Optimization of Nitrogen Fertilization and Seedling Density of A New Rice Type (*Oryza sativa* L.) "IPB 3S"

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Abstract

The new plant type of rice, or 'padi tipe baru' (PTB) in Indonesian, is a new group of rice cultivars with a higher productivity compared to the modern rice varieties ('varietas unggul baru' or VUB). This study was conducted to determine the optimum dose of nitrogen fertilization and the seedling density or number of seedlings per hill to increase growth and yield of the new type of rice "IPB 3". The experiment was conducted in the Bogor Experimental Station in January to June 2015. Nitrogen doses (90, 120, 150, 180 kg $N.ha^{-1}$) and number of seeds per hill (1, 5, 10, 15 and 20) were tested. The results showed that the increased dose of nitrogen fertilizer reduced the percentage of filled grains, the rate of photosynthesis and the grain yield per hectare. Similarly, an increase in the seedling density up to 15 seeds decreased the dry matter of the crop, the number of grains per panicle, and grain weight per plant, but increased the grain yield per hectare. The optimum yield of "IPB 3S" was achieved with 90 kg $N.ha^{-1}$ with 15 seeds per hill. The results of this study have provided a guideline for an improved nitrogen management in relation to rice seedling population to increase yield of a new rice type "IPB3S".

Keywords: "IPB 3S", new plant type, fertilizer, local variety

Introduction

Rice is the main source of carbohydrates consumed by the people in Asia, including Indonesia. In most Asian countries, rice accounts for more than 70% of human caloric intake, and the demand for rice continues to increase with increasing population. The Indonesian population in 2035 is estimated at 305.6 million (Bappenas, 2013), making it a challenge to meet national food needs. Indonesia's rice production in 2013 reached 71.27 million tons with harvest area of 13,793,913 ha and national average productivity of 5,152 tons ha-1 (BPS, 2015). In 2014, 70.83 million tons of dried unhulled rice was produced which showed a decrease by 0.45 million tons (0.63%) compared to 2013. Production decline is predicted to occur due to decrease of harvested area of 41.61 thousand ha (0.30%) and productivity of 0.17 quintals ha^{-1} (0.33%) (BPS 2015). According to Putra (2011), one of the factors causing decreased rice production is the inefficient use of inorganic fertilizers. The most widely applied inorganic fertilizer for rice crop is nitrogen.

Nitrogen (N) is the macro nutrient that promotes crop growth and development. Nitrogen is a basic component for the synthesis of proteins, enzymes, amino acids, nucleic acids, and an integral part of chlorophyll that plays a significant role in controlling all metabolic reactions in plants (Stefanelli et al. 2010, Subhan et al., 2009; Mathius 2009). Nitrogen is absorbed by plants in the form of nitrate ions (NO_3^-) and ammonium (NH_4^+). Nitrates are negatively charged hence they remain in the soil solution and are easily absorbed by plants but can be easily washed away. Ammonium is positively charged so it is bound by the soil colloids and not lost easily leached. Ammonium is absorbed by ion exchange reactions (Miller et al., 2009). N deficiency will inhibit plant growth whereas excessive N could result in decrease of the growth and yield (Duan et al., 2007). Optimizing nitrogen management, uptake and recovery efficiency is an important strategy to reach high rice yield (Ohnishi et. al., 1999).

The use of the correct amount of seeds per hill is one of the ways in increasing the efficiency of inputs in rice crops. Planting a great number of seeds in one hill may lead to competition between rice plants (inter species competition) to access water, nutrients, CO_2, O_2, light and growing space, resulting in poor plant growth (Atman, 2007). Increasing the number of seeds per hill tends to increase the competition, either between plants in one hill or between hills, causing plant stand and dry matter production to decline (Dachban and Dibisono, 2010). Optimizing the amount of seedlings per hill for the new type of rice production is very important because this new type of rice had a reduced number of tillers, therefore requiring more seedlings per hill to increase the number of panicles per hectare. This study was aimed to determine the optimum dose of nitrogen fertilization and the number of seeds per hill for optimum growth and high yield of the new type of rice "IPB 3S". Information on seedling density in relation to the responses of the rice crop to N fertilizer is necessary to achieve maximum productivity.

