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The Role of Net Assimilation Rate and Nitrogen Management in Optimizing Rice (*Oryza sativa* L.) Yield

Faisal[1], Iskandar Lubis[2], Ahmad Junaedi[2], Didy Sopandie[2]

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ABSTRACT

Background: The net assimilation rate (NAR) is a physiological parameter related to leaf area and dry weight per unit of time. It is used to figure out how much grain a plant will produce. This study aims to explain the net assimilation rate of several types of rice at different doses and nitrogen application times.

Methods: The research was conducted from December 2021 to April 2022. The experimental design was a split-plot design consisting of two treatment factors: the variety (main plot) and the time and dose of fertilization N (subplot). The variety factor consists of four varieties: IPB 3S (new type varieties), Inpari 33 (new high-yielding varieties), Hipa 21 (hybrids) and Mentik Wangi (local) at nitrogen 4 levels, namely 0 kg ha^{-1} (N0), 45 kg ha^{-1} applied when planting (N1), 90 kg ha^{-1} applied twice [45 kg at planting and 45 kg at panicle initiation (N2)] and 90 kg ha^{-1} applied three times, namely 45 kg at planting, 22.5 kg at the age of panicle initiation and 22.5 kg at heading (N3).

Result: Results demonstrated that applying 90 kg ha^{-1} nitrogen fertilizer in three split applications (N3) improved agronomic performance by increasing tiller number, leaf area, dry matter accumulation, leaf nitrogen content and grain yield compared to other nitrogen regimes. Our findings newly highlight the vital influence of net assimilation rate (NAR) on panicle development, as NAR was positively correlated with panicle length. Uniquely, among all four varieties tested, the local cultivar Mentik Wangi recorded the highest NAR across N treatments.

Key words: Dry weight, Photosynthesis, Leaf area, Seed filling.

INTRODUCTION

Rice is a vital food crop in Indonesia, with a total harvested area of 10.19 million hectares producing 53.62 million tons of rough rice with an average productivity level of 5.2 tons per hectare in 2023 (BPS, 2024). Despite concerted research and extension efforts over past decades, average rice productivity in Indonesia remains below its potential ceiling and lags behind other major rice growing Asian countries. There remains a significant yield gap estimated at 2-4 tons per hectare between farmers' fields and achievable yields under optimized crop and resource management (Sutardi, 2023). This signals the need to further refine agronomic and physiological factors attributing to sub-optimal rice performance across diverse Indonesian cropping systems and environment. The net assimilation rate (NAR) is an important physiological parameter for rice crops because it shows how quickly photosynthetic carbon is taken up by the plant and how it is distributed between different plant tissues. NAR is a key factor in determining grain yield because it directly affects the buildup of dry matter and, by extension, the increase in sink capacity. The more the net assimilation rate goes up, the better rice plants can use organic matter and turn it into growth and yield. In the context of rice cultivation, understanding and optimizing the net assimilation rate can be critical for maximizing productivity (Purwanto *et al.,* 2021)

The dose of nitrogen application gives positive results to the growth and yield of plants, especially an increase in the number of saplings, number of panicles, the weight of 1000 grains and an increase in grain (Dereje *et al.*, 2017). According to Djaman *et al.*, (2016), applying a dose of N 90 kg ha^{-1} fertilizer gives maximum results in producing aromatic rice varieties. The timing of the stacking provides the best results for rice productivity. The results of the research of Amrutha *et al.* (2016) showed nitrogen application of 50% at the time of planting, 25% at the time of sapling formation and 25% at the time of panicle initiation, recording 19.84% high grain.

Different varieties have varying levels of NAR that can influence their response to nitrogen fertilization applications. Varieties with higher rates of net assimilation tend to be more

[1]Program of Agronomy and Horticulture, Graduate School, Bogor Agricultural Institute. Jl. Meranti, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia.
[2]Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural Institute. Jl. Meranti, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia.

