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RESEARCH PAPER

Growth, yield, and economic performance of hybrid and inbred lowland rice under ANAA and fertilizer regimes

Michael Abarilla Dotollo and Ulysses Alas Cagasan*

Department of Agronomy, Visayas State University, Visca, Baybay City, Leyte, Philippines

*Corresponding author's email: ulycagasan@vsu.edu.ph

Key Message: This study demonstrated that the application of 500 and 1000 ppm ANAA with half the recommended fertilizer rate promoted earlier heading and maturity, while 1000 ppm ANAA combined with half the recommended fertilizer rate produced more productive tillers, a higher percentage of filled spikelets, and heavier panicles, ultimately enhancing grain yield in t ha^{-1}.

Abstract

Plant growth regulators may influence the agronomic performance and yield potential of different rice varieties. Thus, this study aimed to determine the effects of ANAA and inorganic fertilizer on the growth and yield of lowland rice varieties; determine the appropriate concentrations that would give the optimum yield of lowland rice varieties; determine the interaction effects of using ANAA and inorganic fertilizer to the different lowland rice varieties; and evaluate the profitability of rice production per hectare using ANAA as plant growth regulators combined with inorganic fertilizer applied to lowland rice. The experimental area was laid out in a split-plot arranged in a Randomized Complete Block Design (RCBD) with three replications. Lowland rice varieties M_1 = hybrid rice variety and M_2 = inbred rice variety was designated as the main plot while plant growth regulators (T_1 = control [no fertilizer and plant growth regulator application], T_2 = 500 ppm ANAA + ½ RR, T_3 = 1000 ppm ANAA + ½ RR, and T_4 =120-60-60 kg ha^{-1} N, P_2O_5, K_2O [RR]) as the subplot. Results revealed that the application of plant growth regulators significantly affected the morphological and physiological characteristics of hybrid and inbred lowland rice varieties. Rice plants applied with ANAA regardless of the level (500 ppm & 1000 ppm-T_2-T_3), comparable to unfertilized plants headed and matured earlier than the plants applied with full RR 120-60-60 kg ha^{-1} N, P_2O_5, K_2O. Application of 1000 ppm ANAA+ ½ RR produced more numbers of productive tillers $hill^{-1}$ and higher percentage of filled spikelets. Plants that received ANAA regardless of the concentration (T_2-T_3) significantly obtained heavier panicle weight (g) and consequently grain yield (tha^{-1}). Average net income of both rice varieties is more or less similar of PhP50,066.05 for hybrid rice and PhP51,876.76 for inbred rice. The highest reported net income was PhP54,436.33 for hybrid rice and PhP55,156.17 for inbred rice, both under the recommended fertilizer rate of 120-60-60 kg ha^{-1}. It was followed by the hybrid rice receiving 500 ppm ANAA with half the recommended fertilizer rate (T_2) ranked next, at PhP49,991.17 and inbred rice at PhP49,164.67, respectively. © 2026 The Author(s)

Keywords: Alpha-naphthaleneacetic acid, Economic analysis, Fertilizer management, Grain yield, *Oryza sativa* L., Plant growth regulator

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Introduction

Population growth is expected to raise global food demand, with the world population projected to approach 9.7 billion by 2050 (Galanakis, 2024). Rice production systems therefore need to use land and inputs efficiently while maintaining farm productivity and profitability to address the demand for food security (Hamad & Tayel, 2026). Plant hormones regulate key processes throughout plant development (Philips et al., 2024) and help coordinate responses to environmental conditions such as illumination, soil characteristics, water supply, and nutrient availability (McKenzie, 2018). Growth-regulating compounds may be produced within plants or manufactured synthetically; synthetic compounds used to modify plant development are commonly described as plant growth regulators (Hariwal et al., 2025). Phytohormones are plant-produced organic compounds that can act in tissues beyond their site of synthesis, sometimes eliciting responses at very low concentrations (Bajguz & Piotrowska-Niczyporuk, 2023). Functionally, plant hormones include compounds that regulate processes such as cell proliferation and expansion, tissue specialization, tropic movement, flowering, and the development of fruits and seeds (Guleria et al., 2021; Khan, 2025). Other hormonal pathways are more closely linked with defense, injury responses, and adaptation to biotic or abiotic stress (Srivastava, 2002; Chakraborty et al., 2025; Das et al., 2025).

