韓作誌(Korean J. Crop Sci.) 38(3) : 219~227(1993)

Lodging Pattern of Rice Plant in Broadcast-Seeded and Hand-Transplanted Cultivation

Je Kyu Kim* · Moon Hee Lee* and Yun Jin Oh*

벼 湛水表面直播栽培와 손移秧栽培의 倒伏發生 樣相

金帝圭* · 李文熙* · 吳潤鎭*

ABSTRACT : Broadcast-seeded rice in submerged paddy frequently lodge in the field. In general, the causes of lodging in rice cultivation differ with different cultural methods. This study was conducted to investigate the causes of lodging in broadcast-seeded rice (BSR) and hand-transplanted rice (HTR) under four nitrogen (N) levels.

Lodging in BSR was mainly a root lodging due to shallow root distribution, while that in HTR showed a bending type owing to deep rooting system. At the upper soil layer (0~5cm from the surface of ground) the root distribution of BSR (65.2%) was much larger than that of HTR (51.6%), whereas at the 5~10cm soil layer the root distribution of BSR (18.5%) was much smaller than that of HTR (28.0%). The depth of buried culm base was much shallower in BSR (1.2cm) than in HTR (4.0cm).

The plant height, fresh weight, lodging index, culm diameter and thickness in HTR were much greater than those in BSR, and the breaking strength of lower internode was similar in the two cultivation methods indicating that HTR would have more lodging causes than BSR. In spite of the more advantages to lodging resistance in BSR it severely lodged in the field. The main lodging-inducing factors of BSR were the shallow root distribution and shallow depth of buried culm base. Besides these, the higher ratio of gravity center of culm was an important factor. This result suggested that for the fundamental prevention of lodging in BSR, an ideotype of rice plant with "a deep-rooted behavior" should be developed.

Lodging in rice cultivation is one of the major causes of yield reduction and poor grain quality, especially in direct-seeded rice. The degree of lodging depends on morpho-anatomical characteristics[1,2,7,9], chemical composition of the culms[3], root distribution[8] and cultural practices[7,9] as well as environmental factors[6,9]. Among the plant characteristics associated with lodging, culm traits of the rice plant are the most important lodging-inducing factors.

* 作物試驗場(Crop Experiment Station, RDA, Suwon 441-100, Korea) 〈'93. 2. 22 接受〉

The lodged plant had longer internodes particularly the 4th and 5th internodes from the top[6] than the normal one. The increased length of internodes is accompained by a reduction in their diameter and wall thickness, thus lodging resistance is decreased. Many scientists[1,3,5,9] reported that lodging resistance depends not only on the diameter of culm but also on the thickness of culm wall or cross sectional area of culm. Pinthus (1967) observed that the roots of lodging-resistant wheat were extensively spread in a horizontal direction.

Recently, with the expansion of cultivation area of direct-seeded rice, there has been gradual increase in yield reduction due to lodging. The lodging of the rice plant is mainly associated with N application and planting or seeding density. High N application and dense planting or seeding result in a longer culms and longer lower internodes which are thinner and weaker, thus lower lodging resistance. The lodging mechanism of rice plant would also differ depending on cultural methods, BSR and HTR.

This study was conducted to observe the changes in plant characteristics associated with lodging resistance after heading and to investigate the pattern and causes of lodging in BSR and HTR under four N levels.

MATERIALS AND METHODS

The field experiment was conducted at Crop Experiment Station (CES), Suwon, in 1991−1992. We used Hwaseongbyeo, a japonica rice cultivar. The experiment was laid out in a split-plot design combining two cultural methods (BSR and HTR) and four N levels (50, 100, 150 and 200 kg/ha) with three replications.

For HTR, the pregerminated seeds were sown uniformly on the seedbed with 80g seeds per m^2, and 40−day−old seedlings were transplanted in the spacing of 30×15cm by hand. And, for BSR the pregerminated seeds were broadcasted with 50 kg seeds per hectare on the submerged paddy that was uniformly leveled.

Phosphorus and potassium were also applied at 70 and 80 kg/ha, respectively. Nitrogen in HTR was split with 50% at pretransplanting, 20% at 2 weeks after transplanting (WAT), 20% at panicle initiation and 10% at heading stage. Nitrogen in BSR was split with 30% at preseeding, 20% at 3rd leaf stage, 20% at 5th leaf stage, 20% at panicle initiation and 10% at heading.