Corresponding Author: Iskandar Lubis, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural Institute. Jl. Meranti, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia. Email: iskandarlbs@apps.ipb.ac.id

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efficient at absorbing applied nitrates than varieties with lower levels, resulting in increased yields if administered in sufficient quantities at the right time during the plant development stage. On the other hand, too much fertilizer can lead to a decrease in yield due to excessive leaching or loss of volatilization when applied at a stage of maturity where the absorption capacity has been significantly reduced. According to Liu *et al.* (2023), N encourages crop productivity, but excessive fertilizer use also causes adverse effects; therefore, proper timing and dosage are important components for a successful production system by using different types of rice cultivars based on their respective NAR. Based on this, this study was conducted to find out and explain the net assimilation rate in several types of rice at different doses and times of N application.

MATERIALS AND METHODS

Experimental site

The research was conducted at the Research Farm of the Indonesian Agency for Agricultural Research and Development in South Sulawesi, Maros (4°59′05″S, 119°24′01″E), from December 2021 to April 2022. The climatic conditions during the study period were as follows: average temperature was 25.6°C; average relative humidity was 84.1%; average monthly rainfall was 551.78 mm; and average number of rainy days per month was 26 days. The soil texture composition was 33% sand, 41% silt and 23% clay, with a pH of 6.45 and 0.14% nitrogen content.

Treatment and experimental design

The implementation of field research begins with two rounds of tillage with ploughing and raking. Rice is planted with seedlings that are 25 days old. The plot size is 4 m × 4 m with a planting distance of 20 cm × 20 cm. It is planted with three seedlings per planting hole. The fertilizer used is urea with a dose adjusted to the treatment, SP36 50 kg ha^{-1} and KCl 50 kg ha^{-1}.

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 (sub plot). The variety factor consists of 4 varieties, namely IPB 3S (new type varieties), Inpari 33 (new high-yielding varieties), Hipa 21 (hybrids) and Mentik Wangi (local). Nitrogen consists of 4 levels, namely 0 kg ha^{-1} (N0), 45 kg ha^{-1} applied when planting (N1), 90 kg ha^{-1} applied twice applications, namely 45 kg when planting and 45 kg at panicle initiation (N2) and 90 N kg ha^{-1} applied three times application, namely 45 kg when planting, 22.5 kg at the age of panicle initiation and 22.5 kg at heading (N3). Each treatment was repeated three times so that there were 48 experimental units.

Morphological and physiological observations

Morphological observations include number of tillers and leaf area (cm^2) as measured using Leaf Area Meters. Physiological response observations include leaf N content, Crop Growth Rate (CGR) and net assimilation rate (NAR). Calculation of CGR and NAR rate using the formula (Rajput *et al.,* 2017):

$$CGR = \frac{W2 - W1}{P(t2 - t1)}$$

Where

P = Land area,

W1 = Dry weight of the plant m^{-2} recorded at time t1.

W2 = Dry weight of the plant m^{-2} recorded at time t2.

t1 and t2 = Time interval, respectively and it is expressed in g m^{-2} days^{-1}.

$$NAR = \frac{W2\text{-}W1}{A2\text{-}A1} \times \frac{\log e\ A2 - \log s_e A1}{t2\text{-}t1}$$

Where

W2 and W1 = Dry weights of plants at times t1 and t2,

$\log_e$ A2 and $\log_e$ A1 = Natural logs of leaf areas A1 and A2 at times t1 and t2.

Observations of production components include the number of panicles per clump, the number of grains per panicle, the percentage of empty grains, the weight of 1000 grains and the weight of grains per clump. Estimated yield per hectare with 1 m × 1 m tiles converted to hectares.

Statistical analysis

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 0.05.