Plant growth regulators are commercially used in agriculture in several developed regions, including Europe, the

United States, and Japan. Their application is particularly common in high-value horticultural crops, where they are used to modify plant development and improve productivity (Prisa et al., 2026). In field crops, these substances can increase yield either by enhancing total biological production or by improving the harvest index (Basuchaudhuri, 2016). Plant growth regulators may also influence the agronomic performance and yield potential of different rice varieties (Tran et al., 2025; Mohammed et al., 2026). One such compound is naphthaleneacetic acid (NAA), a synthetic auxin associated with the regulation of plant growth and development (Khandaker et al., 2017; Mohamed et al., 2026). Alam (2002) reported that applying NAA at 20 ppm improved straw and grain yields in wheat cultivars. Similarly, Zahir (1998) found that different auxin concentrations significantly influenced rice growth and yield-related characteristics. Basuchaudhuri (2016) further reported that NAA application can stimulate root activity and facilitate nutrient uptake, thereby supporting plant growth and development. Its application may also improve yield-contributing traits, increase grain production, and promote the translocation of assimilates from source tissues to developing sinks by delaying leaf senescence.

Improving rice production also depends on selecting varieties with suitable yield potential. Hybrid rice has been reported to out-yield leading conventional varieties by around 15–20% (Haque et al., 2015; Yang et al., 2026). Such gains are important in rice-dependent regions where population pressure and limited arable land make higher production per unit area increasingly necessary. In view of these considerations, the present study was undertaken to identify suitable concentrations of ANAA plant growth regulator for maximizing the yield of hybrid and inbred lowland rice varieties. The specific objectives were to: (i) evaluate the effects of ANAA and inorganic fertilizer on the morphological and physiological characteristics of different lowland rice varieties; (ii) identify the ANAA concentration that produces the highest yield in lowland rice; (iii) examine the interaction effects of ANAA and inorganic fertilizer on rice growth and productivity; and (iv) assess the economic profitability of lowland rice production per hectare under different combinations of ANAA and inorganic fertilizer.

Materials and Methods

Experimental site and land preparation

Field work took place wet season cropping between January to April 2021 within an irrigated lowland rice production system located in Barangay Tagbibi, Hindang, Leyte, Philippines. The site measured 14 m by 24 m (336 m²). It was flooded for seven days before cultivation began, after which the soil was ploughed and harrowed for two times at one week interval, with the aid of a tractor for land preparation. Following the last harrowing operation, the soil surface was carefully leveled, and bunds were constructed to separate the main experimental plots. Irrigation and drainage channels were also established to facilitate water distribution and regulate water levels throughout the experiment.

Experimental design and treatments

A randomized complete block design (RCBD) with a split-plot treatment structure and three replications was used. Each replication contained five subplots, each 3 m × 4 m (12 m²). The subplot treatments represented the assigned combinations of ANAA plant growth regulator and inorganic fertilizer: The treatments are described as follows:

T1 Control: no fertilizer and no plant growth regulator
T2 500 ppm ANAA + half the recommended fertilizer rate
T3 1,000 ppm ANAA + half the recommended fertilizer rate
T4 Full recommended fertilizer rate (120-60-60 kg/ha N-P_2O_5-K_2O), without ANAA

Soil sampling and laboratory analysis

Before planting, ten soil samples were collected randomly from the experimental field at a depth of 20 cm. The samples were thoroughly mixed to obtain a composite sample, which was air-dried, pulverized, and passed through a 2-mm mesh sieve. Laboratory analyses were performed at the Central Analytical Services Laboratory (CASL), PhilRootcrops, Visayas State University, Visca, Baybay City, Leyte, Philippines. The soil samples were analyzed for pH using the potentiometric method at a 1:1 soil-to-water ratio (Philippine Council for Agriculture and Resources Research [PCARR], 1980); organic matter content using the modified Walkley–Black method (Nelson & Sommers, 1982); total nitrogen using the Kjeldahl method (American Society of Testing and Materials [ASTM], 2001); available phosphorus using the modified Olsen method (Olsen & Sommers, 1982); and exchangeable potassium using the ammonium acetate extraction method (International Soil Reference and Information Center [ISRIC], 1995). After harvesting, three soil samples were collected from each treatment plot. These samples were composited and processed using the same procedures described above. The same soil properties were analyzed to evaluate changes in soil chemical characteristics following the experiment.

Seedling production and transplanting

Seedlings were raised from around 380 g of SL-12H hybrid rice seeds in a 5.04 m² and NSIC Rc216 for inbred rice variety conventional seedbed equipped with irrigation and drainage channels. At 20 days of age, seedlings were moved to the experimental plots. Transplanting was carried out at 20-cm spacing both between rows and between hills, placing two seedlings in each hill.

