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Research Paper

Effect of Nitrogen Topdressing on Seed Yield and Flour Protein Content in Semidwarf Common Buckwheat

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ABSTRACT

This study evaluated the effects of nitrogen topdressing on the semidwarf common buckwheat (line '18-601'), focusing on growth, seed yield, and flour protein content. We conducted a field experiment and applied four nitrogen topdressing treatments at different growth stages: basal fertilization alone (2-0-0), basal fertilization plus nitrogen at flower bud appearance (2-2-0), basal fertilization plus nitrogen at full flowering (2-0-2), and basal fertilization plus nitrogen at both stages (2-2-2), using a randomized complete block design, with each plot measuring 1.2 × 2.5 m. Basal dressing was applied at 2, 8, and 4.7 g m^{-2} N, P_2O_5, and K_2O, respectively. Nitrogen topdressing significantly increased chlorophyll content. The branch number, seed yield, number of seeds per square meter, and flour protein content tended to increase with nitrogen topdressing. The highest seed yield and protein content were observed in the 2-0-2 treatment, suggesting that nitrogen application at full flowering optimizes the yield and nutritional quality of semidwarf buckwheat. These findings highlight the importance of timing in nitrogen topdressing to enhance the agronomic and nutritional value of semidwarf common buckwheat.

INTRODUCTION

Common buckwheat (*Fagopyrum esculentum* Moench) is valued for its significant nutritional contributions, offering a rich source of protein, minerals, and the flavonoid rutin. Despite its benefits, this crop suffers from low and unstable seed yields, especially in Japan, where yields stagnate between 50 and 100 kg/10a (Tanaka, 2016). A major challenge in common buckwheat cultivation is lodging—a condition where stems bend, causing plants to lie horizontally, leading to pre-harvest sprouting and seed shattering, significantly impacting seed yield (Morishita et al., 2020). The development of semidwarf cultivars has emerged as a potential strategy to enhance lodging resistance and yield stability.

Although the identification of dwarf and semidwarf genetic variants within the species has been reported (Ohnishi and Nagakubo, 1982; Minami et al., 1999), the availability of practical semidwarf cultivars for common buckwheat remains limited. Recent progress in breeding programs has led to the development of new semidwarf variants (Morishita et al., 2015). These variants have seed yields that are either similar to or slightly lower than those of standard-height cultivars. It also shows enhanced seed production when influenced by nitrogen fertilizer (Kasajima et al., 2017). Additionally, the National Agriculture and Food Research Organization (NARO) of Japan has developed a semidwarf line resistant to seed shattering and pre-harvest sprouting (Suzuki et al., 2023). These developments highlight the need for optimized cultivation techniques for semidwarf common buckwheat lines.

In wheat cultivation, nitrogen fertilization, especially topdressing after the booting stage, significantly increases grain protein content, influencing yield and nutritional quality (Farrer et al., 2006; Shimazaki and Watanabe, 2010). Similarly, previous research on buckwheat has explored the effects of nitrogen fertilization on seed yield and protein properties (Fang et al., 2018; Wan et al., 2023). Nevertheless, the specific effects of nitrogen topdressing on the seed yield and flour protein content of semidwarf common buckwheat lines have yet to be fully explored. This study aims to examine the effects of nitrogen topdressing on the growth, yield, and flour protein content of a semidwarf breeding line of common buckwheat, and optimize the cultivation practices for this nutritionally valuable crop.

MATERIAL AND METHODS

The common buckwheat variant used in this study was the semidwarf line '18-601', developed by the NARO Hokkaido Agricultural Research Center. It is characterized by a shorter plant height than conventional varieties, attributed to a single recessive gene conferring lodging resistance. A field experiment was conducted in an unused field on a local farm in the Yobito district, Abashiri, Hokkaido, from June to August 2023. Soil samples were collected prior to the application of basal fertilizer and analyzed by a specialized agency, Miraizou Co., Ltd., located in Oita, Japan. The chemical parameters of the field soil are presented in Table 1. Seeding was conducted on June 8, 2023, using seeder tapes (Nippon Plant Seeder Co., Ltd.) with row spacing of 30 cm and a hill distance of 2 cm (one plant per hill) at a seeding rate of 167 seeds/m^2. Basal dressing by chemical fertilizer was applied at rates of 2, 8, and 4.7 g m^{-2} N, P_2O_5, and K_2O, respectively. Nitrogen topdressing treatments in the form of ammonium sulfate were established according to application timing in four treatment plots: 2-0-0 (basal fertilization of 2 g m^{-2} N only), 2-2-0 (basal fertilization plus an additional 2 g m^{-2} N at flower bud appearance stage), 2-0-2 (basal fertilization plus an additional 2 g m^{-2} N at full flowering stage), and 2-2-2 (basal fertilization plus 2 g m^{-2} N at both the flower bud appearance and full flowering stages). Fertilizer applications for basal dressing and during the flower bud appearance and full flowering stages were conducted on June 6, June 30, and July 14, respectively. The time of flower bud appearance was defined as the day on which flower buds were observed on 50% of all plants, and the time of full flowering was the

