

Agronomic Optimization of Wide-Narrow Row Transplanting Spacing for the TU8 Rice Variety in Vietnam

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ABSTRACT

This study evaluated the effects of wide-narrow row planting patterns on growth, biomass accumulation, tillering ability, pest incidence, and yield of the TU8 rice variety. The T3, T4, and T5 planting patterns significantly increased plant height, dry biomass accumulation, and effective tillers compared to conventional patterns (T1 and T2). Simultaneously, these patterns markedly reduced the severity of rice blast, brown leaf spot, bacterial leaf blight, and insect pests, with T5 showing almost no pest incidence. Yield components, including panicles per m², grains per panicle, filled grain percentage, and 1000-grain weight, were improved, resulting in the highest grain yield of 6.64-6.69 t ha⁻¹ in T4 and T5. The results indicate that T4 and T5 are the optimal planting patterns, enhancing growth and yield while minimizing pest damage. This study provides a scientific basis for recommending wide-narrow row planting to achieve sustainable and high-yield rice production in Vietnam.

Keywords: TU8 rice; wide-narrow row planting; tillering ability; biomass accumulation; pest incidence; yield components; grain yield

INTRODUCTION

Rice (*Oryza sativa* L.), belonging to the family Poaceae, is one of the most important staple crops worldwide. It is grown in about 115 countries across most continents except Antarctica (Bouman et al., 2007; Zaman et al., 2000). Approximately 90% of the global rice production area is located in Asia, while Africa accounts for 4.6% and the Americas about 4.7% (Maclean et al., 2013). Rice exhibits wide adaptability and can grow under diverse environmental conditions, ranging from deep-flooded lowlands and drought-prone regions to upland areas with limited soil resources (Connor, 2004). It also provides roughly 13% of the global protein supply (Juliano, 1994) and plays a crucial role in food security and agricultural economic development in Vietnam (Nguyen, 2019).

Planting density and transplanting spacing are important agronomic factors that strongly influence rice yield (Bui, 1999). Appropriate arrangement of spacing and planting density helps improve the photosynthetic efficiency of rice both at the individual plant and population levels by optimizing light interception, leaf formation, and an appropriate leaf area index. These factors also affect tillering capacity, the number of effective tillers per hill, and resistance to pests and diseases, thereby contributing to yield improvement (Nguyen et al., 1997). Research by Nguyen (2003) on the wide-narrow row transplanting technique showed that selecting optimal density and spacing helps limit excessive tillering, reduce ineffective tillers, enhance photosynthetic efficiency, improve light distribution within the canopy, and consequently increase yield.

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The TU8 rice variety is currently cultivated widely in northern provinces of Vietnam (Nguyen 2007), including Thanh Hoa. The growth, tillering, biomass accumulation, and pest and disease tolerance of TU8 are directly affected by planting density and row arrangement. Improper transplanting spacing may lead to competition for light and nutrients, reduced tiller differentiation, fewer panicles, lower yield, and increased pest incidence. In contrast, wide-narrow row arrangement promotes uniform crop development, enhances light penetration into the canopy, reduces competition, improves photosynthesis, increases yield, and minimizes pest and disease damage (Dong et al., 2025; Hassan et al., 2022; Reed et al., 2024).

Although many studies have demonstrated the effectiveness of wide-narrow row transplanting models in various inbred and hybrid rice varieties, specific data for the TU8 variety in Thanh Hoa Province are still lacking. Therefore, determining the optimal wide-narrow row transplanting spacing for TU8 in Thanh Hoa province is essential to provide a scientific basis for technical recommendations, enhance yield, improve production efficiency, and reduce losses caused by pests and diseases.

MATERIALS AND METHODS

Experimental Site and Duration

The experiment was conducted in Thanh Hoa Province, Vietnam, during the Summer-Autumn crop of 2025 on light clay soil with fully controlled irrigation and drainage. The soil at the experimental site had a medium organic matter content, high available potassium, and medium levels of available nitrogen and phosphorus. Soil pH ranged from 5.5 to 6.0, with a cultivation layer of 25-30 cm, good moisture retention and drainage capacity-conditions suitable for rice cultivation. The area experiences a typical tropical monsoon climate, favorable for two rice crops per year.

