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Tailoring nitrogen fertilizer regimes to complement growth dynamics of diverse rice genotypes

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Abstract Vegetative metrics and crop growth dynamics showed distinct trends amongst varieties IPB 3S exhibited early vigor in plant height, HIPA 21 showed prolific tillering while Mentik Wangi maintained conservative resource allocation across nitrogen levels. Yield component distribution and productivity diverged markedly; Hipa 21 achieved maximal grain weights per hill yet spikelet fertility constrained its yields below Inpari 33, which displayed enduring panicle formation and grain filling capacity translated into the highest yields overall. The results showed that the fertilizer at a dose of 90 kg ha^{-1} increased production yield and other production components. Concentrating availability during vegetative establishment and heading stages could show further potential productivity in initially vigorous types like Hipa 21 This research signified that accounting for genotypic growth traits and yield potentials is requisited to strategize nitrogen schemes for optimizing rice cultivar performance.

Keywords: Grain filling, Yield potensial, Varieties, Nutrition

Introduction

Rice is a basic need for the global population, the need for rice will continue to increase along with population growth. Increasing productivity is one of the efforts made to increase production to meet rice needs. Increasing rice production and productivity can be achieved by using superior varieties. High-yielding varieties have high yield potential and are tolerant to several stresses. Efforts to increase rice productivity through the development of superior rice varieties with high yield potential still encounter several problems such as high levels of emptiness. High voids and low grain filling percentages are the main factors that cause high production not to be achieved (Widyaningtias *et al.,* 2020).

Nitrogen application plays a crucial role in the cultivation of rice. Nitrogen is a primary macronutrient needed by rice plants in large quantities. Nitrogen

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plays a vital role in vegetative growth, leaf development, chlorophyll formation, as well as the process of photosynthesis for the production of carbohydrates and plant biomass (Noor *et al.,* 2023) Therefore, meeting nitrogen needs optimally through nitrogen fertilization is very important. Nitrogen (N) is an element needed by plants in large quantities. Nitrogen is a constituent element of protein amino acids, nucleic acids in plant growth (Buhaira, 2009).

Nitrogen has an important role in increasing rice crop production, sufficient availability of N in the generative phase is essential in slowing down the aging process of leaves, and maintaining photosynthesis during the grain filling phase (Syahril *et al.,* 2017). Proper dosing and timing of nitrogen application can significantly improve the yield and quality of rice crops. Splitting nitrogen application into multiple doses based on crop requirements not only reduces nitrogen loss but also enhances nitrogen absorption through increased root growth (Wang *et al.,* 2022). Rice cultivation is a complex process that requires careful attention to detail, especially when it comes to nitrogen application.

Application of the right dose of nitrogen at each phase of plant growth can spur growth and yield increase, while excess or lack of nitrogen can hinder productivity (Asmuliani *et al.,* 2021). In addition, the timing of nitrogen administration in accordance with the plant growth phase also determines the efficiency of absorption and production response (Djaman, 2018). Thus, determining the right dose and timing of nitrogen application based on the variety and planting phase is very important to support maximum rice productivity.

The use of appropriate nitrogen application regimes has been shown to not only enhance the root system for better absorption of water and nutrients but also to improve rice production and productivity. Balancing the nitrogen fertilization to maximize yield while minimizing the risk of lodging is essential for the successful cultivation of rice crops (Zhang *et al.,* 2023). Split nitrogen fertilization has been proven to be effective in rice cultivation, with studies showing that grain yield increases with the increase in split application of nitrogen fertilizer at various stages of the crop (Hirzel *et al.,* 2011).

The next sections will delve further into the importance of nitrogen application in rice cultivation, exploring the various factors that come into play, such as irrigation scheduling, weed management, and the influence of nitrogen on grain yield, quality parameters, and soil microbial activities. Therefore, it is crucial to determine the optimum dosage and timing of nitrogen application in rice cultivation to ensure optimal growth, productivity, and grain quality. Nitrogen is not only essential for the growth and metabolic processes of rice but also plays a pivotal role in the development of yield capacity and maintenance of photosynthetic activity during the grain-filling stage (Zhang *et al.,* 2011).