Table 1. *Chemical parameters of soil sampled in the field.*

pH (H_2O)	EC (mS/cm)	CEC (meq/100 g)	Nitrate nitrogen (mg/100 g)	Ammonium nitrogen (mg/100 g)	Available P_2O_5 (mg/100 g)	Exchangeable cation (mg/100 g)		
						K	Ca	Mg
6.3	0.04	16.0	0.5	0.7	32.8	24.2	251.2	26.0

day the apical inflorescence of the main stem bloomed on all plants. Each plot measured 1.2 × 2.5 m and was arranged in a randomized complete block design with three replications. To determine the chlorophyll content, we measured the SPAD value of five individual plants per plot, using one leaf from either the second or third leaf from the top. The measurements were taken on July 25 using a SPAD meter (SPAD-502, Konica Minolta). Before harvesting the plants, the main stem length and number of primary branches were recorded for ten individuals of average growth per plot. Then, we harvested plants on August 25 when 80% of the seeds changed color from green to black. Twenty individuals per plot were sampled, threshed by hand on site, and dried over two weeks. The seeds were then winnowed, and their dry weight was measured (seed yield). The number of seeds per 20 plants was counted using a multi-auto counter (Fujiwara Scientific Co., Ltd). The 1000-seed weight was calculated from this value, and the number of seeds per square meter was calculated from the seed yield and 1000-seed weight, corrected to a 15% moisture basis. These samples were used to determine the flour protein content. After removing the husks, the seeds were finely ground, and the total nitrogen content was measured using an NC analyzer (SUMIGRAPH NC-22F; Sumika Chemical Analysis Service Ltd., Tokyo, Japan). The protein content in flour was calculated by multiplying the nitrogen value by a nitrogen-to-protein conversion factor of 6.25. Statistical analysis (Dunnett's multiple comparison test) was performed using BellCurve for Excel provided by Social Survey Research Information Co., Ltd.

RESULTS AND DISCUSSION

In this study, lodging was not observed in any of the treatment plots. Remarkably, even after Typhoon No. 7 hit Hokkaido in 2023, lodging was absent across all plots, including those where only basal nitrogen was applied (2-0-0) and those with nitrogen topdressing (2-2-0, 2-0-2, and 2-2-2). This resistance to lodging in common buckwheat is believed to be related to stem strength, which is associated with lignin content (Wang et al., 2015). Thus, the significance of lignin synthesis in enhancing the lodging resistance of semidwarf lines warrants further exploration.

Nitrogen topdressing significantly influenced SPAD values (Fig. 1), indicating its impact on chlorophyll content. The SPAD values were highest in the 2-2-2 treatment, followed by the 2-0-2, 2-2-0, and 2-0-0 treatments. Despite increased nitrogen fertilization, the main stem length remained consistent across treatment plots (Fig. 2), suggesting that the semidwarf common buckwheat line is

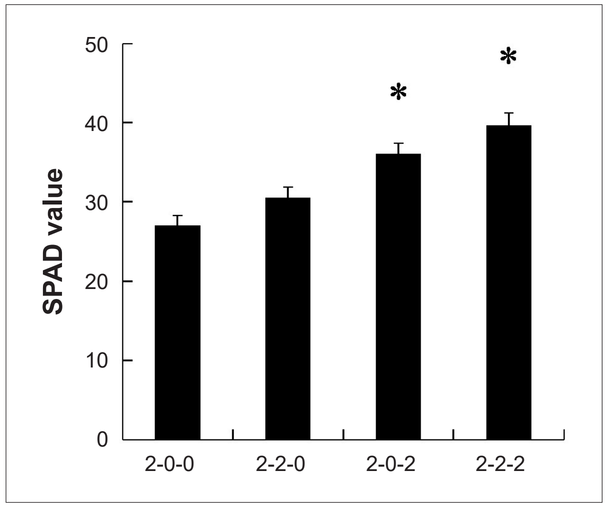

Fig. 1. *Chlorophyll content (SPAD value) in each treatment. Vertical bars represent standard errors based on three replicates. *Asterisks indicate significant differences from the 2-0-0 treatment by Dunnett's multiple comparison test (p < 0.05). Nitrogen topdressing treatments at different growth stages: basal fertilization alone (2-0-0), basal fertilization + nitrogen at flower bud appearance (2-2-0), basal fertilization + nitrogen at full flowering (2-0-2), and basal fertilization + nitrogen at both stages (2-2-2).*

