International Journal of Design & Nature and Ecodynamics
Vol. 20, No. 7, July, 2025, pp. 1605-1613
Journal homepage: http://iieta.org/journals/ijdne

Effects of Water Stress and Goat Manure Fertilizer on the Growth and Yield of Upland Rice in Indonesia

Maria Theresia Sri Budiastuti[1*], Desy Setyaningrum[2], Supriyono[1], Azkya Sabrina Fahma[1]

[1] Department of Agrotechnology, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta 57126, Indonesia
[2] Department of Agribusiness, Vocational School, Universitas Sebelas Maret, Surakarta 57126, Indonesia

Corresponding Author Email: mariatheresia@staff.uns.ac.id

https://doi.org/10.18280/ijdne.200717

Received: 27 June 2025
Revised: 20 July 2025
Accepted: 24 July 2025
Available online: 31 July 2025

Keywords:
field capacity, goat manure fertilizer, number of grains per panicle, number of panicles per hill, water stress

ABSTRACT

High rice consumption, while low rice production, is a challenge for Indonesia, which is exacerbated by decreasing land availability and the impact of climate change. Upland rice cultivation increases rice production by utilizing dry land. The research aims to examine the effect of water treatment and organic fertilizer doses on the growth and yield of upland rice. The study used a Randomized Complete Block Design with two factors. The first factor was water stress with four levels: control, ¾, ½, and ¼ Field Capacity. The second factor was the dose of organic goat manure fertilizer with four levels: 0, 10, 20, and 30 tons.ha^{-1}. Water treatment did not affect the growth and yield of upland rice. The efficiency of water use in the field capacity treatment was 8.35 kg.l^{-1} and increased in the water stress treatment. The dose of cow manure fertilizer of 10 tons.ha^{-1} has encouraged plant height growth, number of leaves, and productive tillers, while the dose of 30 tons.ha^{-1} increased biomass and number of panicles. The combination of field capacity water treatment with 10 tons.ha^{-1} of goat manure fertilizer produced the highest number of grains per panicle. Organic fertilizer can optimize yields in limited water conditions.

1. INTRODUCTION

Rice is a staple food source for the Indonesian people, with an average annual consumption rate of 80.9 kg/capita in 2023 [1]. The need for rice is increasing along with the rapid increase in the Indonesian population, with a growth rate of 1.11% [2]. The population of Indonesia in 2024 is 281,603.8 thousand people. The level of rice consumption is not supported by rice production of only 53,142,726.65 tons [3]. Rice production in 2024 decreased by 1.57% compared to 2023, which was 53,980,993.19. The population of Indonesia is projected to reach 322 million in 2050, and large consumption will increase by 45%. One of the causes of the decline in rice production is the rice harvest area, which is only 10,046,135.36 ha in 2024. The rice harvest area in 2024 decreased by 1.64% compared to 2023, which was 10,213,705.17 ha [4]. In addition, climate anomalies in Indonesia, such as increasing air temperatures and rainfall fluctuations, exacerbate the decline in rice production [5, 6].

Rice is a semi-aquatic plant that depends on rainfall and temperature [7, 8]. High temperatures and shifts in planting seasons cause a decrease in irrigated rice yields by 21%. This is due to reduced photosynthesis, increased aging of functional leaves, reduced biological synthesis of starch and starch addition, duration of grain filling, and decreased grain weight [9]. Wet and dry water management with only 30% water content causes a decrease in biomass, leaf area, panicle density, number of florets per panicle, and lower floret fertility [10]. Alternating wetting and drying treatments in rice cultivation reduce yields by 26% but show 19% higher water productivity than flooding treatments [11]. Rice can withstand soil water tensions of up to 10–20 kPa [12]. These characteristics encourage rice cultivation on non-flooded land with proper irrigation management.

Agricultural intensification efforts, such as upland rice cultivation, can be carried out to address the imbalance between rice consumption and rice production in Indonesia. Upland rice is a rice plant that can grow in aerobic soil conditions [13, 14] because it has thicker leaves and cuticles, and fewer stomata than lowland rice. However, the constraints in upland rice cultivation with limited water are nutrients, soil fertility, and soil organic carbon. Fertilization plays a role in increasing nutrients. Long-term fertilization with chemical fertilizers shows a trend of decreasing yields [15, 16], while the combination of organic and chemical fertilizers increases yields from year to year. Combining organic and inorganic fertilizers can reduce nutrient loss and water use efficiency [16]. The effectiveness of inorganic fertilizers is closely related to water availability [17]. However, continuous application of inorganic fertilizers can reduce soil organic matter, nutrients, minerals, microbial activity, soil fertility, and harden the soil [18, 19]. Applying organic fertilizer effectively improves soil fertility and microbial community structure [20]. One of the organic fertilizers is goat manure, which can increase soil fertility, restore soil organic content, reduce production costs, and increase farmer profits [21]. Goat manure contains lower C/N compared to cow manure, and chicken manure encourages rapid decomposition of organic matter so that nutrient release is faster and more stable [22].

Organic goat manure fertilizer contains high nitrogen, 1.1-1.5% [23]. Nitrogen plays a role in the growth and development of rice because it contributes to the accumulation of carbohydrates in leaves, stems, and sheaths during the pre-cutting stage and in grain during the filling stage by becoming a component of photosynthesis [24, 25]. Rice yield is correlated with soil organic carbon content, total nitrogen, available nitrogen, total phosphorus, and available phosphorus [26]. Based on research [27], applying goat manure fertilizer can increase the growth and yield of rice. High rice yields are supported by increased nitrogen absorption because nitrogen is remobilized from vegetative organs to grain until grain formation is complete [28]. The potential for nitrogen absorption by plants is influenced by water availability [29]. Cultivation of dryland rice with organic fertilizer is an effort to increase dryland productivity and rice yields. Based on research by Alavan et al. The combination of organic and inorganic fertilizers 50:50 produces 10 t ha^{-1} in several dryland rice varieties, namely Cirata, Limboto, Situ Bagendit, and Situ Patenggang. Study [30] found that the watering interval and the method of applying organic fertilizer from manure affect plant height and the number of productive panicles per planting. The novelty of this research is the treatment of water stress based on field capacity and the dose of organic fertilizer from goat manure in dryland rice cultivation. The study aims to examine the effect of water treatment and the dose of organic fertilizer on the growth and yield of dryland rice.

