Jpn. J. Crop Sci. 66(2) : 259—267 (1997)

The Role of Crown Roots from Coleoptilar Node in the Rooting and Development of Transplanted Rice Nursling Seedlings*

Ryouji SASAKI** and Kiyochika HOSHIKAWA
(*Faculty of Agriculture, Tohoku University, Sendai 981, Japan*)
Received February 15, 1996

Abstract : The root system of rice nursling seedlings is composed of a seminal root and crown roots from coleoptilar node. The roots were cut at various locations, and the treated seedlings were grown for seven days after transplanting to clarify the role of the crown roots in the rooting and development. Even when the roots were cut at 1.5 cm from the base of the root, growth of the seedlings was similar to that of the control. However, growth was significantly reduced when cut at a length of 0.5 cm from the base. The growth of transplanted seedlings, including the emergence rate of the third leaf, was barely influenced by excision of the root tips of a seminal root and four crown roots, but growth was severely reduced by cutting at the bases of a seminal root and the longest crown root. The growth of the transplanted seedlings decreased in accordance with the total root length remaining after the treatments. These results indicate that the rooting and development of transplanted nursling seedlings are reduced according to the total length of the root remaining after treatment. It is conjectured that the crown roots from the coleoptilar node play a large role in the absorption of water and nutrients just after transplanting, and promote the rooting and development of transplanted nursling seedlings through emergence of the first nodal roots.
Key words : Coleoptilar node, Crown root, First node, Nursling seedling, Rice, Rooting, Root pruning, Transplanting.

水稲乳苗の活着における鞘葉節冠根の役割：佐々木良治**・星川清親（東北大学農学部）

要　旨：水稲乳苗の活着における鞘葉節冠根の役割を評価するために，乳苗の根系を構成する種子根および鞘葉節冠根に種々の断根処理を施したのち移植し，7日間生育させ活着への影響を調査した．根の基部から 1.5 cm あるいは 3.0 cm ですべての根を切断して移植しても，移植7日後の生育は，断根処理をしない無処理苗の生育と同様であった．しかし，切断位置を根の基部から 0.5 cm にして移植すると，その生育は，無処理苗の生育に比べて有意な低下を示した．また，種子根と4本の鞘葉節冠根の根端を除去して移植しても，第3葉の抽出速度および移植7日後の生育はほとんど影響を受けなかった．一方，種子根と最長の鞘葉節冠根とをその基部で切断して移植すると，移植後の生育は明らかに抑制された．移植7日後の総乾物重（茎葉と根）および移植した苗に残存した根の総根長を，無処理苗に対する処理苗の割合として表し両者の関係をみると，総乾物重は残存した根の総根長と密接に関連し，総根長の減少にともなって低下した．これらの結果は，移植された乳苗の生育は，苗に残存した根の総根長によって影響されることを示唆している．移植された乳苗にとって，鞘葉節冠根は養水分の吸収という点で大きな役割を担い，第1節冠根を速やかに発根させることで活着すると推察される．
キーワード：移植，イネ，活着，冠根，鞘葉節，第1節，断根，乳苗．

In recent years, the transplanting of cultured rice (*Oryza sativa* L.) nursling seedlings has become more spread. This is of considerable practical concern, because more cost-saving techniques cause a reduction in working time and cost[22]. Several studies have been conducted to determine the optimum method and duration for raising the nursling seedling[3,4,10]. We have classified nursling seedlings as green nursling seedlings, which are raised in light, and yellow nursling seedlings raised in darkness[11]. The rooting of transplanted rice seedlings, including nursling seedlings, depends on the growth of new roots[5,6,8]. This is associated with the characteristics of seedlings[6,17] and the amount of damage incurred[6,17,25]. Root pruning, which accompanies the transplanting, is the principle cause of this damage. There have been several research papers published concerning the influence of root pruning on the growth of transplanted rice seedlings[12,13,14,15,23,24,25]. However, few studies have been performed on the root pruning of nursling seedlings[18,26]. It is therefore necessary to understand the effect of root pruning on the rooting and development

* Part of this work was presented at the 199th meeting of the Crop Science Society of Japan (April 1995).
** Present address : Hokuriku National Agricultural Experiment Station, Joetsu, Niigata 943-01, Japan.

of transplanted nursling seedlings.

