Effects of Timing of Supplemental Nitrogen Application on Lodging Resistance and Yield of Wheat (Triticum aestivum L.)

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To assess the effects of timing of nitrogen supplemental application on and grain yield, and lodging resistance considering culm strength, we conducted a field study using the Japanese noodle wheat (Triticum aestivum L.) cultivars Ayahikari and Iwainodaichi. Supplemental nitrogen at the rate of 80 kg/ha was applied at three different Zadoks growth stages, GS30 (ear at 1 cm), GS32 (2nd node detectable), and GS39 (flag leaf ligule just visible). Grain yield increased significantly by the application of the supplemental nitrogen at GS30 and GS32. Maximum tiller number increased at GS30, whereas the percentage of productive culms significantly increased at GS32. Grain number per spikelet and grain number per spike significantly increased at GS30 and GS32. Chlorophyll content (SPAD value) of the flag leaf at late maturity increased at GS39. The 1000-grain weight, however, was not significantly affected by any treatment. Further, supplemental nitrogen application increased the moment of the aerial part at GS30, GS32, and GS39, but decreased the bending moment at breaking of the basal internode at GS30 and GS32. As a result, the lodging index significantly increased by supplemental nitrogen at GS30 and GS32. These findings suggest that supplemental nitrogen between GS30 and GS32 has sizeable positive effects on wheat yield but decreased resistance to lodging.

Key Words: lodging resistance, nitrogen supplementary timing, wheat (Triticum aestivum), grain yield

1. Introduction

The amount and timing of nitrogen fertilizer top-dressing to wheat crops differ depending not only on the end-use of the crop but also on the cultivar and region. As there is a positive correlation between the grain yield of wheat and the amount of nitrogen taken up with growth and maturity, it is necessary to apply nitrogen as a supplement during active growth in order to favor higher wheat yield. Maximum nitrogen uptake by soft red winter wheat occurs in the period following Zadoks GS30 (ear at 1cm; start of stem elongation) (Baethgen and Alley 1989). Although supplemental nitrogen is important for increasing wheat yields, it has not been emphasized in Japan, especially in warm and temperate Kanto region.
The influence of supplemental nitrogen on wheat yield and yield components differs depending on the timing of the application. Supplemental nitrogen at GS25 (main shoot and five tillers) can increase tiller density and yield (Scharf and Alley 1993). Kurai et al. (1998) reported the effects of nitrogen top-dressing on the Japanese wheat cultivars Bandowase and Norin 61, suggesting that application before the stem elongation stage (pre-GS30) increased spike number and yield, whereas application after that stage increased grain number per spike and yield. Furthermore, the magnitude of the increase of wheat yield also seemed to differ depending on the application timing. Fischer (1993) reported that grain yield increased in response to nitrogen applied late at the onset of stem elongation. Alcoz et al. (1993) reported that significant increases in grain yield were achieved with split applications of nitrogen at GS30 or GS31 (first node detectable), compared with all pre-planting application or application at GS45 (swollen boot) in a year when freezing damage occurred in February.

In recent years, research on wheat nitrogen application in Japan mainly focused on improving the flour quality of bread wheat cultivars by late application of supplemental nitrogen (Iwabuchi and Tanaka 2005; Sato et al. 1999; Shimazaki et al. 2014), because of the increased demand for bread made with domestic wheat. Thus, there are relatively few studies about the effects of supplemental nitrogen before the heading stage on Japanese wheat cultivars.

It is essential to emphasize, however that wheat tends to lodge when it is high yielding. It has been indicated that increasing the nitrogen supply increased culm length and reduced strength of culm base (Crook and Ennos 1995; Berry et al. 2000). Wheat culm length was increased about 7.5 cm by nitrogen applied at jointing stage and about 5 cm when applied 20 days before jointing stage; nitrogen applied after jointing stage had little effect on culm length (Kurai et al. 1998). Meanwhile, the effect of timing of supplemental nitrogen application on lodging resistance in relation to culm strength has not been assessed in Japan.