2. RESEARCH METHOD

The research was conducted in the Greenhouse Laboratory at 170 meters above sea level in October 2024 - February 2025. The research location has an average light intensity of 12,500.56 lux and an average air temperature in the morning of 27.78℃, afternoon 32.71℃, and evening 29.47℃. The research used a Complete Randomized Block Design with two factors. The first factor is water stress with four levels: Control or field capacity; ¾ Field Capacity; ½ Field Capacity, and ¼ Field Capacity. The second factor is the dose of organic goat manure fertilizer with four levels, namely 0, 10, 20, and 30 $tons.ha^{-1}$. It was repeated 3 times to obtain 48 experimental units. The soil used for the study had a pH of 5.04 (acidic), total nitrogen 0.70% (high), total phosphorus 6.0 ppm (low), total potassium 157ppm (low), organic carbon 0.14% (very low), and C/N 0.2 (very low). The materials used in the study were upland rice seeds of the Situ Bagendit variety, organic goat manure fertilizer, planting media with alfisol soil, Urea fertilizer, KCl, and SP36. The tools used were 40x50 cm polybags, digital scales, plant ovens, and cultivation measuring tools such as shovels, hoes, and diggers. The goat manure fertilizer used contained 2.33% total nitrogen, 0.47% total phosphorus, 5.60% total potassium, 1.92% organic N, 0.21% N-NH4, 0.21% N-NO3, 35.31% organic C, and a C/N ratio of 15.12.

Rice seeds were soaked in distilled water for 24 hours, and seed treatment was carried out with an insecticide containing the active ingredient thiamectosam 350 g/l (2 drops). Furthermore, the seeds were spread and wrapped for 24 hours. The seeds were planted in polybags with three seeds in one planting hole in the polybag, with a depth of 2-3 cm. The planting distance is 20 cm × 20 cm. Irrigation is carried out every two days in the afternoon with a volume according to the treatment. Field capacity was determined using a pressure-membrane apparatus. Undisturbed soil samples were taken using a core ring, then slowly saturated from the bottom until all the pores of the medium were filled with water. Next, the soil sample was placed on a ceramic plate in a pressure chamber and subjected to a pressure of 0.33 bar (−33 kPa) until the water retained by gravity was expelled and equilibrium was reached. Afterward, the sample was weighed to obtain its wet weight, then dried in an oven at 105 ± 5°C until it reached a constant weight [31]. The determination of water requirements for field capacity treatment was done using the gravimetric method, where the soil in the polybag is weighed first and then watered on the media until saturated and left for 8 hours. The volume of water the soil absorbs is the difference between the volume of water poured and the volume of water collected. Fertilization was done twice, namely, basic fertilizer and follow-up fertilizer. Basic fertilizer was done when planting with 200 kg/Ha Urea, 50 kg/Ha KCL, dan 50 kg/Ha SP36. Follow-up fertilizer KCl and SP36 at 30 Days After Planting (DAP) as much as 50 kg/ha, and Urea at 65 DAP as much as 75 kg/ha. Rice harvesting was carried out at 102 DAP. Harvesting was carried out when the plants had shown maturity, followed by 95% of the grains being golden yellow, the panicles drooping, the grains of rice feeling hard when pressed, and the tips of the leaves beginning to turn brown/dry out. Observations were made on growth variables carried out nine weeks after planting, including plant height, number of leaves, leaf area, and productive tillers. The yield variables were observed at one hundred and four days after planting, including plant biomass, number of panicles per hill, number of grains per hill, weight of dry harvested grain, and weight of 1000 seeds. Calculate leaf area using the gravimetric method at the maximum vegetative phase, which was fifty-four days after planting. The data obtained were analyzed using variance with the F test at a level of 5% and if significant, continued with a real difference test using Duncan's Multiple Range Test (DMRT) at a level of 5%.

3. RESULTS AND DISCUSSION

3.1 Growth

Water treatment did not affect the height of rice plants. The study's results are from research [32], which found that upland rice growth and yield were higher in dry than in flooded cultivation. This is because drought-tolerant upland rice increases aquaporin genes in root tissue, such as OsPIP1; 3 and OsPIP2, to maintain cell turgor under water stress, thereby facilitating more efficient water absorption and internal redistribution [33]. In addition, upland rice roots are longer in the 10-20 cm soil layer under drought conditions [34]. The dose of goat manure fertilizer affects the height of rice plants, and a dose of 10 $tons.ha^{-1}$ shows the highest plant height of 97.64 cm (Table 1). The high nitrogen and phosphorus content in goat manure fertilizer supports this. Nitrogen and phosphorus are macronutrients that affect roots' growth, morphology, and distribution. High nutrient supply can increase the growth of the above and below-ground parts. The organic matter and carbon content in goat manure can improve the soil's ability to bind water, retain nutrients, maintain microbial activity, retain soil moisture, and reduce soil mass density [35]. This encourages root growth and the ability to absorb nutrients [36]. In addition, upland rice roots are spread over a 10-20 cm soil layer compared to lowland rice in a 0-5 cm soil layer in drought conditions. The nature of upland rice roots is correlated with drought resistance and plant nutrient absorption capacity [37, 38].

Table 1. Height of upland rice plants

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	80.83	98.55	95.05	98.01	93.11
3/4 field capacity	87.41	98.05	90.76	97.50	93.43
1/2 field capacity	86.33	95.01	86.61	94.52	90.61
1/4 field capacity	85.81	98.94	95.33	93.94	93.50
Average	85.09c	97.64a	91.94b	96.03ab	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

Water treatment did not affect the number of rice leaves (Table 2). Study [39] shows that upland rice is resistant to low and high levels of water stress and shows high leaf growth. Several studies have demonstrated that water stress can inhibit cell division and reduce photosynthetic capacity, reducing leaf production [34, 40]. The dose of goat manure fertilizer affected the number of upland rice leaves, and a dose of 10 tons.ha^{-1} showed the highest number of leaves, namely 90.07 (Table 2). This is supported by organic matter and organic carbon in cow dung fertilizer, which improve soil structure, increase water holding capacity, and increase microbial activity [41, 42]. These soil conditions will stimulate root proliferation, improving water and nutrient absorption, thereby supporting the physiological process and leaf formation [43, 44]. Applying organic fertilizer can withstand water stress by increasing the availability of organic carbon and soil nutrients, thereby increasing plant growth and yield [45]. In addition, organic goat manure fertilizer contains high nitrogen, which plays a role in photosynthesis, thus affecting leaf structure and nitrogen allocation in leaves [46].

