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Response of upland rice variety to plant population under the low land agro-ecology of Bench Sheko Zone, South-west Ethiopia

Merkine Mogiso[1]* and Tesfaye Tarekegn[2]

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ABSTRACT

Plant population has a strong influence on rice yield. A field experiment was conducted during the 2017 and 2018 main cropping seasons at Guraferda district in Bench Sheko Zone, Southwest Ethiopia. The objective of this study was to determine the optimum plant population and appropriate variety on grain yield and yield components of upland rice. The experiment was carried out using RCBD with three replications. Five levels of plant populations (60, 80, 100, 120, and 140 kg ha^{-1}) and three levels of genotypes (Nerica-4, Suparica-1, and Local check) were studied. The main effect of plant population and variety had significant ($p<0.05$) for most of the parameters investigated. However, the interaction effect had only statistically significant for the number of tillers, panicles, and grain yield. The combined results showed that the maximum grain yield of 5553.3, 5491.0, 5252.5, 5047.6, 5043.1, and 4955.6 kg ha^{-1} were obtained at the respective treatment combinations of Suparica-1 with 80, Suparica-1 with 100, Local check with 140, Suparica-1 with 120, and Local check with 120 and 100 kg ha^{-1} plant populations. In addition to the above result, a Partial budget analysis was also carried out to determine the economic optimum plant population for production. Accordingly, the combination of Suparica-1 at the rate of 80 kg ha^{-1} was appropriate to get a better yield and higher economic benefit. Therefore, it can be possible to suggest the finding for wider production.

Keywords: Grain yield, Seed rate, Economic analysis

[1]*Department of Crop Research, Hawassa Agricultural Research Center, Hawassa, Ethiopia*
[2]*Department of Crop Research, Bonga Agricultural Research Center, Bonga, Ethiopia*

*Corresponding author's email: mogisog22@gmail.com (Merkine Mogiso)

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Introduction

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population, most importantly in developing countries (Seck *et al.*, 2012). More than 90% of the world's rice is grown and consumed in Asia where nearly 60% of the world's people live (GRiSP, 2013). It is the most widely consumed food for a large part of the world's human population. More than a billion households in Asia, Africa, and America depend on rice systems for their main sources of employment and livelihoods (Seck *et al.*, 2012; Siwar *et al.*, 2014). Its production is currently extending across at least 114 countries in the world and the second most-produced cereals in the world after maize. Currently, it has also become a priority commodity for food security in Africa and has grown over 75% of the African countries with a total production of 14 million tons and 16 million metric tons of consumption annually (MoARD, 2010). The world production area in 2014 was approximately 162 million hectares with 755 million tonnes of paddy rice with an average yield of 4.6 tonnes per hectare[5]. The productivity of the crop elsewhere in major rice-producing countries includes 4.1 t ha^{-1} in India, 5.1 t ha^{-1} in Indonesia, 5.8 t ha^{-1} in Vietnam, 7.1 t ha^{-1} in China, and 8.1 t ha^{-1} in Egypt (FAOSTAT, 2020). China is the leading producer of paddy rice followed by India, Bangladesh, Indonesia, Vietnam, and Thailand which account for 30, 24, 7, 7, 5, and 4% of the world production, respectively (Shahbandeh, 2021). In Africa, the largest production of paddy rice has come from Nigeria while the highest productivity is from Egypt.

Currently, rice is gaining the same importance as some of the most common cereal crops for both domestic consumption as well as market use in Ethiopia. Despite its importance, the national productivity of the crop is 3.0 t ha^{-1} (FAOSTAT, 2020), this is by far below the potential of the crop on research plots (5.4 t ha^{-1}) (Taddesse, 2015). Guraferda is one of the potential rice growing areas in Ethiopia. The crop is mainly grown in rainfed upland ecology. The crop is mainly grown in the lowlands of Guraferda especially at Otuwa, Kuja, Berji, Semerta, and

Alenga areas. It plays an important role for farmers, as food for home consumption, and a source of income, as it is an important crop in the local market. Rice is consumed in various ways under Guraferda condition, which includes: *injera, dabbo, asambusa, kinche,* and *shorba*. Although, efforts have been made for a long period to select the most adapted and high-yielding varieties of upland rice through testing varieties for adaptation to the new environments little work has been done on agronomic management practices in the area. Among the agronomic management problems, inappropriate use of plant population, sowing method, and fertilizer application are the major ones. Plant population above or below the optimum may reduce the rice yield (Matsumoto *et al*., 2017). On the other hand, optimum plant population and proper selection of suitable variety are the most important production factors to obtain a higher yield in upland rice. The present study was, therefore, undertaken to determine the optimum plant population and appropriate variety to get maximum yield in upland rice.