Plant Materials

The TU8 rice variety, developed by the Vietnam National Seed Joint Stock Company, was used in the study. The variety has a growth duration of 125-130 days in the Spring crop and 100-105 days in the Summer-Autumn crop.

Experimental Design

The experiment was arranged in a randomized complete block design (RCBD) with five treatments of wide-narrow row spacing (T1-T5) and three replications (Nguyen & Pham, 2005). Each treatment covered an area of 20 m². The treatments were as follows:

T1: Uniform row spacing of 18 cm (control); hill spacing: 18 cm.

T2: Alternating wide rows (24 cm) and narrow rows (18 cm); hill spacing: 18 cm.

T3: Alternating wide rows (30 cm) and narrow rows (18 cm); hill spacing: 18 cm.

T4: Alternating wide rows (36 cm) and narrow rows (18 cm); hill spacing: 18 cm.

T5: Alternating wide rows (42 cm) and narrow rows (18 cm); hill spacing: 18 cm.

Transplanting was done with 10-day-old seedlings, at 2-3 seedlings per hill. Crop management followed standard practices recommended for the TU8 variety.

Measurements and Data Collection

Plant height: Measured from soil surface to the tip of the highest leaf or panicle (cm). In each plot, three sampling points were randomly selected, and five plants per point were measured.

Dry matter accumulation: Five plants were sampled at each observation time. Plant organs (roots, stems, green leaves, and panicles if present) were separated and oven-dried at 80°C to constant weight to determine dry biomass.

Tiller production: During the tillering stage, three points per plot were selected, with five plants per point. Maximum tiller number and effective tiller number (bearing panicles) were recorded. Effective tiller ratio (%) = (effective tillers/maximum tillers) × 100%.

Pest and disease assessment: Surveys were conducted at key growth stages (initial establishment, tillering, panicle initiation, heading, and soft dough). Five fixed points were arranged in an X-pattern per plot, with observations on 10 hills per point. Each hill was scored, and plot averages were used to determine pest severity. A qualitative rating scale was applied (0: no infection; 1: mild infection; 2: moderate infection).

Yield components and grain yield:

Number of effective panicles per m²: Counted based on panicles with at least 10 filled grains.

Filled grains per panicle: Determined from five randomly selected panicles per plot; average values were calculated.

1000-grain weight: Determined using 1000 fully filled grains at 14% moisture content.

Actual yield: Each plot was harvested at full maturity. Grains were sun-dried to 14% moisture and weighed, then converted to tons per hectare.

Data analysis: The experiment included three independent replications. Data were expressed as mean ± standard error and analyzed using ANOVA in IRRISTAT 5.0.

RESULTS AND DISCUSSION

Table 1 shows that the wide - narrow row transplanting treatments had clear effects on the plant height of the TU8 rice variety across different growth stages. At the early recovery stage, plant height ranged from 31.56 to 32.53 cm. Although the differences were not large, T5 and T4 recorded slightly higher values than T2 and T3; however, the narrow variation indicates relatively uniform early growth among treatments.

Table 1. Effects of wide–narrow row transplanting treatments on the plant height of the TU8 rice variety

Unit: cm

Treat ment	Rooting	Tillering	Panicle Initiation	Heading	Dough Stage
T1	32.09 ^b ± 0.26	56.16 ^a ± 0.45	79.51 ^a ± 1.89	97.79 ^a ± 1.35	116.57 ^a ± 1.03
T2	31.56 ^c ± 0.14	55.42 ^{bc} ± 0.79	78.42 ^{ab} ± 0.72	96.57 ^{ab} ± 1.46	117.29 ^a ± 1.11
T3	31.87 ^{bc} ± 0.22	55.28 ^{bc} ± 0.81	78.57 ^{ab} ± 0.85	95.24 ^b ± 0.94	116.75 ^a ± 1.79
T4	32.45 ^{ab} ± 0.09	55.38 ^{bc} ± 0.73	77.05 ^b ± 1.06	96.35 ^{ab} ± 1.06	116.42 ^a ± 1.49
T5	32.53 ^a ± 0.14	54.21 ^c ± 1.06	78.16 ^{ab} ± 0.84	96.83 ^{ab} ± 1.53	116.76 ^a ± 1.92