The root system of nursling seedlings is composed of a seminal root and crown roots from a coleoptilar node. Hoshikawa and Shoji[9] reported that the coleoptilar node's crown roots were the key roots involved in rooting and development of transplanted nursling seedling. A knowledge of the influence of cut crown roots from coleoptilar node on the rooting of transplanted nursling seedling is needed to evaluate the role of the crown roots in the rooting and establishment of nursling seedlings.

This study was undertaken to determine the effect of various root cutting treatments on the growth of nursling seedlings, and to clarify the role of crown roots from the coleoptilar node in the rooting and development of transplanted nursling seedlings.

Materials and Methods

Experiment 1.

Pre-germinated rice seeds, cv. Sasanishiki, were sown in nursery boxes (58×28×3 cm) which contained nursery soil (Kureha-ryujyou-baido, Kureha Chemical Co., Ltd.) May 12 in 1993. The soil was thoroughly watered before sowing. Two hundred and forty grams of imbibed seed was scattered on the soil surface of each box. Before being covered with a thin layer of the soil, the seeds were sprayed with a fungicide (Daconil-1000) in order to prevent infestation of seedling blight. The boxes were placed in a dark nursery chamber and maintained at a temperature of 32°C. After 2 days, the seedlings had developed 1 cm bud. The seedlings were subsequently raised under natural light (5-day-old green nursling seedling; 5d-GNS) and in the dark (5-day-old yellow nursling seedling; 5d-YNS) at a mean temperature of approximately 25°C for 3 days.

At the end of this growth period, seedlings were selected from both 5d-GNS and 5d-YNS, and were then washed free of soil. The roots were cut at 3.0, 1.5 and 0.5 cm from the base of the root. On May 17, the treated and non-treated seedlings were transplanted, 10 seedlings per plastic case (15×5.5×10 cm) in unfertilized soil. Two plastic cases were used for each treatment and a total of 16 cases were used. The soil was flooded prior to transplanting. After transplanting, the cases were placed into containers in a temperature-controlled greenhouse set at 30/25°C with a day/night cycle of 12/12 hrs. The humidity in the greenhouse was not controlled. Water was kept 2 cm above the soil surface for 7 days after transplanting.

Twenty other seedlings were sampled to measure plant length, leaf length, number of roots, and dry weight. The total root length was recorded to calculate the length of root remaining after the treatment. Seven days after transplanting, all of the transplanted seedlings were sampled, and were then washed free of soil. Plant length, plant age in leaf number, the longest root length, number of roots and dry weight were measured.

Experiment 2.

The cultivar and the method of sowing and emergence of seedlings were identical to those described in experiment 1. The seeding date was Sept. 2, 1994. After emergence, the seedlings were raised for 3 days under natural light in a temperature-controlled greenhouse with an air temperature of 30/25°C and a day/night cycle of 12/12 hrs.

Table 1. Characters of two kinds of nursling seedling (Exp.1).

Seedling	Plant length (cm)	Second leaf Sheath (cm)	Second leaf Blade (cm)	Third leaf# (cm)	Number of roots (/plant)	Residual ratio of endosperm nutrients (%)
5d-GNS	6.3	4.3	2.1	0.4	5.3	40.6
5d-YNS	8.9	4.9	2.2	0.1	5.9	32.2
t-test	**	**	ns	—	*	—

: Length of the third leaf as it emerged from the second leaf sheath. *, ** : Significant at the 5% and 1% levels, respectively. ns : Not significant at the 5% level. The rasidual ratio of endosperm nutrients was calculated by dividing the residual mass of seed (dry weight basis) by initial seed dry weight. 5d-GNS : 5-day-old green nursling seedling. 5d-YNS : 5-day-old yellow nursling seedling.

