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# Effects of Growth Retardants on Lodging-related Traits in Direct Seeded Rice on Flooded Paddy Surface

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## ABSTRACT

**This study examined the effects of growth retardants and midsummer drainage on lodging-related characters in direct seeding rice culture on flooded paddy surfaces. Treatments included in this study were continuous flooding, two time midsummer drainages (TTD), and inabenfide or trinexapac-ethyl application after TTD. Culm length was reduced most by 11.4cm in trinexapac-ethyl treatment after TTD, followed by 4.1cm in inabenfide treatment after TTD compared to TTD treatment. A significant reduction in culm length occurred at the 3rd internode in inabenfide treatment applied at 40 days before heading (DBH), while trinexapac-ethyl application at 8 DBH reduced the 3rd > 2nd > 1st internode. The culm diameter of the 4th internode was increased by the application of trinexapac-ethyl following TTD compared to TTD treatment. Thickness of culm wall was significantly increased by trinexapac-ethyl but not by inabenfide applications. Lodging index was the highest in continuous flooding and the lowest in trinexapac-ethyl treatment after TTD. Subsequently, field lodging did not occur in plots treated by trinexapac-ethyl. Rice plants subjected to midsummer drainage or growth retardants showed higher ripened grain ratio and 1000-grain weight, resulting in higher rice yield. These results indicate that trinexapac-ethyl, which can be applied at the relatively later growth stage after proper judgement of lodging occurrence, could be a useful tool for reducing lodging in direct seeding rice culture on flooded paddy fields.**

***Keywords*** : growth retardants, lodging, trinexapac-ethyl, direct-seeded rice.

Lodging in direct-seeded rice significantly reduces rice yield and quality as well as working efficiency during harvesting. Since the occurrence of lodging offsets the labor-saving effect of direct seeding, all the benefits from direct seeding can be obtained only when lodging is prevented.

Lodging in transplanted rices usually occurs due to stormy winds with lower-internode bending caused by a heavy panicle along with aging stem and leaf sheath as the ripening stage proceeds. In contrary, lodging in direct-seeded rice generally occurs as root lodging. Since plants raised by direct seeding have shallow rooting, they have low root-supporting force for the above-ground parts.

In order to minimize lodging in transplanted rice fields, various researches have been directed toward practical techniques such as fertilizer application methods and rates, adjustment of planting density, and water management as a way to suppress lower-internode growth. Whereas, in direct seeding culture which is susceptible to root lodging, research has been conducted on growth regulator application and the development of lodging-resistant varieties as well as cultural practices to prevent root lodging.

According to previous research reports, greater rooting and higher root distribution in deeper soil depth were induced by 2 midsummer drainages in the drill seeding culture in puddled soil (Kim et al., 1995) and also by 3 drainages in the direct seeding culture in dry paddy fields (Choi et al., 1995). By the application of growth retardants such as uniconazole and PP333, a five to eight percent yield increase was obtained in the direct seeding culture on flooded paddy fields (Lee et al., 1989). In another research by Song et al. (1996), the application of paclobutrazol, uniconazole and Kim-112 at 5~20 DBH increased rice yield by 10 to 20 percent.

Field lodging was successfully managed by the use of growth retardants (Kim et al., 1995; Im et al., 1993). They generally suppress plant height by inhibiting biosynthesis of gibberellins which play a major role in cell elongation (Grossmann, 1992; Gianfagna, 1987). Kim et al. (1992) reported that PP333 applied 15 DBH in direct seeding on flooded paddy fields shortened culm length by 3~4cm but the degree of field lodging was not affected by the chemical treatments.

The greatest suppression of rice plants treated by uniconazole at 30 DBH occurred at the 4th and 5th internodes (Choi et al., 1991). Kim et al.(1995) found that inabenfide and IBP applications at 40 and 30 DBH reduced culm length by 9.8cm and 5.0cm, respectively. A growth retardant, trinexapac-ethyl

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which have yet to be registered for rice, showed effective suppression of upper-internodes of transplanted rice plants when applied 5 to 12 DBH (Lim et al., 1993) but there has been no research report showing the trinexapac-etyl effect on direct seeding culture. Therefore, this experiment was conducted to determine effects of trinexapac-ethyl, inabenfide and midsummer drainage on lodging-related traits of direct-seeded rice on flooded paddy fields.