By the tillering stage, plant height among treatments still exhibited small differences (54.21-56.16 cm). T1 recorded the greatest height (56.16 cm) and the difference was statistically significant compared with the other treatments. This suggests that the transplanting density in T1 (traditional uniform spacing) may have created better ventilation conditions, enabling stronger vertical growth during tillering. However, from the panicle initiation to the soft dough stage, the trend changed. T1 continued to maintain superior plant height (79.51-116.57 cm), whereas the remaining treatments had noticeably lower values, particularly T4 and T5, which reached only 77.05-116.76 cm. The differences among treatments during the heading and soft dough stages were both biologically and statistically significant.

Nevertheless, the overall variation was not large (maximum difference of 3-4 cm at the soft dough stage), indicating that the TU8 variety maintains relatively stable morphological characteristics even under different spacing arrangements. This is consistent with the findings of Pham et al. (2023), who reported that some short-duration rice varieties show weak

morphological responses to changes in planting density but respond more strongly in terms of panicle number and grain characteristics.

In general, T1 produced the greatest plant height across most growth stages, suggesting that the wide-narrow row configuration in this treatment is suitable for stem and leaf development of the TU8 variety. The other treatments-particularly T4 and T5-tended to show reduced height at panicle initiation and heading, possibly due to increased light competition or higher effective planting density limiting internode elongation.

Table 2 presents the changes in dry matter accumulation of the TU8 rice variety under different wide-narrow row transplanting treatments across growth stages. At the early recovery stage, dry matter accumulation was still low (0.37-0.47 g/m²) and the differences among treatments were negligible, indicating that planting density and row arrangement had not yet created substantial variation in biomass accumulation at this stage.

Table 2. Effect of wide-narrow row transplanting treatments on accumulated dry matter of TU8 rice

Unit: g/m²

Treatment	Rooting	Tillering	Panicle Initiation	Heading	Dough Stage
T1	0.37 ^a ± 0.01	1.19 ^d ± 0.06	13.65 ^d ± 0.35	23.68 ^d ± 0.17	31.04 ^b ± 0.72
T2	0.38 ^a ± 0.02	1.27 ^c ± 0.12	15.28 ^c ± 0.21	24.17 ^c ± 0.35	31.56 ^b ± 0.29
T3	0.42 ^a ± 0.01	1.41 ^b ± 0.18	16.32 ^b ± 0.35	25.32 ^b ± 0.22	32.09 ^{ab} ± 0.59
T4	0.46 ^a ± 0.03	1.48 ^a ± 0.15	16.49 ^b ± 0.43	26.65 ^a ± 0.41	32.78 ^a ± 0.98
T5	0.47 ^a ± 0.02	1.56 ^a ± 0.07	17.55 ^a ± 0.33	26.57 ^a ± 0.25	32.74 ^a ± 0.73

From the tillering stage to panicle initiation, biomass increased rapidly and clear differences among treatments began to emerge. At the tillering stage, T5 recorded the highest value (1.56 g/m²), followed by T4 (1.48 g/m²), while T1 and T2 were substantially lower. This suggests that treatments with more favorable spacing configurations (such as T4 and T5) promoted stronger canopy development and greater photosynthetic capacity, thereby enhancing dry matter accumulation. This trend is consistent with Pham et al. (2020), who reported that an optimized wide-narrow row pattern reduces light competition and promotes early biomass production.