Materials and Methods

Description of the experimental site

The field experiment was conducted at Guraferda district. Guraferda is found in the southwestern part of Ethiopia, in the Bench Sheko Zone of the Southern Nations Nationalities and Peoples Regional (SNNPR) government at about 630 km southwest of Addis Ababa. The administrative center of the zone is Mizan Teferi. The specific experimental site is Otuwa farmers' association, located about 5 kilometers away from the town of the district, Biftu. The study area represents the lowland agro-ecology of the district. It is located at 06° 50' N latitude and 35° 18' E longitude at an elevation of 1133 meters above sea level.

Experimental materials

The two upland rice varieties and a local cultivar were used as planting material; the improved varieties used were NERICA-4 and Suparica-1, which are released from Pawe Agricultural Research Center in 2006. They were high-yielding and disease-resistant varieties and well adapted to lowland agro-ecology.

Treatments and experimental design

The treatments consisted of the combination of five levels of plant populations (60, 80, 100, 120, and 140 kg ha^{-1}) and three genotypes (NERICA-4, Suparica-1, and a local check) with a total of fifteen treatments were used in this study. The experiment was carried out in randomized complete block design with the factorial arrangement and replicated three times. The total experimental area was divided into three replications, each of which is further divided into fifteen plots. Following the procedure, fifteen treatment combinations were randomly assigned to the fifteen plots in each block. The gross plot area of the experiment was 8 m^2 and from which 6 m^2 was considered as a net plot. The spacing between the replications was 1 m whereas plots were spaced 0.5 m apart from each other.

Experimental field practices

The experimental field was prepared following the standard practices for rice production before sowing (Way and Cockrell, 2008). The field was plowed, leveled, and rows were prepared 25 cm apart from each other. Sowing was done by hand drilling the seeds in rows. A field layout was prepared following its procedure and the treatments were randomly assigned to the experimental plots. The total dose of phosphorus in the form of NPS was applied at sowing and half the rate of nitrogen fertilizer was applied after full emergence and the remaining half of the nitrogen rate was applied at the panicle initiation stage. Weeding was done uniformly in all experimental plots.

Data collection and measurements

Growth parameters

Plant height: was determined by measuring the length of ten randomly selected sample plants from the ground level to the tip of the panicle in each plot at physiological maturity.

Panicle length: done by measuring the length of the panicle from the node where the first panicle branch emerges to the tip of the panicle and determined from an average of ten randomly selected plants per plot.

Yield and yield components

The number of tillers (both productive and unproductive) per m^2: The numbers of tillers were determined by counting the tillers from an area of 0.5 m x 0.5 m row plants by using quadrant in each plot and then converted to square meter area.

The number of panicles per m^2: The number of panicles was determined by counting the panicles from an area of 0.5 m x 0.5 m row plants of each plot and then converted to a square meter area.

The number of total spikelets $panicle^{-1}$: The number of spikelets was determined by counting all spikelets (filled and unfilled) from ten randomly selected panicles of ten sample plants in each plot and averaged.

The number of filled spikelets $panicle^{-1}$: The number of spikelets was determined by counting only filled spikelets from ten randomly selected panicles of ten sample plants in each plot and averaged.

Thousand-grain weight: was determined by weighing randomly drown 1000 grains of well-developed, whole, or undamaged grains and then adjusted to 14% MC.

Grain yield: grain yield was determined by harvesting the rice crop from the net middle plot area of 6 m^2 and threshed cleaned and weighed using an electronic balance and then adjusted to 14% moisture content.

Statistical analysis

The collected data were subjected to factorial analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS version 9.3 (SAS Institute, 2002-2010). The treatment means of significant treatment effects were compared using the Least Significant Difference (LSD) test at a 5% probability level ($p<0.05$). Pearson correlation analysis was carried out using the same software to investigate associations between grain yield and yield components of upland rice varieties.

