Journal of Applied Agricultural Science and Technology
7(3): 314-328 (2023)
E-ISSN: 2621-2528
ISSN: 2621-4709

NITROGEN FERTILIZERS AND PLANT SPACING IN ORGANIC RICE CULTIVATION: A REVIEW

Erythrina Erythrina* , Gagad Restu Pratiwi, Nurwulan Agustiani, Arinal Haq Izzawati Nurrahma

Research Center for Food Crops, Agricultural and Food Research Organization, National Research and Innovation Agency, Bogor, Indonesia

*Corresponding author
Email: erythrina_58@yahoo.co.id

Abstract. *Organic rice cultivation is one of the technologies developed in Indonesia around two decades ago, but it is not growing as expected. Indeed, organic rice production is considered less effective than conventional farming. This review article explores the role of agronomic factors in organic rice cultivation related to organic nutrient availability and plant spacing. The proposed alternative solutions for using organic inputs to improve soil fertility and increase crop yields are also discussed. The effectiveness of organic fertilizers to chemical fertilizers based on the Rice Agro-advisory Service shows that organic rice has lower yields than conventional farming. The yield reduction ranges between 0.5 and 2.2 t ha^{-1} or around 9 to 43%, depending on organic amendments and site characteristics. It is also proven that applying high-nitrogen nutrients from organic fertilizers does not increase rice production. Application of nitrogen fertilizers in the right amount and at the correct plant stage is more essential because it affects the yield component of rice plants. Narrower plant spacing in transplanted organic rice results in higher productivity. An increase in plant population higher than 25 hills m^{-2} no longer significantly increases rice yields. Among the agronomic factors that affect organic rice cultivation are the diversity of organic amendment in nutrient mineralization, especially nitrogen, according to plant needs, and narrow plant spacing that allows lesser weeds to grow among crop plants. These two agronomic factors need to be considered and applied by farmers to get the optimum growth and yield of organic rice cultivation.*

Keywords: *organic farming; organic nutrient management; plant spacing; yield*

1. Introduction

Since COVID-19 happened, consumers have had more awareness of safe and organic food. Many countries report increased organic product sales. People in higher-income countries have a higher demand for organic food. Domestic demand for healthier food continues to rise with Indonesia's growing number of middle classes. With 121,535 hectares of organic land in 2019, Indonesia has grown by only 2.4% over the past decade. Compared to Thailand's 361.7%, Vietnam's 171.5%, the Philippine's 99.2%, and East Timor's 30.5%, Indonesia's organic land area growth rate is modest (Schlatter *et al*., 2022). In recent years, the supply-demand gap is widening. Therefore, government assistance is needed to increase organic rice production dramatically so that farmers can benefit from the global market due to the higher demand for organic rice. Applying excessive amounts of chemical fertilizers especially urea under intensive rice production has resulted in soil-related problems, such as acidification (Dobermann *et al*., 2002; Buresh *et al*.,

Received February 13, 2023; Accepted August 12, 2023; Published August 25, 2023
https://doi.org/ 10.55043/jaast.v7i3.143

2019), loss of organic matter, structural damage, and decreased biological activity and fertility (Saber *et al*., 2021). As a result, crop yields in some areas have stagnated especially in Java (Agus, *et al*., 2019). However, growing competition for land and water, especially in Java, improves rice cultivation by maximizing the efficiency of fertilizer and organic inputs rather than expanding the land. Outside Java, where the cropping index still needs to be improved, access to chemical fertilizers and pesticides is relatively lacking but has abundant sources of organic matter; this could be an area of intensification in the future (Erythrina *et al*., 2021).

Organic rice cultivation follows management practices that do not use all chemical products such as fertilizers, insecticides, fungicides, herbicides, and genetically modified plant seeds (Timsina, 2018). However, this organic rice system's productivity is relatively lower than intensive conventional rice cultivation (He *et al*., 2018). Saber *et al.* (2021) and Arunrat *et al.* (2022) reported that the yield of organic rice was 28-50% lower than conventional rice. The yield gap depends on the crop type; for example, more remarkable for cereals and lower for legumes. A more significant nitrogen limitation or lower nutrient availability in organic crops than in conventional ones causes a difference in the yield gap (Alvarez, 2021). For cereal crops, it could be established that the yield gap tended to be higher when conventional systems received more nitrogen than organic ones; this trend is reversed when organic crops are the ones that receive more nitrogen. Poorer pests, diseases, and weeds control are additional causes of the yield gap in organic farming (Meemken & Qaim, 2018; Röös *et al*., 2018) that were not evaluated here.

Nitrogen (N) is the most essential nutrient in rice. Compared to phosphate (P) and potassium, (K) its availability on almost all types of soil is limited (Dobermann *et al*., 2002). In photosynthesis, plants need nitrogen to make green leaf substances or chlorophyll. Adding N fertilizer according to plant needs is the key to increasing plant growth to obtain optimal results (Buresh *et al*., 2019). Too much N fertilizer will increase the amount of chlorophyll in the leaves so that the leaves become dark green, limp, dense, and watery (Sinha & Tandon, 2020), so plants are more susceptible to pest and disease attacks (Ballini *et al*., 2013). Excessive application of N also slows grain maturation, softens the straw, making it easy for plants to log, and reduces grain quality. Conversely, a deficiency of N causes plants to grow stunted, with limited roots; leaves turn yellow due to low chlorophyll content, reduced biomass production so that yields decrease, and grain tends to fall off easily (Tang *et al*., 2019).

Generally, planting rice more densely than necessary increases planting costs and makes the plants easy to lodge. On the other hand, wider spacing causes lower yields because the number of plants is less than the optimal number needed to obtain a high yield (Tian *et al*., 2017). Irregular spacing reduces rice yields by 20-30% compared to planting straight (IRRI, 1997). The use of planting services with a wholesale system often does not guarantee optimal planting density.