The differentiation among treatments became more pronounced at the panicle initiation and heading stages, where T5 and T4 continued to accumulate the highest amounts of dry matter. At the panicle initiation stage, T5 reached 17.55 g/m², which was 28% higher than T1 (13.65 g/m²). This difference was statistically significant, confirming the importance of canopy structure and light interception during the period of vigorous leaf expansion. During heading and the soft dough stage, biomass accumulation continued to increase, though the rate differed among treatments. T4 and T5 achieved the greatest values (26.57-26.65 g/m² at heading and 32.7 g/m² at the soft dough stage), whereas T1 and T2 remained lower. The differences between the T4-T5 group and the T1-T2 group continued to be statistically significant. These results indicate that wide-narrow row arrangements that increase canopy ventilation not only support early growth but also enhance carbohydrate transport and accumulation during the yield-determining stages.

This trend aligns with several previous studies. Li et al. (2021) and Singh et al. (2019) reported that wider row spacing increases individual leaf area, enhances pre-heading dry matter accumulation, and improves canopy structure and grain yield. Pham et al. (2020) also showed that rice grown at lower density accumulates more dry matter per plant than rice grown at higher density in the Red River Delta.

Overall, T4 and T5 exhibited the highest biomass accumulation throughout the growth cycle, suggesting that their wide-narrow row configurations match the physiological growth characteristics of the TU8 variety. In contrast, T1 and T2 showed considerably lower biomass, likely due to higher density or less optimal spacing that increased light competition and limited photosynthetic efficiency and carbohydrate accumulation.

The results in Table 3 show that transplanting spacing had a pronounced effect on the tillering capacity of the TU8 rice variety. The maximum number of tillers ranged from 8.21 to 9.42 tillers/plant, with treatments featuring more favorable wide-narrow row arrangements (T3, T4, T5) producing clearly higher values. Notably, T5 reached 9.42 tillers/plant, approximately 14.7% higher than T1. This indicates that improved spatial distribution under wide-narrow row spacing enhances light interception, increases effective leaf area, and promotes the differentiation of tiller buds.

Table 3. Effect of wide-narrow row transplanting treatments on tillering of TU8 rice

Treatment	Maximum number of tillers (tillers/plant)	Number of effective tillers (tillers/plant)	Percentage of effective tillers (%)
T1	8.21 ^b ± 0.15	6.34 ^b ± 0.13	77.22
T2	8.35 ^b ± 0.16	6.46 ^b ± 0.18	77.37
T3	9.12 ^a ± 0.26	7.24 ^a ± 0.43	79.39
T4	9.26 ^a ± 0.13	7.37 ^a ± 0.22	79.59
T5	9.42 ^a ± 0.14	7.58 ^a ± 0.33	79.67

The number of effective tillers showed a similar trend, ranging from 6.34 to 7.58 tillers/plant, with T4 and T5 recording the highest values (7.37-7.58 tillers/plant). This pattern is consistent with the increase in maximum tiller number, indicating that tillers formed under better-ventilated canopy conditions and reduced nutrient competition had higher survival and development rates. The percentage of effective tillers was uniformly high across treatments (77.22-79.67%), with no substantial differences, demonstrating that the TU8 variety has a relatively stable capacity for converting tillers into productive ones. These findings are in line with recent studies in Vietnam and the region. Pham et al. (2020) reported that rice grown at lower densities produces more tillers with higher effective tiller ratios compared with high-density planting. Similarly, Singh et al. (2019) and Li et al. (2021) indicated that wider row spacing improves the number of productive tillers and canopy structure, thereby enhancing panicle productivity.

The consistency among studies highlights that wide-narrow row transplanting is a physiologically grounded cultivation technique: tiller development is strongly influenced by light intensity near the plant base and the photosynthetic performance of lower leaves in the canopy. By altering plant distribution in two dimensions, the spatial gaps between rice hills are expanded, reducing shading and creating optimal conditions for tiller bud differentiation and the maintenance of effective tillers.