The efficient use of nitrogen can be further improved by integrating it with irrigation scheduling and effective weed management. By aligning the timing of nitrogen application with irrigation scheduling, the availability of nitrogen to the crops can be enhanced, subsequently increasing the grain yield of rice in aerobic rice cultivation. Furthermore, split application of nitrogen not only influences the grain yield and its attributes but also impacts the quality parameters of the grain and the activities of soil microorganisms (Zhao *et al.,* 2022). Additionally, nitrogen is a major consumer of fertilizer nitrogen and accounts for a significant portion of the total nitrogen consumption in many countries. As such, the application of an optimum dose of nitrogen to rice is imperative to ensure its efficient utilization and the optimal growth and yield of the crops (Zhou *et al.,* 2022). There are significant varietal differences in terms of nitrogen use efficiency and response to N fertilization (Fageria *et al.,* 2011). Therefore, the development of nitrogen management practices tailored to specific varieties is essential to optimize productivity and reduce environmental risks. It is important to note that the dosage and timing of nitrogen application in rice cultivation may vary depending on geographic location, soil conditions, and specific rice varieties. Therefore, it is important to consider these factors and conduct site-specific trials and experiments to determine the most appropriate dosage and timing of nitrogen application for each rice.

The study aimed to determine the effect of nitrogen dose and time on several types of rice, namely new high-yielding varieties, new types of rice, local rice and hybrid rice on growth and production.

Materials and methods

The research was conducted at the Indonesian Agency for Agricultural Research Experimental Station in South Sulawesi, Maros. The research was conducted from December 2021 to April 2022. Climatic conditions during the study were an average temperature of 25.6 ^{0} C, an average humidity of 84.1%, an average monthly rainfall of 551.78 mm, and an average number of rainy days of 26 days. Soil texture is 33% sand, 4% dust and 23% clay, with ph 6.45 and a nitrogen content of 0.14%.

The implementation of field research began with 2 tillages with plowing and harrowing. The first process is carried out 2 weeks before planting and the second process one week before planting. Rice is planted with seedlings aged 14 days; the planting distance used is 20 cm x 20 cm. Planting with 3 seedlings per planting hole. Embroidery is carried out at the time of 2 MST. Pest control is carried out by routinely controlling the symptoms of attacks that occur in the field. The fertilizer used is urea with the dose adjusted to the treatment, SP36 50 kg ha^{-1} and KCl 50 kg ha^{-1}. The application time of urea fertilizer is carried out according to the treatment while the application of SP36 and KCl fertilizers is given at the same time at the time of planting. Weed control is carried out by manual and chemical means. Harvesting is carried out at the time of entering physiological ripening, which is characterized by a yellowing grain color of 90%.

The experimental design used was a split-plot design consisting of two treatment factors, namely variety (main plot) and time and dose of fertilization N (subplot). The variety factor consists of 4 varieties, namely IPB 3S (new type varieties), Inpari 33 (new high-yielding varieties), and Hipa 21 (hybrids), and Mentik Wangi. Nitrogen consists of 4 levels, namely 0 kg N ha^{-1}, 9 (low N), 45 kg N ha^{-1} when planting (medium N), 90 kg N ha^{-1} (N optimum twice the application which is 45 kg when planting and 45 kg at panicle initiation) and 90 kg N ha^{-1} (N optimum three times the application which is 45 kg when planting 22.5 kg at age at panicle initiation and 22.5 kg at heading). So, there are 48 units.

Morphological observations include plant height (cm), number of productive tillers (clumps), and leaf area (cm^2) as measured using Leaf Area Meters. Physiological response observations include net assimilation rate, and Crop Growth Rate (CGR) measurement. Calculation of plant growth rate using the formula (Rajput *et al.,* 2017) and production components.

The effect of the treatment was tested by variance analysis (ANOVA). If it differs markedly, it is continued by separating the median value using the honestly significant difference (HSD) at a level of α 0.5.

Results

Plant height

Result indicated significant differences in plant height between the rice varieties across the observation period (Figure 1). The IPB 3S variety exhibited the greatest plant stature, achieving the tallest height overall as well as at each weekly measurement. For example, at 8 weeks after planting, IPB 3S plants were 90 cm in height, compared to just 76 cm for the shortest variety, Mentik Wangi. In contrast, the plant height of Mentik Wangi was consistently the lowest over time, trailing the other taller varieties.

Furthermore, a general trend of increasing plant height over time was evident across all four rice varieties from 2 to 8 weeks after planting. However, the relative differences between the tallest (IPB 3S) and shortest (Mentik Wangi) varieties remained mostly stable.