Fertilizer and plant growth regulator application

Regional recommendations specified a full fertilizer application of 120–60–60 kg ha^{-1} of N, P_2O_5, and K_2O using

complete and urea fertilizers. The amount supplied to each plot followed its designated treatment. Spray volume was calculated from a field recommendation of ten tanks per hectare, corresponding to 160 L ha^{-1}; therefore, each 12-m^2 plot receiving ANAA required approximately 0.192 L of prepared spray. The solution was diluted to the assigned ANAA concentration before spraying. Application dates and rates are listed in Table 1.

Table 1 Timing and application rate of ANAA plant growth regulator (PGR)

Treatment	ANAA	Time of application
T_1	0	-
T_2	2 ml L^{-1}	20, 30, and 40 DAT
T_3	4 ml L^{-1}	20, 30, and 40 DAT
T_4	0	-

DAT = Days after transplanting

Management of golden apple snail

Golden apple snails (*Pomacea canaliculata* Lamarck), including visible egg masses, were removed by hand before and after transplanting. This operation was intended to limit snail injury to young plants and reduce the formation of gaps caused by missing hills.

Botanical pesticide application

A botanical pesticide prepared from panyawan was applied at a rate of 350 mL per 16 L of water to manage rice insect pests. The application was intended to minimize insect damage and protect the rice crop during its growth and development.

Irrigation and water management

Channels for irrigation and drainage were placed around the plots to regulate water supply and limit water exchange among treatments. Additional drains at the field boundary allowed surplus water to be removed during heavy rainfall. The site was initially flooded for leveling and then drained before transplanting. Irrigation resumed three days after transplanting, with water maintained at about 2–3 cm and raised gradually to 3–6 cm over the following week. Water depth was lowered temporarily during weeding and fertilizer application. The field was drained approximately seven days before harvest to facilitate access and crop collection.

Harvesting and postharvest handling

Rice plants from the designated harvest area were collected once about 85% of the grains on each panicle had attained maturity. Grain maturity was assessed based on the development of a yellow to golden color and the firmness and hardness of the mature grains. A sharp sickle was used to cut the panicles at their bases. Following harvesting, the panicles were threshed, and the grain was dried to approximately 14% moisture content. The dried grain was then winnowed to remove chaff and other impurities before the required yield and related data were collected.

Data collection

Data were collected to evaluate the agronomic performance, yield components, soil chemical properties, and economic returns of the experimental treatments. The agronomic traits recorded included the number of days from sowing to heading, the number of days from sowing to maturity, plant height (cm), leaf area index (LAI), and straw yield on a fresh-weight basis (t ha^{-1}). Yield performance was evaluated by measuring tillers bearing panicles per hill and spikelets containing developed grains as a percentage of total spikelets per panicle, panicle length (cm), panicle weight (g), thousand-grain weight (g), and grain yield (t ha^{-1}). In addition, soil chemical characteristics were analyzed, and an economic assessment was performed to compare the profitability of rice cultivation across the different treatment combinations.

Statistical analysis

Treatment means were calculated and the collected data were subjected to analysis of variance (ANOVA) using SAS statistical software, version 6.12. Tukey's Honestly Significant Difference (HSD) procedure was then used to compare means, with statistical significance assessed at the 5% level.

Results

Soil chemical analysis

The initial soil test showed pH 5.18, organic matter 2.69%, total nitrogen 0.20%, available phosphorus 0.63 mg kg^{-1}, and exchangeable potassium 0.19 me 100 g^{-1} (Table 2). According to Landon (1991), the soil exhibited a markedly acidic pH, relatively limited organic matter and nitrogen levels, and extremely low concentrations of plant-available phosphorus and exchangeable potassium. After harvest, pH and organic matter were lower than at the start, while total nitrogen remained broadly similar to the initial level. Available phosphorus rose in most treated plots but not in the untreated control (T0). Exchangeable potassium was generally lower in the inbred plots (M2) than in those planted with the hybrid variety (M1). Crop uptake may explain some of the observed nutrient declines. The rise in available phosphorus in certain plots, particularly T4 where fertilizer was applied without a growth regulator, may reflect phosphorus supplied in the fertilizer.

Agronomic characteristics

Several agronomic traits responded significantly to the management treatments. The two varieties were generally similar statistically, although the hybrid plants were taller than the inbred plants. Rice receiving 500 or 1,000 ppm ANAA with half the recommended fertilizer rate reached heading and

maturity sooner than plants supplied with the full 120–60–60 kg ha^{-1} N–P_2O_5–K_2O recommendation (Table 3). The untreated control also reached these stages earlier than the full-fertilizer treatment. Both ANAA-plus-half-rate treatments produced the tallest plants, with heights comparable to those under the full fertilizer recommendation. This pattern suggests that ANAA may help maintain vegetative growth under the reduced fertilizer regime used in this experiment.

