Research Article

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

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Abstract | Rice plants are commonly cultivated in a grid system with a plant spacing of 25 cm x 25 cm. The modification of spacing to increase nutrient uptake by providing plant free area (PFA) for better air circulation and sunlight distribution needs to be further studied. This study examined the differences in NPK uptake and rice growth in organic farming using the grid system and the cropping system with longitudinal rows given space in between. The distance between plants within a row is 12.5 cm, and the distance between rows is 25 cm. A PFA of 50 cm is given for every two rows of rice plants. The before-mentioned cropping system is called Jarwo 2:1. The fertilization treatment for both rice cropping systems was the same, which is a mixture of cow manure and neem compost (1:1) at doses of 0, 3, 6, and 9 ton ha^{-1}. The research data are presented in tables and graphs to show the effects of modification of the rice cropping system on the nutrient uptake. The results showed that the Jarwo 2:1 provided a higher N, P, K uptake compared to the Grid system. The provision of PFA had an impact on increasing the number of tillers, the number of productive tillers, and the number of panicles. The best fertilizer application was at a dose of 9 tons/ha^{-1}.

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Introduction

Rice plants require sufficient N, P, and K uptake to achieve optimum growth and yield. Increasing levels of N, P, and K in the soil carried out using chemicals has been commonly practiced by farmers (Moe *et al*., 2019). However, the excessive application of N, P, and K fertilizers causes degradation of agricultural land, which leads to decreased yields. The problem of the degradation of agricultural land due to excessive fertilization has become a major problem in rice-growing areas in Asia (Ladha *et al*., 2003).

The application of chemical fertilizers has been proved to be able to provide nutrients to plants quickly due to the increased availability of nutrients in the soil. However, not all available nutrients in the soil can be uptaken by plants and then changed into permanently available nutrients (Puli *et al*., 2019). There is a dynamic process in the soil, in which the available nutrients change to be unavailable (Bird *et al*., 2001). The increase in the availability of nutrients in the soil, organically, has different characteristics because the release from the fertilizers used occurs slowly (Baghdadi *et al*., 2018).

Links Researchers

The use of organic fertilizers has a negative impact on plant growth due to the immobilization of nutrients, especially nitrogen (Ren *et al*., 2014). The provision of organic fertilizers has a relatively low nutrient input compared to chemical fertilizers so that its application in small doses will certainly not be able to meet the needs of plants (Lee *et al*., 2019). Organic fertilization needs to be done at the right dose to get the expected growth rate of rice plants.

The optimum growth of rice plants is not only determined by the availability of nutrients in the soil, but also by the cropping system. Spacing is one of the agronomic parameters that affect rice growth and yields (Reuben *et al*., 2016). Rice yields decrease as rice plant spacing decreases (Sultana *et al*., 2012; Haque *et al*., 2015). Increasing the space between rows forming a plant-free area (PFA) and a plant spacing of 25 cm results in higher yields (4.4 ton ha^{-1}) compared to 20 cm spacing (4.3 ton ha^{-1}) (Sultana *et al*., 2012). However, spacing does not always affect rice growth and yield, as evidenced by other studies reporting that 15x15 cm spacing results in higher yields than 20x20 cm and 25x25 cm when given a gap (PFA). The application of a rice cropping system by providing a gap (PFA) for every two plant rows is known as Jarwo (Figure 1). The Jarwo cropping system as a whole does not reduce the number of plants per plot because the plant spacing within rows is half of the plant spacing between rows (Nurhayati *et al*., 2016). However, it is necessary to evaluate the effect of PFA on the nutrient uptake, which is enhanced by the application of organic fertilizers. If the Jarwo System proves to be effective in increasing nutrient uptake and ultimately affecting production, it is possible to convert the conventional grid system to the Jarwo system.

Materials and Methods

The study was conducted on organic rice fields in Kebon Agung Village, Imogiri District, Bantul Regency, Yogyakarta, Indonesia. The duration of the study was a planting season of rice from land preparation to harvesting. Organic farming has been implemented at the research site since 2007, in which the soil type is Inceptisol (Fluventic Eutrudepts) according to the soil description by Sijabat (2017). The physical and chemical properties of the soil in the study area were analyzed (Table 1) as an illustration of the initial soil conditions.

Table 1: *Initial soil chemical properties.*

Soil chemical properties	Initial soil
PH	6.6
TOC (%)	2.4
TN (%)	0.9
C/N	2.67
CEC (cmol (+) kg^{-1})	29.4
Avaliable -K (cmol (+) kg^{-1})	0.17
Avaliable -P (mg kg^{-1})	1.5

The organic fertilizers used in this study have met the standards for the content of N, P, K, Ca, and Mg set by the Ministry of Agriculture of the Republic of Indonesia (Soil Research Institute, 2009). The organic fertilizer used is a mixture of cow manure and neem compost with a ratio of 1: 1. Separately, the quality of neem compost has met the standards, but the cow dung used still has a higher C/ N ratio than the existing standards. However, this kind of cow manure is generally used by farmers in the study area. The characteristics of the organic fertilizers used by farmers and then used as research material are presented in Table 2.