Overall, the treatment group T3-T5 appears more suitable for the TU8 variety under the experimental conditions, with T5 producing the highest values for both maximum and effective tillers, suggesting potential for higher yield in subsequent analyses.

The results in Table 4 indicate that the wide-narrow row transplanting method had a significant effect on pest and disease incidence in the TU8 rice variety. In the traditional planting arrangements (T1 and T2), common diseases such as rice blast, brown spot, and bacterial leaf blight appeared at mild to moderate levels (scores 1-3). Notably, rice blast in T1 reached a score of 3, reflecting the dense planting and poor ventilation conditions that favor fungal development. Similarly, the presence of stem borers and leaf folder pests in T1-T2 (score 1) suggests that high planting density increases canopy humidity and light competition,

reducing plant resistance.

Table 4. Effect of wide-narrow row transplanting treatments on pest and disease incidence of TU8 rice

Unit: score

Treatment	Rice blast	Sheath blight	Bacterial leaf blight	Stem borer	Leaf folder	Brown planthopper
T1	3	2	2	1	0	0
T2	2	2	2	1	1	0
T3	1	1	1	0	1	0
T4	1	1	1	0	0	0
T5	0	0	0	0	0	0

In contrast, the wide-narrow row treatments (T3, T4, T5) showed a marked reduction in pest and disease severity. In T3 and T4, most diseases were limited to a score of 1 or were absent, and stem borers were no longer observed. The most remarkable result was in T5, where all pest and disease incidence scores were 0. This highlights the role of an open canopy structure in the wide-narrow row system: enhanced ventilation, reduced leaf wetness, improved light and air circulation, which together suppress fungal and bacterial pathogens and limit insect colonization. These findings are consistent with previous studies. Pham et al. (2020) reported that widely spaced rice had lower incidence of rice blast and brown spot compared to dense planting. Singh et al. (2019) also observed that wider row spacing reduced pest density in rice fields in India. Li et al. (2021) emphasized that improved canopy ventilation is a critical factor in managing diseases in high-yield rice systems.

An important observation in this study is that the TU8 variety exhibited greater pest and disease tolerance when grown under wide-narrow row conditions, demonstrating a positive interaction between the planting technique and varietal characteristics. This provides strong evidence that optimizing planting space not only affects growth and yield but also serves as an effective, low-cost, and environmentally friendly integrated pest management strategy.

Overall, the results suggest that T5 is the optimal treatment, minimizing pest and disease incidence (score 0) while providing favorable conditions for high and stable yield in subsequent analyses.

Table 5 shows that the wide-narrow row transplanting treatments positively affected yield components and the actual grain yield of the TU8 rice variety.

The number of panicles per m² ranged from 250.09 to 256.39 panicles, with T4 achieving the highest value (256.39 panicles/m²), approximately 2.5% higher than T1. Similarly, the number of grains per panicle increased under the wide-narrow row treatments, with T4 and T5 reaching 155.49-155.32 grains/panicle, significantly higher than T1 (152.16 grains/panicle). These results reflect the improved differentiation of panicle primordia and grain formation when plants receive sufficient light and nutrients due to optimal density and row arrangement. These findings are consistent with previous research, such as Nguyen et al. (2016).

Table 5. Effect of wide-narrow row transplanting treatments on yield components and grain yield of TU8 rice

Treatment	Number of panicles per square meter (panicles)	Number of grains per panicle (grains)	Percentage of filled grains (%)	Weight of 1000 grains (g)	Grain yield t ha ⁻¹
T1	250.09 ^c ± 1.68	152.16 ^a ± 2.93	80.32 ^b ± 0.72	22.61 ^a ± 0.32	6.27 ^b ± 0.21
T2	251.62 ^{bc} ± 2.45	152.35 ^a ± 2.69	80.75 ^{ab} ± 0.35	22.67 ^a ± 0.29	6.37 ^{ab} ± 0.16
T3	252.17 ^{bc} ± 2.16	154.31 ^a ± 1.94	80.68 ^{ab} ± 0.56	22.69 ^a ± 0.21	6.46 ^{ab} ± 0.17
T4	256.39 ^a ± 3.21	155.49 ^a ± 1.16	81.49 ^a ± 0.64	22.71 ^a ± 0.28	6.69 ^a ± 0.28
T5	255.65 ^{ab} ± 2.96	155.32 ^a ± 1.79	81.36 ^{ab} ± 0.96	22.65 ^a ± 0.24	6.64 ^a ± 0.24

