight were observed among the soil zones from the 90th day onward.

8. Dry matter distribution of the main and the lateral roots

Changes with time in the percentage distribution of dry matter of the main and the lateral roots are given in Fig 8. The dry matter distribution in the main root showed a maximum level of 22 to 26% at the uppermost zone while it decreased at the lower zones until the 90th day. Thereafter the main root tended to have a higher dry matter accumulation at lower zones. On the 30th day, the lateral root, like the main root, had a maximum dry matter distribution at the uppermost zone and had a

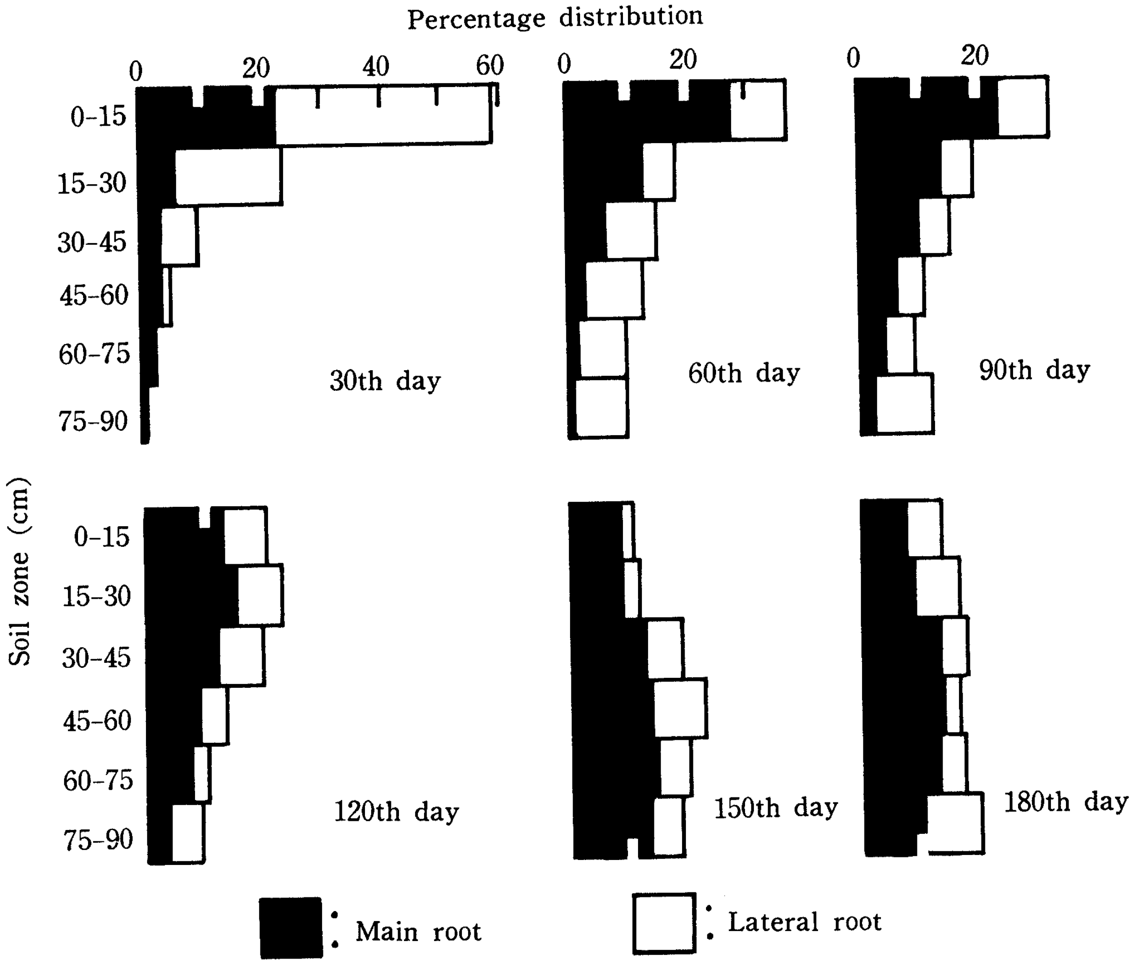

Fig. 8. Dry matter distribution of root in each soil zone.

smaller distribution at the lower zones. The dry matter distribution of the lateral root showed no consistent trend among soil zones from the 60th day onward.

On the 30th day, the main root had a lower percentage distribution of dry matter than the lateral root in the three zones above 45 cm depth. An inverse relationship occurred between the main root and the lateral root in the two zones above the 30 cm depth on the 60th day, and the percentage distributions in the main root were higher than those of the lateral root in all soil zones after the 150th day.

With reference to the total (main + lateral roots) dry matter accumulation, percentage distribution showed a maximum value of 60 % in a 0–15 cm depth and was lower at the lower zones on the 30th day after sowing. This tendency in dry matter distribution changed gradually with time, and the zone with the highest percentage distribution shifted from the upper toward the lower soil zones.

Discussion

From the results of extensive experiments which has been conducted under favourable field conditions, WEAVER has reported that crop roots elongated generally greater than a half inch per day[6]. LUNGLEY[1] has shown that in small seeded species grown under suitable soil conditions the main root elongated 2.0 cm per day. In the present study, the main root of kudzu vine penetrated to the 75–90 cm zone by the 30th day when the plant tops only grew to a length of 2.2 cm with four leaves, and the average elongation rate of the main root was about 3 cm per day in this period. Thus, the main root of kudzu vine had higher elongation rate than that of the other small seeded crops during the early growth period.