Materials and Methods

The materials used were seeds of a new type of rice variety released by Bogor Agricultural University "IPB 3S". Fertilizers used were Urea, SP-36 and KCl. The experiment used a digital scale, leaf color chart (BWD), oven and LI-COR 6400 XT to measure photosynthesis rate. The study was conducted in an irrigated rice field at the IPB Sawah Baru Experimental Plant in Bogor, West Java, Indonesia, in 2015. Soil analysis was conducted in the Soil Chemistry and Soil Fertility Laboratory, Department of the Soil Science and Land Resources of Faculty of Agriculture, Bogor Agricultural University (IPB).

The study was arranged in a split plot randomized block design with three replications. Five doses of nitrogen fertilizer (90, 120, 150, 180 kg N.ha^{-1}) were used as the main plot and the number of seedlings (1, 5, 10, 15 and 20 seedlings per hill) as subplots, totalling 60 experimental units of 5 m x 5 m per unit. Transplanting of rice seedlings was conducted when seedlings were 14-day-old. Weeding, replacement of dead seedlings, and controlling plant pest and diseases were conducted as required. Seedling density tested was 1, 5, 10 and 15 seedling per hill with 30x20 cm distance between hills. N fertilizer was applied three times, 1/3 dose at 1 week after planting (WAP), 1/3 dose at 4 WAP and 1/3 dose at 7 WAP. The SP-36 fertilizer at 100 kg ha^{-1} and KCl fertilizer at 50 kg ha^{-1} were applied for each treatment at 1 WAP. Soil nutrient analysis was conducted prior to the fertilizer application and at the end of the experiment. Harvesting was conducted when the rice crops had reached harvesting criteria, i.e. 90-95% of the spikelets had turned yellow.

Scoring was conducted on plant height, leaf color, plant dry matter, yield components including number of productive tillers, panicle length, number of grains per panicle, percent of grain content, and 1000-grain-weight, grain yield per plant and grain yield per hectare, and the rate of photosynthesis at 9 WAP using LI-COR Photosynthesis 6400 XT. Data were analysed using SAS version 9.2. The plant growth data were analyzed using F-test (multiform analysis) with Duncan Multiple Range Test (DMRT) at 5% when differences between treatments were significant. The rice growth and yield responses to the treatments were determined using the orthogonal polynomial tests.

Results and Discussion

Analysis of Soil Nutrient

The results of soil nutrient analysis before treatment showed that the soil total N was moderate, total P was very low and total K was high (Table 1). These levels were determined based on the criteria of soil chemical properties by Eviati and Sulaiman (2009). In general, all nutrients analyzed from the soil decreased in but there was a tendency that increased doses of N fertilizer would increase total N and total K at the end of the study.

Rice Vegetative Growth

N fertilizer significantly increased the height of rice crops at 7 WAP at different seedling population. The application of 180 kg N.ha^{-1} with 15 seedlings per hill resulted in the tallest crop of 114 cm, although it was not significantly different from those from 10 and 20 seedlings per hill at the same N fertilizer dose (Table 2). Nitrogen plays an important role in the plant growth and production as it is an important constituent of proteins and chlorophyll, thereby contributing to the promotion of leaf formation, stems, roots, and promoting other vegetative growth (Leghari et al., 2016). High doses of nitrogen fertilizer will promote vegetative growth including plant height (Haque, 2013). The higher seedling density is more likely to produce taller plants because increasing the number of tillers will shade each other, creating uneven capture of sunlight and might cause plant etiolation. Etiolation occurring in shaded plants is due to the high production and distribution of auxin, thus stimulating cell elongation which results in taller plants (Susanto and Sundari, 2011).

N fertilizer doses in general did not affect the number of tillers at 7 WAP, but the number of tillers tend to increase along with the increase of N fertilizer dose although the increase was not significant (Figure 1). The number of seedlings per hill had a very significant effect on the number of tillers at 7 WAP; the total number of tillers increased with the increase in seedling density. Density of 20 seedlings per hill resulted in the largest total number of tillers. Planting one seedling per hill resulted in the highest number of tillers (about 19 tillers), whereas 20 seedlings per hill