RESULTS AND DISCUSSION

Morphological character of plants

The interaction between leaf area and nitrogen application (Table 1) indicates that appropriate nitrogen application, both in terms of dosage and timing, can enhance leaf area for each rice variety. In the case of IPB 3S and Hipa 21 varieties, leaf area increased with the N2 treatment. Inpari 33 exhibited increased leaf area with the N1 treatment, while the Mentik variety demonstrated increased leaf area with the N3 treatment. This suggests that the augmentation of leaf area is influenced by the specific variety, nitrogen dosage and the timing of fertilization. As noted by Syaifudin *et al.* (2018), the nitrogen dosage administered to plants significantly impacts leaf area.

The N3 nitrogen application resulted in increased tiller numbers compared to the treatment without nitrogen application (Fig 1). Consistent with findings by Nurhermawati *et al.* (2021), providing an adequate amount of nitrogen promotes cell formation in plant organs, optimizing the photosynthesis process and supporting the increased tiller count. Among the varieties, Hipa 21 exhibited the highest number of tillers.

Dry weight

Dry weight gain from 10 to 80 days after planting (Fig 2) demonstrated an overall increase with each treatment. The

Table 1: Interaction of leaf area of some rice varieties with the dose and timing of nitrogen applications.

Varieties	N0	N1	N2	N3
IPB 3S	620,76s	676,55bcd	910,91ab	842,43abcd
Inpari 33	733,94abcd	931,18a	797,72abcd	890,82ab
Hipa 21	633,03cd	787,71abcd	930.763a	825,61abcd
Mentik Wangi	763,16abcd	809,98abcd	876,34abc	896,77ab

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

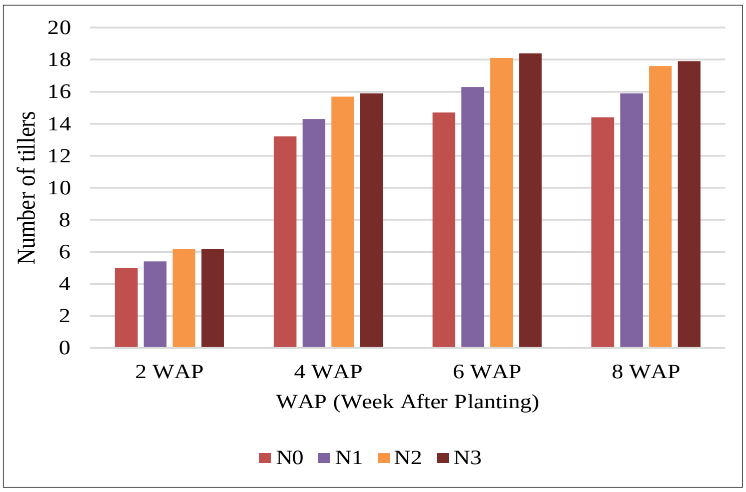

Fig 1: Number of tillers of several varieties of rice at various doses and timing of nitrogen application.

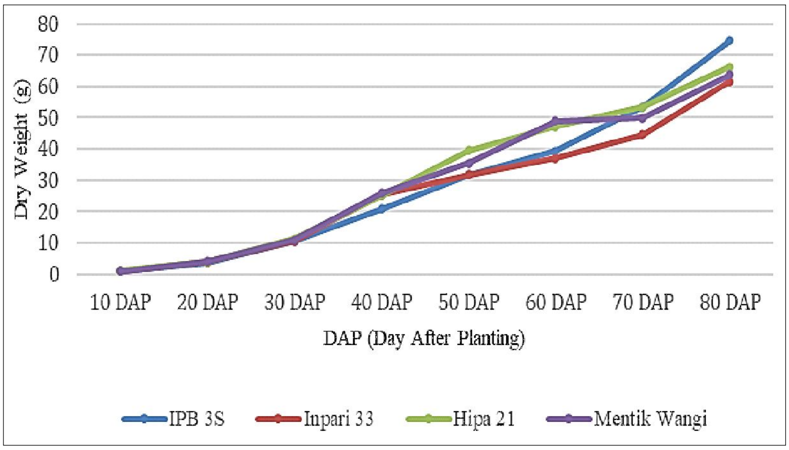

Fig 2: Dry weight several rice varieties at various doses and timing of nitrogen application.