The plant characteristics associated with lodging were observed on the basis of hill unit at 10, 20, 30, 40 and 50 days after heading (DAH). At heading, the amount of root was sampled with paddy soil by a monolith ($35 \times 5 \times$ depth 45cm) and after removing the soil by water the roots were cut at the intervals of 5cm from the ground surface.

The lodging index was determined by the method of Seko (1962) which is expressed by "plant height × fresh weight per tiller × 100 / breaking strength". The culm length+panicle length is called "plant height" in the paper. The breaking strength was determined at the mid-point of 10cm internode from culm base by a breaking strength meter. At maturity, the grain yield and its components were estimated from a sample of $5m^2$ in each plot.

All data were analyzed by the least significant difference test or Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

1. Length of internodes

The internode characters of BSR and HTR were observed at 20 DAH (Table 1 and Fig. 1). The culm length of HTR was significantly longer than that of BSR in all N levels except at 100 kg N/ha. The difference in culm length between HTR and BSR ranged from 3.0 to 8.8cm. As the N level increased the percentage of 1st internode from the top decreased gradually, especially in BSR (Fig. 1). The proportion of the 5th internode in BSR was higher as compared with that in HTR. The higher proportion of the lower internode would be one of important causes of lodging in BSR.

Matsushima (1980) reported that the 4th and 5th internodes from the top were the most closely related trait to the actual lodging of rice plant due to their abnormal elongation. IRRI (1964) also observed the greatest bending stress at the two lowest elongated internodes.

2. Changes of plant characters associated with lodging

The morpho-physiological and mechanical properties of the culm affect the magnitude of the lodging-inducing torque. Figure 2 shows the changes in the plant characters after heading associated with lodging under four N levels.

Table 1. Culm length as affected by different cultural methods and nitrogen levels

Cultural method	Culm length(cm)				Mean
	50N[1]	100N	150N	200N	
Hand-transplanted rice	77.0	79.0	83.5	85.9	81.4
Broadcast-seeded rice	68.2	76.0	77.6	80.2	75.5

[1] 50kg N/ha, LSD .05 in a column is 3.8.

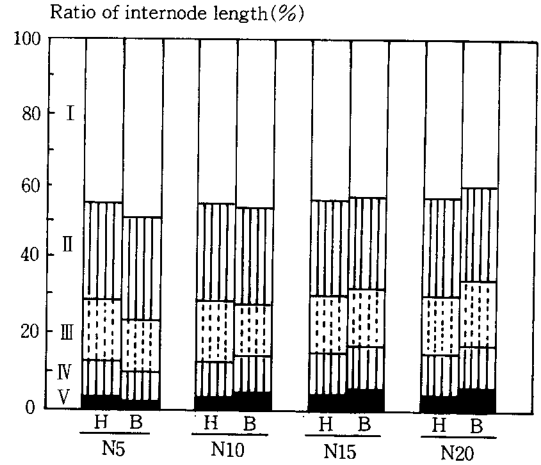

Fig. 1. Distribution of internode length as affected by different cultural methods and nitrogen levels. (H : Hand-transplanted rice, B : Broadcast-seeded rice)

Plant height. The plant height (culm length + panicle length) slightly elongated up to 10−20 DAH and then leveled off (Fig. 2−A). Plant height of HTR was higher than that of BSR in all N levels. In most cereal crops plant height is a critical lodging-inducing factor.

Fresh weight. The fresh weight of culm reached the maximum at 20 DAH in both BSR and HTR and it decreased sharply up to harvest (Fig. 2−B). The culm weight of BSR was much smaller than that of HTR due to the shorter culm length. The culm weight of 10cm from the base decreased from 10−20 DAH (Fig. 2−C).

Similarly Matsushima (1980) reported that at about 21 DAH the rice plant attained at the maximum fresh weight and its accumulated starch in the culm completely disappeared.

Panicle weight. After heading, the panicle weight increased linearly up to about 30 DAH with the advance of grain filling (Fig. 2−D). Therefore, the gravity center of the rice plant moved upward which is an important lodging-inducing factor, especially in BSR.