Prior to transplanting, two kinds of root cutting treatments were conducted as follows ; cutting the root off 2 mm from the root tip (Treatment I), and cutting the root off at its base (Treatment II). The first treatment was performed on a seminal root (RT-1), a seminal root with two (RT-3), or four longer crown roots (RT-5) in order of root length. The second treatment was performed on a seminal root (RB-1) only, or a seminal root with the longest crown root (RB-2).

On Sept. 7, the treated and non-treated (control) seedlings were transplanted four seedlings per hill - three hills per plastic case, 15×5.5×10 cm. The cases contained soil with chemical fertilizer (N, P, K ; 0.2 g/case each). The soil in the cases was flooded prior to transplanting. Two cases were used for each treatment in a total of 12 cases. After transplanting, the seedlings were grown in the same way as described in experiment 1. The measurement parameters for the seedlings and the plants grown for 7 days were similar to those described in experiment 1. In addition, the leaf elongation rate of the third leaf was determined by the daily measurement of a single plant from each hill. In experiments 1 and 2, the plant age in leaf number was designated including incomplete leaf.

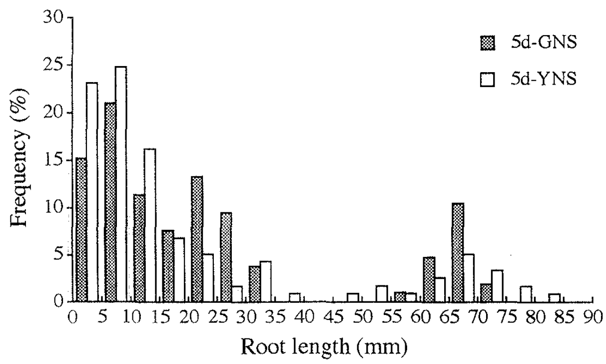

Fig. 1. Frequency of root length distribution of 5d-GNS (n=20) and 5d-YNS (n=20) (Exp. 1).

Results

Experiment 1.

Table 1 shows the characters of 5d-GNS and 5d-YNS. The plant length of 5d-YNS was 2.6 cm longer than that of 5d-GNS. The second leaf sheath of 5d-YNS was 0.6 cm longer than that of 5d-GNS. However there was no significant difference in the length of the second leaf blade. It is well known that the second internode elongates when a rice seedling is raised in darkness[8,20,21]. We observed this elongation of the second internode of 5d-YNS ; its length was 2.1±0.2 cm. The difference in plant length between 5d-GNS and 5d-YNS was primarily due to the elongation of the second internode. If the elongated second internode is discernibly longer compared to the first leaf, it would be impossible for such a seedling to be transplanted with accuracy by a machine.

As the frequency of root length distribution in Fig. 1 shows, the distribution of the root length is separated into two parts, i.e. crown roots from the coleoptilar node, and seminal root. About 95% of the crown roots was less than 30 mm in both 5d-GNS and 5d-YNS, and 90 to 95% of seminal roots had a root

Table 2. The total root length remaining after the treatment and the number of roots cut by the treatment (Exp. 1).

Treatment #	5d-GNS		5d-YNS	
	Total root length remaining* (cm)	Number of roots cut* (/plant)	Total root length remaining* (cm)	Number of roots cut* (/plant)
Control	12.4(100)**	0.0	11.6(100)	0.0
3.0 cm	8.8(71)	1.1	8.0(69)	.2
1.5 cm	5.9(48)	2.6	5.7(49)	1.9
0.5 cm	2.5(20)	4.3	2.6(22)	4.1

: Control=the roots were not cut; 3.0 cm, 1.5 cm and 0.5 cm=the roots were cut at 3.0 cm, 1.5 cm, and 0.5 cm from the base of the root, respectively.

* : The total root length remaining and the number of roots cut were calculated by the root-length distribution (Fig. 1).

** : Figures in the parentheses are calculated as a percentage compared to the control.

Table 3. Effects of root cutting treatment on the growth of nursling seedlings 7 days after transplanting (Exp. 1).