N3 treatment, with the highest nitrogen dose, exhibited the most substantial increase in dry weight compared to other treatments. The observed increase in dry weight signifies the accumulation of organic compounds, particularly non-structural carbohydrates (NSC), comprising dissolved sugars and starch stored predominantly in the stem (Li *et al.,* 2017). Adequate nitrogen supply enables the rice plant to grow properly, especially producing a high number of leaves which lead to increased photosynthetic capacity. The enhanced photosynthesis subsequently provides more photoassimilates to support dry matter accumulation in the plant biomass. Therefore, optimal nitrogen availability allows better vegetative development which improves photosynthetic performance to facilitate carbon fixation and greater biomass production which is manifested as higher plant dry weight (Anas *et al.,* 2020).

Nitrogen content of the leaves

The IPB 3S variety exhibited the highest nitrogen content during the vegetative stage, while the Mentik Wangi variety demonstrated the peak nitrogen content during heading (Fig 3). Elevated nitrogen absorption during the heading phase contributes to delaying the aging process in plants, ultimately optimizing seed filling and yielding higher seeds (Nehe *et al.,* 2020).

As the plant transitions from vegetative to reproductive stages, nitrogen is remobilized from leaves and culms to the developing grains in the panicles. This reallocation of nitrogen to the grain sink results in an overall reduction in leaf nitrogen content during the generative phase. However, maintaining higher nitrogen levels for a longer period can prolong leaf activity and carbon supply for effective grain filling. In summary, sufficient leaf nitrogen status during the vegetative phase promotes canopy buildup and photosynthetic capacity to produce photoassimilates which can later be translocated to grains (Hikosaka *et al*., 2016). While generative stage nitrogen decline is typical, optimized nitrogen management aims to sustain adequate leaf nitrogen for more active photosynthesis and carbon translocation to the grain sink.

Crop growth rate

Plant growth rate, indicative of biomass production over a specific timeframe, showed a consistent increase in each growth phase (Table 2). Nitrogen application in each phase resulted in discernible differences compared to the no-N treatment. According to Taleshi *et al.* (2013), nitrogen positively influences plant growth rate by increasing tiller and leaf numbers. Nitrogen is an essential macro element for plants and plays a crucial role in various biological processes, including carbon metabolism, amino acid metabolism, nucleic acid metabolism and protein synthesis as a regulator of growth and production (Meena *et al.*,2021) The Mentik Wangi variety exhibited the highest growth rate, outperforming the Inpari 33 variety but showing no significant difference from Hipa 21 and IPB 3S. The higher growth rates of Mentik Wangi and Hipa 21 are attributed to their greater number of tillers and leaf areas compared to other varieties.

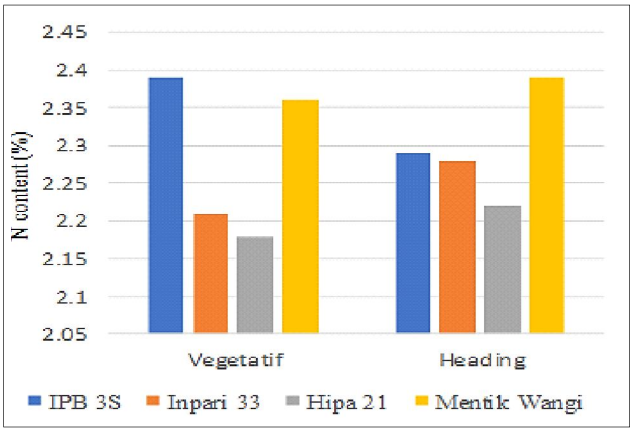

Fig 3: Nitrogen content leaves some varieties of rice at various doses and timing of nitrogen application.

Net assimilation rate

Results showed that net assimilation rate (NAR) increased from the vegetative to primordia phase across varieties, followed by a decline in the heading stage (Table 3). This NAR reduction aligns with decreasing leaf nitrogen content during heading, likely impairing photosynthetic efficiency as nitrogen plays vital roles in chlorophyll production, rubisco activity and assimilate partitioning (Olszewski *et al.*, 2014; Osaki *et al.,* 1995).