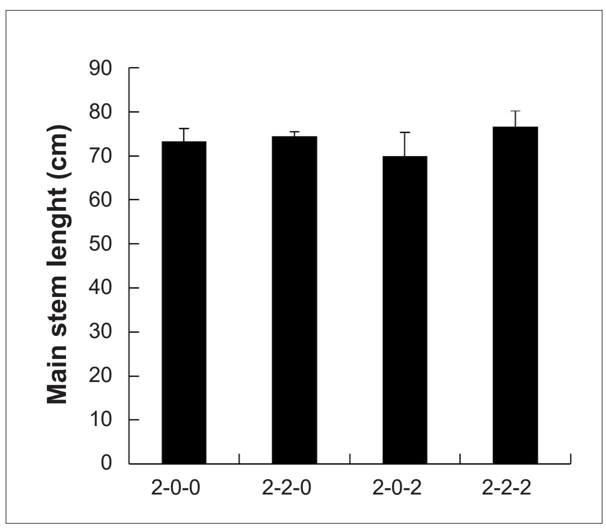

Fig. 2. *Main stem length in each treatment. Vertical bars represent standard errors based on three replicates.*

less susceptible to lodging and benefits from nitrogen topdressing in terms of yield enhancement. Furthermore, the number of branches was generally higher in plots receiving nitrogen topdressing (2-2-0, 2-0-2, and 2-2-2) compared to the plot without the topdressing (2-0-0) (Fig. 3). Given buckwheat's significant plasticity in branching in response to planting density and its reported increase in the number of flower clusters on branches (Kasajima et al., 2023), the nitrogen topdressing-induced increase in branch number may contribute to higher yields, highlighting the need for further research on the underlying mechanism of this process.

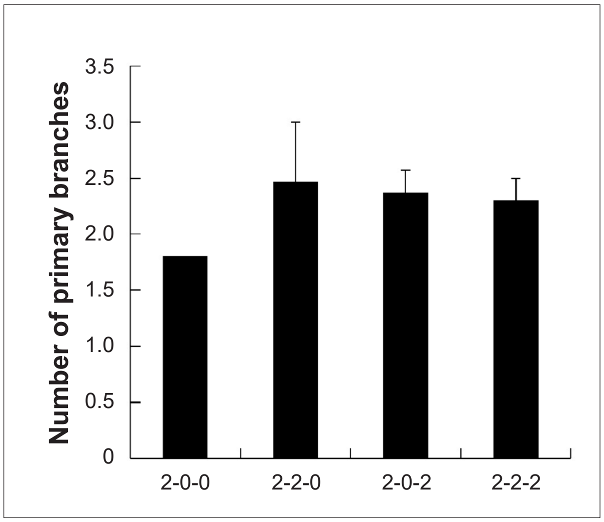

Fig. 3. *Number of primary branches in each treatment. Vertical bars represent standard errors based on three replicates.*

Seed yield was positively influenced by nitrogen topdressing, as shown in Fig. 4. The 2-0-2 treatment resulted in the highest seed yield, followed by the 2-2-0 treatment, with yields of 97.9 g and 89.5 g m^{-2}, respectively, representing increases of 1.34 and 1.23 times compared to 2-0-0. Similar studies in buckwheat have shown that yields are higher when nitrogen is primarily applied as basal fertilization rather than during the flowering stage as topdressing, even when the total amount of nitrogen used is the same. This suggests that nitrogen application timing critically impacts both yield and nitrogen-use efficiency (Sugimoto et al., 2004). This finding supports the notion that the semidwarf trait may enhance nitrogen-use efficiency, which warrants further investigation. Interestingly, no significant yield difference was observed between the 2-2-2 and 2-0-0 treatments. It has been reported that applying nitrogen up to 4 g m^{-2} can increase yields but applying between 4 and 10 g m^{-2} may reduce yields (Sugimoto et al., 2004; Fang et al., 2018). These studies also highlight that excessive nitrogen conditions can increase the vegetative growth of stems and leaves. This indicates that the triple nitrogen dosage in the 2-2-2 treatment might cause nitrogen metabolism imbalance within the plant, highlighting the importance of determining the optimal nitrogen application rate. Thousand-seed weight showed minimal variation across treatments (Fig. 5), and the number of seeds per square

