Reduction of rice yield gap by fertilizer and new varieties in North Sumatera

Dorkas Parhusip\textsuperscript{a} Erpina D. Manurung\textsuperscript{b} Setia S. Girsang\textsuperscript{c}\textsuperscript{*}
North Sumatera Assessment Institute for Agricultural Technology
Jl. Jendral Besar A.H. Nasution No. 1B, Medan, 20143

\textsuperscript{a}Email: girsang313@gmail.com

Abstract. Variety and fertilizer are the important input that affects the increase in rice production. The research was carried out in the farmers' land of Laras II Village, Siantar Subdistrict, Simalung District, North Sumatra DS 2019 (latitude: 2°58'52"N, longitude: 99°8'36"E, 249.5 m a.s.l.). The objective of the study is to determine the amount and time of fertilizer application in several rice varieties to minimize the gap of rice seed yields in North Sumatra. The treatment is a combination of fertilization treatments were rice consulting services (RCS), paddy soil test kits (STK), and farmers' treatment (FFP) while varieties were Ciherang, Mekongga, Inpari 30, 32, 33, 36, 42, and 43 with four replications. The results showed that land suitability class that is very suitable and had the good climate to support rice production in North Sumatera. The RCS fertilization can be a tool to identify gaps and improve nutrient management on rice because the results of the study showed that the RCS fertilization can decreased the yield gap of 2.6 t ha\textsuperscript{-1} compared to farmers in the same season. This is supported by SPAD, biomass, particulate matter per panicle, filled grain, 1000 grains, and production.

1. Introduction
Food security is an important issue that needs attention to ensure an economic and political stability of the countries. As the 6\textsuperscript{th} rice-producing after East Java, West Java, Central Java, South Sulawesi, and South Sumatra with an average productivity of 5.29 t ha\textsuperscript{-1} wherein 2.04\% higher than the national productivity of 5.18 t ha\textsuperscript{-1} [1] but still has a gap of 3.71-4.71 t ha\textsuperscript{-1} compared to production potential in North Sumatra 9-10 tons [2].

One of the factors causing the high gap between potential and actual yield is intensification factors such as fertilization, variety, and climate. In general, farmers in North Sumatra applied fertilizers not based on nutrients available in the soil and/or nutrients for optimal crop production. The average fertilization used is N 278 kg ha\textsuperscript{-1}, P\textsubscript{2}O\textsubscript{5} 203 kg ha\textsuperscript{-1}, K\textsubscript{2}O 279 kg ha\textsuperscript{-1}, and S 56.7 kg ha\textsuperscript{-1} with twice application [3]. This is due to fertilizer application based on experience, do not know, difficult to learn, and difficult to get that it affected variation of rice production, not environmentally friendly, and not sustainable.

On the other hand, the use of new varieties uneven used by farmers. Farmers often use uncertified local or inbred varieties and their use is continuous even though the maximum production of a variety will be actualized, if various aspects related to the management of the cultivation of the variety are optimally available. In principle rice varieties have the potential for genetic yield, the highest yield which is the ability limit of a rice variety to produce grain (productivity), which can be achieved only in "best" climatic conditions and without any limiting factors for the growth environment of any plant [4,5,6].
Climatic factors such as solar radiation, temperature, and rainfall also have an important role in increasing rice production [7]. Based on previous studies, rice production decreased by 10% for a minimum temperature increase of 1°C [8]. Rice production of 9.3 t ha⁻¹ harvested in May and 5 t ha⁻¹ harvested in January [9] where solar radiation is 26 Kcal cm⁻² and 15 Kcal cm⁻², respectively [10]. It is hoped that this research can reduce the gap in rice productivity in North Sumatra.

The objective of this study was to determine the amount of fertilizer application and best variety can reduce the gap of rice yields in North Sumatra.

2. Materials and Methods

2.1. Site Characterization

The experiment was conducted in the period of March 21-July 15, 2019 at the farmer's fields group of Sejahtera III, Laras II Village, Siantar Sub-district, Simalungun District, North Sumatra Province with an altitude of 249.5 m asl, latitude: 20°58'52" N, longitude: 99°08'36" E. Rice-goldfish (fish pond)-rice cropping patterns were being followed in this location. Soil type Entisols in wetlands lowlands [11]. Soil analysis uses a paddy soil test kid (PUTS) tool by taking a soil sample of 5 depth points from 0-20 cm, compiled, then taken 500 gr to be analyzed. Soil analysis showed that the acidic soil pH (pH 4-5), N and K content is low, but P is high category.