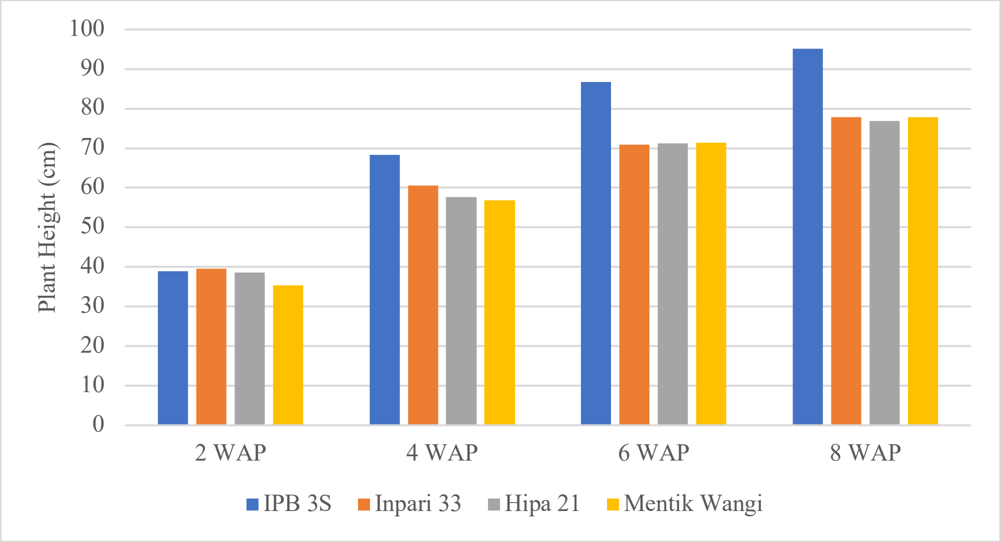

Figure 1. Plant height (cm) of various varieties at several weeks of observation

Number of tillers

The hybrid variety Hipa 21 demonstrated superior tiller formation capabilities producing the highest number of tillers at each measurement interval (Table 1). For instance, Hipa 21 generated 19.3 productive tillers per hill by 8 weeks after planting, 16% more than the next highest variety Inpari 33. In contrast, the new inbred variety IPB 3S exhibited substandard tillering performance, consistently forming the fewest number of tillers over time. These trends were observed at the earliest count at 2 weeks, where Hipa 21 produced 25% more tillers than IPB 3S.

Table 1. The number of saplings of rice varieties for 8 weeks after planting

Varieties	Number of Tiller			
	2 WAP	4 WAP	6 WAP	8 WAP
IPB 3S	4.9b	9.2b	9.8b	9.5b
Inpari 33	5.8ab	16a	18.6a	18.1a
Hipa 21	6a	17a	19.9a	19.3a
Mentik Wangi	6.2a	16.9a	19.3a	19a

Note: Numbers followed by the same letter in the means row show no significant difference based on the HSD test at the level of 5%.

Leaf area

The control with no nitrogen (N0) showing Mentik Wangi exhibited the greatest leaf area, followed by Inpari 33, Hipa 21 and IPB 3S in descending order (Figure 2). It indicated that without fertilization, Mentik Wangi had the most vigorous natural vegetative growth, while IPB 3S showed the lowest leaf area development.At the first level of nitrogen applied (N1 treatment), the variety with the highest leaf area was Inpari 33, surpassing Mentik Wangi from the unfertilized control, while IPB 3S now had the smallest leaf area. When the plants were given a medium quantity of nitrogen (N2), the variety with the greatest leaf area was Hipa 21, reversing its position from the unfertilized control. Inpari 33 now had the lowest leaf area under medium nitrogen rates. Finally, under highest optimal nitrogen (N3), Mentik Wangi again showed the largest leaf area, recovering from its second place position under low nitrogen. Hipa 21 exhibited the smallest leaf area with high nitrogen, dropping from its top position at medium nitrogen. Hence, Mentik Wangi experienced the greatest boost in leaf growth from high nitrogen availability.