## MATERIALS AND METHODS

This study was conducted in the experimental field of Kyonggi Province Agricultural Research and Extension Services(KARES) in 1998. The experiment plot was established by hand sowing of pregerminated Ansanbyeo on flooded paddy fields at the rate of 40kg/ha on May 1. The soil type of the experimental field was sandy loam. Treatments included in this experiment are as follows; 1) continuous flooding, 2) 2-time drainages(TTD) (20 and 40 days after seeding), 3) inabenfide G application(1.2kg ai/ha) at 40 DBH after TTD, 4) trinexapac-ethyl WP application(20g ai/ha) at 8 DBH after TTD.

Treatments were replicated 3 times in a randomized complete block design. Plots were fertilized at rates of 110-70-80kg/ha($N$-$P_2O_5$-$K_2O$). Nitrogen was split-fertilized as basal application(40%), at 5th leaf stage(30%) and at grain-filling stage(30%). Total amount of $P_2O_5$ was applied as basal fertilizer. Seventy percent of potassium was applied as basal fertilizer and the rest at the grain-filling stage.

Lodging-related traits were measured at 20 days after heading by randomly selecting 30 tillers per experimental unit. Breaking weight was measured by the breaking resistance gauge(Model TR-2S, Kiya) from the 4th internode after removing leaf sheaths surrounding it. Culm diameter and thickness were measured by dial-gauge(0.01-10mm) from the middle of the 4th internode. Experimental plots were maintained based on the standard cultural method of KARES and other growth characters were evaluated based on the Manual for Standard Evaluation Methods by Rural Development Administration(1995).

## RESULTS AND DISCUSSION

### Internode and culm length

Effects of midsummer drainage and growth retardants on internode and culm length were presented in Table 1. Plants which were subjected to 2 time drainages(TTD) showed 3.9cm shorter culm length compared to that of plants in continuous flooding plots. Inabenfide and trinexapac-ethyl treatments after TTD shortened culm length by 4.1 and 11.4cm, respectively, compared to that of plants grown with two drainages, indicating effective suppression of culm length by trinexapac-ethyl. In plants treated by inabenfide, the strongest suppression occurred at the 3rd internode which had 1.9cm reduction. Trinexapac-ethyl also reduced the 3rd internode most by 5.2cm, followed by 3.1cm at the 2nd internode and 1.7cm at the 1st internode compared to TTD treatment.

These results were a little different from the report by Im et al.(1993) that the most significant suppression occurred at the 2nd internode followed by the 3rd and 1st internode when trinexapac-ethyl was applied at 7 DBH in the transplanting culture. This discrepancy might be due to the differences in cultivation types and application times which could cause significant effects on GA synthesis or growth responses of rice plants. Although the application of inabenfide or trinexapac-ethyl caused significant reduction in internode length, panicle length was not affected.

### Lodging-related traits and field lodging

Changes in lodging-related characters according to midsummer drainage and growth retardants are shown in Table 2. According to previous reports (Song et al., 1996; Lim et al., 1992), characteristics of the 4th internode such as culm diameter, thickness of culm wall and breaking strength showed a close

**Table 1. Changes of internode and panicle length of rice plants affected by midsummer drainage and growth retardants.**

| Treatments | Internode length (cm) | | | | | | Panicle length (cm) |
|---|---|---|---|---|---|---|---|
| | N1 | N2 | N3 | N4 | N5 | Total | |
| Continuous flooding | 38.5 | 20.0 | 16.7 | 6.1 | 0.8 | 82.1 | 23.1 |
| TTD[†] | 37.0 | 19.4 | 16.0 | 5.3 | 0.5 | 78.2 | 24.0 |
| Inabenfide after TTD | 37.7 | 18.4 | 14.1 | 3.4 | 0.4 | 74.1 | 24.4 |
| Trinexapac-ethyl after TTD | 35.3 | 16.3 | 10.8 | 4.1 | 0.4 | 66.8 | 22.8 |
| LSD(0.05) | 1.86 | 1.86 | 1.81 | ns | ns | - | ns |

[†] TTD, Two-time drainages(20 and 40 days after seeding).
[ns]Not significant at the 0.05 probability level.

relationship with field lodging. In this study, the culm diameter of the 4th internode was not affected by TTD or inabenfide treatment after TTD but trinexapac-ethyl treatment after TTD significantly increased the culm diameter by 0.24mm compared to TTD. Application of trinexapac-ethyl after TTD also increased the thickness of the culm wall compared to TTD. But inabenfide application did not cause changes in the thickness of the culm wall.