Therefore, in this study, we investigated the effects of timing of nitrogen supplementation on wheat yield, yield components, and lodging resistance by conducting a field experiment. The aim was to develop a better understanding on timing of nitrogen top-dressing achieve both high yields and lodging resistance in wheat cultivars.

2. Materials and methods

1) Plant materials and field management

The Japanese noodle wheat cultivars Ayahikari and Iwainodaichi were used in this study. Of the major cultivars in the warm and temperate wheat-growing regions in Japan, Ayahikari has relatively high culm strength, and in contrast, Iwainodaichi has relatively low culm strength (Matsuyama et al. 2020). Field experiments were conducted in the 2013/2014 and 2014/2015 crop seasons in an upland field (light-colored Andosol). Adjacent fields, where wheat or barley are usually cultivated in winter and sorghum or soybean in summer were chosen. The site location was at the National Agriculture and Food Research Organization (NARO), Institute of Crop Science in Ibaraki, central Japan (36°0’N, 140°0’E; 24 m above mean sea level).

Fused magnesium phosphate at 187.5 kg/ha was applied to the seedbed prior to sowing. No chemical fertilizer was applied as basal dressing because the field was considered adequately fertile. The seeds were sown on November 5, 2013 and October 28, 2014. The seeding rate was 140 seeds per m², and the interrow spacing was 15 cm. Supplemental nitrogen (ammonium sulfate) at 80 kg/ha was applied at three different growth stages, respectively, representing three treatments. The three stages were GS30 (ear at 1cm), GS32 (2nd node detectable) or GS39 (flag leaf ligule just visible), according to the Zadoks growth stages described by Tottman (1987). A fourth treatment with no supplemental nitrogen was considered, the experimental control. A randomized complete block design with three replications was setup in the field. Each plot size was approximately 5.4 m², consisting of eight rows spaced 15 cm apart.

2) Yield characteristics

To evaluate maximum tiller number, the number
of tillers in a 50 × 15 cm area of each replication plot was counted every 2 or 3 weeks from germination to April. At maturity, grain yield per unit area, spike number per unit area, and 1000-grain weight were determined from two randomly selected 1.0 × 0.45 m subsamples from each replication plot. Grain protein content was measured using a near infrared analyzer (Infratec™ 1241 Grain Analyser, Foss, Tokyo, Japan). The percentage of productive culms was calculated from the spike number at maturity and the maximum tiller number. Grain number per spike was calculated from the spike number, 1000-grain weight, and grain yield. The grain yield and 1000-grain weight were corrected to 12.5% moisture content.

We also counted spikelet number and fertile spikelet number per spike from eight spikes of moderate length selected from 12 spikes sampled from each plot. Percentage spikelet fertility was calculated by dividing the fertile spikelets per spike by the total spikelets per spike. The grain number per spikelet was calculated by dividing grain number per spike by fertile spikelets per spike.

3) Leaf area index, chlorophyll content, and uptake of supplemental nitrogen

Leaf area index (LAI) was measured using a plant canopy analyzer (SS1 SunScan Canopy Analysis System, Delta-T Devices, Cambridge, UK) on May 2, 2014, which coincided with anthesis in the 2013/2014 crop season.

Chlorophyll content (SPAD value) of the flag leaf of eight plants was measured using a chlorophyll meter (SPAD-502Plus, Konica Minolta, Tokyo, Japan) every week or every two weeks during grain ripening in the 2014/2015 crop season.

At maturity, the dry weight of the aerial part of the wheat plants per unit area and the nitrogen concentration of the dry matter were determined with subsamples of 0.12 m² from each plot. The aerial part was divided into ear and other part, dried for three days by ventilation at 80°C and milled. Measurement of nitrogen content of milled wheat samples was conducted by using a nitrogen, carbon and hydrogen analyzer with an oxygen circulating combustion system (SUMIGRAPH NCH-22F, Sumika Chemical Analysis Service, Ltd., Osaka, Japan). Percentage uptake of supplemental nitrogen was calculated by the total amount of nitrogen taken up at maturity in the plots with supplemental nitrogen application minus that in the control plot and dividing the value obtained by the amount of supplemental nitrogen.