Various agronomic innovations are constantly being developed to improve the Indonesian organic rice production system. Organic rice farming has been developed in different parts of Indonesia but has yet to receive enough positive responses from farmers. Organic rice farming is considered less effective than conventional rice farming (Arunrat *et al.*, 2022). The significant difference in yields between traditional and rice organic farming and the slight difference in product prices makes farmers reluctant to expand their farming scale and adopt the new technology (Timsina, 2018). The low productivity of organic rice compared to conventional rice is because most farmers need to understand the effect of various organic fertilizers in providing nitrogen nutrients using optimal plant density to obtain higher rice yields thorough mineralitation.

Indonesia needs to increase food production in the coming decades. Organic agriculture has been proposed as an alternative that can help to achieve this while protecting the health of consumers and the environment. However, there has been an intense debate regarding the effects of organic agriculture on crop yields, especially rice productivity. But, this aspect of organic production has yet to be studied. This review article aimed to focus on the current knowledge about the role of nitrogen fertilizers and plant spacing as agronomic factors, which primarily play a crucial role in improving organic rice productivity. Agricultural extension workers and key farmers need to be better understood so that small farmers can implement their knowledge in organic rice cultivation to increase farmers' income and, at the same time, protect the environment.

2. Role of Organic Fertilizers in Production and Soil Quality

Maximizing the benefits of crops grown on degraded soils is complex, and the efforts needed to mitigate degraded soils can be even more challenging to be sustainable. Therefore, we must develop and adopt environmentally friendly alternatives that complement or replace chemical fertilizers (Sinha & Tandon, 2020). Organic fertilizers are environmentally friendly and can maintain soil health when used in intensive rice farming. They help to preserve the amount and quality of organic matter in the soil and supply plant-available essential N, P, K, and micronutrients (Setiawati *et al.*, 2020). One of the advantages of organic fertilizers is that the absorption of nutrients is slower than chemical fertilizers (Gong *et al.*, 2021). This slower process allows the plant to process fertilizer more naturally and does not result in over-fertilizing, which can damage the plant.

Unlike chemical fertilizers, organic fertilizers reduce the acidity in the soil and do not cause leaching. They do not kill beneficial microorganisms in the ground. Organic fertilizers also help improve soil structure, including air circulation, which supports beneficial organisms that help release nutrients into the soil (Arunrat *et al.*, 2022). The reduction in soil organic matter content due to intensive cultivation has become a significant concern related to agricultural sustainability.

Therefore, management practices that increase the organic matter content are considered good for soil quality and productivity. Most organic fertilizers can be prepared locally or on the farm itself. The use of organic fertilizers ensures that the food produced is free from harmful chemicals. Therefore, it is suggested that using organic fertilizers or combined applications is more beneficial than chemical fertilizers to maintain soil properties and increase soil productivity (Timsina, 2018).

Bio-fertilizers refer to microbial amendments of organisms such as blue-green algae, Azolla, Rhizobium, Azospirillum, bacteria promoted to stimulate biological N2 fixation, and phosphate solubilizing microorganisms, which can be used for N or P nutrition in organic rice production system (Al-Amri, 2021). Vermicomposting refers to a process whereby earthworms transform organic residues into compost that can be used as a substrate for plant growth (Blouin *et al*., 2019). Liquid organic fertilizer obtained through food composting or from local microorganisms (MOL) banana weevil can also be used to remediate contaminated soils and increase crop productivity (Chiang *et al*., 2016; Pujiwati *et al*., 2021; Tulak *et al*., 2022).

Given the critical importance of N in organic management, the solutions may be used for the split application of highly mineralizable N-rich organic amendments like vermicompost, biofertilizers, and poultry manure, including the split application of nutrient-dense in the form of granular manures. Those can be performed at sensitive growth stages during active tillering and panicle initiation (Keskinen *et al*., 2020). This calls for an integrative approach that harnesses nutrient sources like crop residues, organic manure, and soil biological activity and accommodates legume crops in rotation and natural N fixation (Hazra *et al*., 2018). This approach is expected to reduce the use of chemical fertilizers and synthetic pesticides.

Table 1. White, red and black rice nutrition composition, calculated per 100 g with edible weight 100 % (Ministry of Health, 2018).

Nutrient	White rice		Red rice	Black rice
	Ciherang	Rojolele		
Energy (cal)	357.0	357.0	352.0	351.0
Fat (g)	1.7	1.7	0.9	1.3
CHO (g)	77.1	77.1	76.2	76.9
Fiber (g)	0.2	0.2	0.8	20.1
Ash (g)	0.8	0.8	1.0	0.9
Ca (mg)	147.0	147.0	15.0	6.0
Protein	81.0	81.0	257.0	198.0
Fe (mg)	1.8	1.8	4.2	0.1
Na (mg)	27.0	34.0	10.0	15.0
K (mg)	71.0	112.9	202.0	105.0
Cu (mg)	0.10	0.14	0.36	0.10
Zn (mg)	0.50	0.10	1.90	1.60

3. Variants of Organic Rice Varieties

Organic rice from local rice varieties remains the prima donna in several regions, even though the average yield potential genetically was lower than modern rice cultivars (Mondal *et al*., 2021). The delicious taste and the right texture are the reasons why local varieties of rice are still being sought after. More than that, local rice varieties are a valuable asset as a source of biological wealth. Compared to white rice from mega varieties such as Ciherang and local varieties, the demand for red and black rice tends to increase. Red and black rice are also known as healthier rice because they contain higher protein, fiber, and zinc (Table 1). The deep purplish red and black color comes from anthocyanin compounds indicated to have anti-oxidative activity (Fatchiyah *et al.*, 2020).

Aek Sibundong, Inpari 24, Pamelen, and Pamera are high-yielding red rice released by the Ministry of Agriculture. Pamelen and Pamera, released in 2019, have higher yield potentials than Aek Sibundong and Inpari 24, released in 2006 and 2012, respectively (Table 2). The advantage of the Pamera variety is that it is aromatic brown rice. All the new high-yielding types have a potentially attainable yield of around 10 t ha^{-1} (Sasmita & Nugraha, 2020). Almost all brown and black rice is still grown on a small scale.