Height of gravity center. The ratio of height of gravity center of culm increased linearly up to 40−50 DAH in both BSR and HTR (Fig. 2−E). At higher than 100 kg N/ha, the field lodging occurred at about 50% of height of gravity center in HTR and at 40−45% in BSR. The plant height or culm length was always shorter in BSR, however the ratio of gravity center in BSR was higher than that in HTR regardless of N levels.

Breaking strength. The breaking strength refers to the force required to break a section of 10cm length of the basal culm internodes at its mid-point. The breaking strength decreased rapidly up to 40 DAH in both BSR and HTR, and then increased slightly at 50 DAH due to dryness of culm following final drainage (Fig. 2−F).

Breaking strength of BSR and HTR were not clearly different, however up to 30 DAH it tended to be slightly higher in BSR. It is possible that the number of tillers per hill in HTR was much higher as compared with that in BSR, hence solar radiation in HTR may not penetrate near the culm base where breaking strength was measured.

Sachs (1965) reviewed that light intensity is a decisive factor in internode elongation and it controls the balance between longitudinal and transverse development of vascular tissues. Pinthus (1973) cited that shading promotes internode elongation and reduces culm-wall thickness resulting in the decreased solidness of low internodes and lodging resistance.

Leaf sheath of rice plant has an important role in lodging resistance. Takaya and Miyasaka (1983) showed that the contribution of leaf sheath to the breaking strength was about 50% and the value maintained for about 30 DAH.

Lodging index. Seko (1962) proposed the "lodging index" by which lodging resistance of the plant can be expressed numerically. The larger the index value, the more the rice plant is liable to lodge.

The lodging index reached the maximum value at 30−40 DAH in both BSR and HTR (Fig. 2−G), and the index of HTR was much higher than that of BSR. The breaking strengths of the cultural methods were similar, while the plant height and fresh weight of HTR were much greater than those of BSR resulting in higher lodging index in HTR.

Matsushima (1980) and Lee and Kim (1988) reported that the rice plant started lodging at about 15 DAH and attained the critical stage approximately at 21 DAH. However, Matsushima also cited that the rice plant is liable to lodge progressively as the ripening advances. Therefore, based on the present results the critical stage of lodging of rice plant could be between 20 to 40 DAH and it would depend on N levels and cultural methods as well as environmental factors.

Field lodging. Lodging is highly affected by N supply and cultural practices. No lodging was observed in HTR except at 200 kg N/ha in which a little bending type of lodging occurred. In BSR severe root lodging developed especially at more than 150 kg N/ha (Fig. 2−H). Field lodging in BSR started from 10 DAH at 150−200 kg N/ha, 20 DAH at 100 kg N, and 30 DAH at 50 kg N. Generally, lodging started at the lodging index of about 80 in BSR and 100 in HTR.

Stem lodging commonly occurred in HTR while root lodging generally developed in BSR owing to broadcasted-seeds in the surface of submerged paddy, and bending type lodging could be induced in both BSR and HTR.

3. Causes of lodging

Different cultural practices or methods of rice cultivation would be show various lodging patterns. Nitrogen could also affect the morphological and anatomical culm characters associated with lodging, especially in lower internodes.

Root distribution. The spread of root system affects the anchorage of the plant in the soil and therefore is a major factor in determining