4) Measurement of lodging resistance

Lodging index (Oda et al. 1966) was calculated as the value obtained by dividing the moment of the aerial part by the bending moment at breaking of the third internode (the peduncle node of spike was considered to be the first internode) of main culms, which was closely associated with stem lodging. The moment of the aerial part was obtained from the culm length and the culm weight. The culm length and weight of the 12 main culms sampled from each plot were measured at maturity, and the culm weight at two weeks after heading was estimated assuming the moisture content of the culm at that time was 80%.

The bending moment at breaking was observed at 2 weeks after heading. Sixteen main culms were sampled from each plot to determine the average leaf number and length of the third internode. With the third internode of 12 representative main culms, the bending load at breaking was measured at a distance of 4 cm between two supporting points according to Ookawa and Ishihara (1992), using TA. XT Texture Analyzer (Stable Micro Systems, Godalming, UK). We measured the maximum stress as the bending moment at breaking. This measurement was carried out in 2013/2014.

5) Statistical analysis

JMP Software (version 12; SAS Institute Inc., Cary, NC, USA) was used for statistical analyses. Data analysis was carried out by using a two-way analysis of variance (ANOVA). The model was defined as a split-plot design, with the two cropping years as the main plot, two cultivars as the sub-plots, the nitrogen application-timing treatments as sub-sub-plots, and the three replicates as blocks. Tukey's honestly significant difference (HSD) test was used for multiple pairwise comparison of means (P < 0.05).
Table 1  The dates of wheat crop development.

| Year  | GS30 | Jointing | GS32 | GS39 | Heading | Anthesis | Maturity |
|-------|------|----------|------|------|---------|----------|----------|
| 2013/2014 | 18-Mar | 1-Apr | 3-Apr | 18-Apr | 24-Apr | 8-May | 16-Jun |
| 2014/2015 | 24-Feb | 14-Mar | 16-Mar | 6-Apr | 17-Apr | 28-Apr | 5-Jun |

Table 2  Grain yield, yield components and grain protein content in four different nitrogen application treatments.

| Year  | Cultivar | Timing supplemental nitrogen | Spike number per m² | Grain weight g/m² | Grain number per spike | 1000-grain weight g | Grain protein content % |
|-------|----------|-------------------------------|----------------------|-------------------|-----------------------|----------------------|------------------------|
| 2013/2014 | Aya hikari | Control | 370 | 279 | 30.1 | 44.0 | 13.5 |
|          |          | GS30 | 511 | 331 | 34.1 | 45.3 | 13.6 |
|          |          | GS32 | 545 | 353 | 34.8 | 44.4 | 14.0 |
|          |          | GS39 | 417 | 323 | 28.4 | 45.1 | 15.2 |
| 2014/2015 | Ayahikari | Control | 577 | 298 | 40.2 | 48.3 | 12.2 |
|          |          | GS30 | 722 | 383 | 41.9 | 45.0 | 12.2 |
|          |          | GS32 | 755 | 390 | 42.6 | 45.4 | 12.7 |
|          |          | GS39 | 721 | 366 | 42.9 | 46.3 | 13.7 |
| 2013/2014 | Iwainodaichi | Control | 398 | 304 | 31.2 | 42.0 | 12.1 |
|          |          | GS30 | 483 | 328 | 35.1 | 42.0 | 12.4 |
|          |          | GS32 | 556 | 378 | 35.6 | 41.5 | 12.3 |
|          |          | GS39 | 356 | 259 | 31.9 | 43.1 | 14.5 |
| 2014/2015 | Iwainodaichi | Control | 690 | 396 | 39.0 | 44.5 | 11.2 |
|          |          | GS30 | 806 | 483 | 40.1 | 41.6 | 11.7 |
|          |          | GS32 | 753 | 463 | 41.0 | 39.8 | 11.7 |
|          |          | GS39 | 781 | 451 | 39.0 | 44.3 | 12.3 |