Table 2: *Characteristics of the organic fertilizer.*

Parameters	Cow manure	Neem compost
pH (H_2O)	7.9	5.6
Organic C (%)	31.06	23.85
Total N (%)	0.59	1.33
C/N ratio	52.64	17.93
Total P (%)	0.09	0.10
Total K (%)	1.75	2.57
Total Ca (%)	0.61	0.96
Total Mg (%)	0.92	0.89
Electrical conductivity (mS cm^{-1})	4.39	2.48

The study was a field experiment arranged in a randomized complete block design (RCBD) with two factors and three replications. The first factor was the cropping system, consisting of the grid system (S1) and Jarwo 2: 1 (S2). The second factor was the doses of organic fertilizer made from a mixture of cow dung and neem compost a ratio of 1: 1, consisting of control (F0), 3 ton. ha^{-1} (F3), 6 ton.ha^{-1} (F6), and 9 ton.ha^{-1} (F9).

Field experiment started with the plowing process to homogenize the soil quality. There were 24 plots of crops with a size of 2.5 x 4 m each to accommodate the number of treatments and three replications. The cultivar of the rice plant used is *Mentik Wangi*. The rice seeds were germinated, and after 20 days, they were transferred to different crop plots according to the treatments. The initial fertilization was carried out a week before transplantation. The irrigation applied for all crop plots was the intermittent method.

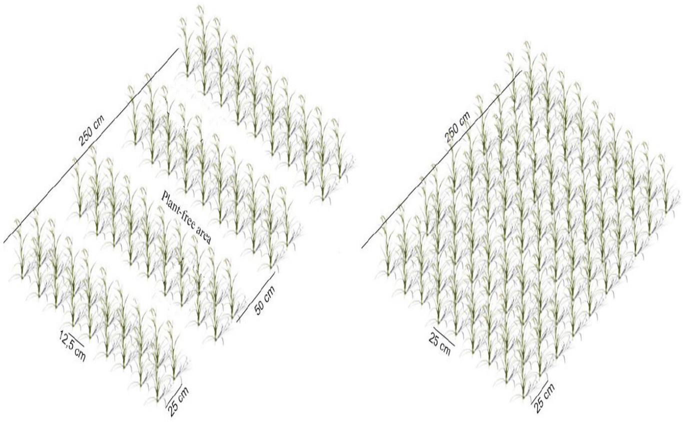

Figure 1: *Grid system and Jarwo 2 : 1 (Abduh et al., 2019)*

The analysis of the soil properties was carried out at 90 days after planting to determine the differences in the variation in measured values. The measurement of soil pH, organic C, total N, available P, and available K was performed using the pH 3+ Double Junction USA, Walkey and Black, wet digestion of H_2SO_4 and H_2O_2, Olsen method, and extraction of NH_4OAC at pH 7, respectively.

The observations of plant height and number of tillers were carried out at 15 days after transplanting (DAT), while the number of productive tillers, number of panicles, and panicle length were observed at 60, 75, and 90 days after transplanting (DAT), consecutively. The stover weight and N tissues were measured using wet digestion of H_2SO_4 and H_2O_2, while the P and K tissues were determined by wet digestion of HNO_3 and $HClO_4$, observed at 60 and 90 days after transplanting (DAT), respectively.

The data of both soil properties and crop characteristics are presented in tables or graphs for better analysis of the changes. Analysis of the changes was carried out descriptively based on graphics because it only included three treatments with three replications so that statistical analysis would not required.

Results and Discussion

Soil chemical properties

The analysis of soil properties after treatments was carried out at 60 and 90 DAT, and the results are presented in Table 3. The application of organic fertilizers and modification of the cropping system generally improved soil chemical properties. The total carbon, total nitrogen, and available P and K of the soil increased along with the increase in the doses of organic fertilizers. These results are in line with the results of Kuzucu (2019), reporting that a linear increase in soil organic carbon occurred with an increasing dose of organic fertilizers. The C cycle is closely related to the N cycle through the production and decomposition process because the main sources of N are animal residues, biological nitrogen fixation, and organic matter (Liu *et al.*, 2012; Bi *et al.*, 2018). On the other hand, the modification of the cropping system (Jarwo 2: 1) only had a clear effect on increasing the available P content of the soil. The increase in P is in line with the increase in soil organic matter. This is following the study by Yang *et al.* (2019).

Soil pH is an important indicator showing the acidity and alkalinity of the soil. Soil pH in this study was in the range of ±6.85. The doses of organic fertilizers and the modification of the grid cropping system into Jarwo 2:1 did not show a significant effect on the soil pH since the application of organic fertilizers can reduce soil pH fluctuations (Vašák *et al.*, 2015). Besides, organic fertilizer functions as a buffer that can increase soil buffering capacity (Yang *et al.*, 2018). In this study, a decrease in pH occurred in the tillering stage, panicle initiation, and panicle exertion. Meanwhile, an increase in soil pH value occurred in the elongation and ripening stages (Figure 2). The decrease in soil pH is associated with the decomposition of organic matter by microbes, as well as the leaching of several basic cations such as potassium, calcium, and magnesium from the upper horizon (Ozlu and Kumar, 2018). Several studies reported that a decrease in soil pH could be associated with the release of H^+ ions by roots (Guo *et al.*, 2010; Liang *et al.*, 2012). Meanwhile, the increase in soil pH is mainly determined by the reduction of Fe and Mn oxides, which consumes H ions (Fageria *et al.*, 2011).