Table 2 Chemical characteristics of the soil before crop establishment and after harvest under ANAA and fertilizer regimes

Treatment	Soil pH	OM (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (me 100g^{-1})
Initial soil analysis	5.18	2.69	0.20	0.63	0.19
Final soil analysis					
Hybrid variety (M_1)					
T_1	4.56	2.59	0.19	0.63	0.19
T_2	4.89	2.52	0.21	0.85	0.17
T_3	4.51	2.41	0.19	0.56	0.14
T_4	4.84	2.41	0.19	1.00	0.18
Inbred variety (M_2)					
T_1	5.04	2.33	0.19	0.43	0.09
T_2	4.91	2.48	0.17	0.82	0.10
T_3	4.84	2.56	0.22	0.89	0.14
T_4	4.40	2.44	0.19	1.11	0.13

M_1 = Hybrid variety; M_2 = Inbred variety; T_1 = Control (no fertilizer and plant growth regulator application); T_2 = 500 ppm ANAA + ½ RR; T_3 = 1000 ppm ANAA + ½ RR; T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, and K_2O (RR); OM = Organic matter; Total N = Total nitrogen %; Available P = Available phosphorous (mg kg^{-1}); Exchangeable K = Exchangeable K (me 100g^{-1})

Table 3 Agronomic characteristics of inbred and hybrid lowland rice cultivars under ANAA and fertilizer regimes

Treatment	Number of days from sowing to		Plant height (cm)	Fresh straw weight (t ha^{-1})
	Heading	Maturity		
Lowland rice varieties				
Hybrid variety (M_1)	78.14	113.14	108.72^{a}	16.64
Inbred variety (M_2)	78.29	113.19	099.39^{b}	15.33
Plant growth regulator				
T_1	76.82^{c}	111.33^{c}	099.03^{d}	11.21^{b}
T_2	78.83^{bc}	114.17^{b}	108.29^{a}	15.89^{a}
T_3	79.17^{b}	113.67^{bc}	107.25^{ab}	16.93^{a}
T_4	80.67^{a}	115.67^{a}	106.06^{abc}	17.21^{a}
C.V. (a) %	0.34	0.27	2.34	20.27
C.V. (b) %	0.86	0.59	2.66	8.48

C.V. = Coefficient of variation; T_1 = Control (no fertilizer and plant growth regulator application); T_2 = 500 ppm ANAA + ½ RR; T_3 = 1000 ppm ANAA + ½ RR; T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR); Means across crop establishment and rice varieties followed by the same letter are not significantly different at 5% HSD

Physiological parameters

The analysis detected no significant variety-by-PGR interaction for the physiological traits. In contrast, the main effects of variety and treatment were significant for most measured variables; harvest index was the exception.

Net assimilation rate (NAR)

Net assimilation rate (NAR) varied significantly with rice variety and treatment during 22–36 and 64–78 days after transplanting (DAT). The inbred variety had higher NAR than the hybrid. During 22–36 DAT, the largest values were recorded among the PGR treatment groups, whereas at 64–78 DAT the highest NAR occurred under the inorganic-fertilizer treatment (T4). Both sets of treatments performed better than the untreated control (T0), which received neither fertilizer nor PGR. These results indicate that the relative contribution of growth regulator and fertilizer inputs to assimilate accumulation changed over the crop cycle (Table 4).

Crop growth rate (CGR) and Leaf area index (LAI)

The hybrid variety achieved the greatest crop growth rate (CGR) in the 50–64 DAT interval (Table 5). Treatment effects on CGR were also significant: plots receiving PGR treatments (T_1–T_4) or inorganic fertilizer alone had higher values than the untreated control (T0). Greater light interception and dry-matter accumulation may help explain this pattern. Leaf area index (LAI) showed a comparable response, consistent with a relationship between canopy development and crop growth.

Root pulling resistance (RPR)

The highest root pulling resistance (RPR) was recorded for plants receiving paclobutrazol (PBZ), at either tested concentration, together with the recommended fertilizer rate of 120–60–60 kg ha^{-1} N–P_2O_5–K_2O (T1–T3). RPR under these treatments exceeded that measured for ANAA combined with the recommended fertilizer rate (T2 and T3) and for fertilizer alone (T4).