Grain filling rate and 1000-grain weight: The treatments did not cause significant differences in grain filling percentage (80.32-81.49%) or 1000-grain weight (22.61-22.71 g), indicating that TU8 forms stable, well-filled grains relatively independent of row arrangement, though a slight increase was observed in T4. This is consistent with Pham et al. (2023), who reported that panicle number and grains per panicle are more responsive to planting density than grain quality (filling rate and grain weight). Similar trends were reported by Pham et al. (2020), Singh et al. (2019), Dong et al. (2022), Li et al. (2021), and Tang et al. (2025), showing that appropriate row spacing improves individual plant growth, photosynthetic efficiency, and effective grain number, ultimately enhancing yield in intensive rice systems.

Actual grain yield ranged from 6.27 to 6.69 t/ha. T4 achieved the highest yield (6.69 t ha⁻¹), followed by T5 (6.64 t ha⁻¹), approximately 6.7% higher than T1. This improvement reflects the combined effects of increased panicle number, grains per panicle, and effective tiller ratio, along with reduced competition for light and nutrients under optimized wide-narrow row arrangements. Therefore, the yield improvement is not only due to greater plant height or biomass but also to optimized tiller and panicle development, combined with reduced pest and disease damage (as shown in Table 4). Overall, the T4-T5 treatments represent the most effective wide-narrow row configurations for TU8, enhancing sustainable yield while lowering pest management costs and being suitable for the ecological conditions of coastal plains and midland regions in northern Vietnam.

CONCLUSION

The wide-narrow row transplanting treatments significantly influenced growth, tillering capacity, biomass accumulation, pest and disease incidence, and yield of the TU8 rice variety. Plants grown under T3, T4, and T5 treatments were taller and accumulated more biomass than those under T1 and T2, with T4 and T5 consistently showing the highest and most stable values. Tillering was markedly improved, with the maximum and effective tiller numbers highest in T5, while the effective tiller ratio remained stable.

The wide-narrow row arrangement substantially reduced the incidence of rice blast, brown spot, bacterial leaf blight, and insect pests; T5 showed almost no pest or disease occurrence throughout the growth period. Yield components including panicle number per m², grains per panicle, grain filling rate, and 1000-grain weight were improved by optimal row arrangements, resulting in the highest actual yields of 6.64-6.69 t ha⁻¹ in T4 and T5. These results indicate that T4 and T5 represent the optimal planting configurations, simultaneously enhancing growth and yield while reducing pest and disease losses.

These findings provide important scientific evidence to support technical recommendations for wide-narrow row transplanting of TU8, contributing to sustainable yield improvement and efficient pest management in rice production in Vietnam.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest related to the publication of this article.