Partial budget analysis

A partial budget analysis was performed using the grain yield to identify economically profitable plant populations for the tested rice varieties. The yield response of rice varieties to the plant population was estimated, where the price of seeds and costs that varied during cultivation determined the economic feasibility of the rate used. The yields of all treatments were adjusted downward by 10% to reflect possible lower yields expected by the farmers due to differences in management factors. The price of seed was ETB 14.46 per kg, the local wage rate was ETB 50 per person per day was considered under variable costs. The farm gate price of grain was ETB 8.00 per kg. A gross farm gate benefit was obtained by multiplying adjusted yield (kg ha^{-1}) with farm gate price (ETB kg^{-1}); while the marginal rate of return for each plant population treatment was calculated as change of benefit divided by change of cost and multiplied by 100 (CIMMYT, 1988). However, economic recommendations were made by arranging the interaction effect of variety and rate of seed used in order of increasing costs and then considering MRR between each treatment. Finally, the treatment with the highest net benefit and MRR was recommended for production in the study area.

$$MRR = \frac{\Delta NB}{\Delta TVC} * 100$$

Where, MRR = Marginal rate of return in percentage, ΔNB = Change in net benefits, ΔTVC = Change in total variable cost.

Results and Discussion

The main effect of plant population and variety significantly ($p<0.05$) affected all the studied parameters. However, the interaction effect was significant only for the grain yield, number of tillers, and number of panicles per m^2.

The varieties showed significant differences in plant height (Table 1). The local check was produced the highest plant height of 111.2 cm, whereas Nerica-4 produced the shortest height of 80.4 cm. The observed difference in height between the varieties may be due to the inherent genetic difference among tested varieties. Rahman (Rahman, 2003) and Jisan (Jisan, 2014) have observed a significant difference in plant height among varieties tested in their previous study. The tallest height was recorded at the rate of 60 kg ha^{-1} (106.2 cm), whereas the shortest height was 84.9 cm when the plant population increased to 140 kg ha^{-1}. The increased height in response to the low plant population was likely due to the low interplant competition, which might increase the possibility to get more nutrients in the soil, which may have promoted vegetative growth of the rice plants. Nitrogen in the soil may have encouraged the vegetative growth of upland rice varieties that promoted the growth of plants, through increasing the length as well as the number of internodes (Turkhede and Rajendra, 1978).

The longest panicle was recorded for local check with a panicle length of 22 cm, whereas Suparica-1 and Nerica-4 produced the shortest panicle length of 19 cm. Among the plant populations 60, 80, and 100 kg ha^{-1} were showed an increased panicle. The length of panicles was significantly decreased with the increasing plant population. The longest panicle was recorded at the rate of 80 kg ha^{-1} (21.1 cm), whereas the shortest was recorded at the rate of 120 and 140 kg ha^{-1} with the respective panicle length of 19.6 and 18.9 cm. This is probably due to better absorption of nitrogen at the lowest plant population due to less competition for nutrients, and this could be enhanced the length of panicles in rice (Manzoor *et al.*, 2006).

The number of spikelets per plant is an important yield determining component in upland rice. The analysis of variance that the main effect of seed rate and variety had a highly significant ($P<0.05$) effect on the total number of spikelets per panicle. The result revealed that local cultivar and Suparica-1 produced more total spikelets per panicle with the respective number of spikelets 124.6 and 120.5. The lowest number of total spikelets per panicle was obtained from Nerica-4 (116). Among the plant populations, the highest number of total spikelets per panicle (142.3) were recorded at the rate of 80 kg ha^{-1}, whereas, the lowest (98.5) was recorded at the highest plant population. The higher number of spikelets per panicle at lower plant population is might be due to less competition of plants and the availability of more nitrogen at lower plant density. This result is similar to the previous findings of Baloch *et al.* (2002), who reported the lowest number of spikelets per panicle at the increasing rate of plant population. Individual plants were better performed at the lower plant population because of the opportunity to acquire more solar radiation for a better photosynthetic process (Baloch *et al.*, 2002).

The result revealed that local check (106) and Suparica-1 (104) were produced more number of filled spikelets per panicle in pooled data.