Table 2. Number of upland rice leaves (strands)

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	35.78	81.44	80.11	87.67	71.25
3/4 field capacity	52.78	92.11	53.89	86.22	71.25
1/2 field capacity	47.56	93.22	67	86.11	73.47
1/4 field capacity	49.89	93.50	84.11	96.78	81.07
Average	46.50c	90.07a	71.28b	89.19a	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

Productive tillers are stems of rice that develop to produce panicles and grain. The number of productive tillers per hill is a component that determines the number of panicles that affect the yield of rice grain (Table 3). Water stress does not affect the number of productive tillers of upland rice. This can be supported by the relatively high water-holding capacity of the soil. Based on research [47] in Malaysia, water limitations caused the number of tillers per clump to decrease, but plant height, leaf dry matter, and panicle length increased. The dose of goat manure fertilizer affects the number of productive tillers of upland rice, with a dose of 10 tons.ha^{-1} showing the highest number of productive tillers, namely 16.21 tillers. Organic goat manure fertilizer contains high organic carbon and balanced macronutrients that initiate and elongate tiller shoots. Excess organic matter in the goat manure fertilizer treatment at doses of 20 and 30 tons.ha^{-1} causes the carbon-to-nitrogen ratio to be disturbed, resulting in immobilization, namely, soil microbes immobilizing the available nitrogen. The total nitrogen content in goat manure fertilizer is 2.33% with a role in protein synthesis, cell division, and photosynthetic capacity, which then encourages the development of productive offspring [48, 49]. Phosphorus and potassium contribute to energy transfer and cellular processes essential for offspring development [50]. In addition, organic matter in goat manure increases soil moisture retention and microbial activity, which can alleviate the negative impacts caused by water stress, thereby strengthening the plant's capacity to maintain productive offspring [51].

Table 3. Number of productive tillers of upland rice

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	6.44	14.66	14.42	15.78	12.82
3/4 field capacity	9.50	16.58	10.62	14.77	12.86
1/2 field capacity	8.56	16.78	11.47	16.30	13.27
1/4 field capacity	8.98	16.83	15.14	16.75	14.67
Average	8.37c	16.21a	12.91b	15.89a	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

Water treatment and goat manure fertilizer dosage did not affect the leaf area of upland rice (Table 4). Rice plants adapt to water stress by reducing leaf area to reduce transpiration and maintain water use efficiency [52, 53]. However, the study's results showed that the leaf area of upland rice did not decrease with water deficit treatment. These results indicate that upland rice is tolerant to drought due to the expression of the OsWRKY97 gene by regulating osmolyte accumulation and maintaining water potential in leaf tissue [54, 55]. This causes plants to maintain cell turgor and relative water content in the leaves, thereby maintaining leaf area [54]. The root oxygen consumption and transport rate are strongly positively correlated with leaf area [56]. Water deficit limits root growth but has little impact on aboveground growth in rice plants because a balanced leaf xylem system maintains leaf water potential [57].

Table 4. Leaf area of upland rice

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	680.69	1165.33	1529.35	1798.70	1293.52
3/4 field capacity	1322.61	1533.34	1405.32	1577.16	1459.61
1/2 field capacity	1291.70	1700.47	1422.75	1953.01	1591.98
1/4 field capacity	1245.91	1770.48	1932.26	1712.51	1665.29

3.2 Yield

Water treatment did not affect the biomass of upland rice plants. Water stress disrupts rice's growth and reproductive stages, resulting in decreased rice grain yields [58]. However, upland rice can adapt to drought conditions because upland rice roots are deeper and thicker, and xylem vessels are larger than lowland rice. The root system can access water from deeper soil layers, which will help plants maintain high plant water status [59]. Water is the primary electron donor during photolysis to produce ATP and NADPH in carbon assimilation. Water deficiency can cause stomatal closure, reduce CO_2 absorption, and interfere with photosynthetic efficiency. However, upland rice shows a relatively stable photosynthetic rate in mild to moderate water deficits due to strong mesophyll conductance and maintains the electron transport process [60, 61]. This buffering capacity is due to physiological adaptations that include rapid modulation of stomatal conductance and preservation of chloroplast integrity, which ensures the supply of photochemical energy for biomass synthesis under water stress. The results showed that the dose of goat manure fertilizer affected the biomass of upland rice plants, and a dose of 30 tons.ha^{-1} showed the highest biomass of 34.36g (Table 5). Goat manure at optimal doses resulted in a significant increase in dry biomass compared to the control under water-limited conditions [62]. This is because the organic matter content in goat manure fertilizer can increase the rate of soil respiration, soil microbial biomass carbon, total carbon, dissolved organic carbon, soil available phosphorus, soil organic phosphorus, microbial biomass phosphorus, and shoot phosphorus concentration [63]. Organic fertilizers can increase phosphorus absorption by rice plants and eliminate the impact of drought, thereby encouraging rice plant biomass production [64]. The water use efficiency in the field capacity treatment was 8.35 kg.l^{-1}. Increasing water stress resulted in increased water use efficiency. The 3/4, 1/2, and 1/4 field capacity treatments showed water stress efficiencies of 12.32, 18.88, and 41.78 kg.l^{-1}. Water deficit reduces relative leaf development and cell division rate, leading to low rice yield [65, 66]. Applying organic fertilizers can improve water holding capacity, soil porosity, and aggregate formation, thereby retaining moisture under drought conditions [67]. Adequate moisture facilitates evaporative cooling, thereby stabilizing leaf temperature, which is closely related to plant health, nutrient uptake, and photosynthetic efficiency [68, 69].

The study showed that water treatment did not affect the number of panicles per hill, and the number of panicles increased in high water stress treatments. This may be because upland rice is tolerant to drought, which is controlled by the Enhanced Response to ABAI (ERAI) gene encoding the β-subunit farnesyltransferase enzyme, which increases the sensitivity of guard cells to abscisic acid (ABA). Stomatal opening and closing are controlled by the phytohormone ABA, which reduces water loss during transpiration [52]. Adaptation of upland rice to drought stress is based on leaf curling, leaf drying, harvest yields, and percentage of plant growth [70]. Loss of cell turgor pressure and stomatal closure in dry conditions causes the carbon assimilation rate to decrease, so plant biomass decreases [71]. In addition, the WRKY gene controls drought resistance in rice plants [72]. The number of panicles per hill is determined by a specific gene whose activity is influenced by the environment.