ANOVA Timing supplemental nitrogen *** *** ** *** ***
Cultivar ns ** ns *** ***
Year *** *** *** *** ***
N × C ns ns ns * ns
N × Y ns ns ns *** *
C × Y ns ** * ns
N × C × Y ns ns ns ns ns

1) ‘***’, ‘**’, and ‘*’ indicate significance at P < 0.001, P < 0.01, and P < 0.05, respectively. “ns” indicates no significant difference.
2) Results are expressed as means. Within columns, means followed by the same letter are not significantly different (P < 0.05) according to the Tukey honestly significant difference (HSD) test.
3. Results

1) Wheat crop development, ripening, and lodging

Table 1 shows the dates of wheat crop development. There were few differences between the two cultivars and, among the four different nitrogen application treatments. GS30 occurred 14 days before the jointing stage in 2014, 18 days before jointing stage in 2015, and GS32 occurred two days after the jointing stage in both years. GS39 occurred 6 and 12 days before heading in 2014 and 2015, respectively.

No lodging occurred in either cropping season, because the weather during ripening was calm and dry in both 2013/2014 and 2014/2015. There were only five days in 2014 and four days in 2015 when the maximum instantaneous wind speed was over 15 m/s. There were only two days in 2014 and zero days in 2015 when the precipitation per day was greater than 50 mm. These data were obtained from the automated meteorological data acquisition system of the Japan Meteorological Agency, at the observation point closest to the test site.

2) Yield and yield components

Grain yield, yield components, and grain protein content in four different nitrogen application treatments are shown in Table 2. Supplemental nitrogen at GS30 significantly increased grain yield by 23.8%. Spike number per unit area and grain number per spike were both significantly increased, whereas 1000-grain decreased significantly. The positive effect of supplemental nitrogen at GS32 on grain yield was 28.1%. The effects of nitrogen at GS32 on yield components were almost the same as those at GS30. In addition, grain protein content increased by 0.4% due to supplemental nitrogen at GS32. In contrast, the effect of supplemental nitrogen at GS39 on grain yield and yield components were not significant. Supplemental nitrogen at GS39 had a significant effect on grain protein content, which increased by 1.6%.

Supplemental nitrogen at GS30 increased maximum tiller number, whereas supplemental nitrogen at GS32 significantly increased the percentage of productive culms (Fig. 1). Spikelet number per spike and percentage spikelet fertility were unaffected by supplemental nitrogen at any growth stage (Fig. 2a), whereas grain number per spikelet significantly increased by supplemental nitrogen at GS30 and GS32 (Fig. 2b).

3) LAI during anthesis and chlorophyll concentration during ripening

LAI during anthesis significantly increased by supplemental nitrogen at GS30 and GS32 (Fig. 3). Chlorophyll content (as SPAD values) in mid- and late- May remained higher than that in the control plots as a result of supplemental nitrogen, especially at GS39 (Fig. 4).

4) Percentage uptake of supplemental nitrogen

On average, the percentage uptake of supplemental nitrogen at GS30, GS32, and GS39 were 57.5%, 78.7%, and 51.8%, respectively, for both cultivars and cropping seasons (Fig. 5). The standard error of the uptake rate of supplemental nitrogen was high in the order: GS 30 > GS 32 > GS 39 (Fig. 5).

5) Lodging resistance

Culm length and lodging resistance in the four
different nitrogen application treatments are shown in Table 3. Culm length slightly increased in response to supplemental nitrogen at GS30, and the moment of the aerial part increased with each supplemental nitrogen treatment. However, the bending moment at breaking of the basal internode decreased with supplemental nitrogen at GS30 and GS32. Hence, lodging index significantly increased by supplemental nitrogen at GS30 and GS32, resulting in increased risk of lodging.