Uniquely revealing varietal differences, our data newly demonstrated that the local upland variety Mentik Wangi sustained the highest NAR across all treatment groups - significantly exceeding the improved lowland variety Inpari 33. The elevated NAR in Mentik Wangi concurred with its larger leaf area at heading, underlying its competitive photosynthetic performance. Supporting the positive influence of NAR on grain yield components, the 90 kg ha^{-1} nitrogen regimen in three split applications (N3) optimized panicle development and productivity traits across varieties compared to lower N rates. According to Aziez *et al.*, (2023) the relationship between NAR and nitrogen in the journal is that nitrogen fertilizer dosage, particularly at 90 kg ha^{-1}, positively influences NAR in both rainfed lowland rice and groundnut plants. This indicates that nitrogen plays a crucial role in enhancing the assimilation and growth processes in these crops.

Table 2: Crop growth rate of several rice varieties at various doses and timing of nitrogen applications.

Nitrogen dosage and varieties	Crop growth rate (g m^{-2} days^{-1})		
	Vegetative (0-20 DAP)	Vegetative-Primordia	Primordia-Heading
Varieties			
IPB 3S	2.04a	20.75a	49.10bc
Inpari 33	2.14a	25.34a	46.16c
Hipa 21	2.13a	25.09a	58.99ab
Mentik Wangi	2.25a	25.88a	61.03a
Nitrogen dosage			
N0	1.86b	20.36b	20.36b
N1	2.14ab	26.31a	54.60ab
N2	2.28a	24.55ab	55.79ab
N3	2.28a	25.84a	59.75a

Numbers followed by the same letter in the Means row show no significant difference based on the HSD test at the level of 5%. DAP: Day after planting.

Production components

Hipa 21 exhibited the highest number of grains per panicle and grain weight per cluster, resulting in significantly higher productivity compared to IPB 3S and Inpari 33, but comparable to Mentik Wangi (Table 4). This suggests that Hipa 21 possesses a larger sink size. The observed increase and subsequent decrease in stem and leaf dry weight from the primordia to heading phases can be attributed to this condition. Notably, hybrid rice, such as Hipa 21, tends to have higher yields compared to inbred varieties (Suyamto

Table 3: Net assimilation rate of some rice varieties at various doses and timing of nitrogen applications.

Nitrogen dosage and varieties	Net assimilation rate (g m^{-2} $days^{-1}$)		
	Vegetative (10-20 DAP)	Vegetative-Primordia	Primordia-Heading
Varieties			
IPB 3S	14.26a	17.83a	17.46ab
Inpari 33	16.53a	20.67a	7.9876b
Hipa 21	16.80a	21.00a	15,216ab
Mentik Wangi	16.98a	19.87a	17.99a
Nitrogen dosage			
N0	15.93a	19.91a	13.07a
N1	17.77a	22.22a	14.12a
N2	14.84a	18.25a	15.24a
N3	16.02a	18.99a	16.21a

Numbers followed by the same letter in the means row show no significant difference based on the HSD test at the level of 5%. DAP- Day after planting.

Table 4: Components of the production of several varieties of rice at various doses and times of nitrogen application.

Nitrogen dosage and varieties	Panicle length	Number of grains per panicle	Percentage of empty grains	Weight of 1000 seeds	Grain weight per clump	Number of panicles per clump	Yield (ton/ha)
Varieties							
IPB 3S	28.25a	191.86a	12.53a	30.01a	5.07b	9.22c	6.10c
Inpari 33	26.71b	207.63a	9.61a	29.81a	5.54b	15.14a	6.48bc
Hipa 21	27.57ab	218.15a	11.69a	27.54b	21.76a	13.5b	8.03a
Mentik Wangi	27.53ab	189.51a	10.59a	30.6a	19.82ab	12.36b	7.4ab
Nitrogen dosage							
N0	26.69b	180.28a	13.87a	28.88b	16.86b	11.42c	6.18b
N1	27.7ab	190.58a	10.61a	29.74ab	19.22ab	12.17bc	7.05ab
N2	27.56ab	218.78a	10.62a	29.16ab	19.61ab	13.11ab	7.19ab
N3	28.11a	217.50a	9.32a	30.18a	20.50a	13.53a	7.57a

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

Table 5: Coefficient correlation between observation parameters of several varieties of rice at various doses and times of nitrogen application.