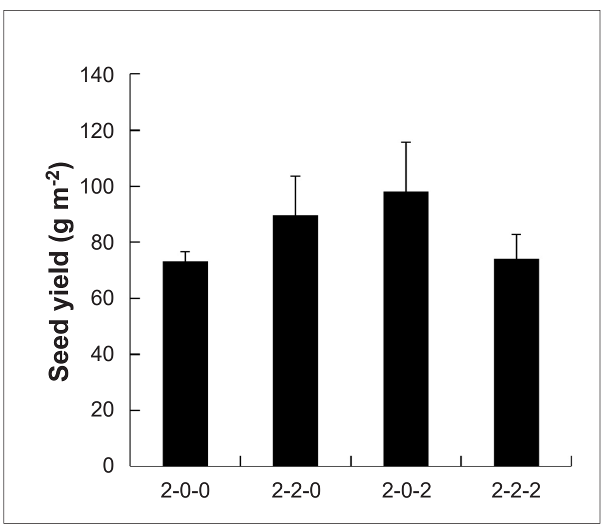

Fig. 4. *Seed yield in each treatment. Vertical bars represent standard errors based on three replicates.*

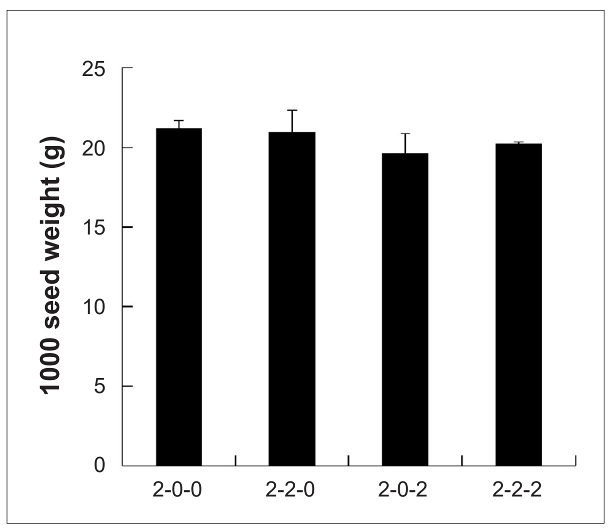

Fig. 5. *1000 seed weight in each treatment. Vertical bars represent standard errors based on three replicates.*

meter mirrored seed yield trends (Fig. 6). This finding suggests that the observed yield increase with nitrogen topdressing at the flowering and flower bud appearance stages is mainly due to an increase in the number of seeds per unit area. However, this study did not investigate yield-forming processes such as fertilization and seed set; thus, further physiological investigations are required.

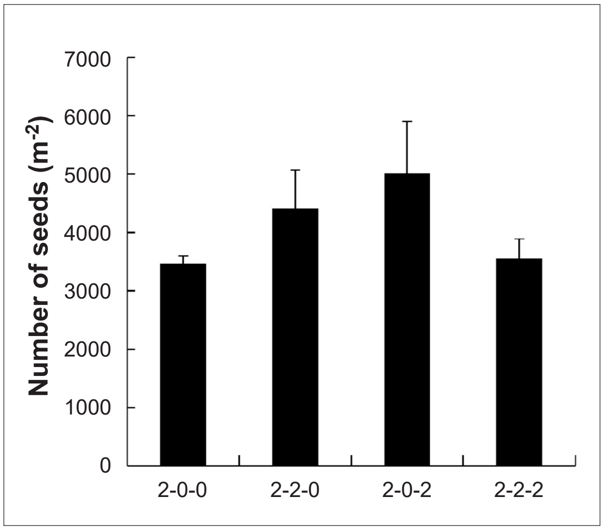

Fig. 6. *Number of seeds per square meter in each treatment. Vertical bars represent standard errors based on three replicates.*