Table 4 Net assimilation rate (NAR) in hybrid and inbred lowland rice varieties under ANAA and fertilizer regimes

Treatment	Net assimilation rate (NAR) (g m^2 d^{-1})			
	22-36 DAT	36-50 DAT	50-64 DAT	64-78 DAT
Lowland rice varieties				
Hybrid variety (M_1)	11.82^b	18.75	32.28^b	24.79^b
Inbred variety (M_2)	13.32^a	21.98	40.10^a	32.61^a
Plant growth regulator				
T_1	09.87^b	16.42	30.34	22.91^b
T_2	11.91^{ab}	19.99	37.51	32.35^a
T_3	12.68^{ab}	21.13	36.91	30.64^a
T_4	12.55^{ab}	21.18	36.32	29.25^{ab}
C.V. (a) %	05.45	56.75	08.31	45.40
C.V. (b) %	12.12	16.03	12.73	12.05

NAR = Net assimilation rate; DAT = Days after transplanting; T_1 = Control (no fertilizer and plant growth regulator application); T_2 = 500 ppm ANAA + ½ RR; T_3 = 1000 ppm ANAA + ½ RR; T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR); C.V. = Coefficient of variation; Means across crop establishment and rice varieties followed by the same letter are not significantly different at 5% HSD

Table 5 Crop growth, leaf area, harvest index, and root pulling resistance of hybrid and inbred rice under ANAA and fertilizer regimes

Treatment	CGR (g m^2 d^{-1})				LAI	HI	RPR
	22-36 DAT	36-50 DAT	50-64 DAT	64-70 DAT			
Rice varieties							
M_1	12.81	34.41	70.61^a	44.44	1.73	0.52	38.78^a
M_2	12.84	33.39	62.41^b	41.35	1.98	0.51	36.21^b
Plant growth regulator							
T_1	10.81^b	28.17^b	57.05^b	35.62^b	1.01^b	0.49	30.16^c
T_2	12.30^{ab}	35.02^{ab}	72.82^a	48.41^a	2.04^a	0.52	37.45^b
T_3	12.50^{ab}	33.43^{ab}	66.47^{ab}	46.33^a	2.13^a	0.54	37.00^b
T_4	12.40^{ab}	35.02^{ab}	65.58^{ab}	43.05^{ab}	1.99^a	0.52	37.61^b
C.V. (%)	52.30	38.73	08.46	38.18	14.52	19.72	04.68
C.V. (%)	10.15	12.14	11.84	12.48	8.88	7.30	02.34

CGR = Crop growth rate; LAI = Leaf area index, HI = Harvest index; RPR = Root pulling resistance; M_1 = Hybrid variety; M_2 = Inbred variety; T_1 = Control (no fertilizer and plant growth regulator application); T_2 = 500 ppm ANAA + ½ RR; T_3 = 1000 ppm ANAA + ½ RR; T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR); C.V. = Coefficient of variation; Means across crop establishment and rice varieties followed by the same letter are not significantly different at 5% HSD

Yield and yield components

The results in Tables 6 and 7 show how the ANAA and fertilizer regimes affected yield and its components in the two rice varieties. Variety significantly influenced productive tillers per hill, filled spikelets per panicle, panicle length, and panicle weight, but the difference in grain yield between varieties was not significant. Inbred rice had more productive tillers, a larger proportion of filled spikelets, and longer panicles; hybrid rice, however, produced heavier panicles. The varieties may therefore have achieved similar grain yields through different combinations of yield components. Frequent rainfall may also have limited the hybrid variety's ability to express its full yield potential. Relative to the untreated control (T0), combining PGR with half the recommended fertilizer rate significantly increased panicle length, although this response was statistically comparable to that under fertilizer alone at 120–60–60 kg ha^{-1} N–P_2O_5–K_2O. Across the ANAA treatments, plants generally had more productive tillers, heavier panicles, and higher grain yields than the control, with results comparable to those obtained using the full fertilizer recommendation.