Table 3: *Soil properties after treatments with three replications.*

Soil chemical properties	DAT	After treatment of organic fertilizer							
		Grid				Jarwo 2:1			
		0-ton ha^{-1}	3-ton ha^{-1}	6-ton ha^{-1}	9-ton ha^{-1}	0-ton ha^{-1}	3-ton ha^{-1}	6-ton ha^{-1}	9-ton ha^{-1}
TOC (%)	90 DAT	2.01	2.21	2.09	2.28	2.12	2.00	2.09	1.98
TN (%)	60 DAT	0.75	0.94	1.10	1.30	0.94	0.84	1.04	1.14
	90 DAT	0.62	0.65	0.89	1.19	0.65	0.94	0.95	1.09
Available-K (cmol (+) kg^{-1})	60 DAT	0.09	0.13	0.15	0.17	0.10	0.13	0.13	0.16
	90 DAT	0.10	0.10	0.12	0.12	0.11	0.13	0.17	0.15
Available-P (mg kg^{-1})	60 DAT	15.96	15.62	17.68	18.65	16.25	19.46	20.06	24.02
	90 DAT	11.49	13.73	13.12	16.79	12.50	15.16	16.90	14.60

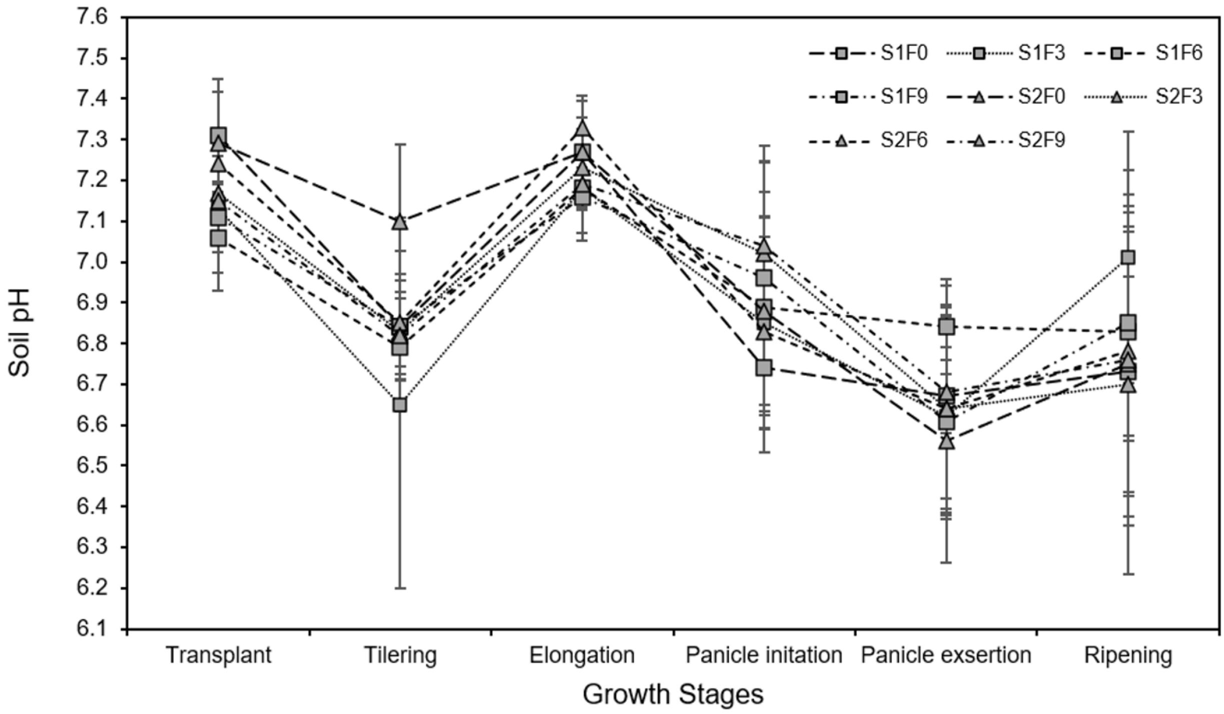

Figure 2: *Soil pH in the rice growth stages. Error bars represent standard deviation of three samples. S1 = grid, S2 = Jarwo 2: 1, F0 = 0 ton ha-1, F3 = 3 ton ha^{-1}, F6 = 6 ton ha^{-1}, F9 = 9 ton ha^{-1}.*

NPK uptake of the rice plants

Nitrogen, Phosphorus, and Potassium are essential nutrients that play a very substantial role in the growth of rice plants. The increasing doses of organic fertilizers and the modification of the grid cropping system into a Jarwo 2: 1 had a fairly good effect on increasing levels and uptake of NPK in plant tissues.

The increasing uptake of nitrogen (Figure 3) and potassium (Figure 4) slightly improved the plant growth performance. Nitrogen has an important role in the process of plant metabolism because N is an essential constituent of the amino acids that make up protein. Meanwhile, potassium plays a role in the movement of water, nutrients, and carbohydrates in plant tissues, and is involved with the activation of enzymes in plants that affect the production of protein, starch, and adenosine triphosphate (ATP). ATP production can determine the rate of photosynthesis.

In general, the mobility of nitrogen is quite high in the soil, especially in the rice fields, as a result of the inundation and drying process. Microbial activity can lead to increased K availability in the soil (Han *et al*., 2016). However, the K contained in the soil solution is in a form that can be absorbed by plants, which can be easily washed (Juniarso *et al*., 2018).