REFERENCES

- Bouman, B. A. M., Humphreys, E., Tuong, T. P., & Barker, R. (2007). Rice and water. *Advances in Agronomy*, 92, 187–237. [https://doi.org/10.1016/S0065-2113\(04\)92004-4](https://doi.org/10.1016/S0065-2113(04)92004-4)
- Bui, H. D. (1999). *Some issues on the rice plant*. Agriculture Publishing House, Hanoi.
- Connor, D. J. (2004). Cropping systems: Irrigated rice and wheat of the Indo-Gangetic Plains. In *Encyclopedia of Plant and Crop Science* (pp. 355–357). Marcel Dekker Inc.
- Counce, P. A., Keisling, T. C., & Mitchell, A. J. (2000). A uniform, objective, and adaptive system for expressing rice development. *Crop Science*, 40(2), 436–443. <https://doi.org/10.2135/cropsci2000.402436x>
- Dong, L., Li, X., Guo, T., & Wang, Y. (2022). Phytochrome-mediated shade avoidance and its role in plant architecture in rice. *Frontiers in Plant Science*, 13, 851234.
- Dong, L., Yang, T., Ma, L., & Li, Y. (2025). Optimization of row and hill spacing patterns improved rice population structure and increased rice yield. *Frontiers in Plant Science*, 16, 1570845. <https://doi.org/10.3389/fpls.2025.1570845>
- Hasan, M., Hossain, M., Uddin, M., Kobir, M., & Kabir, M. (2022). Effect of plant × row spacing on two varieties of Boro rice. *SAARC Journal of Agriculture*, 19(2), 95–106. <https://doi.org/10.3329/sja.v19i2.57674>
- Juliano, B. O. (Ed.). (1994). *Rice chemistry and technology* (2nd printing). The American Association of Cereal Chemists.
- Li, H., Zhou, M., & Liu, J. (2021). Effects of hill and row spacing on canopy structure, photosynthesis, and yield of rice under dense planting. *Field Crops Research*, 274, 108321.
- Maclean, J., Hardy, B., & Hettel, G. (2013). *Rice almanac: Source book for one of the most important economic activities on Earth* (4th ed.). International Rice Research Institute (IRRI).
- Nguyen, H. T., et al. (1997). *Textbook of food crops, Vol. I: Rice*. Agriculture Publishing House.
- Nguyen, T. L., & Pham, T. D. (2005). *Textbook of experimental methods*. Agricultural Publishing House.
- Nguyen, V. H. (2003). *Rice and high-yield cultivation techniques for farmers*. Nghe An Publishing House.
- Nguyen, H. N. (2007). *Vietnamese specialty rice*. Agricultural Publishing House.
- Nguyen, X. D., Le, Q. A., Do, T. T. H., & Le, T. T. (2016). Study on determining wide–narrow row transplanting spacing to exploit the border-row effect in hybrid rice (Thai Xuyen 111) production in Nam Dinh Province. *Vietnam Journal of Agricultural Science and Technology*, 5(66), 58–65.
- Nguyen, T. D., & Nguyen, T. T. T. (2019). Study on the growth characteristics, development, and yield of several new pure rice varieties in the summer-autumn crop in Tu Son Town, Bac Ninh Province. *Vietnam Journal of Agricultural Science and Technology*, 4(101), 52–55.
- Pham, T. V., Nguyen, Q. B., & Tran, H. P. (2020). Effects of planting distance on the growth and yield of rice in the Red River Delta. *Vietnam Journal of Agricultural Science*, 18(3), 55–63.
- Reed, N. H., Butts, T. R., Norsworthy, J. K., Hardke, J. T., Barber, L. T., Bond, J. A., Bowman, H. D., Bateman, N. R., Poncet, A. M., & Kouame, K. B. J. (2024). Ecological implications of row width and cultivar selection on rice (*Oryza sativa*) and barnyardgrass

- (Echinochloa crus-galli). *Scientific Reports*, 14, 24844. <https://doi.org/10.1038/s41598-024-76849-1>
- Singh, A. K., Pal, S., & Sharma, R. K. (2019). Plant spacing and nitrogen levels influence growth and yield attributes of transplanted rice. *International Journal of Current Microbiology and Applied Sciences*, 8(2), 1234-1242.
- Tang, L., Song, J., Cui, Y., Fan, H., & Wang, J. (2025). Research progress on a wide and narrow row cropping system. *Agronomy*, 15(1), 248. <https://doi.org/10.3390/agronomy15010248>
- Zaman, Q. U., Javaid, S., Nazir, S., & Sharif, S. (2000). Rice plant growth and development. In *Rice production knowledge and practices for ensuring food security* (pp. 10-17).