Profitability analysis

Table 8 compares gross margins and net returns for the hybrid and inbred varieties under the different ANAA and fertilizer

regimes. Differences in gross margin reflect variation in harvested yield as well as variable production expenses. Mean net income was PhP50,066.05 for hybrid rice and PhP51,876.76 for inbred rice, with the inbred variety returning slightly higher than the hybrid. The highest reported net income was PhP54,436.33 for hybrid rice and PhP55,156.17 for inbred rice, both under the recommended fertilizer rate of 120-60-60 kg ha^{-1}. It was followed by the hybrid rice receiving 500 ppm ANAA with half the recommended fertilizer rate (T_2) ranked next, at PhP49,991.17 and inbred rice at PhP49,164.67. These outcomes suggest that profitability depended on the particular variety-treatment combination and whether the value of additional yield offset the input costs. In contrast, the 1,000-ppm ANAA treatment combined with the full recommended fertilizer rate (T_4) produced the lowest net incomes: PhP36,261.50 for hybrid rice and PhP36,417.83 for inbred rice. Higher variable expenditure appears to have reduced the return from this combination. The untreated control (T0) generated PhP45,060.83 for hybrid rice and PhP50,200.67 for inbred rice; the lower hybrid return was associated with its lower grain yield.

Table 6 Yield and yield-component measurements for hybrid and inbred lowland rice under the ANAA and fertilizer regimes

Treatment	NPTH	PFSP	PL	PW	W1000G	GY
Rice varieties						
M_1	11.30^{b}	78.91^{b}	24.70^{b}	7.67^{a}	30.61	6.86
M_2	14.93^{a}	87.06^{a}	26.56^{a}	3.46^{b}	29.21	6.50
Plant growth regulator						
T_1	09.27^{b}	77.92^{b}	24.80^{b}	4.90^{b}	29.93	5.62^{b}
T_2	13.40^{a}	84.06^{a}	25.68^{ab}	5.81^{a}	29.85	6.89^{a}
T_3	13.82^{a}	83.90^{a}	25.79^{ab}	5.71^{a}	29.90	6.57^{a}
T_4	13.80^{a}	83.29^{a}	25.90^{a}	5.32^{a}	29.87	6.58^{a}
C.V. (a) %	06.22	2.43	05.22	12.66	07.01	9.88
C.V. (b) %	06.32	3.75	02.30	06.97	00.71	7.51

NPTH = Number of productive tillers hill^{-1}; PFSP = Percentage of filled spikelets panicle^{-1}; PL = Panicle length (cm); PW = Panicle weight (g); W1000G = Weight of 1,000 grains (g); GY = Grain yield (t ha^{-1}); M_1 = Hybrid variety; M_2 = Inbred variety; C.V. = Coefficient of variation; T_1 = Control (no fertilizer and plant growth regulator application); T_2 = 500 ppm ANAA + ½ RR; T_3 = 1000 ppm ANAA + ½ RR; T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR); C.V. = Coefficient of variation; Means across crop establishment and rice varieties followed by the same letter are not significantly different at 5% HSD

Table 7 Variety-specific productive tiller counts under ANAA and fertilizer regimes

Plant growth regulator	Rice varieties	
	Hybrid	Inbred
T_1 = Control	08.53^{c}	10.00^{bc}
T_2 = 500 ppm ANAA + ½ RR	11.67^{b}	15.13^{a}
T_3 = 1000 ppm ANAA + ½ RR	12.13^{b}	15.50^{a}
T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	11.70^{b}	15.90^{a}

Means across crop establishment and rice varieties followed by the same letter are not significantly different at 5% HSD

Table 8 Profitability analysis for hybrid and inbred rice under ANAA and fertilizer regimes

Treatments	Grain yield (t ha^{-1})	Gross income (PhP ha^{-1})	Total variable cost (PhP ha^{-1})	Net income (PhP ha^{-1})
M_1 = Hybrid variety				
T_1 = Control (no fertilizer and plant growth regulator application)	5.70	96,843.33	51,782.50	45,060.83
T_2 = 500 ppm ANAA + 1/2 RR	7.16	121,776.67	71,785.50	49,991.17
T_3 = 1000 ppm ANAA + ½ RR	6.81	115,770.00	79,508.50	36,261.50
T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	6.78	115,373.33	60,937.00	54,436.33
Mean	6.86	116,611.90	66,545.86	50,066.05
M_2 = Inbred variety				
T_1 = Control (no fertilizer and plant growth regulator application)	5.56	94,406.67	44,206.00	50,200.67
T_2 = 500 ppm ANAA +1/2 RR	6.62	112,596.67	63,432.00	49,164.67
T_3 = 1000 ppm ANAA + ½ RR	6.34	107,723.33	71,305.50	36,417.83
T_4 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	6.38	108,516.67	53,360.50	55,156.17
Mean	6.50	110,467.62	58,590.86	51,876.76