Treatment #	Plant length (cm)	Plant age in leaf number	Longest root length (cm)	Number of roots (/plant)
5d-GNS				
Control	21.3	3.4	18.4	11.2
3.0 cm	21.7	3.3	17.6	10.3
1.5 cm	21.1	3.3	17.5	10.2
0.5 cm	19.7***	3.3	16.8	11.0
5d-YNS				
Control	18.5	3.7	16.1	12.0
3.0 cm	18.8	3.7	16.2	10.3**
1.5 cm	18.6	3.6**	16.1	11.7
0.5 cm	17.2**	3.5***	13.9**	11.5

Refer to Table 2.
** and *** indicate significant difference from the control on a LSD test at the 1% and 0.1% levels, respectively.

Table 4. Increase in shoot dry weight (mg /plant) for 7 days after transplanting (Exp. 1).

Treatment*	5d-GNS	5d-YNS
Control	11.3(100)**	9.9(100)**
3.0 cm	10.9(97)	9.9(100)
1.5 cm	10.6(94)	9.6(97)
0.5 cm	8.9(79)	7.5(76)

* : Refer to Table 2.
** : Figures in the parentheses are calculated as a percentage compared to the control.

length ranging from 60 to 75 mm in 5d-GNS, and from 50 to 80 mm in 5d-YNS. The number of roots to undergo the root cutting treatment, and the total length of the root remaining after treatment were calculated using the frequency distribution of root length (Table 2). The total length of remaining root decreased, and the number of roots cut increased as the cutting position neared the root base. The total root length for 5d-GNS and 5d-YNS with the 3.0-cm treatment was assessed as 70% of the original seedlings. It was calculated that 80% of the total root length was removed by the 0.5-cm treatment.

Seven days after transplanting, no significant differences in plant length and the longest root length between the 3.0-cm treatment and the control, or between the 1.5-cm treatment and the control, were observed for both nursling seedlings (Table 3). For the 0.5-cm treatment, however, the plant length and the longest root length were lower compared with the control, but the number of roots was not lower. Significant differences in plant age between the treatments and the control were not observed for the 5d-GNS, but observed for 5d-YNS. It was restricted to 0.1-0.2 lower compared with the control by the 1.5-cm and 0.5-cm treatments.

Table 4 shows the increase in shoot dry weight for 7 days after transplanting. The incease of the seedlings with the 1.5-cm treatment and the 3.0-cm treatment was more than 94% of the control. The increase in shoot dry weight of the seedlings with the 0.5-cm treatment was 76 to 79% of the control.

Experiment 2.

The plant length and the plant age in leaf number of the transplanted seedlings was 7.5 cm and 2.2, respectively. The residual ratio of endosperm nutrients of the seedlings was 41.4%. Table 5 shows the number of roots to undergo root cutting treatments and the total root length remaining after the treatments. The total root length remaining after the treatments was calculated using the distribution of root length (data not shown). Modification by cutting the root base reduced the total root length to 32% (RB-2) or 53% (RB-1) of the control, while the total root length was barely

Table 5. Number of roots cut by the root cutting treatment and total root length remaining after the treatment (Exp. 2).

Treatment	Number of roots cut (/plant)			Total root length remaining**
	Seminal	Crown	Total	(cm)
Control	0	0	0	14.1 (100)
Cutting the root off 2 mm from the root tip				
RT-1	1	0	1	13.9 (99)
RT-3*	1	2	3	13.5 (96)
RT-5*	1	4	5	13.1 (93)
Cutting the root off at its base				
RB-1	1	0	1	7.5 (53)
RB-2*	1	1	2	4.5 (32)

* Longer crown roots in order of root length were selected for the teatment.

** Total root length remaining after the treatment was calculated by the root length distribution of the original seedling. Figures in the parentheses are calculated as a percentage compared to the control.

changed by cutting the root tip.

The length of the third leaf as it emerged from the second leaf sheath (Fig. 2A) was scarcely changed by the RT-1, RT-3 (data not shown) and RT-5 treatments during the first 5 days after transplanting. Seven days after transplanting, however, there was a significant difference in the plant length between the RT-5 and control (Table 6). This difference was due to the length of the third leaf blade. On the other hand, the RB-1 and RB-2 treatments restricted the length of the third leaf as it emerged from the second leaf sheath to a shorter value compared to the control after transplanting (Fig. 2B). The emergence rate for the third leaf decreased in proportion to the total root length until 3 days after transplanting. As a result, seven days after transplanting (Table 6), the plant length of seedlings with the RB-1 treatment was 1.2 cm lower than that without the treatment. The plant length of seedlings with the RB-2 treatment decreased by 3.4 cm compared to those without.