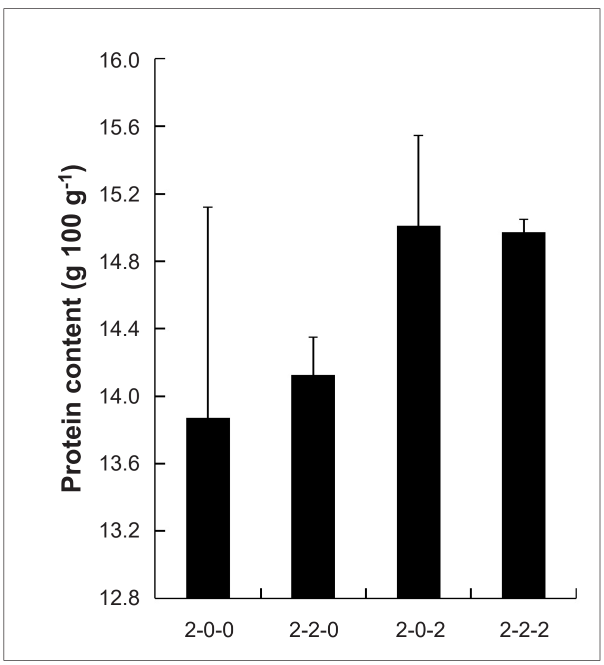

Fig. 7. *Flour protein content in each treatment. Vertical bars represent standard errors based on three replicates.*

The flour protein content exhibited an upward trend with nitrogen topdressing (Fig. 7), with the highest protein content observed in the 2-0-2 treatment, followed by the 2-2-2 treatment. Both treatments had a protein content of 15.0 g/100 g, representing a relative increase of 108% compared to the 2-0-0 treatment. Shimazaki and Watanabe (2010) indicated that applying nitrogen fertilizer after the booting stage of wheat, when the sink capacity is almost determined, is the main factor in increasing the grain protein concentration. A similar mechanism may be involved in buckwheat, necessitating further research into nitrogen allocation between vegetative and reproductive growth, given buckwheat's indeterminate growth habit (Funatsuki et al., 2000). Moreover, the protein content of buckwheat flour is crucial for its noodle-making quality (Matsuura et al., 2010), advocating for additional cultivation trials focused on processing suitability.

CONCLUSION

This study confirms that nitrogen topdressing can boost seed yield and protein content in semidwarf common buckwheat without increasing lodging risk. The observed lack of statistical significance in most parameters, except chlorophyll content (SPAD value), suggests variability in plant responses, highlighting the need for further research to optimize nitrogen application rates and avoid metabolic imbalances. Despite these complexities, our findings highlight a viable path to enhance the nutritional and agricultural value of buckwheat, a crucial crop for diversifying global food sources. Future efforts should focus on understanding the physiological mechanisms behind these benefits and assessing their impact on buckwheat's processing quality, ensuring the full potential of nitrogen topdressing is realized.

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REFERENCES

Farrer, D.C., R. Weisz, R. Heiniger, J.P. Murphy, J.G. White, 2006. Minimizing protein variability in soft red winter wheat: Impact of nitrogen application timing and rate. Agronomy Journal 98, 1137-1145. https://doi.org/10.2134/agronj2006.0039

Fang, X., Y. Li, J. Nie, C. Wang, K. Huang, Y. Zhang, Y. Zhang, H. She, X. Liu, R. Ruan, X. Yuan, Z. Yi, 2018. Effects of nitrogen fertilizer and planting density on the leaf photosynthetic characteristics, agronomic traits and grain yield in common buckwheat (*Fagopyrum esculentum* M.). Field Crops Research 219, 160-168. https://doi.org/10.1016/j.fcr.2018.02.001

Funatsuki, H., W. Maruyama-Funatsuki, K. Fujino, M. Agatsuma, 2000. Ripening habit of buckwheat. Crop Science 40: 1103-1108. https://doi.org/10.2135/cropsci2000.4041103x

Kasajima, S., K. Hatae, T. Morishita, 2017. Seed-setting habit of a semidwarf common buckwheat line. Fagopyrum 34: 5-12. https://doi.org/10.3986/fag0001

Kasajima, S., W. Watanabe, M. Kitade, H, Itoh, 2023. Effects of planting density on branching habit in common and Tartary buckwheat. Fagopyrum 40: 15-21. https://doi.org/10.3986/fag0030

Matsuura, K., E. Kashimura, T. Izumisawa, Y. Iida, A. Horigane, 2010. Relationship between crude protein content of buckwheat flour and noodle-making quality. Abstracts of Meeting of the CSSJ 230: 374. https://doi.org/10.14829/jcsproc.230.0.374.0

Minami, M., A. Ujihara, G. C. Campbell. 1999. Morphology and inheritance of dwarfism in common buckwheat line, G410, and its stability under different growth conditions. Breeding Science, 49: 27-32. https://doi.org/10.1270/jsbbs.49.27

Morishita, T., T. Hara, T. Hara, 2020. Important agronomic characteristics of yielding ability in common buckwheat; ecotype and ecological differentiation, preharvest sprouting resistance, shattering resistance, and lodging resistance. Breeding Science 70: 39-47. https://doi.org/10.1270/jsbbs.19020

Morishita, T., T. Suzuki, Y. Mukasa. 2015. Characteristics of a novel 'semidwarf material' in common buckwheat. Fagopyrum, 32: 9-14.