2.2. Experimental Design

The treatments were arranged in a split plot design where variety is main plot and fertilizer is sub plot with four replications. The variety treatments are Ciherang (V1), Mekongga (V2), Inpari 30 (V3), 32 (V4), 33 (V5), 36 (V6), 42 (V7), and 43 (V8) while the fertilizer treatments are soil test kid as P1, rice consulting service (LKP) as P2, and farmers fertilizer practice (FFP) as P3. Farmer fertilization and farmer consulting services are the results of a survey of cooperative farmers and then inputted on the website while the recommendations for fertilizing PUTS are based on the results of soil analysis. The STK recommendations (N 115 kg ha⁻¹; P₂O₅ = 18 kg; and K₂O = 60 kg ha⁻¹); RCS recommendations (N 129.5 kg ha⁻¹; P₂O₅ = 37.5 kg ha⁻¹; and K₂O = 37.5 kg ha⁻¹); FFP recommendations (N 149.6 kg ha⁻¹; P₂O₅ = 40.5 kg ha⁻¹; and K₂O = 52.5 kg ha⁻¹; and S = 12 kg ha⁻¹).

2.3. Crop Management

The crop management for transplanting, agrochemical inputs, water management, and the method of tillage were the same for all treatments. Land preparation in the field involved full tillage with four passes of a rotavator on a two-wheel tractor before the establishment of the crop. Rice variety is Ciherang (116 days), Mekongga (116 days), Inpari 30 (111 days), 32 (120 days), 33 (107 days), 36 (114 days), 42 (112 days), and 43 (111 days) were manually transplanted at 7 days after seedling (DAS) with plant spacing (25 cm x 12.5 cm) x 50 cm or Superior Paired Row Geometry Technology (Jarwo) 2:1 where the population of > 200,000 plants per hectare. Nevertheless, fertilizer application for P₂O₅ and K₂O twice as basal and active tillers while for N as much as 3 times as N as basal, active tillers, and panicle initiation.

2.4. Observations

Several observations are climate and agronomics which consist of: Climate data during the plant growth period 21 March-15 July 2019 such as rainfall, humidity, solar radiation, wind speed, minimum and maximum temperature. Agronomic observations include chlorophyll and the number of tillers when productive, primordial, and booting stage at 2 rows x 0.5 m (0.25 m x 0.125 m) x 0.50 m, yield components such as plant height (cm), number of tillers m⁻², 1000 grain of grain (g), and the percentage of unfilled grain is 2 rows x 1m (0.25 m x 0.125 m) x 0.50 m, while for harvest with a size of 3 x 2.5 m.
2.5. Data Analysis
Data taken from each treatment and combination treatment were analyzed using Software for Agricultural Statistics (SAS) package version 9.3 (SAS Institute, Cary, NC, USA, 2003). Tukey-Kramer test (Honest Significant Difference or HSD) was used to compare treatment means based on a probability level of 5% or lower.

3. Results and Discussions
3.1. Characterization of the climate and locations
A field experiment was conducted on puddled soils in the warm tropical climate during the dry season of 2019 (March to July). The full cropping season was about 113 days from sowing to harvest. The short duration of a growing season because the mean solar radiation from sowing to harvest was high (52.5 MJ m\(^{-2}\)) wherein the highest was 64.4 MJ m\(^{-2}\) during flowering to harvest (Table 1). An increase in solar radiation during dry season partly contributed to yield increase [12]. It is supported by [13] experiment that the maximal grain yield is depending on radiation during flowering and grain filling. Furthermore, the cumulative rainfall of 1297 mm was recorded from sowing to harvest. The total rainfall is enough for plant growth for one season will produce irrigation efficiency. Based on [14] the range of water used for flooding during the growing season is estimated range between 100 to 940 mm (depth of water per surface area), is related to the level of the water control and soil soaking time interval from the beginning to the establishment of the plant. Further, to reduce cost rice production by reduced supply of irrigation water [3].

On the other hand, the mean maximum, and minimum temperature were 21.2 °C dan 30.5 °C, respectively. Temperature affects the number of tillers and production were grain yield in the dry season was achieved by 94% for 2003 and 35% for 2004 compared to wet season [15,16,17]. The location has a mean humidity of about 84.9%. Based on climate data (Table 1.) the land suitability class at the study site is in the S1 category (very appropriate) for rice [18] that is an area has a great potential in increasing rice production in North Sumatra.