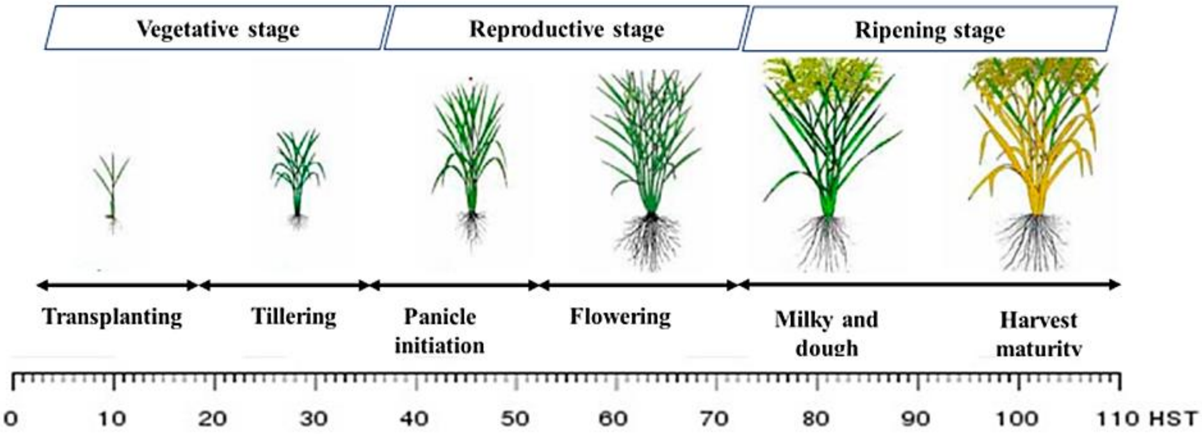

Figure 1. Growth stage of the rice plant

Table 2. High-yielding varieties of red rice and black rice released by the Ministry of Agriculture.

Variety	Age (days)	Amylose content (%)	Attainable yield (t ha^{-1})	Group	Year released
Aek Sibundong	108-125	22.0	8.0	Red rice	2006
Inpari 24	111	18.0	7.7	Red rice	2012
Pamelen	112	18.6	11.9	Red rice	2019
Pamera	113	21.1	11.3	Red rice	2019
Jeliteng	113	19.6	9.9	Black rice	2019

4. Growth Stages in Rice Cultivation

According to Fageria (2007), rice plants are generally considered to have three stages: vegetative, reproductive, and ripening (Figure 1). The growth stages of rice plants include slow growth stages from the first week to the fifth week after planting. The initial growth stages are often associated with low plant growth because the leaf area index remains small. Applying N fertilizer at once at the beginning of planting (0 to 10 days after transplanting) can reduce labor costs, but at that time, the plants do not need large amounts of N nutrients. Fast growth stages from the sixth to eighth weeks after planting are the phase of active tiller formation. In the active tillering (around 23 to 27 days after transplanting) and panicle initiation or primordia (at 40 to 44 days after transplanting), depends on variety, plants need more N to support optimal growth, which is determined by the indigenous N supply and N fertilizers applied (Witt *et al.*, 2007). The panicle number hill^{-1} is dominantly determined during the vegetative phase. The number of grain panicle^{-1} and the weight of 1000 grains are determined during the reproductive phase, and the percentage of filled grains during the reproductive and flowering stages (Fageria, 2007).

5. Time and Amount of Nitrogen Application

Organic rice farmers need to be made aware that to get a higher yield level, it is necessary to add nutrients to plants. Even if fertilizer is available, farmers often need help understanding how, when, and how much to apply to obtain optimal results (Cassman & Dobermann, 2022). This is because agricultural extension workers still use blanket fertilizers recommendations for all types of land (Buresh *et al.*, 2019).

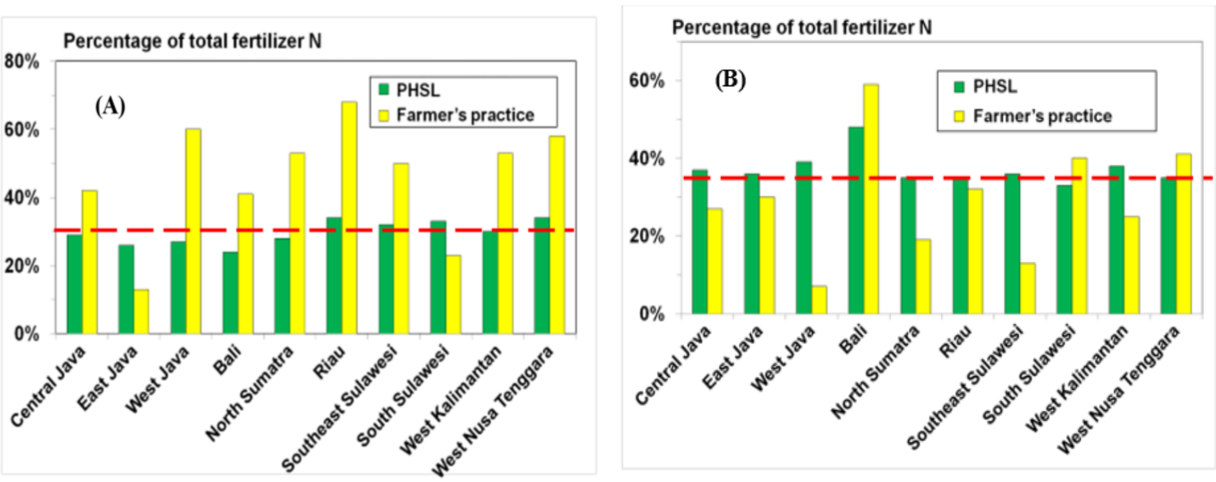

Figure 2. Percentage of total fertilizer N applied by farmers at 0-10 (A) and within 40-45 days after transplanting (B)

The application of nitrogen fertilizer in the right amount and at the correct plant stage so that it can support each step of rice plant growth is crucial because it affects the yield components of rice plants (Sharma *et al.*, 2019). The Ministry of Agriculture in collaboration with the International Rice Research Institute (IRRI), through research has developed a computer-based decision tool, namely Site-Specific Nutrient Management or Pemupukan Hara Spesifik Lokasi (PHSL), to help extension and farmers in efforts to increase rice productivity in Indonesia. PHSL field test results in eight provinces in Indonesia show that, compared to farmers' fertilization practices (FP), the use of PHSL recommendations on average, increased grain yield by 0.2 t ha^{-1} in 75 farms across Java and 0.6 t ha^{-1} in 231 farms across six provinces outside Java and increased farmer income by Rp. 1.1 million in Java to Rp. 2 million/ha/planting season outside Java (Buresh *et al.*, 2012). Currently, PHSL has changed its name to Layanan Konsultasi Padi (LKP) version 1.0 (http://webapps.irri.org/id/lkp/) and can be accessed free of charge via the Google Play Store website or Amazon Appstore, and others.