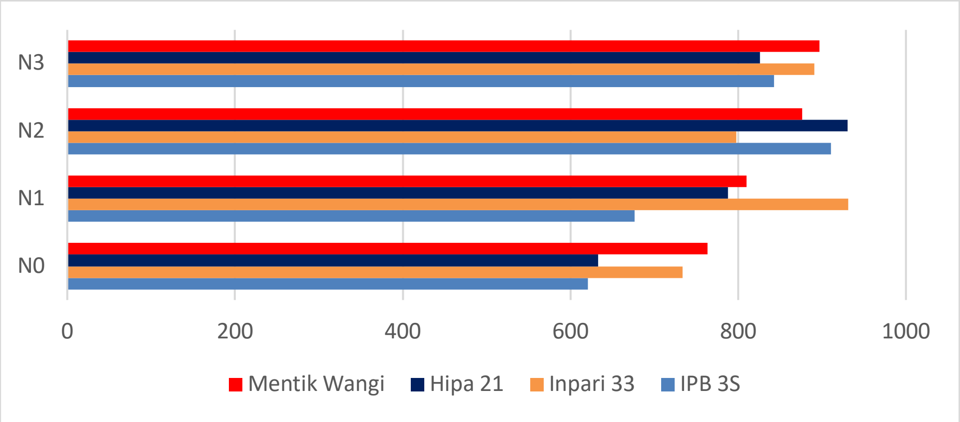

Figure 2. Leaf area of rice varieties at various doses of nitrogen

Crop growth rate

During the early vegetative phase (the first 20 days after planting), IPB 3S and Inpari 33 attained superior crop growth rates which exceeded 25 g m² day⁻¹, outpacing the other two varieties is show in Figure 3. However, distinct trends were noticeable across later developmental stages amongst the genotypes. While IPB 3S experienced a subsequent decline in crop growth rate after vegetative establishment, Inpari 33 demonstrated an ability to maintain rapid, consistent biomass accumulation well into the primordia formation and heading stages. Contrastingly, the crop growth rate of Mentik Wangi and hybrid Hipa 21 and progressively tapered off as the plants transitioned beyond early vegetative development, indicating its focus on prioritizing robust seedling establishment and initial growth.

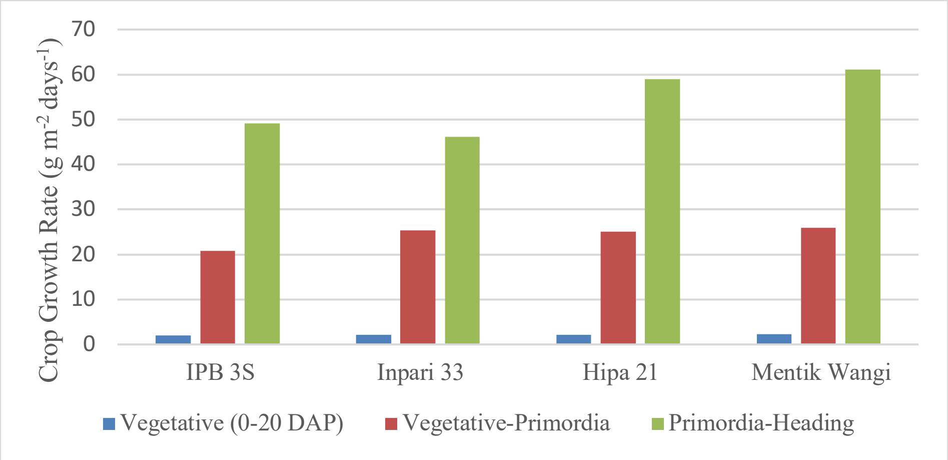

Figure 3. Crop growth rate at several phases of plant growth

Net assimilation rate

There was no variation in net assimilation rate among the varieties, showing a steady rate from the vegetative phase to the primordia phase (Figure 4). The rate of net assimilation increased in the vegetative period (10–20) DAP. The Mentik Wangi variety and the Inpari 33 variation differed noticeably in primordia-heading. In the primordia heading phase, the Inpari 33 variety exhibited the lowest variety, whereas fragrant picking yields the best absorption rate. The net absorption rate of the vegettative-primordia phase of all kinds decreased in the heading primordia phase.

Productivity

The Hipa 21 variety produced more grains per panicle and more weight of grains per clump as compared to IPB 3S and Inpari 33; nonetheless, its productivity is the same as Mentik Wangi (Figure 5). Conversely, Mentik Wangi is identical to IPB 3S. IPB 3S'slow performance in this study which may be caused by a high level of grain emptiness. It implied that the size of a Hipa 21 washbasin in this state was enormous. The variety Hipa 21 achieved the highest grain yield, reaching 8.03 ton/ha with no difference across nitrogen rates. Hybrid rice varieties can significantly outyield other rice varieties, with a 9-20% yield advantage over inbred rice varieties.