Table 5. Biomass of upland rice plants

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	13.65	31.49	23.36	31.71	25.05
3/4 field capacity	18.32	32.71	21.69	38.18	27.72
1/2 field capacity	21.55	34.93	25.78	31.01	28.32
1/4 field capacity	17.83	32.17	33.80	36.54	30.08
Average	17.84c	32.82ab	26.16b	34.36a	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

The dose of goat manure fertilizer affects the number of panicles per hill, and the dose of 30 tons.ha^{-1} shows the highest number of panicles per hill, which is 12.15 panicles (Table 6). The high nitrogen and phosphorus content in goat manure fertilizer supports this. Nitrogen deficiency causes low tillering and panicle initiation stages and reduced grain yields [73]. The absorption of nitrogen and phosphorus by upland rice plants is correlated with the number of panicles and rice yields [74]. Applying fertilizers with high nitrogen and phosphorus content can increase the accumulation of dry matter and its translocation to the reproductive organs, thereby supporting panicle formation [75]. Nitrogen, the main component of amino acids, proteins, and nucleic acids, stimulates enzyme biosynthesis, encouraging vegetative and tillering growth that supports panicle formation [76]. Meanwhile, phosphorus plays a role in synthesizing adenosine triphosphate, which is needed during the reproductive development phase. Phosphorus supports root development and nutrient absorption, thus facilitating the transport of photosynthates to the panicle [77]. Efficient assimilative translocation is essential for panicle differentiation and filling. However, excessive nitrogen application causes a preferential allocation of assimilates to vegetative organs at the expense of grain filling [78].

Table 6. Number of panicles per hill of upland rice

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	6.11	12	11	10.11	9.80
3/4 field capacity	7.77	12.22	9	14.11	10.77
1/2 field capacity	9.78	12.11	10	11	10.72
1/4 field capacity	8.22	10.78	14.22	13.78	11.75
Average	7.97b	11.77a	11.05a	12.15a	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

The combination of water treatment with goat manure fertilizer doses affected the number of grains per panicle (Table 7). The combination of field capacity water treatment with a fertilizer dose of 10 tons.ha^{-1} showed the highest number of grains per panicle, 1489.33. It was not significantly different from the treatment of 3/4 field capacity with 20 and 30 tons.ha^{-1} doses. The results showed that organic fertilizer treatment could boost rice yields under water stress conditions. This is supported by the content of organic matter and carbon in goat manure fertilizer, thereby increasing water retention capacity and improving soil structure, which is important under water-limited conditions [79]. Goat manure fertilizer increases nutrient absorption in rice on dry land [80, 81]. The nutrient content of goat manure fertilizer, supported by water availability, encourages increased photosynthesis [82]. Most of the photosynthesis results are used to fill grain. The increased photosynthate rate will fulfill the assimilates from photosynthesis during grain filling [83].

Table 7. Number of grains per panicle of upland rice

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	458.67g	1489.33a	983.33bcdef	990.67bcdef	980.50
3/4 field capacity	799.67defg	1201.00abcd	566.50fg	1316.16abc	970.83
1/2 field capacity	614.83efg	1346.83ab	1033.50bcde	898.00cdef	973.29
1/4 field capacity	755.33efg	1030.33bcde	1245.33abc	1214.83abcd	1061.46
Average	657.13c	1266.88a	957.17b	1104.91ab	+

Description: Numbers followed by the same letter in the same row and column indicate no significant difference according to the 5% DMRT, and the (+) sign means there is an interaction.

Table 8. Weight dry grain harvest

Water Treatment	Dosage of Goat Manure Fertilizer				Average
	0	10	20	30	
Field capacity	8.60	20.16	18.67	17.65	16.27
3/4 field capacity	13.51	20.13	14.67	22.09	17.60
1/2 field capacity	12.76	22.71	15.82	13.68	16.24
1/4 field capacity	12.76	16.10	19.46	16.67	16.24
Average	11.90	19.77	17.15	17.53	-

Description: Numbers followed by the same letter indicate no significant difference according to the 5% DMRT, and the (-) sign means there is no interaction.

The weight of grain per hill is influenced by the number of productive tillers, panicle length, number of grains per panicle, percentage of whole grain, and weight of 1000 seeds [84]. The results showed that water treatment and goat manure fertilizer doses did not affect the weight of dry grain harvested in upland rice (Table 8). This can be caused by upland rice saving 70-80% of water compared to lowland rice, so water limitations do not affect upland rice yield. Based on research in Thailand, water stress treatment affects grain yield, namely 4.03 tons.ha^{-1} in the Alternate Wetting and Drying treatment and 4.13 tons.ha^{-1} in the flooding treatment [85]. Based on other Southeast Asian research, mineral fertilizer combined with water stress, namely alternating wetting and drying, causes a 14% decrease in yield, lower than the continuous flooding treatment. Upland rice can increase the formation of lateral roots in limited water conditions, so a higher root-fertilizer ratio encourages the growth and yield of upland rice. In addition, upland rice has xylem vessels with a higher number, diameter, and area than lowland rice, affecting water conductance and maintaining leaf temperature. Synergistic interactions between soil moisture and organic fertilizers occur during rice growth to increase rice yields and the efficiency of water and nitrogen [86, 87].

4. CONCLUSIONS

Water treatment did not affect upland rice growth and yield. However, the dosage of goat manure fertilizer affected plant growth, specifically plant height, number of leaves, productive tillers, yield, plant biomass, panicles per hill, and grains per panicle. A dose of 10 tons.ha^{-1} cow manure stimulated plant height, number of leaves, and productive tillers, while a dose of 30 tons.ha^{-1} optimally increased biomass and number of panicles. The combination of 100% field capacity water treatment with 10 tons of goat manure/ha produced the highest number of grains per panicle. It was similar to the treatment of 3/4 field capacity water and 20–30 tons.ha^{-1} dose. Controlled water stress and the use of goat manure are low-carbon adaptive strategies that improve water efficiency, soil fertility, and the resilience of rice agroecosystems to climate change.

ACKNOWLEDGMENT

Thanks to Sebelas Maret University for providing Non-APBN funding for research through the Research Group Research Program with contract No.: 371/UN27.22/PT.01.03/2025.

REFERENCES

[1] Juniarsih, T., Nazaruddin, L.O., Rahmat, A.F., Szendrő, K. (2025). Exploring rice consumption patterns and carbohydrate source diversification among the Indonesian community in Hungary. Open Agriculture, 10(1): 20250439. https://doi.org/10.1515/opag-2025-0439

[2] Ariyanto, E., Nugraha, M.K.R. (2024). Population vs. poverty level in the future in Indonesia: Holt's linear trend method. International Journal of Sustainable Development and Planning, 19(7): 2763-2770. https://doi.org/10.18280/ijsdp.190733

[3] Widyawati, W., Hanani AR, N., Syafrial, S., Sujarwo, S. (2025). Crafting the future of rice in Indonesia: Sustainable supply through systems thinking. Cogent Social Sciences, 11(1): 2488113. https://doi.org/10.1080/23311886.2025.2488113

[4] BPS. (2023). Indonesia rice harvest area 2023. Badan Pusat Statistik, Jakarta, 2023. https://www.bps.go.id/en/pressrelease/2023/10/16/2037/paddy-harvested-area-and-production-in-indonesia-2023--preliminary-figures-.html.