The height of central gravity and fresh weight were in the following order: TTD > Inabenfide treatment after TTD > trinexapac-ethyl after TTD. Whereas, the order of the breaking strength of the 4th internode was trinexapac-ethyl after TTD > inabenfide after TTD > TTD > continuous flooding. It was considered that greater breaking strength in plots treated by growth retardants was due to the increase in culm diameter and thickness of culm wall. Accordingly, the lodging index representing the combined effects of various lodging-related factors was decreased by 24 in TTD, by 45 in inabenfide after TTD, and by 75 in trinexapac-ethyl after TTD in comparison to 185 at the continuous flooding treatment (Table 2). Actually, severe root lodging occurred in continuously-flooded fields, whereas lodging did not occur in the plots treated by trinexapac-ethyl after TTD.

Low field lodging in plots treated by growth retardants could be attributed to the increase in breaking strength induced by shorter culm length, greater culm diameter and thicker culm wall. These results were in good agreement with the results of the previous reports by Choi et al.(1991), Im et al.(1992), and Kim et al.(1983).

**Plant growth, yield components and yield**

Although no difference in heading date was found between plots treated with growth retardants, heading was delayed by one day in plots treated with growth retardants compared to continuous flooding (Table 3). The difference of panicle exsertion between trinexapac-ethyl treated and nontreated plants was not statistically significant. Trinexapac-ethyl applied at 8 DBH seemed to have little effect on panicle exsertion probably because flag leaves, which are closely related to panicle exsertion, were fully elongated before the time of applications (Im et al., 1993).

The number of panicles per $m^2$ was not affected by inabenfide and trinexapac-ethyl treatments since they were applied after completion of the tillering stage (Table 3). The number of grains per panicle was also

**Table 2. Lodging-related characters and field lodging of rice plants affected by drainage and growth retardants.**

| Treatments | Height of center gravity (cm) | Fresh weight (g) | Culm diameter of N4 (mm) | Thickness of N4 culm wall (mm) | Weight of stem base‡ (g) | Breaking wt. of N4 (g) | Lodging index | Field lodging (0~9)§ |
|---|---|---|---|---|---|---|---|---|
| Continuous flooding | 37.1 | 13.21 | 4.12 | 0.86 | 2.17 | 745 | 185 | 9 |
| TTD† | 35.8 | 12.25 | 4.08 | 0.88 | 2.16 | 780 | 161 | 5 |
| Inabenfide after TTD | 34.0 | 11.54 | 4.19 | 0.91 | 2.19 | 813 | 140 | 3 |
| Trinexapac-ethyl after TTD | 32.6 | 10.95 | 4.32 | 0.97 | 2.22 | 883 | 110 | 0 |
| LSD(0.05) | 1.08 | 0.57 | 0.20 | 0.04 | ns | 23.7 | 14.2 | - |

† TTD, Two-time drainages(20 and 40 days after seeding).
‡ Weight of stem base was measured from the 10cm of stem above soil surface.
§ Scale of 0-9(0 = no lodging, 9 = complete lodging)
ns Not significant at the 0.05 probability level.

**Table 3. Yield components and yield of rice plants affected by drainage and growth retardants.**

| Treatments | Heading date | Panicle exsertion (cm)‡ | No. of panicle per $m^2$ | No. of grain per panicle | Ripened grain ratio (%) | 1,000-grain weight | Milled rice yield (T/ha) |
|---|---|---|---|---|---|---|---|
| Continuous flooding | Aug.10 | 8.9 | 450 | 100 | 66.7 | 17.5 | 3.57 |
| TTD† | Aug.10 | 8.8 | 446 | 105 | 83.0 | 18.7 | 4.55 |
| Inabenfide after TTD | Aug.11 | 8.9 | 451 | 107 | 84.8 | 19.0 | 4.88 |
| Trinexapac-ethyl after TTD | Aug.11 | 8.0 | 454 | 106 | 87.3 | 18.8 | 4.96 |
| LSD(0.05) | - | ns | ns | ns | 2.91 | 0.43 | 0.109 |