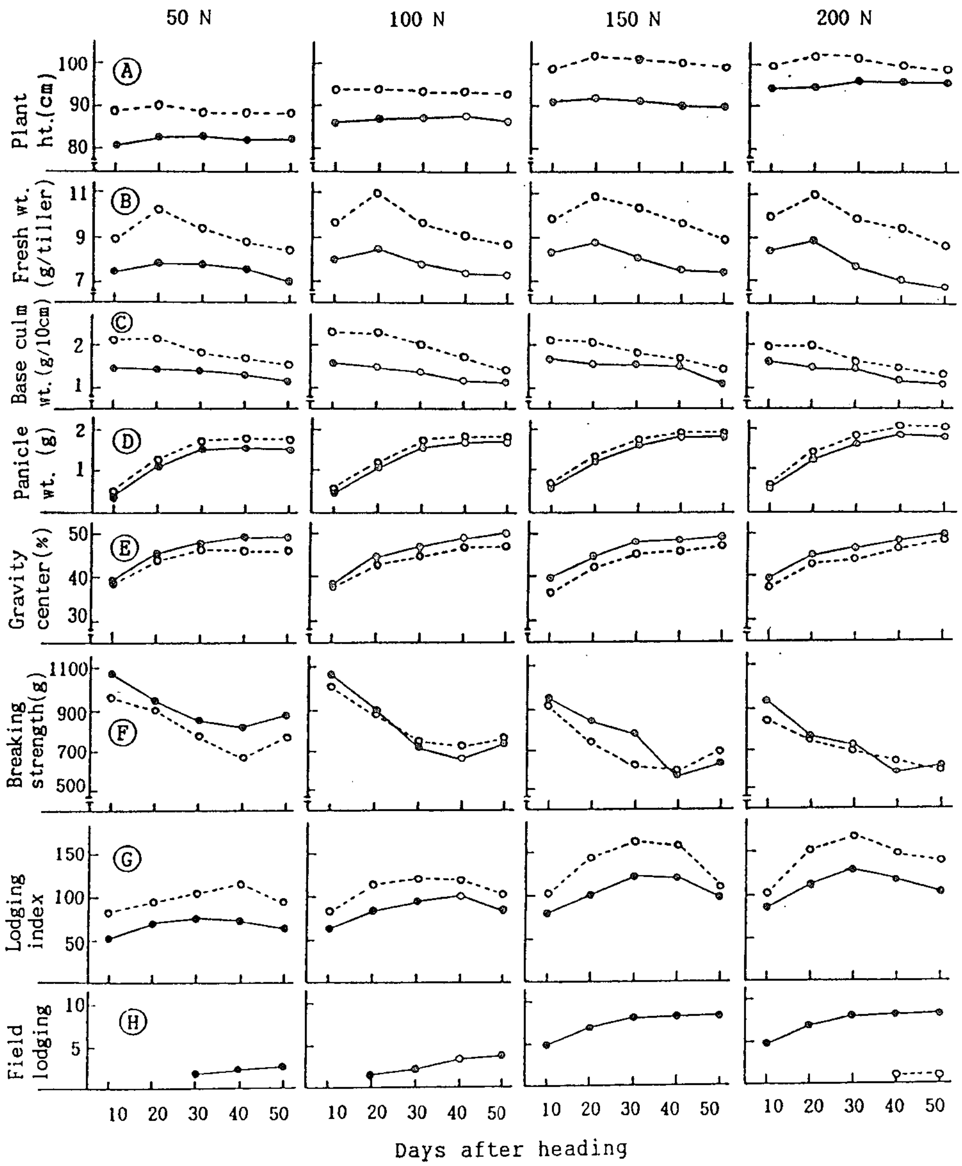

Fig. 2. Changes of plant characters associated with lodging at four nitrogen levels after heading.
○ ········ ○ Hand-transplanted rice, ● —— ○ Broadcast-seed rice

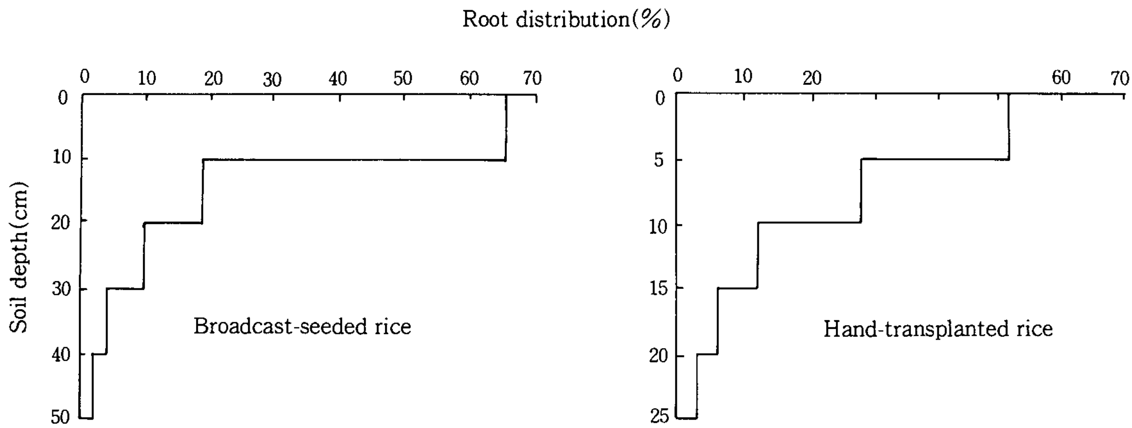

Fig. 3. Vertical root distribution as affected by different cultural methods. (Values are the average of four nitrogen levels, 50, 100, 150 and 200kg /ha)

resistance to root lodging.