[5] Van Oort, P.A., Zwart, S.J. (2018). Impacts of climate change on rice production in Africa and causes of simulated yield changes. Global Change Biology, 24(3): 1029-1045. https://doi.org/10.1111/gcb.13967

[6] Ansari, A., Pranesti, A., Telaumbanua, M., Alam, T., Wulandari, R.A., Nugroho, B.D.A. (2023). Evaluating the effect of climate change on rice production in Indonesia using multimodelling approach. Heliyon, 9(9): e19639. https://doi.org/10.1016/j.heliyon.2023.e19639

[7] Chen, H., Wu, Y.C., Cheng, C.C., Teng, C.Y. (2023). Effect of climate change-induced water-deficit stress on long-term rice yield. Plos One, 18(4): e0284290. https://doi.org/10.1371/journal.pone.0284290

[8] Amarasinghe, K.I.C., Jayakody, L.K.R.R., De Silva, C.S. (2020). Adverse effects of climate change-induced temperature and water stress on growth and yield of rice (*Oryza sativa* L.) variety Suwandel. Sri Lanka Journal of Food and Agriculture, 6(2). https://doi.org/10.4038/sljfa.v6i2.85

[9] Shrestha, S., Mahat, J., Shrestha, J., KC, M., Paudel, K. (2022). Influence of high-temperature stress on rice growth and development. A review. Heliyon, 8(12): e12651. https://doi.org/10.1016/j.heliyon.2022.e12651

[10] Devkota, K.P., Manschadi, A.M., Lamers, J.P.A., Humphreys, E., Devkota, M., Egamberdiev, O., Gupta, R.K., Sayre, K.D., Vlek, P.L.G. (2013). Growth and yield of rice (Oryza sativa L.) under resource conservation technologies in the irrigated drylands of Central Asia. Field Crops Research, 149: 115-126. https://doi.org/10.1016/j.fcr.2013.04.015

[11] Akbar, G., Islam, Z., Khalil, S.H. (2025). Effect of land and water management on rice yield and water productivity in silty loam soil. Plant and Soil, 508(1): 179-191. https://doi.org/10.1007/s11104-024-06790-9

[12] Sudhir-Yadav, S.Y., Gill, G., Humphreys, E., Kukal, S.S., Walia, U.S. (2010). Effect of water management on dry seeded and puddled transplanted rice. Part 1: Crop performance. Field Crops Research, 120(1): 112-122.

[13] Kankwatsa, P., Muzira, R., Mutenyo, H., Lamo, J. (2019). Improved upland rice: Adaptability, agronomic and farmer acceptability assessment under semi-arid conditions of south western Uganda. Open Access Library Journal, 6: e5660. https://doi.org/10.4236/oalib.1105660

[14] Langangmeilu, G., Sahu, M., Sarthi, D.P., Pusparani, K., Heisnam, P., Moiragthem, A. (2023). Moisture stress in upland rice (Oryza sativa L.) and measures to overcome it under changing climate: A review. International Journal of Environment and Climate Change, 13(10): 337-347.

[15] Wei, W., Guan, D., Ma, M., Jiang, X., et al. (2023). Long-term fertilization coupled with rhizobium inoculation promotes soybean yield and alters soil bacterial community composition. Frontiers in Microbiology, 14: 1161983. https://doi.org/10.3389/fmicb.2023.1161983

[16] Peng, G.A.O., Zhang, T., Huang, J., Zhang, Z.H., Zhang, H.M. (2023). Improvement of soil fertility and rice yield after long-term application of cow manure combined with inorganic fertilizers. Journal of Integrative Agriculture, 22(7): 2221-2232. https://doi.org/10.1016/j.jia.2023.02.037

[17] Babalola, T.E., Adabembe, B.A., Faloye, O.T. (2022). Water use-yield relationship of maize as influenced by biochar and inorganic fertilizer applications in a tropical sandy clay loam soil. Agricultural Water Management, 271: 107801. https://doi.org/10.1016/j.agwat.2022.107801

[18] Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B., Kamili, A.N. (2021). Chemical fertilizers and their impact on soil health. In Microbiota and Biofertilizers, pp. 1-20. https://doi.org/10.1007/978-3-030-61010-4_1

[19] Liang, Y., Al-Kaisi, M., Yuan, J., Liu, J., Zhang, H., Wang, L., Cai, H., Ren, J. (2021). Effect of chemical fertilizer and straw-derived organic amendments on continuous maize yield, soil carbon sequestration and soil quality in a Chinese Mollisol. Agriculture, Ecosystems & Environment, 314: 107403. https://doi.org/10.1016/j.agee.2021.107403

[20] Han, J., Dong, Y., Zhang, M. (2021). Chemical fertilizer reduction with organic fertilizer effectively improve soil fertility and microbial community from newly cultivated land in the Loess Plateau of China. Applied Soil Ecology, 165: 103966. https://doi.org/10.1016/j.apsoil.2021.103966

[21] Meng, X., Sørensen, P., Møller, H.B., Petersen, S.O. (2023). Greenhouse gas balances and yield-scaled emissions for storage and field application of organic fertilizers derived from cattle manure. Agriculture, Ecosystems & Environment, 345: 108327. https://doi.org/10.1016/j.agee.2022.108327

[22] Mindari, W., Widjayani, B.W., Sasongko, P.E., Isnaini, F., Siswanto, S. (2024). Effect of liquid organic fertilizer from chicken, goat, and cow manure on the content of nitrogen, phosphorus, potassium, and lead in soil, and on stem and fruit yield of tomato. Agrotechnology Research Journal, 8(2): 148-156.