Current price of palay= PhP 17.00 kg^{-1}

Discussion

The improved growth performance observed following the application of ANAA plant growth regulator (PGR) may be associated with the role of plant hormones in regulating cell division, cell expansion, shoot development, and physiological processes involved in plant growth. Auxin-related compounds can influence apical growth, root development, and the distribution of assimilates between vegetative and reproductive organs. Improved root activity may also enhance the acquisition of water and mineral nutrients, thereby supporting shoot growth and the development of yield-related traits. Similar findings were reported by Basuchaudhuri (2016) who discussed the potential of naphthaleneacetic acid (NAA) to promote rice growth and yield through improved root functioning, nutrient uptake, and assimilate translocation. However, the extent of these responses depends on the regulator used, its concentration, application timing, rice genotype, and environmental conditions. The previous field studies support the potential of NAA to improve rice performance. Hasnain et al. (2020) reported that NAA application improved paddy yield and economic returns under different irrigation regimes, with the best response obtained at 90 mL ha^{-1} under an irrigation depth of 75 cm. Similarly, Hussain et al. (2021) found that NAA application at appropriate growth stages increased biomass production, grain yield, harvest index, leaf area index, and bioeconomic efficiency in coarse rice. These findings support the possibility that carefully managed PGR application can improve crop growth and productivity. However, formulations, application rates, and experimental conditions differ among studies. These results should be regarded as supporting evidence rather than direct confirmation of the precise mechanism operating in the present experiment. The effects of PGRs on plant growth are not necessarily uniform. Depending on the active compound and its concentration, a regulator may stimulate shoot elongation or restrict excessive vegetative growth while improving other agronomic characteristics. Therefore, plant height should be interpreted alongside stem diameter, tiller production, root development, and reproductive performance.

Leaf development and photosynthetic activity are important determinants of crop productivity because leaves intercept solar radiation and produce assimilates required for vegetative growth and grain formation (Banerjee et al., 2024). Chlorophyll concentration contributes to light absorption, while the distribution and orientation of leaves influence the amount of radiation intercepted by the crop canopy (Liu et al., 2021; Zhou et al., 2024). Consequently, treatments that improve leaf development or maintain photosynthetic activity may support the accumulation of biomass and the transfer of assimilates to developing grains (Ye et al., 2024; Song et al., 2025). Congruous with our findings, Xia et al. (2018) reported that paclobutrazol (PBZ) application could increase the intensity of green leaf coloration. However, darker leaves alone do not establish that photosynthesis has increased, because chlorophyll content, photosynthetic rate and crop productivity are related but distinct characteristics. Recent research provides additional evidence that growth regulation can influence canopy characteristics and productivity in rice. Liu et al. (2025a) reported that paclobutrazol improved the canopy light environment and photosynthetic characteristics of direct-seeded rice while modifying leaf angle and plant architecture. These changes contributed to improved lodging resistance and grain yield.

Plant architecture is relevant to lodging and anchorage, particularly where crops experience strong winds, rainfall, or saturated soils (Liu et al., 2025b). Features such as culm diameter, internode dimensions, tissue strength, and root development may affect the ability of a plant to remain upright. Evidence from tomato reported by Pal et al. (2016) indicates that paclobutrazol can alter plant height, stem thickness, leaf production, and root growth. In this rice experiment, the greater root pulling resistance (RPR) measured in PGR-treated plants may reflect stronger anchorage. Possible explanations include changes in shoot growth and assimilate allocation that affect the relationship between aboveground biomass and root development. Increased root biomass, a wider root distribution, or closer root–soil contact could each raise the force needed to uproot a plant, but RPR measurements alone cannot distinguish among these mechanisms. Measurements of root length, biomass, distribution, and soil moisture would be needed to test them. Liu et al. (2024) likewise found that paclobutrazol improved lodging resistance in direct-seeded rice in association with changes in basal internodes, culm dimensions, tissue properties, and structural compounds such as cellulose and lignin. Collectively, these findings support the possibility that growth-regulator-induced changes in plant structure can influence mechanical stability.

Rice yield reflects several components acting together: productive tiller number, spikelets per panicle, spikelet fertility, individual grain weight, and assimilate movement into developing grains (Espino, 2014). An improvement in one yield component does not necessarily result in a significant increase in final grain yield, as its positive contribution may be offset by changes in other yield components (Čupić et al., 2026). In this experiment, variety significantly affected productive tiller number, filled-spikelet percentage, panicle length, and panicle weight, whereas grain yield did not differ significantly between varieties. The inbred variety had higher values for tiller number, filled spikelets, and panicle length, while the hybrid produced heavier panicles. The two varieties may therefore have reached similar yields through different component profiles, with heavier hybrid panicles partly compensating for lower values in other traits. ANAA treatments generally improved productive tiller number, panicle weight, and grain yield relative to the untreated control. Thousand-grain weight, however, was not significantly affected by PGR application. This suggests that the observed yield response was more closely related to the number or development of reproductive structures than to a change in individual grain mass.