Table 1. Soil nutrient analysis before and after fertilizer application

Treatment	Parameter	Criteria
	N Total (%)	
Pre treatment	0.24	Medium
After treatment (N kg.ha^{-1})		
90	0.19	Low
120	0.19	Low
150	0.20	Low
180	0.21	Medium
	P Total (ppm)	
Pre treatment	5.39	Very Low
After treatment (N kg.ha^{-1})		
90	4.12	Very Low
120	4.84	Very Low
150	3.63	Very Low
180	3.78	Very Low
	K Total (me/100g)	
Pre treatment	0.96	High
After (N kg.ha^{-1})		
90	0.28	Medium
120	0.34	Medium
150	0.36	Medium
180	0.46	Medium

Table 2. Interaction between N fertilizer and seed density per hill on plant height at 7 WAP

N (kg. ha^{-1})	Seedling density per hill				
	1	5	10	15	20
90	108.07abc	105.73abc	109.00abc	109.00abc	108.87abc
120	94.53d	109.87ab	111.53ab	113.867a	109.80ab
150	97.87cd	104.80abcd	107.40abc	109.53ab	106.53abc
180	100.33bcd	100.33bcd	113.20a	114.00a	113.20a

Note: values followed by the same letters within a column are not significantly different according to DMRT at 5 %.

only resulted in seven tillers (Figure 2).

The dose of N fertilizer affected leaf color intensity at 4 WAP. Nitrogen at 90 kg N.ha^{-1} resulted in a significantly lower leaf color scales of 3.5 than the other treatments (Figure 3). This value (3.5) is lower than the critical value of the leaf color chart of rice of 4 according to IRRI (IRRI-CREMNET 2001). Number of seeds per hill did not affect the color of the leaves (Figure 4).

Plant Dry Matter

N fertilizer doses did not significantly affect plant dry weight at 14 WAP. The lowest dry weight was with the application of 120 kg N.ha^{-1} whereas N fertilizer at 150 kg.ha^{-1} had the greatest dry weight (Figure 5). The number of seedlings per hill significantly affected plant dry weight; the dry weight decreases with increasing number of seedlings per hill up to 15 seeds per hill. The highest dry weight was produced by the treatment of one seed per hill, whereas the lowest dry weight was from the treatment of 15 seedlings per hill. The dry weight was again increased to 20 seedlings per hill (Figure 6). The large dry weight with the treatment of one seed per hill was possibly due to less interspace competition between plants, so there was optimal growth of stems and canopy. Competition in utilizing nutrients, light and growing space occurs where there was more seedlings

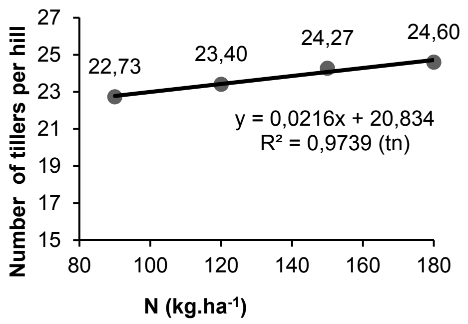

Figure 1. Effects of N fertilizer dose on number of tillers per plant at 7 WAP

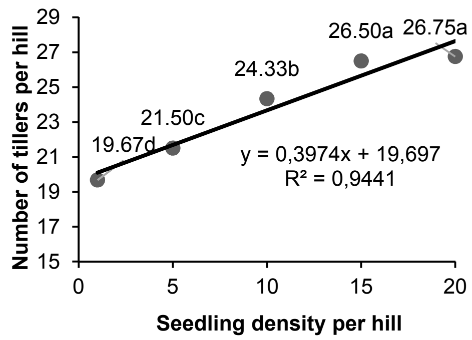

Figure 2. Effects of seedling density on number of tillers per hill at 7 WAP

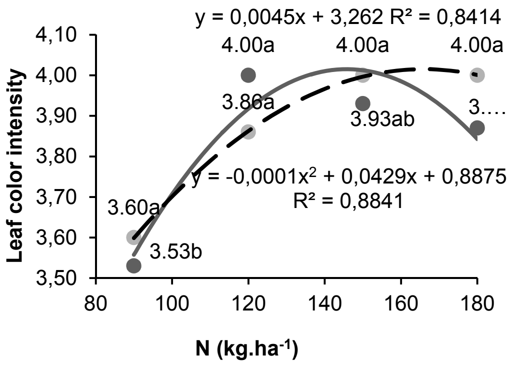

Figure 3. Effects of N fertilizer doses on leaf colour intensity at 4 (-) and 6 (- - -) WAP