A reduction in the number of roots, the total root length and the longest root length for each of the treatments by cutting at the root tip was not observed (Table 6). Cutting the base of the root also did not reduce the number of roots and total root length. However the longest root length was restricted to a lower value compared with that of the control by the

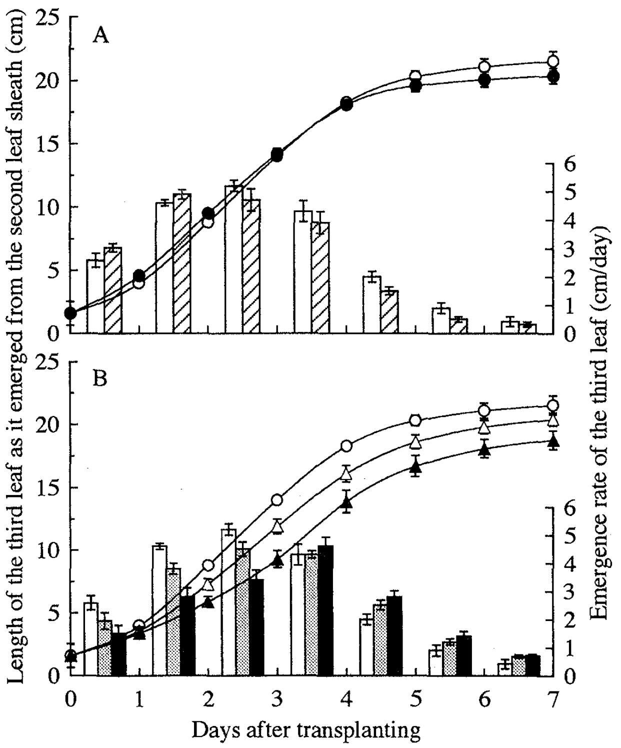

Fig. 2. Effects of two kinds of root cutting treatments (A, cutting the root off 2 mm from the root tip; B, cutting the root off at its base) on the length of the third leaf as it emerged from the second leaf sheath and the emergence rate of the third leaf (Exp. 2). Vertical bars represent the standard error of six plants. Control (○, □), RT-5 (●, ▨), RB-1 (△, ▩), RB-2 (▲, ■). Data of RT-1 and RT-3 treatments were omitted.

Table 6. Effects of the root cutting treatments on some morphological characteristics of the plants 7 days after transplanting (Exp. 2).

Treatment #	Plant length (cm)	Third leaf		Plant age in leaf number	Number of roots (/plant)	Total root length (cm)	Longest root length (cm)
		Sheath (cm)	Blade (cm)				
Control	27.5	13.5	14.1	3.1	9.0	39.9 (2.8)	8.4
Cutting the root off 2 mm from the root tip							
RT-1	27.1	13.6	13.5	3.3**	9.2	41.6 (3.0)	9.3
RT-3	28.4	14.4**	14.0	3.2	9.2	42.3 (3.1)	9.1
RT-5	26.2*	13.3	12.9**	3.3**	10.0**	42.1 (3.2)	8.6
Cutting the root off at its base							
RB-1	26.3*	13.4	13.0**	3.2	8.5	39.1 (5.2)	7.4*
RB-2	24.1**	12.2***	12.0**	3.2	8.3	36.4 (8.1)	7.1**

Refer to Table 5.
*,** and *** indicate significant difference from the control on a LSD test at the 5%, 1% and 0.1% levels, respectively.
Figures in parentheses indicate the relative values to the total root length at transplanting shown in Table 5.