In contrast to N and K that only increased slightly, 0.01 % N content and 1.6 g plant^{-1} N uptake and 0.16 % K content and 7.27 g plant^{-1} K uptake, there was a high increase in the P content and uptake in rice, 0.4 % P content and 104.52 g plant^{-1} P uptake (Figure 5). This result is in line with previous studies by Puli *et al*. (2017). Available P is P that can be taken directly by plants, and it generally comes from the total P in the soil. The availability of P increases with increasing soil organic matter (Yang *et al*., 2019). P generally functions in stimulating seed germination and root development, as well as maintaining plant vigor, flower and seed formation, and crop yields. Therefore, P is essential at all stages of development, from germination to ripening stage (Malhotra *et al*., 2018).

NPK levels in plant tissues in the panicle initiation stage were lower than in the ripening stage. Meanwhile, the NPK uptake in the panicle initiation stage was higher than in the ripening stage. The highest plant nutrient uptake occurs when the plant reaches its maximum vegetative point, which is in the panicle initiation stage.

The growth of the rice plants

The growth curve of the rice plant height (Figure 6), generally corresponds to the common plant growth curve, which increases from the transplanting stage to panicle initiation and then declines until the ripening phase. From the graph, it can be seen that the organic fertilizer dose of 9 ton/ha resulted in the highest plant height in both planting systems.

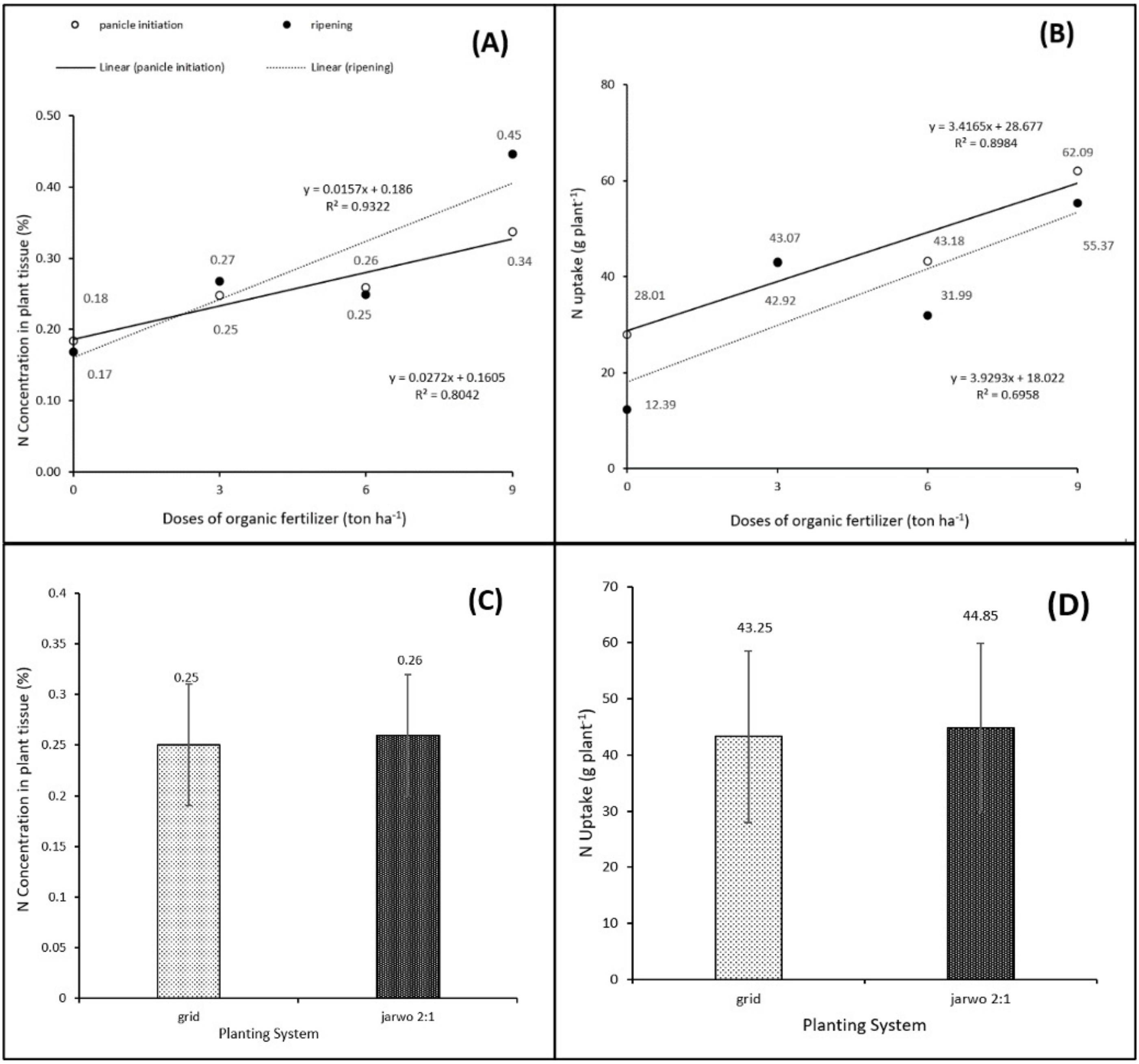

Figure 3: *Nitrogen concentration (a) in plant tissue and Nitrogen uptake (b) at different doses of organic fertilizer. Nitrogen concentration (c) in plant tissue and Nitrogen uptake (d) at different cropping systems. Error bars represent standard deviation. Arrows of continuous and dotted lines show the trend between doses of organic fertilizer and NPK in whole plant.*