[23] Andharesta, A.B., Sundahri, S. (2024). Effect of cow manure and plant growth promoting rhizobacteria on the

yield of common bean. Jurnal Ilmu Pertanian Indonesia, 29(3): 435-446. https://doi.org/10.18343/jipi.29.3.435

[24] Li, G., Zhang, Y., Xu, J., Zhu, C., Hu, Q., Xu, K. (2025). Nitrogen uptake and carbon-nitrogen synergistic translocation improve yield and nitrogen use efficiency in the dep1 rice line. Journal of Integrative Agriculture. https://doi.org/10.1016/j.jia.2025.02.050

[25] Amin, B., Luo, J., Shi, J., Huang, W., Fang, Z. (2024). Physiological and transcriptomic analysis provides novel insight into growth in Kam sweet rice under different nitrogen supplies. Physiologia Plantarum, 176(1): e14162. https://doi.org/10.1111/ppl.14162

[26] Gao, H., Liu, Q., Gong, D., Liu, H., et al. (2023). Biodegradable film mulching reduces the climate cost of saving water without yield penalty in dryland rice production. Resources, Conservation and Recycling, 197: 107071. https://doi.org/10.1016/j.resconrec.2023.107071

[27] Devi, N.T., Devi, A.S., Singh, K.R. (2025). Impact of chemical fertilizer and composts application on growth and yield of rice in Northeast India. Scientific Reports, 15(1): 8575. https://doi.org/10.1038/s41598-025-93684-0

[28] Zhang, J., Ge, L.A., Yang, Y., Zhang, X., Wang, C., Sun, H., Chen, H., Zhou, S. (2025). Production and subsequent application of different biochar-based organic fertilizers to enhance vegetable quality and soil carbon stability. Journal of Soil Science and Plant Nutrition, 25(1): 147-159. https://doi.org/10.1007/s42729-024-02123-y

[29] Ahmad, S., Nadeem, M. Y., Gao, S., Li, Q., Ding, Y., Liu, Z., Jiang, Y., Li, W., Li, G. (2025). Subsurface placement of controlled-release blended fertilizers mitigates ammonia volatilization by promoting nitrogen transformation in rice fields. Agriculture, Ecosystems & Environment, 386: 109624. https://doi.org/10.1016/j.agee.2025.109624

[30] Supriyono, S., Setyaningrum, D., Pardono, P., Nurrohmah, M.A. (2025). The Effect of water level and cow manure fertilizer application method on rice yield and Cyperus rotundus weed. BIO Web of Conferences, 155: 01013. https://doi.org/10.1051/bioconf/202515501013

[31] Nasta, P., Franz, T.E., Gibson, J.P., Romano, N. (2023). Revisiting the definition of field capacity as a functional parameter in a layered agronomic soil profile beneath irrigated maize. Agricultural Water Management, 284: 108368. https://doi.org/10.1016/j.agwat.2023.108368

[32] Zhang, Y.J., Cheng, Y.D. (2020). The effects of water and nitrogen on the roots and yield of upland and paddy rice. Journal of Integrative Agriculture, 19(5): 1363-1374. https://doi.org/10.1016/S2095-3119(19)62811-X

[33] Verma, H., Devi, K., Baruah, A.R., Sarma, R.N. (2020). Relationship of root aquaporin genes, OsPIP1; 3, OsPIP2; 4, OsPIP2; 5, OsTIP2; 1 and OsNIP2; 1 expression with drought tolerance in rice. Indian Journal of Genetics and Plant Breeding, 80(1): 50-57.

[34] Zhang, Y., Liu, G., Huang, W., Xu, J., Cheng, Y., Wang, C., Zhu, T., Yang, J. (2020). Effects of irrigation regimes on yield and quality of upland rice and paddy rice and their interaction with nitrogen rates. Agricultural Water Management, 241: 106344. https://doi.org/10.1016/j.agwat.2020.106344

[35] Ghosh, M., Devi, A. (2019). Assessment of crop growth, soil properties and crop yield in an upland acidic soil with inorganic fertilizer blended with organic amendments in summer rice cropping seasons. International Journal of Recycling of Organic Waste in Agriculture, 8(Suppl 1): 1-9. https://doi.org/10.1007/s40093-019-0252-z

[36] Shaheb, M.R., Venkatesh, R., Shearer, S.A. (2021). A review on the effect of soil compaction and its management for sustainable crop production. Journal of Biosystems Engineering, 46(4): 417-439. https://doi.org/10.1007/s42853-021-00117-7

[37] Li, Z., Zhang, Y., Du, H. (2024). Upland rice retains genetic elements conferring drought adaptation. Molecular Plant, 17(12): 1791-1793. https://doi.org/10.1016/j.molp.2024.10.006

[38] Shrestha, K., Miyazaki, A., Yoshii, D., Sakata, M., Moritsuka, N. (2024). Effect of localized fertilizer application on deep root development during early growth in upland rice under upland condition. Plant Production Science, 27(3): 240-252. https://doi.org/10.1080/1343943X.2024.2376296

[39] Niu, X., Zhai, N., Yang, X., Su, M., et al. (2022). Identification of drought-resistant genes in Shanlan upland Rice. Agriculture, 12(2): 150. https://doi.org/10.3390/agriculture12020150

[40] Nithya, N., Beena, R., Stephen, R., Abida, P.S., Jayalekshmi, V.G., Viji, M.M., Manju, R.V. (2020). Genetic variability, heritability, correlation coefficient and path analysis of morphophysiological and yield related traits of rice under drought stress. Chemical Science Review and Letters, 9(33): 48-54. https://doi.org/10.37273/chesci.cs142050122

[41] Sung, J., Kim, W., Oh, T.K., So, Y.S. (2023). Nitrogen (N) use efficiency and yield in rice under varying types and rates of N source: Chemical fertilizer, livestock manure compost and food waste-livestock manure compost. Applied Biological Chemistry, 66(1): 4. https://doi.org/10.1186/s13765-022-00766-y

[42] Iqbal, A., He, L., Ali, I., Ullah, S., et al. (2020). Manure combined with chemical fertilizer increases rice productivity by improving soil health, post-anthesis biomass yield, and nitrogen metabolism. Plos One, 15(10): e0238934. https://doi.org/10.1371/journal.pone.0238934

[43] Zhao, M., Gao, Z., Kuang, C., Chen, X. (2024). Partial root-zone drying combined with nitrogen treatments mitigates drought responses in rice. Frontiers in Plant Science, 15: 1381491. https://doi.org/10.3389/fpls.2024.1381491

[44] Amiroh, A., Yunus, A., Purwanto, E., Haryanto, E.T., Lestari, M.W. (2025). Effectiveness of organic ameliorant for improving physical, chemical, and biological properties of drought-stress in soil. IOP Conference Series: Earth and Environmental Science, 1497(1): 012002. https://doi.org/10.1088/1755-1315/1497/1/012002

[45] Liang, D., Ning, Y., Ji, C., Zhang, Y., Wu, H., Ma, H., Zhang, J.W., Wang, J. (2024). Biochar and manure co-application increases rice yield in low productive acid soil by increasing soil pH, organic carbon, and nutrient retention and availability. Plants, 13(7): 973. https://doi.org/10.3390/plants13070973

[46] Mu, X., Chen, Y. (2021). The physiological response of photosynthesis to nitrogen deficiency. Plant Physiology and Biochemistry, 158: 76-82.