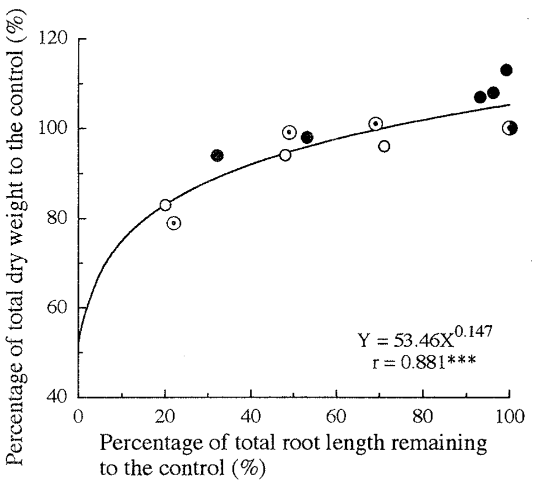

Fig. 3. Relationship between the percentage of total root length remaining after the root cutting treatments compared to the control and the percentage of the total dry weight (shoot and root) compared to that of the control 7 days after transplanting. Open circle and circle with dot indicate the data of 5d-GNS and 5d-YNS in Exp. 1, respectively. Closed circle indicates the data obtained in Exp. 2. *** : Significant at the 0.1% level. ns : Not significant at the 5% level.

RB-1 and RB-2 treatments.

The total (shoot and root) dry weight obtained in experiment 1 and 2 was calculated as a percentage compared to that of the control, and the data was then plotted against the percentage of the total root length remaining after the treatments compared to the control in Fig. 3. The total dry weight percentage decreased with the decrease in the percentage of the total root length. The values match a exponential function.

Discussion

The noteworthy observations in this study are ; (a) even when the roots of rice nursling seedlings are cut off 1.5 cm from the root base, seven days after transplanting the growth of the seedlings with the 1.5-cm treatment is similar to those seedlings without the treatment, and (b) the rooting and the growth of transplanted nursling seedling is reduced through the total length of the root remaining after the treatment.

Root pruning often accompanies the transplanting of rice seedlings[7,25]. This causes an imbalance between water absorption and transpiration[25]. Transplanting injuries primarily occur due to this imbalance[25]. In experiment 1, when the roots of yellow nursling seedling were cut off 3 cm from their root base, the number of new roots which emerged during the week after transplanting decreased against the control. However, the difference in root number between the treated plant and the control was only 1.7 per plant. The plant length, the plant age in leaf number, the longest root length and the increase in the shoot dry weight was barely affected by the treatment. Thus, it can be stated that the growth of transplanted nursling seedlings is not substantially affected by the 3.0-cm treatment. These findings are identical to the results obtained by several other studies[12,13,14,15,24]. In addition, in the present study, no significant differences in growth were observed between the nursling seedlings with the 1.5-cm treatment and those without the treatment. This is probably related to the root system and the leaf area of the nursling seedlings. Even when the roots of the nurling seedlings were cut off 1.5 cm from the base of the root, 50% of the total root length remained after the treatment (Table 2). The expanded leaf blade of the nursling seedlings was only the second leaf at transplanting. Consequently, it would appear that an imbalance between water absorption and transpiration did not occur. Moreover, the transplanted seedlings left 30-40% of their endosperm reserves (Table 1), but substantial photosyntesis did not occur even in 5d-GNS as well as 5d-YNS[19]. Therefore it is likely that the residual endosperm reserves make up for a lowering of nutrient absorption caused by the root-cutting treatment and promote rooting of the transplanted seedlings.

Contrary to these observations, the measurement of plant length, the longest root length and the increase in the shoot dry weight showed that the 0.5-cm treatment caused a significant reduction in the growth of seedlings one week after transplanting. The total length of the remaining root after treatment was calculated to be approximately 20% of that without the treatment (Table 2). Thus, it is conjectured that the reduction in growth is attributable to an insufficient supply of water and nutrients received from the remaining root. It was expected that three crown roots from the coleoptilar node would be partially cut by the 0.5-cm treatment. Hoshikawa and Shoji[9] reported that the crown root from the coleoptilar node was the root for the rooting and development of transplanted nursling seedlings. It is not clear whether the influence of the 0.5-cm treatment on the growth resulted from the total length of roots cut by the treatment, or from restricting the elongation of coleoptilar nodal roots by the treatment.