† TTD, Two-time drainages(20 and 40 days after seeding).
‡ Length from flag leaf to panicle node.
ns Not significant at the 0.05 probability level.

not different among treatments. However, ripening ratio and 1000-grain weight were higher in the plots of trinexapac-ethyl treatment than those of continuously-flooded plots which experienced severe field lodging. Milled rice yield was higher with TTD treatment than continuous flooding treatment, and the yield advantage of 0.08T/ha with trinexapac-ethyl treatment compared to inabenfide treatment was not statistically significant. Differences in rice yield among treatments were obviously due to differences in field lodging that greatly influenced ripening ratio and 1000-grain weight of rice plants.

Consequently, growth retardants could be effective for reducing field lodging especially in the direct seeding culture. It seems that the application of trinexapac-ethyl at later stages of plant growth (8DBH), at which panicle elongation and spikelet differentiation are completed, is more effective than the application of inabenfide at 40DBH. Thus, trinexapac-ethyl can be applied after a reliable diagnosis of lodging occurrence and seems to have less effect on rice yield.

## Root growth and rice grain quality

Total root dry weight tended to be lower in the continuous flooding treatment compared to TTD, but no difference was found between growth retardant treatments and TTD (Table 4). In root distribution at soil depth below 5cm, continuous flooding seemed to have less rooting than other treatments even though no significant difference was found among treatments probably due to great variation among replications. These results are somewhat in agreement with those of the previous report by Kim et al.(1995) that the application of growth regulators or midsummer drainage in drill seeding culture in puddled soil induced higher root distribution at deeper soil depths. Similar findings were also reported by Choi et al.(1991) that rooting in direct seeding culture on dry paddy increased as the frequency of midsummer drainage increased.

As expected, a close relationship between lodging and grain quality was observed. The deterioration of grain quality in terms of imperfect grain ratio was obviously due to lodging(Table 5). Accordingly, the perfect grain ratio was highest at trinexapac-ethyl treatment after TTD, followed by inabenfide after TTD, TTD and continuous flooding. The green grain ratio was higher with continuous flooding than any other treatments.

Our data indicates that growth retardant, trinexapac-ethyl can be utilized as an effective tool for the lodging prevention especially for direct-seeded rice on flooded paddy fields.

**Table 4. Root distribution of rice plants at different soil depths as affected by the drainage and growth retardants.**

| Treatments | Root dry weight (mg/cm$^3$) | | | |
|---|---|---|---|---|
| | 0~5cm | 5~10cm | 10~15cm | Total |
| Continuous flooding | 6.9 | 0.8 | 0.4 | 8.1 |
| TTD† | 7.0 | 1.2 | 0.5 | 8.7 |
| Inabenfide after TTD | 7.3 | 1.2 | 0.7 | 9.2 |
| Trinexapac-ethyl after TTD | 6.9 | 1.2 | 0.6 | 8.7 |
| LSD(0.05) | ns | ns | ns | - |

†TTD, Two-time drainages(20 and 40 days after seeding).
nsNot significant at the 0.05 probability level.

**Table 5. Rice grain quality affected by drainage and growth retardants.**

| Treatments | Perfect grain ratio(%) | Imperfect grain ratio(%) | | | |
|---|---|---|---|---|---|
| | | Green grain | Immatured grain | Others | Total |
| Continuous flooding | 69.7 | 17.5 | 3.9 | 8.9 | 30.3 |
| TTD† | 88.2 | 7.6 | 2.7 | 1.5 | 11.8 |
| Inabenfide after TTD | 89.4 | 7.4 | 2.0 | 1.2 | 10.6 |
| Trinexapac-ethyl after TTD | 90.5 | 5.9 | 2.5 | 1.1 | 9.5 |
| LSD(0.05) | 5.85 | 2.39 | ns | 1.24 | - |

† TTD, Two-time drainages(20 and 40 days after seeding).
nsNot significant at the 0.05 probability level.

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