Observations on N fertilizer management based on LKP data often found that farmers need to apply nutrients more effectively. Many rice farmers use too much N fertilizer in the first ten days (Figure 2A), while LKP recommends only 30% of total N fertilizer in the early application. Farmers apply too little N fertilizer at other sites during active tillering or panicle initiation (Figure 2B), while LKP recommends 35% of total N fertilizer at each critical stage (Buresh *et al.*, 2012).

6. Organic Nutrient Management

Organic rice cultivation may be recommended as a more sustainable agricultural practice than conventional methods from an ecological point of view (Timsina, 2018). Organic rice farming maintains soil fertility primarily through composted organic matter compared to traditional rice farmers, which combine high-yielding varieties with chemical fertilizers and apply large amounts of pesticides (Chew *et al.*, 2019). The organic rice system uses a combination of organic additives from agricultural and off-farm sources, including manure, rice straw compost, goat manure, cow manure, Azolla, sesbania, vermicompost, and other sources of organic fertilizers.

The comparison of the relative effectiveness of these organic fertilizers with the recommended inorganic fertilizers based on the LKP is shown in Table 3. Yields of organic rice crops have lower productivity, generally ranging from 0.5 to 2.3 t ha^{-1} or about 9 to 43%, depending on organic amendments, ecological changes, and site characteristics, compared to conventionally grown rice based on LKP. The site characteristics may include weeds, insects and pests, rice varieties, and farm management practices (Hazra *et al.*, 2018).

The percentage of nitrogen (N) in organic fertilizers varies greatly between organic rice farmers. However, high N rates (more than 150 kg N ha^{-1}) from organic fertilizers do not ensure a high yield (Table 3). Under organic rice production systems, there is often no synchronization between crop requirements at each growth stage and the degree of mineralization of various organic matter. The release of nutrients from organic fertilizers is slower than from chemical fertilizers, so the ability of organic fertilizers to deliver N is highly dependent on the speed and amount of nutrient availability and suitability with plant needs. This cause balancing nitrogen supply and demand difficult in organic rice production (Lal, 2020). To minimize the lack of synchrony between the availability and demand for nitrogen, it would be better to provide different organic input sources rather than relying on one organic fertilizer base. Application of split-faster mineralized N-high organic additives such as vermicompost, biofertilizers, and nutrient-rich fertilizers in the form of granular fertilizers shows better prospects (Gong *et al.*, 2021; Hermawan *et al.*, 2021).

Table 3. The relative effectiveness of rice yield of organic fertilizers (OF) compared to inorganic fertilizers for conventional farming (CF).

Quantity (t ha^{-1})	OF Nutrient content (kg ha^{-1}) a)			CF[b)] Nutrient content (kg ha^{-1}) b)			Grain yield		Yield decrease		Ref
Source/s	N	P_2O_5	K_2O	N	P_2O_5	K_2O	OF (t ha^{-1})	CF (t ha^{-1})	(t ha^{-1})	(%)	
3.33 RSC	23	0.3	53	90	22	22	2.9	5.1	-2.2	-43.1	(Farmia, 2009)
10 B	35	17	231	86	19	19	3.2	4.1	-0.9	-22.0	(Komatsuzaki & Syuaib, 2010)
2.5 CM + PGPB	47	20	90	112	22	22	4.1	5.8	-1.7	-29.3	(Soebandiono, *et al*, 2021)
3 CM + 3 FYM	67	25	73	112	22	22	4.2	5.5	-1.4	-23.6	(Haryati & Adi, 2019)
5 CM	70	10	75	116	26	26	4.3	5.8	-1.5	-25.9	(Soebandiono, *et al*, 2021)
10 CM	124	17	135	112	22	22	4.6	5.8	-1.2	-20.7	(Haryati & Adi, 2019)
8 CM	152	64	288	109	30	30	5.1	5.6	-0.5	-8.9	(Atman *et al*, 2018)
10 GM	250	88	48	116	26	26	4.4.	5.7	-1.3	-22.8	(Setiawati *et al*, 2020)
10 GM + 2 A	278	116	112	116	26	26	4.7	5.7	-1.0	-17.5	(Setiawati *et al*, 2020)
10 GM + 2 S	295	91	80	116	26	26	4.7	5.7	-1.0	-17.5	(Setiawati *et al*, 2020)

[a)]Based on the nutrient content of organic fertilizer in the research article; [b)] Based on LKP for chemical fertilizer rates; RSC =rice straw compost; B =Bokashi; CM =cow manure; PGPB =plant growth-promoting bacteria; FYM =farm yard manure; GM =goat manure; A =Azolla; S =sesbania.

7. Closer Plant Spacing vs. Wider Plant Spacing

Most organic rice farmers use a wider spacing or a minimum of 30cm x 30cm, which comes from the principles of the rice intensification system (SRI) (Thakur *et al.*, 2010). Farmers prefer planting with wider spacing because they see the large number of tillers produced per hill. Among the cultivation techniques, plant spacing or the number of plant populations per unit area is crucial in manipulating plants to optimize yields. The number of tillers is mainly determined by the plant population. An increase in planting density or closer spacing naturally can increase yields by allowing more tillers per unit of land and fewer weeds to grow under the plants (Dunn *et al.*, 2020).

Researchers (Utami *et al.*, 2020; Frasetya *et al.*, 2019; Latif *et al.*, 2005; and Kashkool *et al.*, 2020) found that closer spacing of transplanted organic rice resulted in higher productivity, as shown in Table 4.