At the upper soil layer (0~5cm), the root distribution of BSR (65.2%) was much larger than that of HTR (51.6%), whereas the root distribution of the 5~10cm soil layer in BSR (18.5%) was much smaller as compared with that in HTR (28.0%) indicating a shallow root distribution in BSR and a deep root distribution in HTR (Fig. 3). Moreover, the depth of buried culm base was much deeper in HTR (4.0cm) than in BSR, 1.2cm (Table 3). Thus, when the gravity center of rice plant moves upward with intensive grain filling, the roots of BSR could not strongly support the upper part of the rice plant. The shallow root distribution in BSR could be the major factor of root lodging in BSR. This shows that the root distribution of HTR was similar to a deep-rooting system, while that of BSR is closely related to a shallow-rooting system. Therefore for the prevention of lodging in BSR, a lodging-resistant variety having deep-rooting habit should be developed.

Water regimes and percolation have a significant effect on root elongation and distribution. In BSR the shallow or intermittent drainage is needed for deeper root growth and prevention of lodging.

Pinthus (1967) reported that the roots of lodging-resistant wheat were spread more extensively in a horizontal direction than those of the susceptible cultivar. This indicated that lodging grade was negatively correlated with the spreading angle of the roots. He also summarized the positive relationships between lodging resistance and number of coronal roots or its diameter (Pinthus, 1973).

Plant characteristics. The causes of lodging in rice would differ depending on the cultural practices or methods. The plant height, fresh weight, panicle weight, lodging index, the outer diameter and cross sectional area of culm internode (Table 2 and 3) were much greater in HTR than in BSR. Moreover, the breaking strength of BSR and HTR were similar (Table 2) indicating that HTR had more lodging-inducing factors than BSR. In spite of the more advantages to lodging in BSR, it severely lodged in the field.

The reason for the severe lodging in BSR could be explained by the root distribution, depth of buried culm base and gravity center of culm. It was observed that in BSR the shallow root distribution and shallow depth of buried culm are the most important lodging-inducing factors (Fig. 3 and Table 3). On the other hand the ratio of gravity center of culm in BSR was always higher than that in HTR although the plant height of BSR was shorter (Table 3). During the period of intensive grain filling, the gravity center of culm moves upward and is one of important causes of lodging in cereal crops.

The number of internodes exposed above the ground surface was much greater in BSR compared with HTR (Table 3). The average

Table 2. Plant characters and lodging as affected by different cultural methods and nitrogen levels at 20 days after heading

Cultural method	Nitrogen applied(kg/ha)	Plant height(cm)	Fresh weight(g/tiller)	Panicle weight(g)	Breaking strength(g)	Lodging index	Field lodging(0-9)
Hand-transplanted rice	50	91.1b	9.5b	1.23c	907a	94c	0
	100	93.9b	10.9a	1.20c	885a	116bc	0
	150	102.1a	10.9a	1.35b	705b	148a	0
	200	103.8a	11.0a	1.49a	755b	151a	1
	Mean	97.5	10.6	1.32	824	127	0−1
Broadcast-seeded rice	50	83.5b	7.9b	1.17b	952a	69c	2
	100	86.5b	8.6ab	1.12b	886b	84bc	4
	150	92.1a	8.8a	1.27a	816bc	99ab	8
	200	94.8a	9.0a	1.32a	760c	112a	8
	Mean	89.2	8.6	1.22	854	91	2−8

* Within columns in a cultural methods, means followed by the same letter are not significantly different P=0.05 according to DMRT.