The form of the main root of leguminous crops at the final growth stage has been classified into three types by TANAKA[4] : extensive thickening type (alfalfa type), basal thickening type (soybean type) and little-thickening growth type (pea type). He has observed that in the extensive growth thickening type, though the secondary thickening growth in the main root extended to the whole length of it, the main root became thinner gradually from the base toward the tip and it had a burdock root shape. In the present study, the diameter of the main root decrersed at the 5-10 cm portion from the base, progressively increased from the 15 to 65 cm depth and then declined toward the root tip on the 150th and 180th days after sowing. This result indicates that the thickening growth in kudzu root progresses much more toward the root tip than that of other crop roots belonging to the extensive thickening growth type. MATSUI[2] has reported that in his field experiment the main roots of 2-year old kudzu plants had a conspicuously thickened part at 10 to 20 cm below the base. These results suggest that the portion of main root, at which the most vigorous thickening growth occurs, varies greatly with soil conditions and that the thickest part of the main roots becomes progressively conspicuous with time. Soil moisture content in the 30-75 cm depth is found to be generally lower than that of the other soil depths. The more vigorous thickening growth of the main root observed in this depth may be associated with this soil condition.

Dry weight-to-volume ratio of the main root showed a remarkable increase between the 30th and 60th days and between the 120th and 150th days after sowing. The increase in this ratio seems to indicate the formation of the root tissues and larger accumulation of assimilation products in the root in early and late growing seasons, respectively.

TANAKA *et al.*[3] has reported that in peanuts the root branching proceeded from the base downward. In peanuts the quarternary, tertiary, secondary branch roots occurred at depths of up to 6, 21 and 36 cm from the base of the main root on the 66th day after sowing. Only the primary branch roots existed below 36 cm deep from the base of the main root. Kudzu vine was similar in the advance of root branching to peanut plants until the 60th day, however it produced the quarternary branch roots in all soil zones on the 120th day after sowing.

Kudzu vine had more primary branch roots nearer to the base of the main root like peanuts[3] until the 90th day. The number of the primary branch roots per plant reached a maximum level during the 60th to the 90th day, and it decreased thereafter. It is assumed that the thickness of the primary branch roots is established in the early stage of the growth and that the decrease in the number of the primary roots in the latter part of the development period is thought to result from the death of the primary roots which ceased the thickening growth due to unknown causes.

RUSSELL[6] has suggested that production of the lateral roots was concentrated in the part of the main root that was lying in favourable soil layer in order to compensate for the poor root growth in unfavourable conditions when part of the main root was under unfavourable soil conditions. In the present study the lowermost soil zone had a greater number of the primary branch roots than four soil zones above the 60 cm depth from the 120th day onward. This could be attributed to the compensatory effect made by the adjoining portion of the main root for the growth suppression of the penetrated deeper portion of the main root into the underlying firm soil layer.

It has been reported that the thickening growth of the main root was closely related to that of the lateral root. Lateral roots, arising near the base of the main root, showed only vigorous thickening growth in soybeans belonging to the basal thickening growth type, whereas stout primary branch roots were distributed not only in the vicinity of the base but also near the root tip in alfalfa belonging to the extensive thickening growth type[5] In this study, the primary branch roots with fairly large diameters at their bases were observed in all soil zones. This is thought to be associated with vigorous thickening growth in the main roots of kudzu vine even at a great soil depth.

In this paper, root morphological study was conducted only for one-year old seedlings of kudzu vine. From the results of this study, it is considered that kudzu seedlings require several years to produce suitable roots for a crude drug. It remains for future studies to show how the roots swell from the second year onward.

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クズ１年生実生の根群の発達

津川兵衛・丹下宗俊・小林良平・西川欣一

要　約

本研究では，長さ１*m*，直径 32 *cm*の塩化ビニール管に，管の上端から10*cm*の深さまで砂壌土（風乾重 78 *kg*）をつめ，クズ実生を栽培した。栽培期間は1982年６月上旬から12月上旬までで，この期間中１ケ月間隔で根を採取し，基部から15*cm*ごとに６階層に分けて根群の諸形質を調査した。

主根は播種後30日目までは１日当り約３*cm*の割合で伸長した。主根の２次肥大生長は90日目までは基部附近で旺盛であり，その後は主根全体に及んだ。主根の乾重一体積比は30日と60日目および120日と150日目の間で急増した。根の分枝は主根基部から下方へ進み，120日目までにすべての階層で４次分岐根が発生した。各階層の１次分岐根の数は播種後60日目ないし90日目で最高に達し，その後減少した。ごく少数の１次分岐根のみが90日目以降に基部肥大を示した。主根乾物重は各階層とも120日目から150日目にかけて急増した。また主根乾物重は120日目までは下層より上層の方がより大きい傾向があったが，それ以後は逆転した。各階層間の側根乾物重の差は一定の傾向を示さなかった。

本研究結果から，生薬としてのクズの根の生産には播種後数年を要すると考えられる。したがって，今後の研究では播種後２年目以後の根群の発達過程を明らかにする必要があろう。