By changing the rice planting geometry, the system legowo planting increased plant population per unit area (Utami *et al.*, 2020; Frasetya *et al.*, 2019). Closer spacing results in lower grain yields per hill but is compensated for by more plants per unit area. Farmers planting rice closer than necessary increases planting costs and can cause crops easier to lodge. Conversely, the wider spacing will reduce yields if the number of plants is less than the optimal number needed to achieve high yields. Expanding the plant population beyond 25 hills m^{-2} or 20 cm x 20 cm spacing did not significantly increase rice yields. A narrow spacing of 20 cm x 20 cm reduces the number of productive panicles per hill and increases the number of panicles that do not emerge completely (Liu *et al.*, 2019; Dass *et al*, 2016; Chapagain & Yamaji, 2010; Yasmin *et al.*, 2018).

Table 4. Relative effectiveness of different plant spacing for organic rice production.

Plant population		Grain yield	Yield increase/decrease		Remarks	Ref
Spacing (cm)	Density (m^{-2})	(t ha^{-1})	(t ha^{-1})	(%)		
Legowo 2:1	21.3	5.2	0.8	18.2	*	(Utami *et al*, 2020)
25 x 25	16	4.4				
Legowo 2:1	21.3	6.7	1.9	39.6	**	(Frasetya *et al*, 2019)
25 x 25	16	4.8				
25 × 15	26.7	7.53	2.43	47.6	**	(Latif *et al.*, 2005)
40 x 40	6.3	5.10				
15 × 25	26.7	6.7	1.10	19.6	**	(Kashkool *et al.*, 2020)
20 × 30	16.7	5.6				
	21	7.51	1.13	15.0	*	(Liu *et al.*, 2019)
	27	6.38	1.43	19.0	NS	
	33	6.08	1.91	25.4	NS	
	39	5.60	–	–	NS	
20 x 20	25	6.10	-0.29	-4.5	NS	(Dass *et al.*, 2016)
25 x 25	16	6.39				
30 x 18	18.5	7.32	-0.36	-4.7	NS	(Chapagain & Yamaji, 2010)
30 x 30	11.1	7.68				
20 x 15	33.3	4.53	-0.39	-8.6	**	(Yasmin *et al*, 2018)
25 x 15	26.7	4.92				

[1)] Legowo 2:1 [(12.5x25cm) x 50cm], paired row geometry for transplanting, where rice rows are alternately wide and have closer spacing within rows. – =not applicable; * =significant; ** =highly significant; NS =non significant.

The high price of chemical fertilizers due to rising oil prices and limited government funds to continue providing fertilizer subsidies, causing farmers to use organic fertilizers to reduce the use of chemical fertilizers. Plant residues are an economical organic material for producing organic fertilizers, which are widely used by organic fertilizer manufacturers. Crop residue can be easily harvested depending on the area planted. Statistical data (CBS, 2020) show that about 10.7 million hectares of rice are harvested annually in Indonesia, but the utilization rate of rice straw still needs to be higher. Indonesia's palm oil production has nearly tripled in the last few decades. Palm oil waste can be used better, such as by fermenting palm oil waste into powdered organic fertilizer (Poh *et al.*, 2020; Kahar *et al.*, 2022). Other plant residues, such as coconut shells, are reasonably high in potassium and silica and have high C/N ratios, making them excellent organic feedstocks

(Xing *et al.*, 2021). Indonesia aims to develop the livestock and poultry industry. There are 17.6 million cattle, 263.9 million chickens, and 36.6 million goats (CBS, 2020). As the number of livestock increases, the amount of livestock waste also increases significantly. Animal waste contains nutrients beneficial to plant growth and production. However, if animal waste is not disposed properly, it can pose a hazard to public health and the environment (Khoshnevisan *et al.*, 2021). Above all, it is possible and necessary to utilize complete livestock manure in Indonesia.

8. Conclusions

A more significant limitation of nitrogen in organic rice than in conventional ones causes the difference in the yield gap of rice productivity. The lower yields of organic rice could be due to the application of nitrogen rates higher in traditional management. However, although the nitrogen rates did not differ, there is commonly non-synchronization between the nitrogen mineralization of manures and compost concerning crop uptake, leading to more marked nitrogen deficiencies during the growing cycle in organic rice. Matching the nitrogen demands of crops with the timing of nitrogen supply is a critical factor of nitrogen management within organic rice farming to attain high yields. This condition is exacerbated when organic rice farmers often use wider plant spacing, where the number of plants is less than the optimal number needed to achieve high yields.

References

Agus, F., Andrade, J.F., Edreira, J.I.R., Deng, N., Purwantomo, D.K.G., Agustiani, N., Aristya, V.E., Batubara, S.F., Herniwati. Hosang, E.Y., Krisnadi, L.Y., Makka, A., Samijan, Cenacchi, N., Wiebe, K., & Grassini, P. (2019). Yield gaps in intensive rice-maize cropping sequences in the humid tropics of Indonesia. *Field Crops Res*., 237, 12–22. https://doi.org/10.1016/j.fcr.2019.04.006

Al-Amri, S. M. (2021). Application of bio-fertilizers for enhancing growth and yield of common bean plants grown under water stress conditions. Saudi Journal of Biological Sciences, 28(7), 3901-3908. https://doi.org/10.1016/j.sjbs.2021.03.064

Alvarez, R. (2022). Comparing productivity of organic and conventional farming systems: a quantitative review. *Archives of Agronomy and Soil Science*, 68(14), 1947-1958. https://doi.org/10.1080/03650340.2021.1946040

Arunrat, N., Sereenonchai, S., Chaowiwat, W., Wang, C., & Hatano, R. (2022). Carbon, nitrogen and water footprints of organic rice and conventional rice production over 4 years of cultivation: A case study in the Lower North of Thailand. *Agronomy*, 12(2), 380. https://doi.org/10.3390/agronomy12020380

Atman, A., Bakrie, B., & Indrasti, R. (2018). Effect of Cow Manure Dosages as Organic Fertilizer on the Productivity of Organic Rice in West Sumatra, Indonesia. *International Journal of Environment, Agriculture and Biotechnology*, 3(2), 506-511. https://doi.org/10.22161/ijeab/3.2.25