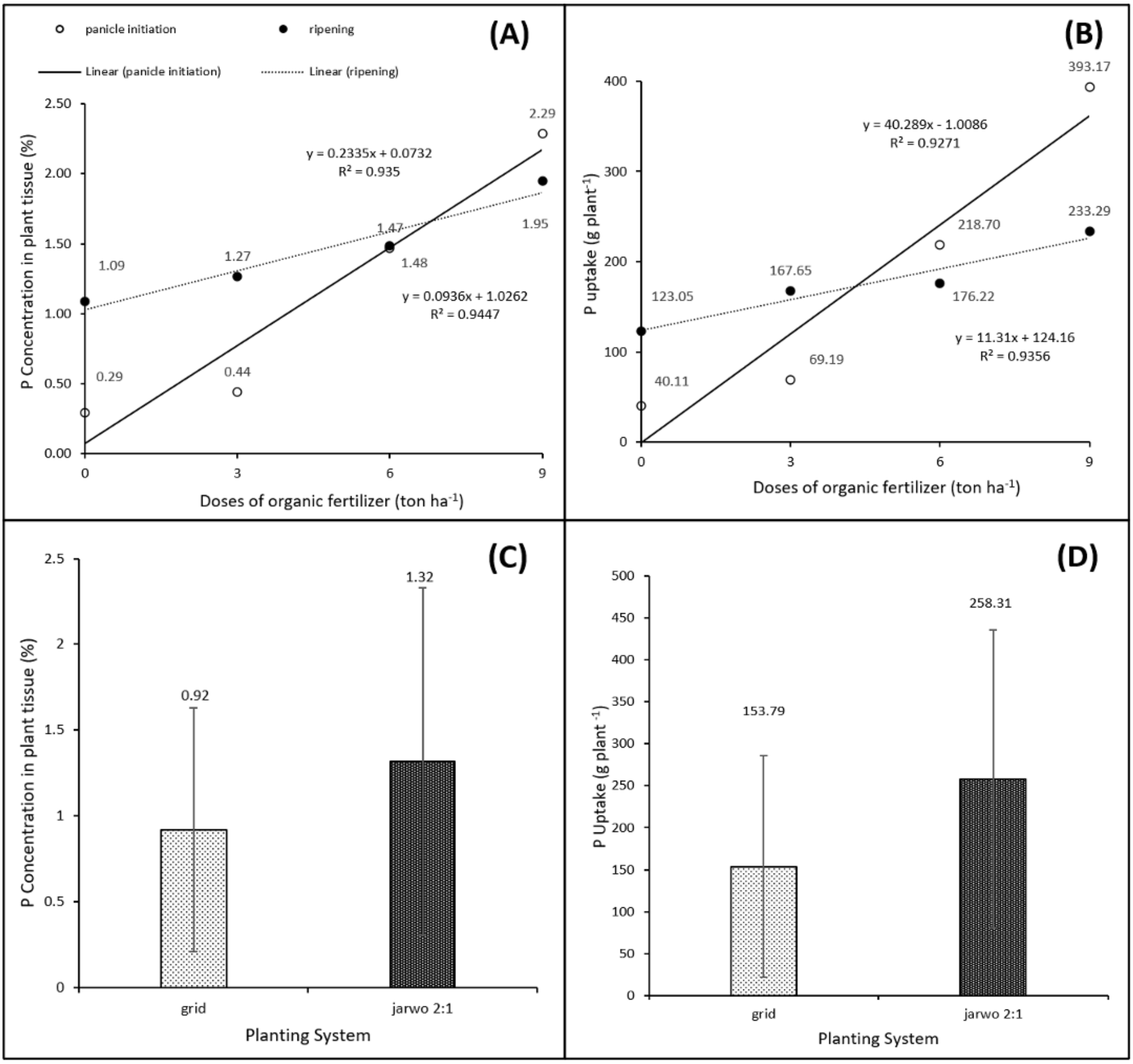

Figure 4: *Potassium concentration (a) in plant tissue and Potassium uptake (b) at different doses of organic fertilizer. Potassium concentration (c) in plant tissue and Potassium uptake (d) at different cropping systems. Error bars represent standard deviation. Arrows of continuous and dotted lines show the trend between doses of organic fertilizer and NPK in whole plant.*

The increasing doses of organic fertilizers and the modification of the grid system into Jarwo 2: 1 showed a significant effect on the increase in the number of tillers, productive tillers, and panicles in the initiation stage. The number of tillers (Figure 7d) decreased after panicle initiation, as some of the tillers died during this stage. The decrease in the number of tillers is thought to be caused by drainage carried out in the previous 15 days, causing a water shortage, thereby reducing the number of productive tillers, as explained by Kusmiyati *et al*. (2017). Productive tillers (Figure 7e) experienced an increase in the ripening stage along with the grain filling, around 20 to 33 number of productive tillers. The higher number of tillers in the Jarwo 2:1 cropping system indicates that a wider spacing does not always result in a higher number of tillers. The presence of a gap in Jarwo 2: 1 causes plants to get more sunlight, thereby increasing the rate of photosynthesis and eventually improving plant growth (Abduh *et al*., 2019).