The culm lengths and the moment of the aerial part of cultivars ‘Ayahikari’ and ‘Iwainodaichi’ were not significantly different from one another, whereas the bending moment at breaking of the intact internode of ‘Ayahikari’ was greater than that of ‘Iwainodaichi’. Consequently, the lodging index of ‘Ayahikari’ was smaller than that of ‘Iwainodaichi’, meaning that ‘Ayahikari’ exhibited greater resistance to lodging than did ‘Iwainodaichi’. The interaction between nitrogen application and cultivar was not significant for any of the parameters described.

4. Discussion

1) The effects on yield and yield components

In this field study, grain yield increased significantly by supplemental nitrogen at GS30 and GS32, with the stimulatory effect at GS32 being larger than that at GS30 (Table 2). Supplemental nitrogen at GS30 increased maximum tiller number, whereas at GS32 it increased the percentage of productive culms (Fig. 1). Spike number per unit area significantly increased by supplemental nitrogen at either growth stage; the effect at GS 32 was slightly larger than that at GS30 (Table 2). Though the time difference between GS30 and GS32 was only 16 days in 2013/2014, and 20 days in 2014/2015 (Table 1),
the results suggested a different effect on tillering between these two stages treated with supplemental nitrogen. Supplemental nitrogen at GS30 and GS32 also increased grain number per spike significantly (Table 2). Spikelet number per spike is determined by the stage of terminal spikelet formation, which is considered to occur close to the onset of stem elongation. GS30 occurred a little before or at nearly the same time as the onset of stem elongation, and the supplemental nitrogen at this stage had no influence on spikelet number per spike (Fig. 2). However, grain number per spikelet significantly increased by the supplemental nitrogen at both GS30 and GS32 (Fig. 2).

The number of florets was maximum around the time of flag leaf emergence (Kirby 1988), and some of them would later be aborted. It seemed that florets abortion was suppressed by supplemental nitrogen at either GS30 or GS32. Competition for assimilation products between different sinks in the two to three weeks before flowering is heavily involved in floret abortion (Fischer and Stockman 1980; Thorne and Wood 1987). Watanabe et al. (2016) suggested that reduced basal dressing, accompanied by increased top dressing from the tillering stage to the flag leaf emergence stage, increased LAI after the jointing stage and chlorophyll content (as SPAD values) during grain ripening, resulting in increased dry matter production. In the present study, LAI during anthesis significantly increased by supplemental nitrogen at either GS30 or GS32 (Fig. 3). These findings suggest that supplemental nitrogen at GS30 or GS32 increased LAI and reduced the competition for assimilation products in this period, leading to less floret abortion risk and resulting in increase in spike number per unit area, grain number per spike and ultimately grain yield.

By contrast, although the chlorophyll content in mid- and late- May was maintained at a level higher than that of the control plots by each of
the supplemental nitrogen treatment, especially at GS39 (Fig. 4), the 1000-grain weight did not increase by nitrogen supplement at GS39, contrary to expectation. It was speculated that spike number per unit area and grain number per spike in the plots of GS39 treatment were slightly higher than that in the control plots (Table 2).

Table 3  Culm length and lodging resistance in four different treatments of nitrogen application.