Ballini, E., Nguyen, T. T., & Morel, J. B. (2013). Diversity and genetics of nitrogen-induced susceptibility to the blast fungus in rice and wheat. *Rice*, 6, 32–37. https://doi.org/10.1186/1939-8433-6-32

Blouin, M., Barrere, J., Meyer, N., Lartigue, S., Barot, S., & Mathieu, J. (2019). Vermicompost significantly affects plant growth. A meta-analysis. Agronomy for Sustainable Development, 39, 1-15. https://doi.org/10.1007/s13593-019-0579-x

Buresh, R. J., Zaini, Z., Syam, M., Kartaatmadja, S., Suyamto, R., Torre, C. J., Sinohin, P.J., Girsang, S. S, Thalib, A., Abidin, Z., Susanto, B., Hatta, M., Haskarini, D., Budiono, Nurhayati, R., Zairin, M., Sembiring, H., Mejaya, M. D., & Tolentino, V. B. J. (2012). Nutrient manager for rice: a mobile phone and internet application increases rice yield and profit in rice farming. International Rice Seminar, 11-12 July, Indonesian Center for Rice Research, Sukamandi, West Java, Indonesia.

Buresh, R. J., Castillo, R. L., Torre, J. C. D., Laureles, E. V., Samson, M. I., Sinohin, P. J.& Guerra, M. (2019). Site-specific nutrient management for rice in the Philippines: Calculation of field-specific fertilizer requirements by Rice Crop Manager. *Field Crops Research*, 239, 56–70. https://doi.org/10.1016/j.fcr.2019.05.013

Cassman, K. G., & Dobermann, A. (2022). Nitrogen and the future of agriculture: 20 years on. *Ambio*, 51(1), 17-24. https://doi.org/10.1007/s13280-021-01526-w

Central Bureau of Statistics Indonesia [CBS]. (2020, January 2023). Statistical Yearbook of Indonesia 2020. Jakarta, Indonesia, p. 790. ISSN 0126-2912. https://www.bps.go.id/publication.html

Chapagain, T., & Yamaji, E. (2010). The effects of irrigation method, age of seedling and spacing on crop performance, productivity and water-wise rice production in Japan. *Paddy and Water Environment*, 8, 81–90. https://doi.org/10.1007/s10333-009-0187-5

Chew, K. W., Chia, S. R., Yen, H. W., Nomanbhay, S., Ho, Y. C., & Show, P. L. (2019). Transformation of biomass waste into sustainable organic fertilizers. *Sustainability*, 11(8), 2266. https://doi.org/10.3390/su11082266

Chiang, P. N., Tong, O. Y., Chiou, C. S., Lin, Y. A., Wang, M. K., & Liu, C. C. (2016). Reclamation of zinc-contaminated soil using a dissolved organic carbon solution prepared using liquid fertilizer from food-waste composting. Journal of hazardous materials, 301, 100-105. https://doi.org/10.1016/j.jhazmat.2015.08.015

Dass, A., Chandra, S., Choudhary, A. K., Singh, G., & S. Sudhishri. (2016) Influence of field re-ponding pattern and plant spacing on rice root–shoot characteristics, yield, and water productivity of two modern cultivars under SRI management in Indian Mollisols. *Paddy and Water Environment*, 14, 45–59. https://doi.org/10.1007/s10333-015-0477-z

Dobermann, A., Witt, C., Dawe, D., Abdulrachman, S., Gines, H. C., Nagarajan, R., Satawathananont, S., Son, T. T., Tan, P. S., Wang, G. H., Chien, N. V., Thoa, V. T. K., Phung, C. V., Stalin, P., Muthukrishnan, P., Ravi, V., Babu, M., Chatuporn, S., Sookthongsa, J., Sun, Q., & Adviento, M. A. A. (2002). Site-specific nutrient management for intensive rice cropping systems in Asia. *Field Crops Research*, 74(1), 37-66. https://doi.org/10.1016/S0378-4290(01)00197-6

Dunn, B. W., Dunn, T. S., Mitchell, J. H., & Brinkhoff, J. (2020). Effects of plant population and row spacing on grain yield of aerial-sown and drill-sown rice. *Crop and Pasture Science*, 71(3), 219-228. https://doi.org/10.1071/CP19421

Erythrina, E., Anshori, A., Bora, C. Y., Dewi, D. O., Lestari, M. S., Mustaha, M. A., Ramija, K. E., Rauf, A.W., Mikasari,W., Surdianto, Y., Suriadi, A., Purnamayani, R., Darwis, V., & Syahbuddin, H. (2021). Assessing Opportunities to Increase Yield and Profit in Rainfed Lowland Rice Systems in Indonesia. *Agronomy*, 11(4), 777. https://doi.org/10.3390/agronomy11040777

Fageria, N. K. (2007). Yield physiology of rice. *Journal of plant nutrition*, 30(6), 843-879. https://doi.org/10.1080/15226510701374831

Farmia, A. (2009). Development of organic rice farming in a rural area, Bantul regency, Yogyakarta special region province, Indonesia. *Journal of Developments in Sustainable Agriculture*, 3(2), 135-148. https://doi.org/10.11178/jdsa.3.135

Fatchiyah, F., Sari, D. R. T., Safitri, A., & Cairns, J. R. (2020). Phytochemical compound and nutritional value in black rice from Java Island, Indonesia. *Systematic Review in Pharmacy*, 11(7), 414-421. https://www.researchgate.net/profile/Fatchiyah-Fatchiyah-2/publication/344085896_Phytochemical_Compound_and_Nutritional_Value_in_Black_Rice_from_Java_Island_Indonesia/links/6067ffbda6fdccad3f699427/Phytochemical-Compound-and-Nutritional-Value-in-Black-Rice-from-Java-Island-Indonesia.pdf

Frasetya, B., Harisman, K., Sudrajat, D., & Subandi, M. (2019). Utilization of rice husk silicate extract to improve the productivity of paddy Ciherang cultivar. *Bulgarian Journal of Agricultural Science*, 25(3), 499-505. https://agrojournal.org/25/03-11.pdf