However, the lower (94) number of filled spikelets per panicle was obtained from Nerica-4. On the other hand, among the plant populations, the highest number of filled spikelets per panicle were recorded at the rate of 80 kg ha^{-1}, whereas, the lowest was recorded at the rate of 140 kg ha^{-1}. The number of filled spikelets decreased with the increasing plant population from 80 to 140 kg ha^{-1} with the spikelet number from 123 to 80, respectively. This result indicated that as the plant population increased, the filled grains per panicle remarkably reduced. This might be due to the availability of more nitrogen at lower plant density as the result of less nutrient competition. The plants grown with a lower plant population had more solar radiation to absorb for a better photosynthetic process and performed better (Baloch *et al.,* 2002). Garba *et al.* (2013) reported that the higher the plant population the more sterility observed in rice. A similar result was reported by Harris and Vijayaragavan (2015). This result is consistent with the result of Oziegbe and Faluyi (2007) who reported that the increment in plant population did not affect spikelet production per plant. In higher plant density, there is competition among plants for light and nutrients and which leads to the reduction of yield components (Baloch *et al.,* 2002).

Regarding thousand seed weight, it was significantly influenced by both varieties and plant populations. The result indicated that the local check was recorded the higher thousand seed weight (37 g) followed by Suparica-1 (29.6 g). Nerica-4 was recorded the lower (26.8 g) thousand seed weight. Among the plant populations, the highest thousand seed weight was recorded from the lowest plant population. Thousand seed weight was increased when the plant population was decreased from 140 to 60 kg ha-1 with the respective value from 26.8 to 34.8 g. The result agrees with the previous report of Harris and Vijayaragavan (2015). The plants grown with a lower plant population had more solar radiation to absorb for a better photosynthetic process and assimilate translocation to grain formation (Baloch *et al.,* 2002).

Table 1. Combined effect of variety and plant population on plant height, panicle length, number of spikelet, filled spikelet and thousand seed weight at Guraferda.

Variety	Plant height (cm)	Panicle length (cm)	Total spikelet m^2	Filled spikelet m^2	1000 grain weight (g)
NERICA-4	80.4	19.2	115.0	93.8	26.8
Suparica-1	96.5	19.3	120.5	104.0	29.6
Local	111.2	22.0	124.6	105.5	37.3
LSD (0.05)	2.8	0.6	4.8	5.4	1.1
Seed rate					
60	106.2	20.8	129.1	109.3	34.8
80	101.3	21.1	142.3	122.6	33.2
100	95.7	20.4	119.6	101.9	31.8
120	92.1	19.6	110.7	91.6	29.6
140	84.9	18.9	98.5	80.0	26.8
Means	96.0	20.2	120.0	101.1	31.2
LSD (0.05)	3.6	0.8	6.2	7.0	1.4
CV (%)	5.7	5.6	7.7	10.3	6.5

LSD (%) = Least significant difference at $P < 0.05$; CV (%) = Coefficient of variation.

Tiller is one of the most important yield components that determine rice productivity. The interaction effect of variety and plant population was significant for the number of tillers per square meter (Table 2). The interaction effect indicated that the highest number of tillers per square meter was obtained from the interaction of Local check at 100, 120 and 140, Suparica-1 at 80, 100 and 120 and Nerica-4 at 120 kg ha^{-1} plant populations. However, the lowest tiller number was recorded at the maximum and minimum plant populations combined with Nerica-4 and Suparica-1 except for the local check at the highest rate. The number of tillers increased when the plant population increased from 60 and 120 kg ha^{-1}. The result showed that Nerica-4 increased the production of tillers when the plant populations increased from 60 to 120 kg ha^{-1} and declined above this rate. Suparica-1 increased the production of tillers when the plant population increased up to 100 kg ha^{-1}, which is not statistically different from the rate of 80 kg ha^{-1}. On the other hand, an increase above 100 kg ha^{-1} did not significantly affect the production of tillers. The local check was increasing the production of tillers when the rates increased from the lowest to the highest plant population but the rates starting from 100 up to 140 kg ha^{-1} were not significantly different. That means there was no significant effect in tiller production when the rate increased from 100 to 140 kg ha^{-1}. The production of tillers per unit area depends to a great extent on the genetic character of the variety and the environment where it grows (Tyeb *et al.,* 2013). Thus, the varieties were continued to produce more tillers as the plant population increased.

Table 2. Interaction effect of variety and plant population on number of tillers m² combined over years at Guraferda.