https://doi.org/10.1016/j.plaphy.2020.11.019
[47] Zakaria, N.I., Berahim, Z., Hatta, M.A.M., Omar, M.H., Azhan, H.M. (2024). Physiological and yield performance of commercial rice varieties under cyclic water stress in Malaysia. Sains Malaysiana, 53(7): 1589-1603. http://doi.org/10.17576/jsm-2024-5307-09
[48] Wu, K., Wang, S., Song, W., Zhang, J., et al. (2020). Enhanced sustainable green revolution yield via nitrogen-responsive chromatin modulation in rice. Science, 367(6478): eaaz2046. https://doi.org/10.1126/science.aaz2046
[49] Lamptey, S., Li, L., Xie, J. (2018). Impact of nitrogen fertilization on soil respiration and net ecosystem production in maize Original Paper. Plant, Soil and Environment, 64(8): 353-360. https://doi.org/10.17221/217/2018-PSE
[50] Wang, Y., Chen, Y.F., Wu, W.H. (2021). Potassium and phosphorus transport and signaling in plants. Journal of Integrative Plant Biology, 63(1): 34-52. https://doi.org/10.1111/jipb.13053
[51] Samudin, S., Rauf, A. (2025, May). The response of Dongan cultivar to the application of NPK fertilizer and liquid organic fertilizer (POC). IOP Conference Series: Earth and Environmental Science, 1497(1): 012011. https://doi.org/10.1088/1755-1315/1497/1/012011
[52] Zahedi, S.M., Karimi, M., Venditti, A., Zahra, N., Siddique, K.H., Farooq, M. (2025). Plant adaptation to drought stress: The role of anatomical and morphological characteristics in maintaining the water status. Journal of Soil Science and Plant Nutrition, 25(1): 409-427. https://doi.org/10.1007/s42729-024-02141-w
[53] Yang, C., Zhang, J., Zhang, G., Lu, J., et al. (2022). Potassium deficiency limits water deficit tolerance of rice by reducing leaf water potential and stomatal area. Agricultural Water Management, 271: 107744. https://doi.org/10.1016/j.agwat.2022.107744
[54] Lv, M., Hou, D., Wan, J., Ye, T., et al. (2023). OsWRKY97, an abiotic stress-induced gene of rice, plays a key role in drought tolerance. Plants, 12(18): 3338. https://doi.org/10.3390/plants12183338
[55] Li, Q., Zhu, P., Yu, X., Xu, J., Liu, G. (2024). Physiological and molecular mechanisms of rice tolerance to salt and drought stress: Advances and future directions. International Journal of Molecular Sciences, 25(17): 9404. https://doi.org/10.3390/ijms25179404
[56] Tamaru, S., Yabuta, S., Goto, K., Khanthavong, P., Sakagami, J.I. (2023). Oxygen consumption and transportation in rice roots are highly dependent on leaf area and root dry weight ratio. Rhizosphere, 25: 100644. https://doi.org/10.1016/j.rhisph.2022.100644
[57] Ouyang, W., Yin, X., Yang, J., Struik, P.C. (2022). Do shoot anatomical characteristics allow rice to grow well under water deficit?. Journal of Agronomy and Crop Science, 208(6): 763-776. https://doi.org/10.1111/jac.12509
[58] Sandar, M.M., Ruangsiri, M., Chutteang, C., Arunyanark, A., Toojinda, T., Siangliw, J.L. (2022). Root characterization of Myanmar upland and lowland rice in relation to agronomic and physiological traits under drought stress condition. Agronomy, 12(5): 1230. https://doi.org/10.3390/agronomy12051230
[59] Li, B., Zhang, X., Morita, S., Sekiya, N., Araki, H., Gu, H., Han, J., Lu, Y., Liu, X. (2022). Are crop deep roots always beneficial for combating drought: A review of root structure and function, regulation and phenotyping. Agricultural Water Management, 271: 107781. https://doi.org/10.1016/j.agwat.2022.107781
[60] Da Mata, C.R., De Castro, A.P., Lanna, A.C., Bortolini, J.C., De Moraes, M.G. (2023). Physiological and yield responses of contrasting upland rice genotypes towards induced drought. Physiology and Molecular Biology of Plants, 29(2): 305-317. https://doi.org/10.1007/s12298-023-01287-8
[61] Esmaeilzadeh-Moridani, M., Esfahani, M., Aalami, A., Moumeni, A., Khaledian, M. (2022). Profiling the physiological response of upland and lowland rice (*Oryza sativa* L.) genotypes to water deficit. Journal of Crop Science and Biotechnology, 25(3): 289-300. https://doi.org/10.1007/s12892-021-00131-3
[62] Isnawan, B.H., Aini, L.N., Hanudin, E. (2023). Rice (*Oryza sativa* L.) response with the Application of Manure and Liquid Organic Fertilizer. IOP Conference Series: Earth and Environmental Science, 1287(1): 012017. https://doi.org/10.1088/1755-1315/1287/1/012017
[63] Novair, S.B., Hosseini, H.M., Etesami, H., Pirmoradian, N., Lajayer, B.A., Price, G.W. (2024). Straw application improved soil biological properties and the growth of rice plant under low water irrigation. Environmental Research, 255: 119138. https://doi.org/10.1016/j.envres.2024.119138
[64] Sutardi, Pertiwi, M.D., Praptana, R.H., Anda, M., et al. (2022). Increasing yield and economic value of upland rice using inorganic fertilizer and poultry manure in dryland. Agronomy, 12(11): 2829. https://doi.org/10.3390/agronomy12112829
[65] Li, Y., Šimůnek, J., Wang, S., Yuan, J., Zhang, W. (2017). Modeling of soil water regime and water balance in a transplanted rice field experiment with reduced irrigation. Water, 9(4): 248. https://doi.org/10.3390/w9040248
[66] Bhandari, U., Gajurel, A., Khadka, B., Thapa, I., et al. (2023). Morpho-physiological and biochemical response of rice (*Oryza sativa* L.) to drought stress: A review. Heliyon, 9(3): e13744. https://doi.org/10.1016/j.heliyon.2023.e13744
[67] Roy, R., Núñez-Delgado, A., Wang, J., Kader, M.A., Sarker, T., Hasan, A.K., Dindaroglu, T. (2022). Cattle manure compost and biochar supplementation improve growth of Onobrychis viciifolia in coal-mined spoils under water stress conditions. Environmental Research, 205: 112440. https://doi.org/10.1016/j.envres.2021.112440
[68] Xu, Y., Liu, X., Yan, L., Huang, X., Wang, J. (2024). The addition of organic fertilizer can reduce the dependence of dryland yield on rainfall-based on a 32-year long-term study. Science of The Total Environment, 915: 170152. https://doi.org/10.1016/j.scitotenv.2024.170152
[69] Sarma, B., Kashtoh, H., Lama Tamang, T., Bhattacharyya, P.N., Mohanta, Y.K., Baek, K.H. (2023). Abiotic stress in rice: Visiting the physiological response and its tolerance mechanisms. Plants, 12(23): 3948. https://doi.org/10.3390/plants12233948
[70] Mustikarini, E.D., Tri Lestari, S.P., Ratna Santi, S.P., Prayoga, G.I., SP, M., Cahya, Z. (2022). Evaluation of F6 generation of upland rice promising lines for drought stress tolerance. Biodiversitas Journal of Biological Diversity, 23(7): 3401-3406.