Gong, X., Zhang, Z., & Wang, H. (2021). Effects of Gleditsia sinensis pod powder, coconut shell biochar and rice husk biochar as additives on bacterial communities and compost quality during vermicomposting of pig manure and wheat straw. *Journal of Environmental Management*, 295, 113136. https://doi.org/10.1016/j.jenvman.2021.113136

Haryati, N., & Adi, S. M. (2019). Development strategy of rice organic farming sustainability towards food safety: a case study in Kediri Indonesia. *Russian Journal of Agricultural and Socio-Economic Sciences*, 85(1). https://doi.org/10.18551/rjoas.2019-01.29

Hazra, K. K., Swain, D. K., Bohra, A., Singh, S. S., Kumar, N., & Nath, C. P. (2018). Organic rice: Potential production strategies, challenges and prospects. *Organic agriculture*, 8(1), 39-56. https://doi.org/10.1007/s13165-016-0172-4

He, X., Qiao, Y., Liang, L., Knudsen, M. T., & Martin, F. (2018). Environmental life cycle assessment of long-term organic rice production in subtropical China. *Journal of Cleaner Production*, 176, 880-888. https://doi.org/10.1016/j.jclepro.2017.12.045

Hermawan, A., Sulistyani, D. P., & Bakri. (2021). Performance of paddy crop in swampland under organic pellet fertilization from Azolla and vermicompost. *Jurnal Ilmiah Pertanian*, 17(2), 60-66. https://doi.org/10.31849/jip.v17i2.5807

IRRI. (1997). Rice Production Manual. Rice Knowledge Bank. International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/training/fact-sheets/crop-establishment/manual-transplanting

Kahar, P., Rachmadona, N., Pangestu, R., Palar, R., Adi, D. T. N, Juanssilfero, A. B., Yopi, Manurung, I., Hama, S., & Ogino, C. (2022). An integrated biorefinery strategy for the utilization of palm-oil wastes. *Bioresource Technology*, 344, 126266. https://doi.org/10.1016/j.biortech.2021.126266

Kashkool, H. R., Radhi, N. J., & Hassan, W. F. (2020). Effect of plant spacing system and soil amendment in growth and yield of rice plants (*Oryza sativa* L.). *Plant Archives*, 20(1), 2710-2714. e-ISSN:2581-6063. https://www.researchgate.net/profile/Haider-

Kshkooll/publication/340720937_EFFECT_OF_PLANT_SPACING_SYSTEM_AND_SOIL_AMENDMENT_IN_GROWTH_AND_YIELD_OF_RICE_PLANTS_ORYZA_SATIVA_L/links/5e9a105a4585150839e4002c/EFFECT-OF-PLANT-SPACING-SYSTEM-AND-SOIL-AMENDMENT-IN-GROWTH-AND-YIELD-OF-RICE-PLANTS-ORYZA-SATIVA-L.pdf

Khoshnevisan, B., Duan, N., Tsapekos, P., Awasthi, M. K., Liu, Z., Mohammadi, A., Angelidaki, I., Daniel-Tsang, C. W., Zhang, Z., Pan, J., Ma, L., Aghbashlo, M., Tabatabaei, M., & Liu, H. (2021). A critical review on livestock manure biorefinery technologies: Sustainability, challenges, and future perspectives. *Renewable and Sustainable Energy Reviews*, 135, 110033. https://doi.org/10.1016/j.rser.2020.110033

Komatsuzaki, M., & Syuaib, M. F. (2010). Comparison of the farming system and carbon sequestration between conventional and organic rice production in West Java, Indonesia. *Sustainability*, 2(3), 833-843. https://doi.org/10.3390/su2030833

Lal, R. (2020). Soil organic matter and water retention. *Agronomy Journal*, 112(5), 3265-3277. https://doi.org/10.1002/agj2.20282

Latif, M. A., Islam, M. R., Ali, M. Y., & Saleque, M. A. (2005). Validation of the system of rice intensification (SRI) in Bangladesh. *Field Crops Research*, 93(2-3), 281-292. https://doi.org/10.1016/j.fcr.2004.10.005

Liu, K., Li, Y., Han, T., Yu, X., Ye, H., Hu, H., & Hu, Z. (2019). Evaluation of grain yield based on digital images of rice canopy. *Plant methods*, 15(1), 1-11. https://doi.org/10.1186/s13007-019-0416-x

Meemken, E. M., & Qaim, M. (2018). Organic agriculture, food security, and the environment. *Annual Review of Resource Economics*, 10, 39-63. https://doi.org/10.1146/annurev-resource-100517-023252

Ministry of Health. (2018). The Indonesian Food Composition data (DKPI) Working Group 2018. the Ministry of Health of the Republic of Indonesia. Retrieved from https://www.panganku.org/en-EN/cari_nutrisi

Mondal, D., Kantamraju, P., Jha, S., Sundarrao, G. S., Bhowmik, A., Chakdar, H., Mandal, S., Sahana, N., Roy, B., Bhattacharya, P. M., Chowdhury, A. K, & Choudhury, A. (2021). Evaluation of indigenous aromatic rice cultivars from sub-Himalayan Terai region of India for nutritional attributes and blast resistance. *Scientific reports*, 11(1), 4786. https://doi.org/10.1038/s41598-021-83921-7

Poh, P. E., Wu, T. Y., Lam, W. H., Poon, W. C., & Lim, C. S. (2020). Oil Palm Plantation Wastes. In. Poh, P. E., Wu, T. Y., Lam, W. H., Poon, W. C., & Lim, C. S. (Eds*.). Waste Management in the Palm Oil Industry. Plantation and Milling Processes.* (pp. 5-20). Springer, Cham. https://doi.org/10.1007/978-3-030-39550-6_2

Pujiwati, H., Setyowati, N., Wahyuni, D. D., & Muktamar, Z. (2021). Growth and Yield of Soybean on Various Types and Concentrations of Liquid Organic Fertilizer in Ultisols. Journal of Applied Agricultural Science and Technology, 5(2), 74-83. https://doi.org/10.32530/jaast.v5i2.28

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C., & Watson, C. A. (2018). Risks and opportunities of increasing yields in organic farming. A review. *Agronomy for sustainable development*, 38, 1-21. https://doi.org/10.1007/s13593-018-0489-3