Our findings were in parallelism with the earlier report of Hussain et al. (2021) who found that NAA application at appropriate developmental stages improved grain yield and several associated agronomic characteristics. Aryan et al. (2023) also reported that auxin application during flowering helped alleviate the adverse effects of heat stress on spikelet fertility and yield attributes in rice. Their findings demonstrate that auxin-related treatments can influence reproductive performance, although the magnitude of the response depends on genotype and environmental conditions. Together, these studies provide supporting evidence for investigating PGRs as a means of improving rice productivity. The present findings also indicate that the response to PGR treatment varied between rice varieties. Such differences may arise from variation in plant architecture, growth duration, tillering capacity, reproductive development, and sensitivity to growth regulators. Therefore, a treatment that performs well in one variety may not produce the same response in another. This varietal dependence highlights the importance of evaluating PGR treatments in combination with the selected rice genotype rather than assuming that a single treatment will produce a uniform response across all varieties. The significant interaction between rice variety and PGR treatment for productive tillers per hill and panicle length indicates that the effect of the regulator depended on the variety being cultivated. PGR application significantly increased both traits in the inbred variety relative to the hybrid variety, suggesting that the inbred genotype responded more strongly under the conditions of this experiment. Differences in these characteristics could influence how additional growth regulation affects the production of productive tillers and the elongation of panicles.

The economic value of a PGR treatment depends not only on its biological effects but also on the additional costs of the regulator, fertilizer, labour, and application. A treatment that increases yield may not necessarily generate the highest net income if the associated production costs are disproportionately high. Conversely, a moderate yield response may provide a better financial return when achieved with lower input expenditure. In the present study, the highest net income was obtained from the inbred variety treated with 500 ppm ANAA plus the recommended rate of inorganic fertilizer (T2), with a net income of PhP 55,156.17. This was followed by the hybrid variety receiving recommended fertilizer rate (T4), which generated PhP 54,436.33. These results indicate that the economic performance of the treatments depended on the combination of rice variety, PGR concentration, fertilizer rate, grain yield, and total variable costs. The superior economic performance of T2 suggests that the combination used in this treatment provided a favourable balance between production expenditure and returns under the conditions of the experiment. The higher variable costs associated with this treatment may have reduced its profitability despite the application of PGR and the full fertilizer rate. This finding emphasizes that increasing the concentration of a growth regulator or applying more fertilizer does not automatically improve net returns. Input use must be matched to the crop's response so that the additional revenue generated by the treatment exceeds its additional costs. Previous studies have demonstrated that the profitability of rice production depends on the interaction between input costs, crop yield, and the selection of suitable management practices. Bakhsh et al. (2012) reported that the combined application of naphthalene acetic acid (NAA) and phosphorus improved rice productivity and economic returns, with the most favourable results obtained at 90 mL ha^{-1} NAA and 100 kg ha^{-1} phosphorus. The treatment produced grain yields of 7.62 and 7.82 t ha^{-1} and benefit–cost ratios of 1.64 and 1.70 in the two experimental years, respectively. Similarly, Chouhan et al. (2020) found that applying chitosan along with the recommended fertilizer dose improved grain yield, monetary returns, and the benefit-cost ratio of transplanted rice.

Conclusion and Recommendations

Under the conditions of this experiment, ANAA treatment affected several morphological and physiological traits in both hybrid and inbred lowland rice. Application of ANAA with half the recommended fertilizer rate was associated with earlier heading and maturity and increases in plant height and leaf area index. The T2 and T3 combinations also improved yield-related performance in both varieties. A variety-by-treatment interaction was detected for productive tillers per hill, and the inbred variety generally produced more productive tillers than the hybrid. The economic results indicated that several ANAA-based regimes, including those using reduced fertilizer inputs, returned more than the untreated control. The highest reported net income was PhP55,156.17 ha^{-1} for the inbred variety and PhP54,436.33 ha^{-1} under the full recommended fertilizer rate of 120-60-60 kg ha^{-1}. These findings suggest that application of 500–1,000 ppm did not merit the yield performance of inbred and hybrid rice varieties under VSU conditions. Thus, multi-location and multi-season trials are needed before broader recommendations can be made.

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Declarations

i. Ethics approval and consent to participate: This study did not involve human participants, human data, or animal studies; therefore, ethical approval was not required.

ii. Competing interests: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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