The Legowo 2: 1 cropping system combined with the appropriate dose of organic fertilization improved plant growth, thereby increasing the productivity of the rice plants. The Legowo 2: 1 cropping system

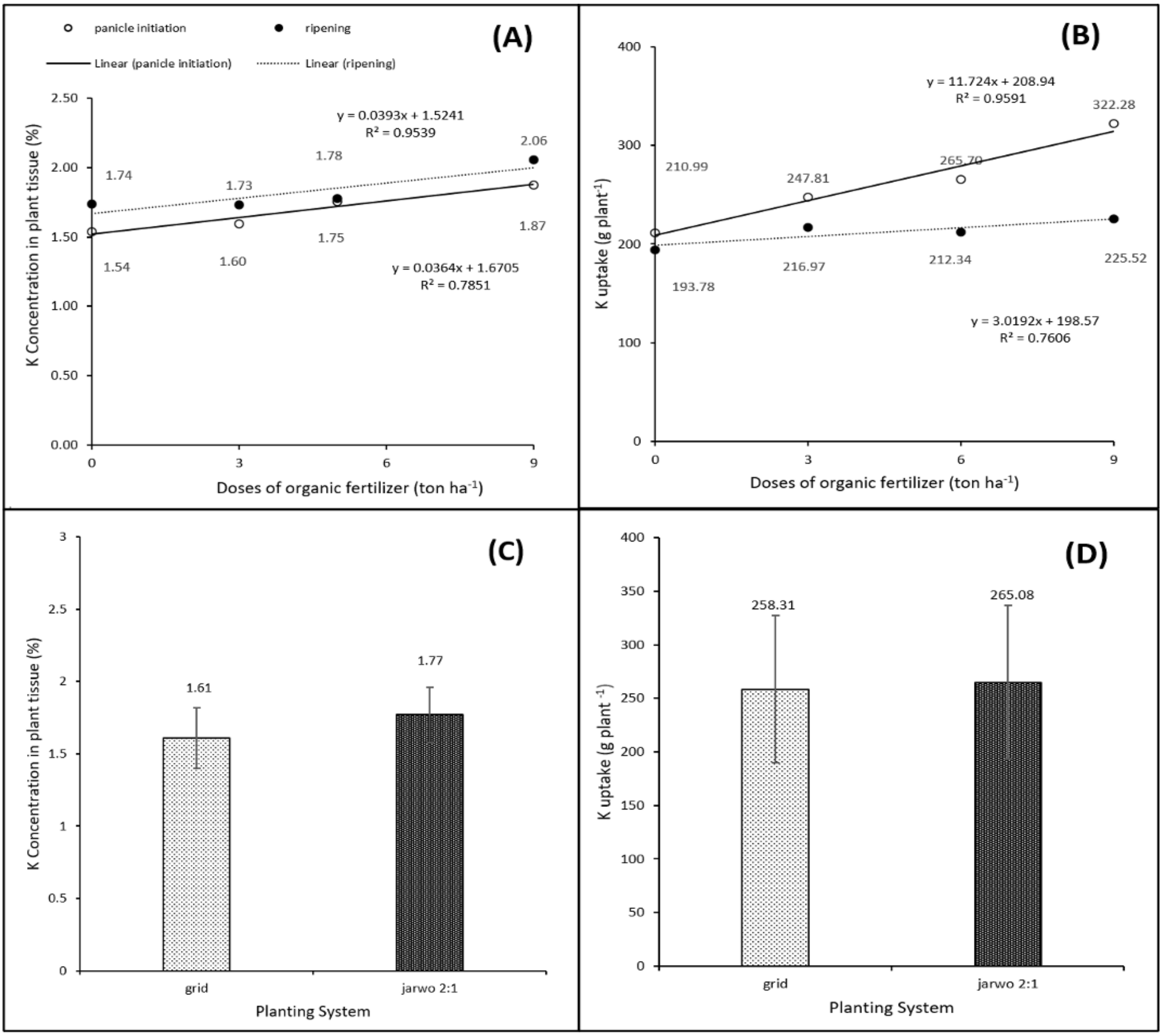

Figure 5: *Phosphate concentration (a) in plant tissue and Phosphate uptake (b) at different doses of organic fertilizer. Phosphate concentration (c) in plant tissue and Phosphate uptake (d) at different cropping systems. Error bars represent standard deviation. Arrows of continuous and dotted lines show the trend between doses of organic fertilizer and NPK in whole plant.*