Saber, Z., van Zelm, R., Pirdashti, H., Schipper, A. M., Esmaeili, M., Motevali, A., Nabavi-Pelesaraei, A., & Huijbregts, M. A. J. (2021). Understanding farm-level differences in environmental impact and eco-efficiency: The case of rice production in Iran. *Sustainable Production and Consumption*, 27, 1021-1029. https://doi.org/10.1016/j.spc.2021.02.033

Sasmita, P., & Nugraha, Y. (2020). Rice Breeding Strategy for Climate Resilience and Value Addition in Indonesia. In. Lestari, P., Mulya, K., Utami, D. W. Satyawan, D., Supriadi, Mastur (eds.). *Strategies and Technologies for the Utilization and Improvement of Rice*. (pp. 67-82). IAARD PRESS. ISBN: 978-602-344-309-3.

Schlatter, B., Trávníček, J., Meier, C., & Willer, H. (2022). Current Statistics on Organic Agriculture Worldwide: Area, Operators and Market. In. Willer, H., Trávníček, J., Meier, C., & Schlatter, B (Eds.). *The World of Organic Agriculture Statistics and Emerging Trends 2022*. (pp.34-87). Research Institute of Organic Agriculture FiBL, Frick, and IFOAM. http://www.organic-world.net/yearbook/yearbook-2022.html

Setiawati, M. R., Prayoga, M. K., Stöber, S., Adinata, K., & Simarmata, T. (2020). Performance of rice paddy varieties under various organic soil fertility strategies. *Open Agriculture*, 5(1), 509-515. https://doi.org/10.1515/opag-2020-0050

Sharma, S., Rout, K. K., Khanda, C. M., Tripathi, R., Shahid, M., Nayak, A., Satpathy, S., Banik, N. C., Iftikar, W., Parida, N., Kumar, V., Mishra, A., Castillo, R. L., Velasco, T., & Buresh, R. J. (2019). Field-specific nutrient management using Rice Crop Manager decision support tool in Odisha, India. *Field Crops Research*, 241, 1-13. https://doi.org/10.1016/j.fcr.2019.107578

Sinha, D., & Tandon, P. K. (2020). Biological Interventions Towards Management of Essential Elements in Crop Plants. In. Mishra, K., Tandon, P. K., Srivastava, S. (eds). *Sustainable Solutions for Elemental Deficiency and Excess in Crop Plants*. (pp. 209-258). Springer, Singapore. https://doi.org/10.1007/978-981-15-8636-1_9

Soebandiono, S., Muhibuddin, A., Purwanto, E., & Purnomo, D. (2021, February). Effect of indigenous organic fertilizer on the growth and yield of paddy. In *IOP Conference Series: Earth and Environmental Science*, 653(1), 012058. IOP Publishing. https://doi.org/10.1088/1755-1315/653/1/012058

Tang, S., Zhang, H., Liu, W., Dou, Z., Zhou, Q., Chen, W., Wang, S. & Ding, Y. (2019). Nitrogen fertilizer at heading stage effectively compensates for the deterioration of rice quality by affecting the starch-related properties under elevated temperatures. *Food Chemistry*, 277, 455-462. https://doi.org/10.1016/j.foodchem.2018.10.137

Thakur, A. K., Rath, S., Roychowdhury, S., & Uphoff, N. (2010). Comparative performance of rice with system of rice intensification (SRI) and conventional management using different plant spacings. *Journal of Agronomy and Crop Science*, 196(2), 146-159. https://doi.org/10.1111/j.1439-037X.2009.00406.x

Tian, G., Gao, L., Kong, Y., Hu, X., Xie, K., Zhang, R., Ling, N., Shen, Q., & Guo, S. (2017). Improving rice population productivity by reducing nitrogen rate and increasing plant density. *PLoS One*, 12(8), e0182310. https://doi.org/10.1371/journal.pone.0182310

Timsina, J. (2018). Can organic sources of nutrients increase crop yields to meet global food demand?. *Agronomy*, 8(10), 214. https://doi:10.3390/agronomy8100214.

Tulak, A., Inrianti, I., Maulidiyah, M., & Nurdin, M. (2022). The Impact of Using a Mixture of Organic Fertilizers (Compost And Liquid Organic) and Plastic Mulch, on the Development of Cayenne Pepper Plants. Journal of Applied Agricultural Science and Technology, 6(2), 98-106. https://doi.org/10.55043/jaast.v6i2.60

Utami, S. N. H., Abduh, A. M., Hanudin, E., & Purwanto, B. H. (2020). Study on the NPK uptake and growth of rice under two different cropping systems with different doses of organic fertilizer in the Imogiri Subdistrict, Yogyakarta Province, Indonesia. *Sarhad Journal of Agriculture*, 36(4),1190-1202. http://dx.doi.org/10.17582/journal.sja/2020/36.4.1190.1202

Witt, C., Buresh, R.J., Peng, S., Balasubramanian, V., & Dobermann, A. (2007). Nutrient management. In. Fairhurst, T., Witt, C., Buresh, R. J., Dobermann, A. (Eds.). *Rice: A Practical Guide to Nutrient Management*. (pp. 1–45). International Rice Research Institute (IRRI), Los Baños, Philippines and International Plant Nutrition Institute (IPNI) and International Potash Institute (IPI), Singapore. http://books.irri.org/getpdf.htm?book=97898179494

Xing, T., Yun, S., Li, B., Wang, K., Chen, J., Jia, B., Ke, T., & An, J. (2021). Coconut-shell-derived bio-based carbon enhanced microbial electrolysis cells for upgrading anaerobic co-digestion of cow manure and aloe peel waste. *Bioresource Technology*, 338, 125520. https://doi.org/10.1016/j.biortech.2021.125520

Yasmin, R., Paul, S. K., Paul, S. C., & Salim, M. (2018). Effect of plant spacing and integrated nutrient management on the yield performance of Binadhan-14. *Archives of Agriculture and Environmental Science*, 3(4), 354-359. https://dx.doi.org/10.26832/24566632.2018.030404