Table 3. Characters of culm internode, height of gravity center and internode number above the ground as affected by different cultural methods and nitrogen levels at 20 days after heading

Cultural method	Nitrogen applied (kg/ha)	Culm[1] diameter (mm)	Culm wall[1] thickness (mm)	Cross sectional area(mm²)	Ratio of[2] gravity center(%)	Depth of buried culm base(cm)	Internode number above the ground
Hand-transplanted rice	50	3.97a	0.68a	6.99a	43.4a	4.0a	3.3a
	100	3.86ab	0.61ab	6.18b	42.9a	4.0a	3.5a
	150	3.72b	0.57b	5.63bc	42.5a	4.1a	3.7a
	200	3.55c	0.54b	5.11c	43.7a	3.9a	3.8a
	Mean	3.78	0.60	5.98	43.1	4.0	3.6
Broadcast-seeded rice	50	2.91a	0.62a	4.43a	45.3a	1.4a	4.7a
	100	2.93a	0.59ab	4.29ab	45.1a	1.1a	4.8a
	150	3.04a	0.51c	4.04b	45.2a	1.1a	5.1a
	200	3.05a	0.55bc	4.08b	45.4a	1.0a	5.4a
	Mean	2.98	0.57	4.21	45.3	1.2	5.0

[1] Average value of the major and minor axis in the center of 4th internode from the top.

[2] The ratio of height of gravity center(%) $= \frac{\text{Height of gravity cneter}}{\text{Culm length} + \text{Panicle length}} \times 100$

number of the internodes in BSR was 5.0, but actually most of the internodes were above the ground resulting in severe root lodging.

In case of HTR, the rice seedlings were transplanted at about 4~5cm depth into the paddy soil, therefore the internodes lower than 4th internodes from the top were under the ground and could support the rice plant from lodging. On the other hand, for BSR the rice seeds were broadcasted in the surface of submerged paddy, so that the rice roots were distributed near the soil surface, and most of the internodes were exposed above the ground.

4. Grain yield and its components

The effect of lodging on grain yield is dependent on its severity and on the time of its occurrence. Among the yield components, panicle number per unit area of BSR was higher than that of HTR but spikelet number per panicle was much lower in BSR, thus spikelet number per unit area which is the most prescise indicator of grain yield was similar with each other. However, the percentage of ripened grain was much lower in BSR due to lodging. The average grain yield of four N levels in BSR was 82% as compared with that in HTR indicating that the yield limiting factor of BSR is the reduced percentage of ripened grain due to lodging (Table 4).

Lee et al. (1986) reported that in the experiment with artificially induced-lodging at different ripening stages, the ratio of yield reduction was 34% at milky, 22% at dough and 20% at yellow stages. This indicates that the earlier the lodging after heading, the more severe is the yield reduction. Lodging of rice plant during the early stage of grain filling would be the major cause of poor grain quality due to the lower percentage of ripened grain.

摘　　要

本 試驗은 벼 湛水表面直播栽培 (以下는 湛水直播)에서 가장 問題가 되는 倒伏發生의 原因을 손移秧栽培와 比較, 究明하기 위하여 作物試驗場 畓作圃場에서 1991~1992年에 遂行되었다. 供試品種은 자포니카인 花成벼를 이용하였고, 벼 栽培

Table 4. Grain yield and its components as affected by different cultural methods and nitrogen levels

Cultural method	Nitrogen applied(kg/ha)	Panicles perm²	Spikelets per panicle	Ripened grain(%)	1,000 grain wt.(g)	Yield in brown rice(t/ha)
Hand-transplanted rice	50	313c	71.9c	89.3a	21.5a	4.84b
	100	364b	75.2bc	88.3ab	21.7a	5.10b
	150	401a	78.4ab	86.1b	21.2b	5.56a
	200	420a	82.4a	79.8c	20.8c	5.83a
	Mean	375	77.0	85.9	21.3	5.33(100%)
Broadcast-seeded rice	50	322b	64.0b	80.7a	21.9a	3.69c
	100	404ab	69.7ab	76.0b	21.7a	4.42b
	150	445a	73.8a	73.6bc	21.2b	4.78a
	200	474a	72.8a	71.9c	20.1b	4.63ab
	Mean	411	70.1	75.3	21.7	4.38(82%)

* Within columns in a cultural method, means followed by the same letter are not significantly different at P=0.05 according to DMRT.