In experiment 2, therefore, two kinds of root cutting treatments were performed to clarify this point; (I) cutting off the root tip to restrict the elongation of the root, and (II) cutting the base of the root to reduce total root length. The root tip region includes the root apex, the root cap and the cell division zone of the root[8,16]. A daily measurement of the length of the third leaf as it emerged from the second leaf sheath (Fig. 2) showed that the emergence of the third leaf was not inhibited by Treatment I, but it was inhibited by Treatment II. This observation suggests that the emergence of the third leaf is basically not sensitive to the excision of the root tip of the crown roots from coleoptilar node, but it is sensitive to the total length of the roots remaining after root cutting.

The length of the third leaf blade was reduced by cutting the base of a seminal root. However the 1.5-cm treatment did not reduce the length of the third leaf blade (data not shown). About 50% of the total root length was removed by each treatment. The difference of the effect of each treatment may result from the amount of branch root removed by these treatments. Because the seminal root had branch roots emerged from the basal side of it. The cutting at the root base of the seminal root and longest crown root reduced the total root length to 30%. As a result, the extension of the third leaf sheath, as well as the extension of the third leaf blade, was inhibited. Cell enlargement and cell division are markedly reduced by water stress[1]. Thus inhibition may be due to an imbalance between water absorption and transpiration.

When a seminal root and four crown roots from coleoptilar node were cut at their root tip, it was expected that the reduction of the total root length would be less than 10%. However the treatment inhibited that enlargement of the third leaf blade, while promoting root emergence. The cause of this effect is not clear. However it is well known that plant hormones, such as abscisic acid, which increases following water stress[2] or cytokinins, are produced at the root tip. An increase in root growth may be related to these hormonal effects.

The effect of these treatments on root growth was considerably smaller than on shoot growth. In general, root growth is favored relative to shoot growth, although total plant growth is reduced during water stress[1]. The emergence of crown roots from the first node following the coleoptilar node was not inhibited by any treatments. Although approximately 50% and 70% of the total root length of the original was removed by the RB-1 and RB-2 treatments, respectively, seven days after transplanting the total root length was unaffected by the treatments. The dry matter to root distribution ratio depends on the degree of the root-cutting treatment[24], i.e. the length of root cut. Consequently it is suggested that the positive distribution of dry matter to root recovered rapidly the root system after transplanting, even though a considerable part of root is removed.

The increase in the total dry weight (shoot and root) during the early period after transplanting depend on the percentage of the total root length remaining after the treatments compared with the control (Fig. 3). The results obtained in the two experiments suggest that the crown roots from the coleoptilar node play a large role in supplying water and nutrients just after transplanting, and promote the rooting and development of transplanted nursling seedling due to the emergence of the first nodal roots. In our previous report[19], we suggested that the substantial photosynthesis of nursling seedling raised in the light after emergence occurs when the plant age in leaf number attains 2.4. We deduced that the transplanted nursling seedlings with this age developed using the emerging crown roots from the first node. This idea is supported by findings obtained in this study.