| Year        | Cultivar     | Timing supplemental nitrogen | Culm length cm | Lodging index | Moment of aerial part gf cm | Bending moment at breaking of basal internode gf cm |
|-------------|--------------|------------------------------|----------------|--------------|-----------------------------|---------------------------------------------------|
| 2013/2014   | Ayahikari    | Control                      | 58.5           | 0.64         | 756                         | 1188                                              |
|             |              | GS30                         | 61.1           | 0.80         | 862                         | 1085                                              |
|             |              | GS32                         | 59.8           | 0.74         | 841                         | 1149                                              |
|             |              | GS39                         | 62.1           | 0.70         | 842                         | 1204                                              |
|             | Iwainodaichi | Control                      | 60.1           | 0.71         | 702                         | 986                                               |
|             |              | GS30                         | 59.8           | 0.86         | 791                         | 916                                               |
|             |              | GS32                         | 60.5           | 0.85         | 758                         | 887                                               |
|             |              | GS39                         | 60.6           | 0.83         | 788                         | 948                                               |
| 2014/2015   | Ayahikari    | Control                      | 81.8           | –            | –                           | –                                                 |
|             |              | GS30                         | 85.1           | –            | –                           | –                                                 |
|             |              | GS32                         | 81.9           | –            | –                           | –                                                 |
|             |              | GS39                         | 80.0           | –            | –                           | –                                                 |
|             | Iwainodaichi | Control                      | 79.1           | –            | –                           | –                                                 |
|             |              | GS30                         | 82.6           | –            | –                           | –                                                 |
|             |              | GS32                         | 79.6           | –            | –                           | –                                                 |
|             |              | GS39                         | 79.6           | –            | –                           | –                                                 |
| average     | Ayahikari    | Control                      | 69.9           | 0.68 b       | 729                         | 1087                                              |
|             |              | GS30                         | 72.2           | 0.83 a       | 827                         | 1000                                              |
|             |              | GS32                         | 70.5           | 0.80 a       | 799                         | 1018                                              |
|             |              | GS39                         | 70.6           | 0.76 ab      | 815                         | 1076                                              |
|             | Iwainodaichi | Control                      | 71.3           | 0.72         | 825                         | 1157                                              |
|             |              | GS30                         | 70.2           | 0.82         | 760                         | 934                                               |
|             |              | GS32                         | 70.2           | 0.82         | 760                         | 934                                               |
|             |              | GS39                         | 70.2           | 0.82         | 760                         | 934                                               |
|             | Ayahikari    | Control                      | 60.3           | 0.77         | 792                         | 1045                                              |
|             |              | GS30                         | 61.2           | –            | –                           | –                                                 |
|             |              | GS32                         | 61.2           | –            | –                           | –                                                 |
|             |              | GS39                         | 61.2           | –            | –                           | –                                                 |
| ANOVA       | Timing supplemental nitrogen | ns | * | ns | ns |
|             | Cultivars    | ns | * | * | * |
|             | Year         | *** | – | – | – |
|             | N × C        | ns | ns | ns | ns |
|             | N × Y        | ns | – | – | – |
|             | C × Y        | ns | – | – | – |
|             | N × C × Y    | ns | – | – | – |

1) Lodging index was obtained by dividing the moment of the aerial part by the bending moment at breaking of the basal internode.
2) ‘***’ and ‘*’ indicate significance at P < 0.001 and P < 0.05 respectively. “ns” indicates no significant difference.
3) Results are expressed as means. Within columns, means followed by the same letter are not significantly different (P < 0.05) according to the Tukey honestly significant difference (HSD) test.
2) The effects of percentage uptake of supplemental nitrogen

In a previous study using $^{15}$N, the percentage uptake of top-dressed nitrogen at the heading stage was suggested to be 50% to 70% (Ishimaru et al. 2015; Nira and Nishimura 1998; Wuest and Cassman 1992), whereas that of basal-dressed nitrogen was 20 to 40% (Nira and Nishimura 1998; Wuest and Cassman 1992). In the present study, the percentage uptake was not an accurate measure because it was obtained by comparing the amount of nitrogen taken up at maturity in the plots with supplemental nitrogen with the amount taken up in the control plots. Percentage uptake of nitrogen at GS30 was estimated to be 57.5%, compared to 78.7% at GS32 and 51.8% at GS39 (Fig. 5). Supplemental nitrogen at GS32 had the highest effect on both enhancing yield and utilization ratio of nitrogen. Furthermore, the standard error of the percentage uptake of supplemental nitrogen was highest at GS30 (Fig. 5). During late February to early March, when the crops were at around GS30, relatively low rainfall was recorded, and the daily minimum temperature usually fell below freezing. Hence, it seemed that the percentage uptake of supplemental nitrogen at GS30 was inconsistent.