3.2. Crop Performance
Plant performance showed no interaction between varieties and fertilization (Tables 2 and 3). A significant positive response of variety on SPAD readings, tiller number, biomass, and yield component on rice. The relatively high SPAD readings at 44 DAT is 37.2 (Inpari 32). Furthermore, more productive tillers m\(^{-2}\) were obtained with Inpari 30 (24 DAT), Inpari 36 (44 DAT, and Mekongga (harvest) than the rest of the treatments. The tiller number ranged from 314.7 to 529.8 m\(^{-2}\) with a mean 409.5 m\(^{2}\). On the other hand, the highest Biomass at the different variety and stages were obtained of 3.1; 7.9; 16.9 t ha\(^{-1}\) at 44, 60, and 113 HST, respectively.

Based on [19], suitable varieties and applying appropriate fertilizers as well as the optimal irradiation process for plants can produce optimum yield. Other result, varieties and fertilizer application are an important factor to increase lowland rice production [20]. The optimum fertilizer application can increase total dry matter production at maturity [21]. Based on survey data 2019, the average production in Siantar sub-districts is 6.3 t ha\(^{-1}\), this is similar with BPS data 2019 that the average production in Siantar District is 6.2 t ha\(^{-1}\).
Table 1. Number of days, mean solar radiation, cumulative rainfall, mean minimum temperature, and maximum temperature based on growth stages from sowing to harvest.

| Parameter                        | Sowing to transplanting | Transplanting to pi | Pi to flowering | Flowering to harvest | Sowing to harvest |
|----------------------------------|--------------------------|---------------------|-----------------|----------------------|------------------|
| Number of days                   | 8                        | 45                  | 20              | 40                   | 113              |
| Mean solar radiation (MJ m⁻²)    | 30.4                     | 59.1                | 56.2            | 64.4                 | 52.5             |
| Cumulative rainfall (mm)         | 141.0                    | 593.0               | 220.0           | 343.0                | 1297.0           |
| Mean minimum temperature (°C)   | 21.4                     | 21.1                | 21.3            | 20.8                 | 21.2             |
| Mean maximum temperature (°C)   | 31.0                     | 29.6                | 30.6            | 30.8                 | 30.5             |
| Humidity (%)                     | 87.2                     | 84.7                | 83.7            | 83.9                 | 84.9             |

Table 2. Effect of variety on SPAD readings, tiller number, biomass, and yield component of rice in North Sumatera.

| Treatment | Spad 44 Dat | Tiller No. 44 Dat (%) 113 Dat | Biomass (t ha⁻¹) | Spikelet per Panicle (No. M⁻²) | Filled spikelet/ Panicle (%) | Filled grain (%) | 1000 grain ns (g) |
|-----------|-------------|-------------------------------|------------------|-------------------------------|------------------------------|------------------|------------------|
| V1        | 35.3 ab     | 314.7 abc                     | 478.8 ab         | 425.5 ab                      | 2.1 d                        | 7.0 b            | 15.3             |
|           | 102.6 a     | 75.4 ab                       | 73.7             | 24.9              |
| V2        | 33.5 abc    | 301.7 abc                     | 471.7 a          | 442.1 ab                      | 2.2 ab                       | 7.4 bc           | 14.6 d           |
|           | 101.2 a     | 68.6 b                        | 71.5             | 25.0              |
| V3        | 33.0 abc    | 366.3 abc                     | 469.3 ab         | 450.4 ab                      | 3.1 a b                       | 7.9 a bc          | 16.1 ab           |
|           | 105.6 a     | 79.9 a b                      | 89.5             | 25.2              |
| V4        | 37.2 a      | 322.7 abc                     | 458.7 a          | 450.4 ab                      | 3.1 a b                       | 7.9 a bc          | 16.1 ab           |
|           | 105.6 a     | 79.9 a b                      | 89.5             | 25.2              |
| V5        | 36.3 ab     | 316.4 abc                     | 410.1 abc        | 416.0 ab                      | 2.6 bc                       | 7.6 bc           | 16.2             |
|           | 102.6 a     | 70.6 b ab                     | 68.9             | 25.2              |
| V6        | 31.1 bc     | 323.6 abc                     | 529.8 bc         | 397.0 bc                      | 2.6 cd                       | 7.3 ab           | 16.3 a           |
|           | 98.9 a      | 75.8 ab                       | 78.1             | 23.8              |
| V7        | 30.3 ab     | 339.6 abc                     | 504.9 abc        | 304.0 de                      | 3.0 ab                       | 7.6 ab           | 16.9 a           |
|           | 82.8 b      | 73.7 ab                       | 90.3             | 23.7              |
| V8        | 33.9 abc    | 346.7 abc                     | 508.4 ab         | 368.6 e ab                    | 2.8 ab                       | 7.2 ab           | 16.6 a           |
|           | 93.6 ab     | 73.9 ab                       | 70.6             | 23.4              |

Within rows for a given parameter, means followed by the same lower-case letter are not significantly different according to Tukey–Kramer (0.05).