References

1. Begg, J.E. and N.C. Turner 1976. Crop water dificits. Adv. Agron. 28 : 161—217.
2. Davies, E.J. and J. Zhang 1991. Root signals and the regulation of growth and development of plants in drying soil. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42 : 55—76.
3. Himeda, M. 1991. "Mechanical transplanting of nursling seedling" on the reduction of rice production cost. Present status and problems in the development of transplanting technology. Syokucho 25 : 21—29*.
4. ———— 1994. Cultivation technique of rice nursling seedlings. Review of research papers and its future implementation. Agric. Hortic. 69 : 679—683, 791—796*.
5. Hoshikawa, K. 1971. Physiology of "young" rice seedling and its raising technique. Nobunkyo, Tokyo. 183—192***.
6. ———— 1976. Theory and technique on the raising of paddy rice seedlings for mechanical transplanting (35). Agric. Hortic. 51 : 354—358***.
7. ———— 1976. Young and middle rice seedlings - their physiology and cultivation technique. Nobunkyo, Tokyo. 1—241***.
8. ———— 1989. The Growing Rice Plant. An anatomical monograph. Nobunkyo, Tokyo. 11—205.
9. ———— and K. Shoji 1990. Nursling seedlings, their optimum ages for good rooting and the mechanism of rooting. Jpn. J. Crop Sci. 59 (Extra issue 2) : 173—174***.
10. ———— 1992. Recent development in rice seedling raising in Japan, with special reference to the "Nursling Seedlings", Korean J. Crop Sci. 37 : 198—208.
11. ————, R. Sasaki and K. Hasebe 1995. Development and rooting capacity of rice nursling seedlings grown under different raising conditions. Jpn. J. Crop Sci. 64 : 328—332.
12. Ishizuka, Y. and A. Tanaka 1969. The nutriophysiology of rice plant. Yokendo, Tokyo 96—158*.
13. Kabaki, N., K. Tajima and A. Amemiya 1983. Physiological study of growth inhibition in rice plant as affected by low temperature. I. Physiological mechanism of growth retardation caused by cool temperature. Bull. Natl. Inst. Agric. Sci. D34 : 1—68**.
14. Konno, K. and T. Murakami 1984. Effects of root pruning treatment at transplanting time on the rooting of rice seedling. Rep. Hokkaido Branch, Crop Sci. Soc. Jpn. and Soc. Breed. Jpn. 24 : 8***.
15 Matsuda, K. 1939. Effects of some treatments of seedling at the time of tansplanting upon the subsequent growth and yield of rice plant. Proc. Crop Sci. Soc. Japan. 11 : 91—100***.
16. Matsuo, T. and K. Hoshikawa 1993. Science of the Rice Plant. Morphology. Food and Agriculture Policy Research Center, Tokyo. 123—132.
17. Mimoto, H. 1983. Studies on the seedling establishment of transplanted lowland rice in the northern part of Tohoku district. Bull. Aomori Agric. Exp. Stn. 27 : 1—69**.
18. Sasaki, R. and K. Hoshikawa 1994. Effects of root pruning and ventilation on rooting characteristics of rice nursling seedlings. Jpn. J. Crop Sci. 63 (Extra issue 1) : 38—39***.
19. ———— and ———— 1997. Changes in energy dependence and morphological characteristics with the development of rice nursling seedlings raised under different light and temperature conditions. Jpn. J. Crop Sci. 66 : 252—258.
20. Takahashi, K. and K. Wada 1972. Internode elongation of rice plant. I. Effects of light and gibberellic acid on the second internode elonga-

tion. Proc. Crop Sci. Soc. Japan. 41 : 431—436**.
21. ————, H. Watanabe and K. Hoshikawa 1995. Varietal differences and geographical distributions in the growth of mesocotyl and internodes of rice (*Oryza sativa* L.) seedlings. Jpn. J. Crop Sci. 64 : 66—72**.
22. Umemoto, M. 1993. Technological problems for the reduction of rice production cost and economic effects of infant nursery. Nougyou Gijyutsu 48 : 304—307, 353—355***.
23. Yamamoto, Y. and K. Wada 1974. Effect of root cutting treatments at transplanting time on the early growth of rice plants in paddy field, especially in comparison with direct sowing or early transplanting. Rep. Tohoku Branch. Crop Sci. Soc. Jpn. 16 : 19—21***.
24. ————, K. Maeda and K. Hayashi 1978. Studies on transplanting injury in rice plant. I. The effects of root cutting treatments on the early growth of rice seedlings after transplanting. Jpn. J. Crop Sci. 47 : 31—38**.
25. ———— 1991. Studies on transplanting injury and its culture significance in rice plant. Mem. Fac. Agric. Kochi Univ. 54 : 1—167**.
26. ————, A. Ikejiri and Y. Nitta 1993. Effects of endosperm and/or root removal of various leaf-aged rice seedlings in the heterotrophic stage on the rooting ability and the early growth after tansplanting. Jpn. J. Crop Sci. 62 (Extra issue 1) : 14—15***.

* In Japanese. The title is translated by the present authors.
** In Japanese with English summary or abstract.
*** In Japanese.