Variety	Plant population (kg ha^{-1})					Mean
	60	80	100	120	140	
NERICA-4	250.0	305.7	315.3	367.3	256.0	298.9
Suparica-1	302.0	370.0	389.0	369.3	276.7	341.4
Local	289.0	340.7	352.3	375.0	415.3	354.5
Mean	280.3	338.8	352.2	370.6	316.0	
LSD (%)			74.5			
CV (%)			19.5			

LSD (%) = Least significant difference at P < 0.05; CV (%) = Coefficient of variation.

The number of panicles per unit area is considered as one of the most important yield components, which increases the rice yields (Fageria, 2007). The interaction effect of variety and plant population was significant for the number of panicles per square meter (Table 3). The interaction effect indicated that the highest number of panicles per square meter was recorded from Suparica-1 for combined effect at 80 and 100 kg ha^{-1} plant population, the local check at 100, 120 and 140 kg ha^{-1} plant population and Nerica-4 at 80 kg ha^{-1}. On the other hand, the lowest number of panicles was obtained at the least plant population for all the varieties tested and the rates above 80 kg ha^{-1} in the case of Nerica-4 and Suparica-1. However, unlike others, the number of panicles increased for the local check when the rate increased from 60 to 140 kg ha^{-1}. This suggests that when the seed rate increased above 100 kg ha^{-1} had no marked difference in panicle production. The number of panicles per unit area is a key factor that determines grain yield (Miller *et al.*, 1991). Optimum plant population helps plants to grow properly by utilizing more solar radiation and nutrients. In contrast, Wu *et al.* (1998) reported an increased number of tillers plant^{-1} with the decrease of plant densities in direct-seeded rice. Merkine (2020) also reported that the elevated plant density had no marked change in yield and yield components of rice.

Table 3. Interaction effect of variety and plant population on number of panicles m² combined over years at Guraferda.

Variety	Plant population (kg ha^{-1})					Mean
	60	80	100	120	140	
NERICA-4	212.7	280.0	236.7	261.0	209.7	240.0
Suparica-1	246.7	316.3	285.3	240.7	227.3	263.3
Local	232.3	244.7	273.0	283.3	309.7	268.6
Mean	230.6	280.3	265.0	261.7	248.9	
LSD (%)			46.9			
CV (%)			15.8			

LSD (%) = Least significant difference at P < 0.05; CV (%) = Coefficient of variation.

The highest grain yield of the upland rice was recorded at the plant populations starting from 80 to 120 and even at the highest rate in the case of the local check. The yield of local cultivars was significantly increased up to 140 kg ha^{-1}. The highest grain yield was produced by varieties Suparica-1 at 80 (5555.3 kg ha^{-1}), 100 (5491.0 kg ha^{-1}), 120 (5047.6 kg ha^{-1}) kg ha^{-1} plant population and local check at 100 (4955.6 kg ha^{-1}), 120 (5043.1 kg ha^{-1}) and 140 (5252.5 kg ha^{-1}) kg ha^{-1} plant population. Suparica-1 and local cultivar at the plant populations of 80, 100 and 120 and 100, 120 and 140 kg ha^{-1}, respectively gave statistically the same higher grain yield as compared to the other treatment combinations. However, the lowest grain yield was recorded when Nerica-4 combined with 60 and 140 kg ha^{-1} plant population and the local check at 60 kg ha^{-1} plant population. Proper plant population is an important factor that enables good rice yield. The increase in plant population per unit area increases the grain yield up to a certain limit and above its optimum, the yield starts to decline due to the competition between plants for natural resources (Shahbandeh, 2021). As the seed rate increased above 80 kg ha^{-1} number of filled spikelets per plant was decreased so that, the increased grain yield may be due to the number of panicles per unit area. In contrast, the earlier study indicated that the highest grain yield at 40 kg ha^{-1} plant population and declined when the rate above this under irrigation (Yoseph and Gebre, 2014). Yield is a complex trait that is directly correlated with the number of panicles and tillers per unit area. This result is in line with the findings of Zeng and Shannon (2000) who reported that increased plant population had no change in the production of grain yield.

Table 4. Interaction effect of variety and plant population on grain yield combined over years at Guraferda.