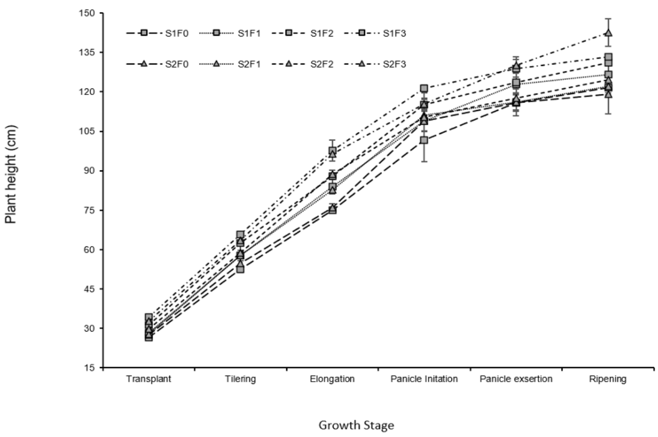

Figure 6: *The dynamics of plant height (a) affected by cropping system and organic fertilizer doses. Error bars represent standard deviation of three samples. S1 = grid, S2 = Jarwo 2:1, F0 = 0 tons ha^{-1}, F3 = 3 tons ha^{-1}, F6 = 6 tons ha^{-1}, F9 = 9 tons ha^{-1}.*

produces a plant population of 213,300 clumps per ha, thus increasing the population by 33.31% compared to the Grid System (25x25) cm that is only producing 160,000 clumps per ha. The increase in plant population due to the Jarwo System applied in the study was higher than what had been reported by previous researchers, reporting an increase of 29% (Hatta, 2012; Giamerti and Yursak, 2013). The increase in plant population is expected to increase yield productivity (Amanah *et al*., 2017). Abduh *et al*. (2019) reported that the number of panicles and filled grains, the total weight of dry grain, and the weight of 1000 dry grains were higher in the Jarwo 2: 1 cropping system. Ogbodo *et al*. (2010) mentioned that the more vigorous plants, with particularly higher

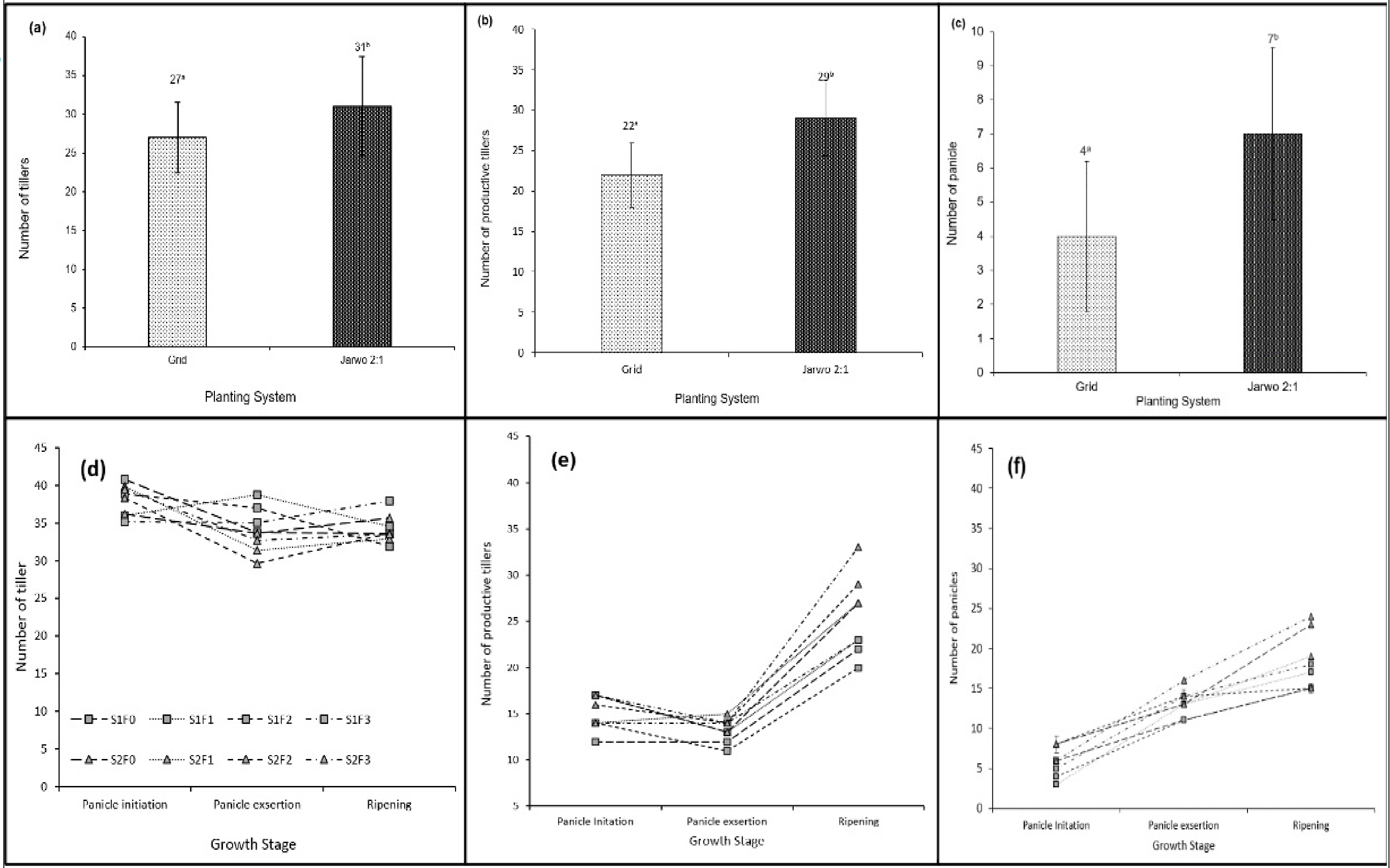

Figure 7: *Number of tillers (a), productive tillers (b), and panicle (c) affected by different cropping pattsystems. The dynamics of the number of tillers (d), productive tillers (e), and panicle (f) as affected by cropping systems and organic fertilizer doses. Error bars represent standard deviation.*