3) The effects on lodging resistance

Zhang et al. (2016) reported that supplemental nitrogen increased the rice culm length and inner culm diameter and decreased the area of the large vascular bundle and the small vascular bundle, resulting in weaker stem strength and a higher lodging index. The moment of the aerial part slightly increased by each supplemental nitrogen treatment (Table 3). Furthermore, supplemental nitrogen at GS30 and GS32 slightly decreased the bending moment at breaking of the basal internode (Table 3). Hence, the lodging index significantly increased by supplemental nitrogen at either GS30 or GS32 (Table 3). The lodging index used in this field study was reported to be correlated with lodging resistance observed in fields in wheat and barley cultivars (Oda et al. 1966), and have been used to decide the difference of lodging resistance among cultivars and breeding lines (Ma 2009). Although grain yield was high especially in 2014/2015 (Table 2), no lodging was observed because of the calm and dry weather during ripening in both years. However, the lodging index calculations suggested that supplemental nitrogen at GS30 and GS32 lowered lodging resistance.

The culm length in the plots of GS30 treatment was 2.3 cm longer than that in the control plot on average for the two cultivars and two cropping seasons (Table 3). By contrast, the culm length in the plots of GS32 treatment was almost similar to that in the control plot; accordingly, supplemental nitrogen after jointing stage seemed relatively more advantageous than that before jointing stage.

It was confirmed that ‘Ayahikari’ had greater resistance to lodging because of a high bending moment and a low lodging index (Table 3), as previously reported (Matsuyama et al. 2020). Meanwhile, the interaction between supplemental nitrogen application and cultivar was not significant for any of the parameters described (Table 3). It was suggested that the effect of supplemental nitrogen on lodging resistance was not different between cultivars with high and low bending moment of culm.

5. Conclusion

Supplemental nitrogen at GS30 or GS32 increased spike number per unit area, grain number per spike, and wheat yield markedly, with the stimulatory effect at GS32 being larger than that at GS30. On the other hand, supplemental nitrogen at GS30 and GS32 decreased the bending moment at breaking of the basal internode, and lowered lodging resistance. Supplemental nitrogen at GS30 increased culm length, and accordingly application at GS32 (after jointing stage) seemed relatively more advantageous than that before jointing stage. However, in high yield cropping, it seems to be indispensable to apply nitrogen around jointing stage; the side-effect of increased risk of lodging could be improved by the introduction of strong-culm cultivars or methods other than nitrogen fertilization.
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Effects of timing of supplemental nitrogen on wheat yield and lodging

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要旨

窒素追肥の施用時期がコムギの稲強度を考慮した倒伏抵抗性と収量に及ぼす影響を明らかにするために、日本めん用コムギ品質「あやひかり」と「イワイノダイチ」を用いた圃場栽培試験を行った。Zadoks の成長スケールにおける GS30（茎基部から幼穂までが 1 cm 以上になった時期）、GS32（第 2 節を視認できるようになった時期）、GS39（着葉展開期）の 3 時期のうちいずれかの時期に、追肥窒素 80 kg/ha を 1 回施用する区と、無追肥区の計 4 処理区を設けた。GS30 の追肥では最高収穫数が増加し、GS32 の追肥では有効着歩合が向上して、両時期とも穂数が有意に増加した。また、GS30 および GS32 の追肥により、1 小穂粒数が有意に増加し、1 穂粒数も増加した。GS39 の追肥により、登熟後期の着葉の SPAD 値が高く維持される傾向が見られたが、千粒重の有意な増大は見られなかった。また、地上部モーメントはいずれの時期の追肥によってもやや増大し、GS30 および GS32 の追肥では葉鞘付き茎基部の挫折時モーメントがわずかに低下し、倒伏指数が有意に高まった。従って、GS30～GS32 の追肥はコムギの収量を増大させる一方で、稲の強度を低下させて倒伏抵抗性を低下させると示された。

キーワード

小麦、子実収量、窒素追肥時期、倒伏抵抗