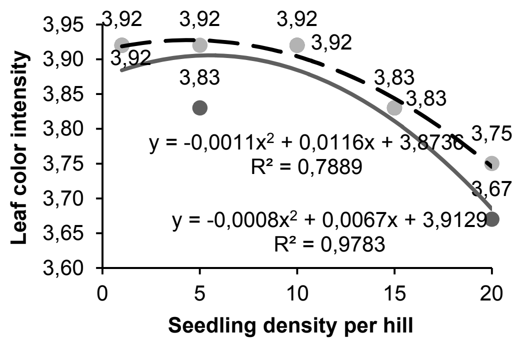

Figure 4. Effects of seedling density on leaf colour intensity 4 (-) and 6 (- - -) WAP

growing close together, resulting in smaller canopy coverage and thinner stems. Sumardi (2010) stated that high seedling density limits the growing space to produce optimal growth and development of plant organs.

Rice Yield Components

N fertilizer dose did not significantly affect the number of productive tillers (Figure 7), the number of grains per panicle (Figure 9), and 1000-grain weight (Figure 11), but significantly affected the percentage of filled grains. Increased dosage of N fertilizer up to 180 kg ha^{-1} caused the percentage of filled grains to decrease. The 90 kg N.ha^{-1} treatment yielded the highest percentage of filled grains of 84.13%, whereas the 180 kg N.ha^{-1} treatment had the lowest yield of 76.15% (Figure 13). Pirngadi et al. (2007) reported that N fertilizer application of over 90 kg N.ha^{-1} would decrease filled grains.

Increasing the number of seeds per hill increased the number of productive tillers. Treatment with 20 seedlings per hill resulted in the highest number of productive tillers compared to other treatments. The average number of productive tillers with 20 seeds was between 10 to 14 or % higher than whereas the treatment of one seedling per hill produced 12 (Figure 8).

In general, the number of seeds per hill affected the number of grains per panicle. Planting one seedling per hill resulted in the highest amount of grains per panicle compared to those of other seedling densities (Figure 10). Zeng and Shannon (2000) demonstrated that the number of grains per plant, the number of grains per panicle, and filled grains per panicle decreased with increasing population density. A study with Indica rice (Shao-hua, et al., 2002) reported that increasing seedling density from one to two seedlings per hill increased the number of tiller and spike. In addition, grain yield with two seedlings per hill was higher than that under conventional cultivation of one seedling per hill (Shao-hua, et al., 2002).

The seedling density per hill had a significant effect on weight of 1000- grains; weight of 1000-grain tends to increase with increasing seedling density (Figure 12). The seedling density, however, did not affect the percentage of filled grains (Figure 14).

Dry grain yield per plant increased with the increase in N fertilizer dose, but started to decrease at the dose of 180 kg N.ha^{-1} (Figure 15). The decline was possibly due to nutrient imbalances in the soil due to fertilizer application that did not meet the nutrient requirements