Ohnishi, O., T. Nagakubo. 1982. Population genetics of cultivated common buckwheat, *Fagopyrum esculentum* Moench. II. Frequency of dwarf mutants in Japanese populations. The Japanese Journal of Genetics, 57: 641-650.

Shimazaki, Y., Y. Watanabe, 2010. Grain protein concentration of wheat (*T. aestivum* L.) - Can cultivation techniques control the grain protein concentration of wheat? Japanese Journal of Crop Science 79: 407-413. https://doi.org/10.1626/jcs.79.407

Sugimoto, H., 2004. Effects of nitrogen application on the growth and yield of summer buckwheat cultivated in western Japan with special reference to dry matter production and nitrogen absorption. Japanese Journal of Crop Science 73: 181-188. https://doi.org/10.1626/jcs.73.181

Suzuki, T., K. Tsujimoto, G. Maruo, T. Hara, K. Katsu, A. Matsuura, T. Morishita, T. Hara, K. Ishiguro, S. Otsuka, 2023. Development of semidwarf breeding line with shattering resistance and preharvest-sprouting resistant in buckwheat (*Fagopyrum esculentum*). Plant Breeding 142: 527-536. https://doi.org/10.1111/pbr.13101

Tanaka-Katsube, T., 2016. Buckwheat production, consumption, and genetic resources in Japan. In: Meiliang, Z., I. Kreft, S. H. Woo, N. Chrungoo, and G. Wieslander (Eds.), Molecular Breeding and Nutritional Aspects of Buckwheat, pp. 61-80, Academic Press, London.

Wan, C., L. Gao, J. Wang, X. Lei, J. Tao, B. Feng, J. Gao, 2023. Effects of nitrogen fertilizer on protein synthesis, accumulation, and physicochemical properties in common buckwheat. The Crop Journal 11: 941-950. https://doi.org/10.1016/j.cj.2023.01.002

Wang, C., R. Wu Ruan, X. Hui Yuan, D. Hu, H. Yang, Y. Li, Z. Lin Yi, 2015. Effects of nitrogen fertilizer and planting density on the lignin synthesis in the culm in relation to lodging resistance of buckwheat. Plant Production Science 18: 218-227. https://doi.org/10.1626/pps.18.218

IZVLEČEK

Vpliv dognojevanja z dušikom na pridelek semen in vsebnost beljakovin v moki polpritlikave navadne ajde

V raziskavi so ocenjeni učinki dognojevanja z dušikom na polpritlikavo navadno ajdo (linija ‚18-601'), pri čemer je raziskava osredotočena na rast, donos semen in vsebnost beljakovin v moki. Izvedli smo poljski poskus in uporabili štiri dognojevanja z dušikom v različnih fazah rasti: samo osnovno gnojenje (2-0-0), osnovno gnojenje z dušikom ob pojavu cvetnih popkov (2-2-0), osnovno gnojenje z dušikom ob polnem cvetenju (2-0-2) in osnovno gnojenje z dušikom na obeh stopnjah (2-2-2) z uporabo naključne zasnove blokov, pri čemer vsaka parcela meri 1,2 × 2,5 m. Osnovno gnojenje je bilo uporabljeno pri 2, 8 in 4,7 g m^{-2} N, P_2O_5 oziroma K_2O. Dodatek dušika je znatno povečal vsebnost klorofila. Število vej, pridelek semen, število semen na kvadratni meter in vsebnost beljakovin v moki so se povečali z dodatkom dušika. Najvišji pridelek semen in vsebnost beljakovin sta bili ugotovljeni pri obdelavi 2-0-2, kar kaže, da uporaba dušika pri polnem cvetenju optimizira pridelek in hranilno kakovost polpritlikave ajde. Te ugotovitve poudarjajo pomen časovnega usklajevanja pri dodajanju dušika za povečanje agronomske in hranilne vrednosti polpritlikve navadne ajde.