[71] Salsinha, Y.C.F., Maryani, Indradewa, D., Purwestri, Y. A., Rachmawati, D. (2021). Leaf physiological and anatomical characters contribute to drought tolerance of Nusa Tenggara Timur local rice cultivars. Journal of Crop Science and Biotechnology, 24(3): 337-348. https://doi.org/10.1007/s12892-020-00082-1

[72] Sahebi, M., Hanafi, M.M., Rafii, M.Y., Mahmud, T.M.M., et al. (2018). Improvement of drought tolerance in rice (Oryza sativa L.): Genetics, genomic tools, and the WRKY gene family. BioMed Research International, 2018(1): 3158474. https://doi.org/10.1155/2018/3158474

[73] Hussain, T., Anothai, J., Nualsri, C., Soonsuwon, W. (2018). Evaluating performance of sixteen upland rice genotypes under field conditions for further breeding process. Journal of Agricultural Science, 10(3): 144-150.

[74] Hussain, T., Gollany, H.T., Hussain, N., Ahmed, M., Tahir, M., Duangpan, S. (2022). Synchronizing nitrogen fertilization and planting date to improve resource use efficiency, productivity, and profitability of upland rice. Frontiers in Plant Science, 13: 895811. https://doi.org/10.3389/fpls.2022.895811

[75] Qin, X., Rao, X., Liu, H., Hong, J., Tang, W., Yan, S., Yang, G., Chen, H., Hu, Y. (2025). Effect of nitrogen and phosphorus fertilizers on dry matter accumulation and translocation of two amylose content indica rice on yield. Plants, 14(10): 1536. https://doi.org/10.3390/plants14101536

[76] Zhou, Q., Guo, W., Chen, N., Wang, Z., Li, G., Ding, Y., Ninomiya, S., Mu, Y. (2023). Analyzing nitrogen effects on rice panicle development by panicle detection and time-series tracking. Plant Phenomics, 5: 0048. https://doi.org/10.34133/plantphenomics.0048

[77] Ahmad, S., Nadeem, M. Y., Gao, S., Li, Q., Tao, W., Li, W., Ding, Y., Li, G. (2023). Mitigating ammonia volatilization without compromising yield and quality of rice through the application of controlled-release, phosphorus-blended fertilizers. Agronomy, 13(2): 448. https://doi.org/10.3390/agronomy13020448

[78] Sekiya, N., Asano, A., Peter, M.A., Gichuhi, E.W., Menge, D.M., Kikuta, M., Kondo, M., Makihara, D. (2025). Effects of nitrogen application in upland rice cultivars: Balancing sink-source relationships for sustainable yield in water-limited environments. Field Crops Research, 332: 110012. https://doi.org/10.1016/j.fcr.2025.110012

[79] He, H., Peng, M., Lu, W., Hou, Z., Li, J. (2022). Commercial organic fertilizer substitution increases wheat yield by improving soil quality. Science of the Total Environment, 851: 158132. https://doi.org/10.1016/j.scitotenv.2022.158132

[80] Arianti, F.D., Pertiwi, M.D., Triastono, J., Purwaningsih, H., et al. (2022). Study of organic fertilizers and rice varieties on rice production and methane emissions in nutrient-poor irrigated rice fields. Sustainability, 14(10): 5919. https://doi.org/10.3390/su14105919

[81] Sulistijo, E.D., Benu, I., Oematan, G., Rosnah, U.S., Hilakore, M.A., Jelantik, I.G.N. (2024). Enhancing nutrient intake, digestibility, rumen fermentation, and blood metabolites in Kacang goats using compost-enriched hydroponic maize fodder. Tropical Animal Science Journal, 47(4): 475-482. https://doi.org/10.5398/tasj.2024.47.4.475

[82] Pangaribuan, D.H., Ginting, Y.C., Afifa, M.N. (2024). Enhancing leafy vegetable growth and yield with goat urine, moringa leaf, and banana stem-based liquid organic fertiliser. Pertanika Journal of Tropical Agricultural Science, 47(3): 1037-1055. https://doi.org/10.47836/pjtas.47.3.27

[83] Shi, Y., Guo, E., Cheng, X., Wang, L., Jiang, S., Yang, X., Ma, H., Zhang, T., Li, T., Yang, X. (2022). Effects of chilling at different growth stages on rice photosynthesis, plant growth, and yield. Environmental and Experimental Botany, 203: 105045. https://doi.org/10.1016/j.envexpbot.2022.105045

[84] Howlader, N.C., Bulbul, M.T.A., Islam, M.Z., Arafat, E., Rana, M.S., Hasan, M.Z. (2025). Assessing rice genotypes based on agro-morphological characterization and diversity analysis in southern Bangladesh. Discover Plants, 2(1): 189. https://doi.org/10.1007/s44372-025-00253-w

[85] Wichaidist, B., Intrman, A., Junhom, P., Puttrawutichai, S., Rewtragulpaibul, C., Suksaroj, C. (2025). The effect of irrigation practices on stress-related physiological characteristics, water productivity, and water footprint in rice cultivation. Environmental and Sustainability Indicators, 26: 100695. https://doi.org/10.1016/j.indic.2025.100695

[86] Lee, B., Kim, M., Geem, K.R., Sung, J. (2025). Improving nutrient use efficiency of rice under alternative wetting and drying irrigation combined with slow-release nitrogen fertilization. Plants, 14(10): 1530. https://doi.org/10.3390/plants14101530

[87] Ji, Y., Ma, J., Ma, L., Xu, W., Ji, Y., Wang, L., Feng, Y., Feng, Z. (2025). Combination of water-saving irrigation and controlled-release fertilizer application reduced gaseous nitrogen loss in single-crop paddy soil. Journal of Environmental Management, 377: 124695. https://doi.org/10.1016/j.jenvman.2025.124695