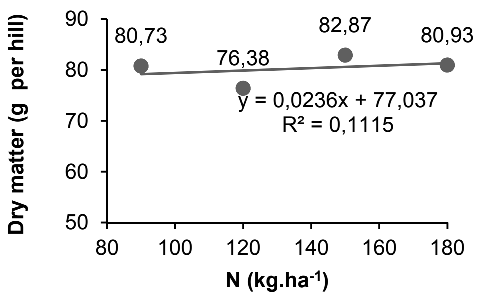

Figure 5. Effects of N fertilizer dose on above ground plant dry matter

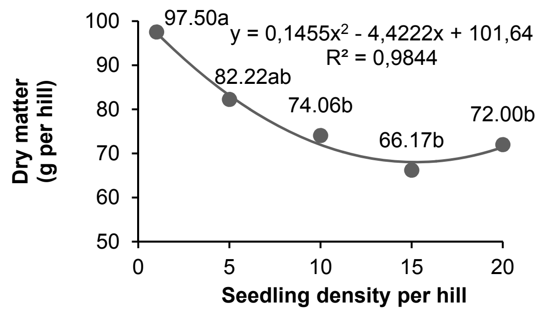

Figure 6. Effects of seedling density on above ground plant dry matter

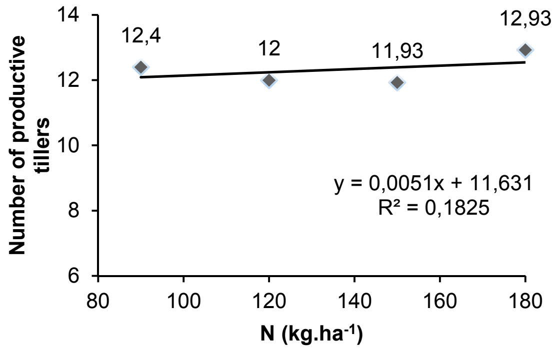

Figure 7. Effects of N fertilizer dose on number of productive tillers

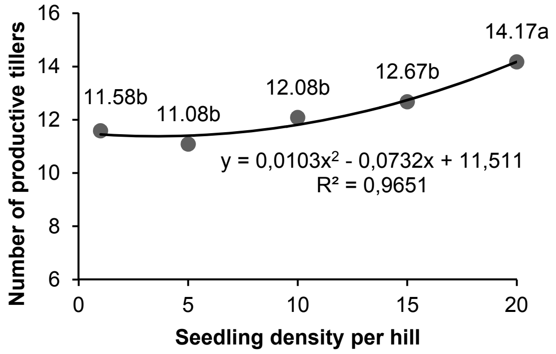

Figure 8. Effects of seedling density on number of productive tillers

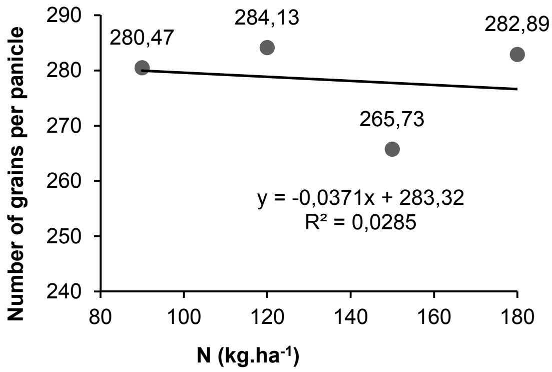

Figure 9. Effects of N on number of grain per panicle

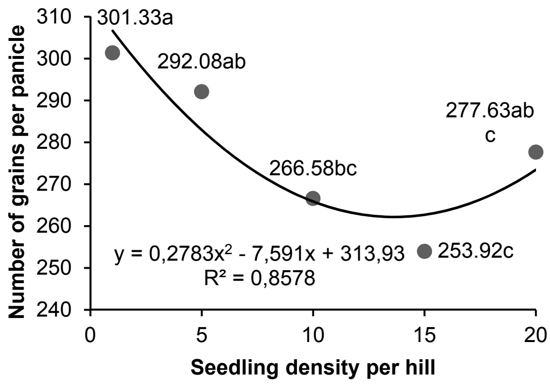

Figure 10. Effects of seedling density on number of grains per panicle

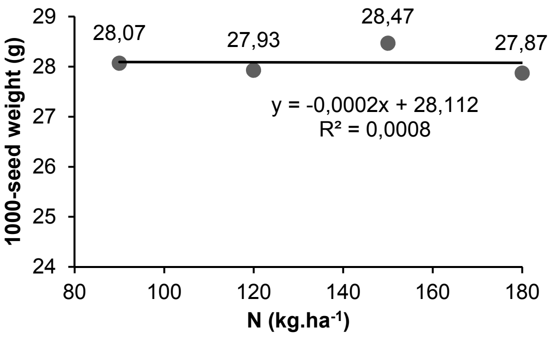

Figure 11. Effects of N fertilizer dose on 1000-seed weight