Fertilizer recommendation had a significant effect on SPAD readings, tiller number, and biomass (Table 2), also a combination of recommendation at three stages on SPAD readings and tiller number (Figure 1 and 2). SPAD readings, tiller number, and biomass were significantly higher in P2 compared P1 (STK) and P3 (FFP) at 24 and 44 HST (SPAD readings), 24 HST (tiller number), also 44 and 113 HST (biomass). [22] reported that the use of the color chart for N management without any other change in farmers’ fertilizer and crop management increased mean grain yield by 0.3–0.4 Mg ha⁻¹ across villages and seasons. The relationship between leaf N and SPAD values was significantly improved with an r-value of 0.81 [23]. The other component is tiller number that is an important agronomic trait and is strongly correlated with panicle number which is an important variable for grain production [24]. This is consistent with the findings of [15] that under flooded conditions about 10-30 tillers appear per plant after transplanting. Furthermore, the highest tiller number at P2 in the combination of three growth stages (416.3 m⁻²) was the result of N 129.5 kg ha⁻¹; P₂O₅ = 37.5 kg ha⁻¹; and K₂O = 37.5 (3 times application of N and 2 times for P₂O₅ and K₂O). [26] also noted that that optimum nitrogen concentration resulted in a linear increase in relative tillering rate. According to [15], nitrogen is very
crucial for rice in all stages, at early growth stages used to produce more straw than grain, and at later growth stages, it is used to produce more grain than straw.

3.3. Grain yield and yield-contributing parameters
As presented in Table 2 and 3, the spikelet/panicle (no.m⁻²), filled spikelet/panicle (%), filled grain (%), and 1000 grains were monitored during the Harvest. Results of the combination of variety and fertilizer recommendation were insignificantly increased, inversely, significant increased on variety and fertilizer recommendation, respectively. All components were increased in the Inpari 32 (V4) treatment and LKP fertilization (P2). Inpari 32 has a potential yield of 8.42 t ha⁻¹, has resistance to bacterial strain III leaf foliar disease, resistant to Strain IV leaf foliage, resistant to 033 blast, resistant to Tungro, and susceptible to brown planthopper biotypes 1, 2 and 3 [26]. Applied N which is sufficient at an early and PI stage would reflect a high straw and high number of numbers and panicle size [15]. Earlier researchers reported similar results [27, 28] that rice grain yield is closely related to total plant N at physiological maturity. High fertilizer efficiency can increase leaf area index and result in more dry matter accumulation, more photo-assimilates production and also increased grain yield. It is similar to the results of [29] where nitrogen fertilization increased yield, panicle density, spikelet sterility, dry matter production and N uptake at maturity. [30], RCS recommendation based on N omission plot, K is a combined yield-gain+nutrient-balance approach, and fertilizer P rates using a nutrient-balance approach, which estimated field specific P inputs from crop residue means that RCS can be a tool for both identifying knowledge gaps and using new knowledge and information to rapidly improve countrywide nutrient management.

On the other hand, lodging also affected high N treatment (FFP = 149.6 kg ha⁻¹) where is affected of rice production. Lodging can increase yield gap [31] and every 2% lodging reduced 1% grain yield [32]. Solar radiation also has an important role in this study where a decline as much as 3 MJ m⁻² during PI to flowering compared to transplanting to panicle initiation. Solar radiation had a positive correlation with grain yield [33] and high solar radiation after panicle initiation was associated with a high yield of rice [34].