tillering ability, produced more photosynthates than the less vigorous plants with smaller spacing. The plants planted with wider plant spacing (planting free area) are more effective in mobilizing photosynthate and grain filling, compared with the plants with smaller plant spacing (Baloch *et al*., 2003). This system takes advantage of sunlight for plants that are on the edge of the line. The more sunlight that hits the plant, the higher the photosynthesis process by the plant leaves so that it will get a heavier fruit weight. The Jarwo technique is a planting technique by adjusting the spacing between clumps and between rows (Bobihoe, 2013). Optimal density will effectively utilize soil moisture, nutrients, sunlight etc. (Chandrasekaran *et al*., 2010).

The increasing doses of organic fertilizer up to 9 tons/ha significantly increased the availability of P in the soil and resulted in the best growth performance. The application of organic fertilizers also positively affected the physical and microbiological properties of the soil as a decomposition agent. The process of organic matter decomposition in the soil produces simpler organic compounds that can increase the availability of plant nutrients in the soil. Organic acids can also act as a forming agent for stable soil structure, thereby improving the internal drainage conditions of the soil. Soil with a high organic content of about 2% will provide a suitable physical environment for root growth.

Organic fertilizer used in this study is composed of a mixture of cow dung (Neem seed Cake) and neem compost that has different functions. Neem seed cake acts as a natural fertilizer with pesticidal properties. Lokanadhan *et al*. (2012) reported that neem seed retarded the activity and growth of the bacteria responsible for nitrification and denitrification, and Polifenols in Neem Cake prevented the bacterial activity in nitrification and denitrification (Kartikawati *et al*., 2011). Moreover, Neem seed cake exhibits the properties of insecticides, nitrification retardation, and inhibitor of pesticide degradation (Parmar, 1986; Oyinlola *et al*., 2017). The good effect of neem compost on rice growth has been reported by Ardiantika (2018), and this effect is related to higher N availability due to low nitrification and denitrification.

The rice fields used in this study have been used for organic farming for> 10 years. Soil organic content in the control field has been quite high due to the long history of organic processing carried out. The application of organic fertilizers that have a higher C / N number than the standard indicates that the decomposition process is still ongoing, thereby requiring solar energy and good aeration. The presence of spacing every two rows in the Jarwo 2: 1 cropping system allows the fulfillment of energy and oxygen needs for the organic decomposition process. The nutrients contained in organic fertilizers become available to plants, thus improving the plant growth. The increasing sunlight intensity and good aeration cause rice plants to be healthier, as stated by Eryhtrina and Zulkifli (2014). In detail, Eryhtrina and Zulkifli (2014) convey three positive effects of providing PFA between plant rows, which are increasing sunlight intensity, reducing the likelihood of pest attack (especially rats), and reducing the likelihood of disease attack. Spacing between every two rows causes air circulation to take place freely, decreasing air humidity so that plants become healthy (Yoshida, 1981; Baloch *et al*., 2003; Cahyono, 2003). The roots of rice plants become more developed with the presence of PFA, thus improving the plant growth (Ogbodo *et al*., 2010; Giamerti and Yursak, 2013). Besides, the presence of PFA allows the fertilization process and other plant maintenance efforts to be easier.

The physical environmental conditions of soil that contain available nutrients, along with micro-agro climatic conditions, allow rice grown using the Jarwo 2: 1 cropping system, in general, to have better N, P, and K uptake and growth compared to that grown using the Grid system. Better N, P, and K uptake resulting in better rice growth has also been proven by several previous studies (Sohel *et al*., 2009; Ogbodo *et al*., 2010). The more suitable growing environmental conditions improved the plant growth indicated by the higher number of tillers, productive tillers, and panicles.

Conclusions and Recomendations

There was an increase in the growth of rice plants on the organic rice field with the Jarwo 2: 1 cropping system by 33.3% compared to the Grid system. The measurement of growth increase is based on the variables of the number of tillers, productive tillers, and panicles. Providing a spacing in every two rows in Jarwo 2:1 increased the sunlight intensity received by plants and improved the air circulation. The microagroclimatic conditions around the plants also allow the soil organic decomposition process to run well. The application of organic fertilizer (a mixture of neem compost and neem seed cake) at a dose of 9 ton/ha could provide a better physical soil environment for plant growth and a soil chemical environment that increases nutrient availability. The combination of the soil environment and micro-agro climatic environment, as well as the plant health, increased N, P, and K uptake, thereby increasing the rice yields.

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Novelty Statement

Providing plant free area would increase nutrient uptake and improve rice growth.

Author's Contribution

SNHU Corresponding author, responsible for the processing of budged funding, data analysis, manuscript writing and addressing reviewers' comments, and revising the manuscript, AMA coordinated the researchers, accessing data, directly involved in the research design and discussion of results, manuscript writing, EH guided laboratory measurements for soil characteristics, responding to reviewers' comments, BHP guided field measurements for soil properties and nutrient uptake, provided inputs for revision.

Conflict of interest

The authors have declared no conflict of interest.

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