Parameters	NT	LA	N	DW	CGR	NAR	PL	NG	NP	GE
LA	0.47**									
N	0.09	0.35*								
DW	0.47**	1.00**	0.35*							
CGR	0.29*	0.56**	0.29*	0.56*						
NAR	-0.18	0.19	0.18	0.19	0.72**					
PL	-0.20	0.18	0.22	0.18	0.42**	0.46**				
NG	0.23	0.24	0.06	0.24	0.17	-0.03	-0.03			
NP	0.58**	0.23	-0.26	0.23	0.04	-0.26	-0.34	0.26		
GE	-0.17	-0.41	-0.08	-0.41	-0.02	0.03	-0.02	-0.39	-0.25	
PD	0.50**	0.50**	0.24	0.50**	0.34**	0.20	0.38**	0.09	0.05	-0.20

* = Real correlation at α = 0.05; ** = Real correlation at α = 0.01; JA = Number of tillers; LA = leaf area; N = Leaf nitrogen; DW = Dry weight; CGR = Crop growth rate; NAR = Net assimilation arte; PL = Panicle length; NG = Number of grains per panicle; NP = Number of panicles per clump; GE = Grain empty; PD = Productivity.

et al., 2015). In this study, IPB 3S exhibited lower productivity, potentially linked to a higher incidence of grain emptiness.

These differential varietal responses concur with past evidence that genotypic variability in nitrogen response might be influenced by factors such as nutrient availability, application timing and concurrent growth-limiting stresses - highlighting the importance of strategic nitrogen management tailored to each variety in fully capturing its yield potential (Moharana *et al.,* 2019).

The correlation coefficient between observations

Productivity correlated with the number of tillers, leaf area, dry weight and CGR. Leaf area and actual dry weight correlated with CGR (Table 5). Significant interaction effect on the grain yield, which means that the combination of crop establishment method, rice varieties and nitrogen levels had a noticeable impact on the amount of rice produced (Nitrogen significantly correlated with dry weight, highlighting the pivotal role of nitrogen in increasing dry weight, developing leaf area and enhancing photosynthetic efficiency (Dordas and Sioulas, 2008). Dry weight exhibited a significant correlation with productivity, as it serves as a source of assimilates remobilized to seeds. During seed filling, flowering and physiological maturation stages, dry matter production has a higher correlation than in the early growth stages (Fageria, 2007). NAR significantly correlated with panicle length, indicating its efficiency in measuring each unit of leaf area's photosynthetic performance for plant dry matter accumulation (Sumardi *et al.,* 2019).

CONCLUSION

Optimizing nitrogen management is imperative to improve net assimilation rate (NAR) and panicle development in rice. Our findings newly demonstrate that applying N 90 kg ha^{-1} in three split doses (N3) elicited the highest NAR across varieties, concurring with N3 stimulation of tiller production, leaf area expansion, dry matter accumulation, leaf nitrogen content and grain yield compared to lower N rates. Of the four genotypes, the local variety Mentik Wangi uniquely recorded the top NAR under N3 regime. Moreover, NAR was positively associated with panicle length, supporting its influence on yield components.Accordingly, synchronizing N 90 kg ha^{-1} in three splits application with rice varieties - especially high NAR-types like Mentik Wangi - is recommended as the optimal combination to unlock yield potential.

Conflict of interest

No conflict of interest for this manuscript on behalf of all authors.

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