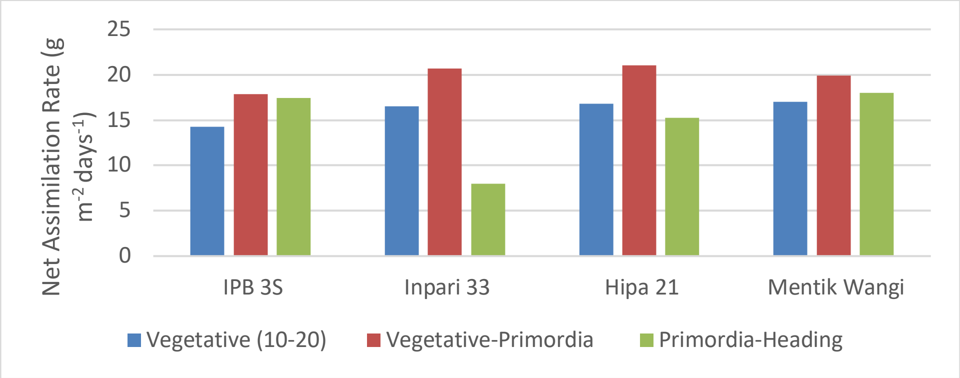

Figure 4. The Net of assimilation rate of plants in phases of plant growth

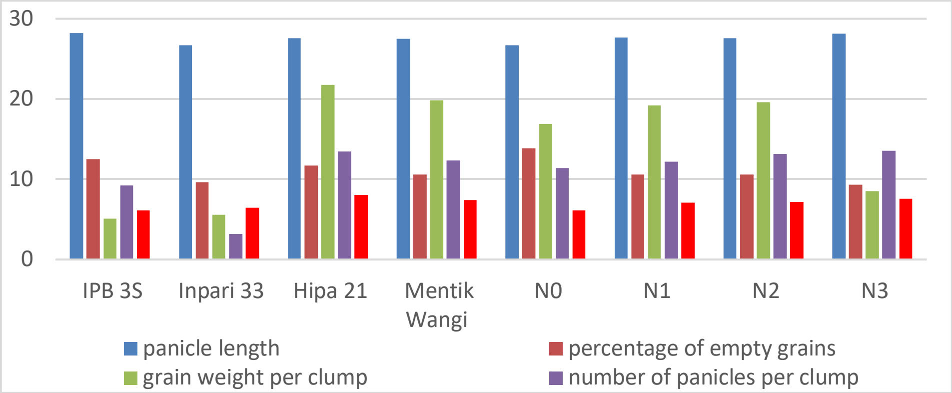

Figure 5. Production components on different varieties and doses of nitrogen

Discussion

The varietal differences in plant height suggest dissimilar early growth vigor and shoot elongation rates between taller, more rapidly growing varieties such as IPB 3S and shorter, slower growing types like Mentik Wangi, as morphological characteristics are key indicators for assessing plant responses (Darmadi *et al.,* 2021). Determining optimal nitrogen application regimens may require balancing requirements for enhancing the stature of shorter varieties without excessively increasing vertical growth of already taller varieties. Further field experiments should explore impacts of tailored nitrogen rates and timing specific to the inherent growth patterns exhibited by each distinct rice variety.

The variations in plant height among different rice varieties may be influenced by their genetic makeup and their response to different levels of nitrogen fertilizer applied (Anamul *et al.,* 2022).

Hybrid rice produces a greater number of tillers compared to other varieties. This is supported by research on hybrid rice genotypes, which found that tiller number is an important trait associated with yield in rice (Bian *et al.,* 2015). Additionally, a study on the agronomic performance and yield of hybrid rice genotypes in Indonesia revealed that the number of tillers per plant was one of the traits used for selection, indicating its significance in determining yield (Kartina *et al.,* 2020). It is evident that the inherent genotypic traits for prolific tillering differed appreciably between varieties, with the hybrid Hipa 21 optimized for abundant tiller initiation and emergence. Meanwhile, IPB 3S seemed to focus more growth efforts into vertical shoot elongation rather than lateral tiller development during early crop establishment, perhaps indicating a trade-off between plant height and tiller quantity. Developing site-specific, variety-tailored nitrogen management plans should hence account for this range of morphological strategies across rice types. Matching fertilizer rates and timing to complement the exponential tillering capacity of varieties like Hipa 21 or boosting the restricted tillering ability of types similar to IPB 3S may aid optimization of nitrogen efficiency (Singh *et al.,* 2023).