Table 3. Effect of fertilizer on yield component of rice at harvest.

| Treatment | SPAD  | Tiller No. (No.m⁻²) | Biomass (kg ha⁻¹) | Spikelet/panicle (no.m⁻²) | Filled spikelet/panicle (%) | 1000 grains (g) |
|-----------|-------|--------------------|-------------------|---------------------------|-----------------------------|-----------------|
|           | 24 Dap | 44 Dap             | 24 Dap            | 44 Dap                    | 113 Dap                     | 113 Dap         |
| P1        | 37.8 b  | 33.0 b             | 342 a             | 2.5 b                     | 15.9 b                      | 95.9 b          |
| P2        | 39.5 a  | 35.2 a             | 347 a             | 2.9 a                     | 16.4 a                      | 105.8 a         |
| P3        | 36.9 b  | 32.8 b             | 309 b             | 2.3 c                     | 15.4 c                      | 96.1 b          |

Within rows for a given parameter, means followed by the same lower-case letter are not significantly different according to Tukey–Kramer (0.05). Dap = day after planting
Figure 1. Effect of fertilizer recommendation on SPAD readings at three stages of rice

Figure 2. Effect of fertilizer recommendation on tiller number at three stages of rice

Table 4. Effect of varieties on harvest index (HI) and grain yield at harvest in North Sumatra

| Variety | HI         | Grain Yield (t ha⁻¹) |
|---------|------------|----------------------|
|         | P1        | P2        | P3        | P1        | P2        | P3        |
| V1      | 0.47 ABBc | 0.50 Aab  | 0.45 Ba   | 7.1 Bc    | 7.7 Abc   | 6.8 Ba    |
| V2      | 0.52 Aab  | 0.51 Aab  | 0.43 Ba   | 8.0 Aab   | 8.1 Aab   | 6.5 Bab   |
| V3      | 0.56 Aa   | 0.53 Aa   | 0.41 Ba   | 8.0 Aab   | 7.9 Ab    | 6.0 Bb    |
| V4      | 0.51 Aab  | 0.52 Aab  | 0.44 Ba   | 8.2 Aa    | 8.6 Aa    | 6.7 Bab   |
| V5      | 0.43 ABCc | 0.47 Aabc | 0.41 Ba   | 7.3 Abc   | 7.7 Abc   | 6.3 Bab   |
| V6      | 0.43 Ac   | 0.41 Ac   | 0.41 Aa   | 7.2 Ac    | 7.0 Ac    | 6.3 Bab   |
| V7      | 0.47 ABCc | 0.46 ABBc | 0.42 Ba   | 8.1 Aa    | 8.1 Aab   | 6.6 Bab   |
| V8      | 0.49 Aabc | 0.46 Aabc | 0.39 Ba   | 8.0 Aa    | 8.0 Aab   | 6.5 Bab   |
Within columns, means followed by the same lower-case letter are not significantly different according to Tukey–Kramer (0.05). Within rows for a given parameter, means followed by the same upper-case letter are not significantly different according to Tukey–Kramer (0.05).

The significant correlation of variety and fertilizer found in Harvest Index (HI) and grain yield (Table 5). The HI was higher in treatment P1 (0.56) than P3 (0.39). Harvest index is the product of dry weight of the total filled grain yield by total dry matter weight. Almost all combinations of varieties and fertilizer at FFP showed significantly different except in treatment V6. Based on [35], the average HI of rice in favorable growing condition in DS is 0.45 to 0.50 (high) with the yield potential 10 Mg ha\(^{-1}\). Furthermore, cumulative solar radiation which was also high in DS that possibly influenced HI where solar radiation increased, there was increased production of spikelet and grain [36].

Furthermore, grain yield varies from 6.0 to 8.6 t ha\(^{-1}\) where the application of N three times based on growth stages can be increased yield by 2.6 t ha\(^{-1}\) (Table 5). The survey results [37] the average production in the study location is 6.3 t ha\(^{-1}\), 1.6% higher than the average production in Simalungun District. Based on [16] grain yield is the function of biomass accumulation during ripening and translocation of biomass accumulated before flowering to grains. This proves that the provision of sufficient N fertilizer at the plant growth stage can increase rice production.

4. Conclusions

The field experiment is the S1 land suitability category (very suitable) for rice, recommended to be one of the districts in meeting the needs of rice in North Sumatra. Time and amount of fertilizer application based on the history of farmers’ cultivation are very important in increasing rice production. Inpari 32 is superior in this location compared to other varieties. This is supported by SPAD, biomass, particulate matter per panicle, filled grain, 1000 grains, and production. Inpari 32 with RCS fertilization can increase production of 2.3 t ha\(^{-1}\) compared to the average farmers (survey data) and decrease the yield gap of 2.6 t ha\(^{-1}\) compared to farmers in the same season. Suggestions for conducting research in the wet season to find out the recommendation of fertilizing RCS and Inpari 32 varieties can still increase production and reduce yield gaps in North Sumatra.

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