方法은 湛水直播와 손移秧으로 하였으며, 窒素施肥量은 4水準(50, 100, 150, 200kg /ha)으로 處理하였다.

1. 벼의 地上部生重은 出穗後 20日경에 가장 무거웠으며, 그 후 계속 減少되었고, 重心高比率은 成熟期까지 점진적으로 增加되었다. 또 挫折重은 出穗後 40日까지 계속 減少되었으며, 倒伏指數는 出穗後 30~40日경에 가장 컸다.

2. 손移秧에서의 稈長, 地上部 生重, 倒伏指數는 湛水直播에서 보다 현저히 크고, 挫折重은 서로 비슷하였으나 실제 圃場倒伏은 湛水直播에서 더 甚하였는데 이는 두 栽培樣式 間에 倒伏原因이 서로 다르다는 것을 나타낸다.

3. 손移秧은 窒素 200kg /ha에서 彎曲型 倒伏이 있었으나, 湛水直播는 窒素 150kg /ha 以上에서 뿌리倒伏이 甚하게 發生되었다.

4. 湛水直播에서 뿌리倒伏이 甚했던 主된 原因은 벼 뿌리의 淺根化 現象때문인데, 土層表面(0~5cm)의 뿌리分布는 湛水直播(65.2%)가 손移秧(51.6%)보다 현저히 많았으나 土層 5~10cm에서는 湛水直播(18.5%)가 손移秧(28.0%)보다 적었다. 또, 稈基部의 埋沒깊이가 손移秧은 4.0cm로 깊었으나 湛水直播는 1.2cm로 얕기 때문에 登熟의 進展과 더불어 地上部의 무게重心이 높아질 때 湛水直播의 경우 뿌리의 植物體 支持力이 弱化되어 倒伏이 쉽게 發生되었다.

5. 湛水直播는 손移秧에 비하여 單位面積當 穗數는 많았으나 穗當粒數가 적고 倒伏으로 인하여 登熟比率이 낮았다. 벼 收量은 平均的으로 湛水直播는 손移秧의 약 82% 정도였으며, 湛水直播의 收量制限要因은 倒伏으로 인한 낮은 登熟比率이었다.

REFERENCES CITED

1. IRRI(International Rice Research Institute). 1964. Annual report for 1964. Los Banos, Laguna, Philippines. 37−48.
2. Joarder, N. and A. M. Eunus. 1981. An analysis of some mechanical tissues in lodging and non-lodging rice varieties. Oryza 18 : 85−89.
3. Lee, D. B., T. O. Kwon and K. H. Park. 1990. Influence of nitrogen and silica on the yield and the lodging related traits of paddy rice. Res. Rept. RDA(S & F) 32(2) : 15−23.
4. Lee, M. H., Y. H. Kwak, S. H. Park and R. K. Park. 1986. Lodging effect on rice grain yield and quality. Res. Rept. RDA (Crops) 28(1) : 63−67.
5. Lee, S. S. and T. J. Kim. 1988. Lodging related traits and yield of rice as affected by time of paclobutrazol application. Korean J. Crop Sci. 33(4) : 336−342.
6. Matsushima, S. 1980. Rice cultivation for the million. Japan Scientific Societies Press, Tokyo. 276P.
7. Nishiyama, I. 1985. Lodging of rice plants and countermeasures against it. International seminar on plant growth regulators in agriculture. Tokyo, Japan. 1−20.
8. Pinthus, M. J. 1967. Spread of the root system as indicator for evaluating lodging resistance of wheat. Crop Sci. 7 : 107−110.
9. ______. 1973. Lodging in wheat, barly, and oats : The phenomenon, its causes, and preventive measures. Advances of Agronomy 25 : 209−263.
10. Sachs, R. M. 1965. Stem elongation. Annu. Rev. Plant Physiclogy 16 : 73−76.
11. Seko, H. 1962. Studies on the lodging of paddy rice. Bull. Kyushu Natl. Agric. Expt. Stn., No. 7. 419−499.
12. Takaya, T. and A. Miyasaka. 1983. Prevention of lodging of rice plants under direct sowing culture on well-drained paddy field. Ⅱ. Transition of the characters related to lodging resistance after the heading. Japan. J. Crop Sci. 52(1) : 7−14.