Variety	Plant population (kg ha^{-1})					Mean
	60	80	100	120	140	
NERICA-4	3267.4	4519.7	4558.8	4334.7	3717.8	4079.68
Suparica-1	4464.7	5553.3	5491.0	5047.6	4581.5	5027.62
Local	3583.5	4535.5	4955.6	5043.1	5252.5	4674.04
Mean	3771.87	4869.50	5001.80	4808.47	4517.27	
LSD (%)			922.84			
CV (%)			17.47			

LSD (%) = Least significant difference at P < 0.05; CV (%) = Coefficient of variation.

Partial budget analysis

Partial budget analysis was used in this study to calculate the total costs that vary and net benefits for each treatment. Based on this, the highest net benefit (38,427 ETB ha^{-1}) was obtained from treatment combination of Suparica-1 at the plant population of 80 kg ha^{-1} plant population while the lowest net benefit (22,158 ETB ha^{-1}) was obtained from the combination of Nerica-4 at 60 kg ha^{-1} plant population (Table 5). The marginal rate of return is important to compare treatments because of economic profitability rather than only looking at the maximum biological yield (CIMMYT, 1988) and which helps to remove unprofitable treatments before recommendation. Consequently, the marginal rate of return was done to determine the economic benefit of the technology for the recommendation. Based on this, the highest marginal rate of return was recorded from the combination of Suparica-1 with 80 kg ha^{-1}(Table 6).

Table 5. Partial budget analysis for the variety and plant population on upland rice yield.

VxSR (kg ha^{-1})	HGY (kg ha^{-1})	AGY (kg ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})
Nx60	3267.40	2940.66	23525.28	1367.60	22157.68
Nx80	4519.70	4067.73	32541.84	1556.80	30985.04
Nx100	4558.80	4102.92	32823.36	1846.00	30977.36
Nx120	4334.70	3901.23	31209.84	2035.20	29174.64
Nx140	3717.80	3346.02	26768.16	2324.40	24443.76
Sx60	4464.70	4018.23	32145.84	1367.60	30778.24
Sx80	5553.30	4997.97	39983.76	1556.80	38426.96
Sx100	5491.00	4941.90	39535.20	1846.00	37689.20
Sx120	5047.60	4542.84	36342.72	2035.20	34307.52
Sx140	4581.50	4123.35	32986.80	2324.40	30662.40
Lx60	3583.50	3225.15	25801.20	1367.60	24433.60
Lx80	4535.50	4081.95	32655.60	1556.80	31098.80
Lx100	4955.60	4460.04	35680.32	1846.00	33834.32
Lx120	5043.10	4538.79	36310.32	2035.20	34275.12
Lx140	5252.50	4727.25	37818.00	2324.40	35493.60

VxSR = Variety by plant population; N = NERICA-4; S = Suparica-1, L = Local cultivar; HGY. = Harvest grain yield; AGY.= Adjusted grain yield; GB = Gross benefit; TVC = Total variable cost; and NB = Net benefit

Table 6. Marginal rate of return for the variety and plant population on upland rice yield.

VxSR (kg ha^{-1})	AGY (kg ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Sx60	4464.7	32145.84	1367.60	30778.24	
Sx80	5553.3	39983.76	1556.80	38426.96	4043
Sx100	5491.00	39535.20	1846.00	37689.20	D
Sx120	5047.6	36342.72	2035.20	34307.52	D
Lx140	5252.5	37818.00	2324.40	35493.60	D

VxSR = Variety by plant population; N = NERICA-4; S = Suparica-1, L = Local cultivar; AGY.= Adjusted grain yield; GB = Gross benefit; TVC = Total variable cost; NB = Net benefit and MRR = Marginal rate of return

Conclusion

Appropriate plant population is one of the most important production factors to obtain higher economic yield. The result of this study indicated that yield and yield components were significantly influenced by variety and plant population. However, the interaction effect was only significant for the number of tillers and panicles per meter square and grain yield. Based on the mean value of treatments, the highest grain yield was recorded in the combination of Suparica-1 at 80, 100 and 120 and the Local check at 100, 120 and 140 kg ha^{-1} plant populations. However, comparing treatments because of economic profitability growing of Suparica-1 at the rate of 80 kg ha^{-1} gave better yield and higher economic benefit than others.

Hence, it can be possible to suggest the technology for wider production in the location.

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