Mentik Wangi exhibit substantial expansions in leaf area at higher nitrogen levels, indicating a capacity to exploit available nitrogen for growth enhancement. Other cultivars like Mentik Wangi maintain relatively consistent leaf area across all nitrogen treatments. This suggests that different rice varieties may have varying responses to nitrogen application, and it is important to consider the specific characteristics of each variety when determining the dosage and timing of nitrogen application in rice cultivation (Tao *et al.,* 2022) Therefore, it is crucial for farmers to assess the specific needs and characteristics of their rice varieties, as well as factors such as soil conditions and geographic location.

The optimal dosage and timing of nitrogen application in rice cultivation depend on various factors such as the rice variety, location, soil conditions, and crop growth stage. Overall, the dosage and timing of nitrogen application in rice cultivation play a crucial role in maximizing crop yield, minimizing environmental risks, and catering to the specific needs of different rice varieties (Sangothari *et al.,* 2023).

Mentik Wangi and Hipa 21 demonstrated relatively consistent net assimilation rates over time rather than stage-specific fluctuations, implying steady nitrogen-use efficiency despite transitions between developmental milestones. These trends showcase the range of potential photosynthetic patterns amongst rice genotypes. Tailoring timely nitrogen additions to boost net assimilation rates during the most responsive windows for each variety, whether the early vegetative stage for IPB 3S or later reproductive phase for Inpari 33, is key for optimizing nitrogen-use efficiencies. Research has shown that the growth and productivity of rice, including the varieties IPB 3S and Inpari 33, are influenced by the timing and type of fertilizer applications. For instance, the impact of nitrogen reduction on growth, biochemical compounds, and metabolites in rice varieties, including Inpari 33, has been studied, emphasizing the importance of fertilization in promoting growth and yield (Slameto *et al*., 2023; Zhang *et al.,* 2023).

Variety significantly affected key yield components whereas nitrogen fertilization level impacted grain quality and some yield aspects. The rice varieties showed differences in panicle length, filled spikelets per panicle, number of productive tillers, and ultimately grain yield. In contrast, nitrogen mainly exhibited an effect on sterile or unfilled grains percentage and to a limited degree, panicle measures. This is supported by findings that leaf nitrogen content significantly affects starch accumulation in grain, especially during panicle initiation (Nurhermawati *et al*., 2023). However, no interaction was found between variety and nitrogen level for any observed yield parameters. This suggests the two factors operate independently on separate yield mechanisms in the rice crop.

This yield advantage is mainly attributed to higher biomass production and lodging resistance, especially under high nitrogen (N) fertilizer environments (Xu *et al.,* 2021) Grain yield plateaued at the highest nitrogen level of 28 kg N/ha, yielding 7.57 ton/ha. Factors intrinsic to the variety, such as genotype, influence grain filling or weight (Ma *et al.,* 2023). The grain weight and grain-filling rate (GFR) parameters are mainly influenced by genotype, while grain-filling period parameters are mainly influenced by the environment. There is a significant difference in GFR parameters among cultivar groups based on grain weight, indicating that high-grain-weight cultivars have higher GFR (Miao *et al.,* 2018)

In conclusion, significant differences were observed amongst rice varieties for growth attributes and yield component distribution in response to nitrogen supply. Initial vigorously growing hybrid types like Hipa 21 demonstrated substantial early vigor in traits like plant height and tillers, potentially benefiting from greater nitrogen provisions during key vegetative processes to maintain robust biomass production. Dosage of nitrogen administration 90 kg N ha^{-1} (N optimum three times the application which is 45 kg when planting, 22.5 kg at age at panicle initiation and 22.5 kg at heading) showed the best results grain yield improvement and production components.

Meanwhile, continually responsive elite lines exhibited enduring capacity for reproductive development, effectively translating nitrogen resources into elevated sink formation and grain filling even at later crop stages. This highlights the importance of customizing nitrogen regimes to match variety-specific growth phenology and nitrogen utilization dynamics.

Tailoring application rates and timing to complement the innate assimilation capacities and developmental patterns of genotypes like high-yielding Hipa 21 hybrids versus emerging elite inbred lines is shown to be integral to unlock genetic yield potentials across diverse rice varieties for current and future sustainable production.

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