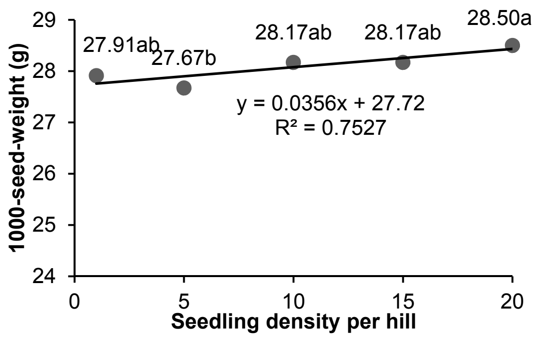

Figure 12. Effects of seedling density on 1000-seed-weight

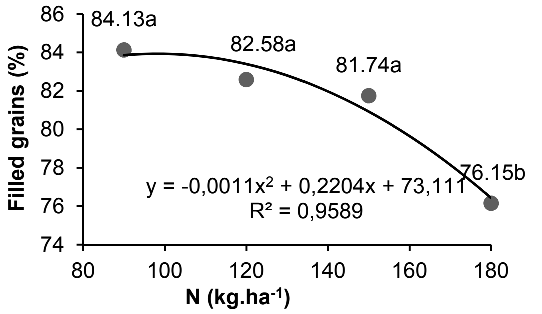

Figure 13. Effects of N fertilizer dose on percentage of gabah bernas

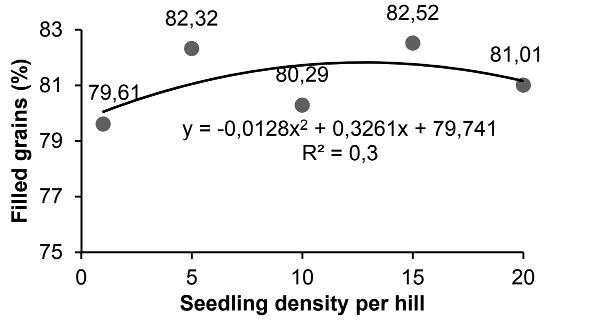

Figure 14. Effects of seedling density on percentage of bernas grains

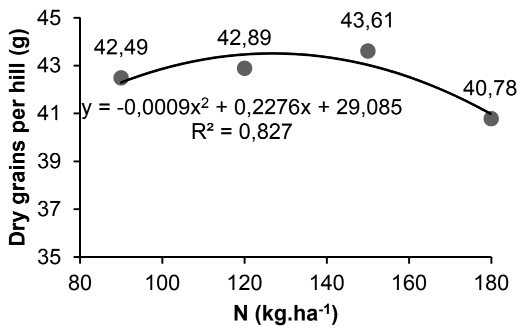

Figure 15. Effects of N fertilizer dose on grain yield per plant

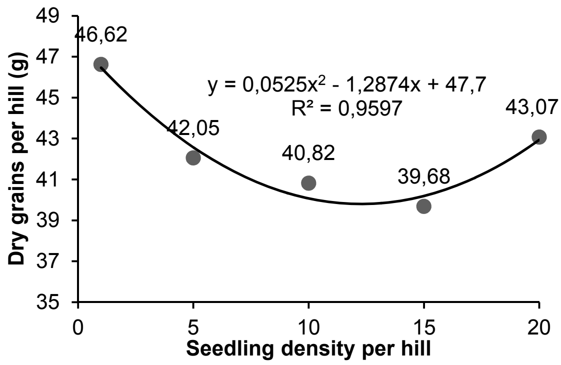

Figure 16. Effects of seedling density on grain yield per plant

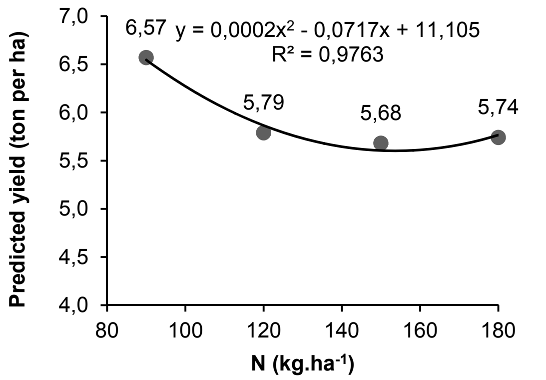

Figure 17. Effects of N fertilizer dose on grain yield per hectare

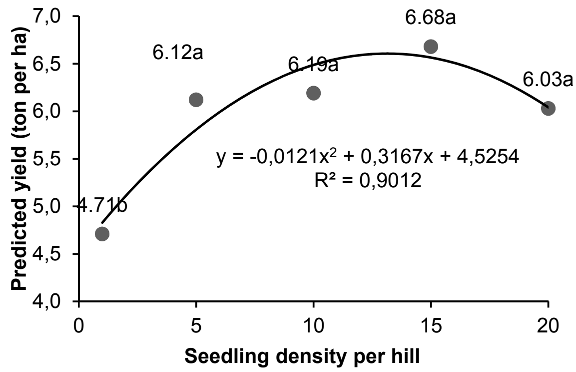

Figure 18. Effects of seedling density on grain yield per hectare

of the crops (Abdulrachman and Sembiring, 2007).

Number of seedlings per hill had no significant effect on dry grain yield per plant, but planting one seedling per hill tends to produce higher dry grain per plant (46.6 g) compared with other seedling densities. Treatment of 15 seedlings per hill had the lowest dry grain per plant of 39.7 g (Figure 16). The treatment of N fertilizer doses did not significantly affect grain yield per hectare. The 90 kg N.ha^{-1} treatment resulted in the highest grain yield per hectare of 6.57 ton ha^{-1}, whereas N fertilizer at 150 kg N.ha^{-1} had the lowest grain yield per hectare of 5.68 toN.ha^{-1} (Figure 17).

Grain yield per hectare was shown to increase with increasing seedling density. The highest yield per hectare was produced by the treatment of 15 seeds per hill, while the lowest was produced by the number of seeds 1 per hill. Treatment of 15 seedlings per hill yielded grain per hectare 41.8% higher than the treatment of 1 seed per hill (Figure 18). According to Sumardi (2010) the rice grain yield per hectare increases with the increase in population per unit land area. Grain yield per hectare in this study began to decrease in the treatment of 20 seedlings per hill. The yield reduction at high population could be caused by population-dependent stresses due to plant competition to access water and nutrition.

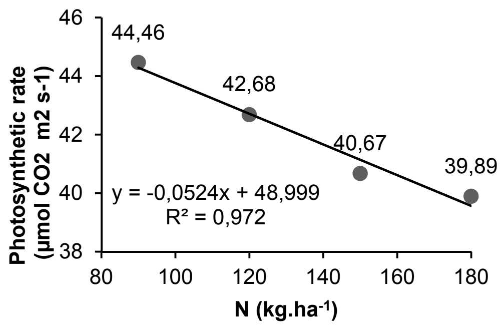

Figure 19. Effects of N fertilizer dose on photosynthetic rate

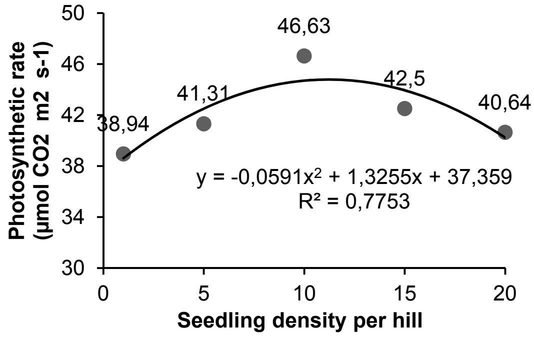

Figure 20. Effects of seedling density on photosynthetic rate

Photosynthetic Rates

The rate of photosynthesis measured at 9 WAP decreased with the increase in N fertilizer rates (Figure 19). The decline in the rate of photosynthesis affects will reduce the assimilates which will impact the rice production. Long et al (2006) reported that there is a close relationship between increased photosynthesis, biomass, and yield; increased photosynthesis will increase the rice production. The number of seedlings per hill had no significant effect on the rate of photosynthesis, but the effect of the number of seeds on the rate of photosynthesis formed a quadratic curve. An increase in the seedling density to 10 per hill can increase the rate of photosynthesis whereas planting more than 10 seedlings per hill will decrease the rate of photosynthesis (Figure 20).

The results of this study have provided a guideline for an improved nitrogen management in relation to rice seedling population to increase yield of a new rice type "IPB3S".

Conclusion

Applying more than 90 kg $N.ha^{-1}$ decreased the percentage of filled grains, decreased photosynthetic rate, and grain yield per hectare. Increased seedling density up to 15 seedlings decreased the dry weight of the crop, number of grains per panicle, grain yield per plant, however, it increased the predicted rice yield per hectare. The optimum yield of the new type of rice "IPB 3S" was achieved with the application of 90 kg $N.ha^{-1}$ fertilizer with 15 seedlings per hill.

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