Evaluating the implementation of fertilizer-based decision support systems to increase yield productivity and efficiency of irrigated rice farming in West Java

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Abstract. Nutrient management and fertilizer application are paramount elements for increasing rice productivity. However, most of farmers are still applying fertilizer in an improper way and hence economic benefit of the yield remain low. The objective of this study was to examine various fertilizer recommendations and hence the best and efficient dose of fertilizer can be obtain to increase growth and yield of rice. This experiment was conducted in farmers irrigated lowland Sukabumi, West Java in dry season 2019. The material used was high yielding IR-64 rice variety subjected to six fertilizer recommendation, namely urea only (A), LKP (B), factory’s recommendation (C), PUTS, (D), KATAM (E) and farmer’s practice (F). This experiment was arranged in randomized block design (RBD) with four replications. The quantitative morphological and physiological traits and financial analysis were observed. The result showed that fertilizer significantly affected morphological, physiological parameters and grain yield of rice. PUTS and KATAM (9,7t/ha) treatments had higher grain yield compared to other treatments. Fertilizer by farmer’s practice tended lower in morphological, physiological and grain yield responses compared to other fertilizer recommendation. Similar pattern showed for yield components such as panicle number, grains number and % empty grain were also affected by fertilizer recommendation. Based on the financial analysis that treatment with LKP fertilizer recommendation had higher profit (75.61%) compared with farmer’s practice. That treatment can reduce fertilizer costs by 61.57%, can increase revenue by 14.04% and give a profit of Rp. 5,580,969,-.

1. Introduction
Rice (Oryza sativa L.) is an important food crop commodity because most Indonesians consume rice as their staple food. The need for rice has increased in line with the increasing population in Indonesia. The average consumption of rice in Indonesia during the week is 1.5 kg per capita. In 2019, the rice harvested area in Indonesia reached 10.67 million ha with a production of 54.60 million tons of unhusked dry rice ready for milling (GKG)[1].

Efforts to increase rice production continue to be carried out in Indonesia to meet national food needs. One of the efforts made is to improve rice cultivation through proper fertilization management.
Fertilization is a key factor in rice cultivation to add nutrients in the soil according to the needs of the plant so that the yield increases [2]. The supply of nutrients in the soil and the response of various plant production to soil nutrients, differences in plant growing environment, soil conditions, and climate are the main problems in rice fertilization management [3-4]. However, there is still a lot of fertilization done by farmers that has not been adjusted to the needs for plants so that it is not efficient and the economic benefits of the yield are still low [5]. In addition, fertilizer recommendations for rice are still general so that site-specific fertilization doses are needed.

Nitrogen (N), phosphorus (P), and potassium (K) are essential macro nutrients and play an important role in physiological processes, growth, and plant production [6] and are the main limiting factors [7]. Nitrogen plays an important role in the growth and yield of rice, especially plant height, number of tillers, number of panicles, weight of 1,000 grains, and weight of grain [8-9]. Phosphorus plays a role as a constituent of DNA and RNA, storing and transferring energy in the form of ADP and ATP [10]. Potassium plays an important role in regulating osmotic pressure and turgor, influencing cell growth and development, and opening and closing stomata [11], but its availability is influenced by soil type, clay content, mineral type, organic matter content, and climatic conditions [12]. Potassium can increase the number of grains per panicle, the percentage of grain content, and the weight of 1000 grains [13].

The addition of nutrients in sufficient quantities is needed to increase rice yields, especially for high-yielding varieties [14]. Lack of nutrients N, P, and K will cause the physiological processes of plants to be disrupted, growth stunted, and production low. Excessive fertilization of N, P, and K will also cause nutrient toxicity, disruption of nutrient uptake, increase in production costs, decrease soil fertility [15], and low nutrient use efficiency [16]. Fertilization should be done with the proper dose hence a nutrient balance is achieved in which the nutrients are applied according to the plant's needs and can preserve the environment. Indonesian Agency for Agricultural Research and Development (IAARD) has developed various fertilization technologies such as Integrated Cropping Calendar (KATAM), Rice Agro-advisory Service (LKP), and Paddy Soil Test Kit (PUTS). This fertilization technology was developed according to the concept of balanced fertilization to increase fertilization efficiency and rice yields. However, the fertilization technology developed still needs to be tested to determine its effectiveness and efficiency. The purpose of this study was to examine various fertilizer recommendations so that the best and efficient dose of fertilizer can be obtained that can increase the growth and yield of rice.

2. Materials and Method
The experiment was conducted in farmer’s irrigated lowland, at Gunungjaya village, Cisaat Sub-District, Sukabumi District, West Java Province during dry season (DS) in 2019. The material used was high yielding paddy IR-64 variety. This experiment was arranged in randomized block design (RBD) consisting of six fertilization recommendations as treatments with for replications, namely only urea (A), LKP (B), factory’s recommendation (C), PUTS (D), KATAM (E), and farmer’s practice (F). The dosage of fertilizer and the application time for each treatments as shown in Table 1 and 2 respectively.

| Treatments          | Phonska | Urea | KCl | TSP |
|---------------------|---------|------|-----|-----|
| Urea only (A)       | 0       | 200  | 0   | 0   |
| LKP (B)             | 150     | 200  | 0   | 0   |
| Factory’s recommendation (C) | 300 | 200  | 0   | 0   |
| PUTS (D)            | 250     | 170  | 40  | 0   |
| KATAM (E)           | 200     | 250  | 0   | 0   |
| Farmer’s practice (F) | 0     | 125  | 125 | 125 |
Table 2. The application time of fertilizer for each treatments.

| Treatments               | Application Time (Day After Transplanting/ DAT) |
|--------------------------|-----------------------------------------------|
|                          | 6-7 DAT | 20 DAT | 35 DAT |
|                          | Phons | Urea | K | Cl | TS | Phons | Urea | K | Cl | TS | Phons | Urea | K | Cl | TS |
| Urea only (A)            |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |
| LKP (B)                  |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |
| Factory’s recommendation (C) |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |
| PUTS (D)                 |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |
| KATAM (E)                |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |
| Farmer’s practice (F)    |        |      |   |    |    |        |      |   |    |    |        |      |   |    |    |

The 21 days old seedlings was transplanted with the rate of 3 seedlings per hill and spacing of 25 cm x 25 cm. All plots were maintained under non-water limiting conditions (flood irrigated) and protected from the pests throughout the experiment. The irrigation water was drained out from the plots 15 days before harvest. The crop cut sample was harvested in the center of each plots with size of 6.25 m² (2.5 m x 2.5 m). From each plot, 5 hill were randomly selected to measure the yield components and the remaining was separately threshed and measured the water content. Grains were sun-dried and cleaned. Finally, grain yield was adjusted and converted to units of hectares at 14% of moisture content.

The variables observed included plant height, number of tillers, panicle length, number of filled grains per panicle, number of unfilled grains per panicle, number of grains per panicle (filled+ unfilled grains), 1000-grains weight, and grain yield and financial analysis. Plant height was measured three times at 35, 70 and 100 days after transplanting (DAT). A SPAD chlorophyll meter (Minolta SPAD-502 meter) (Tokyo, Japan) was used to measure chlorophyll density. During 35 and 70 DAT, SPAD meter readings were recorded between 9.00 and 11.00 h, on three fully expanded leaves of three plants per plot and averaged for each replication. Plant biomass at physiological maturity was done by collection of 0.5 m², made sub-sample and dried until constant weight at 60 °C. For yield component, harvested plants at 0.5 m² area at physiological maturity were observed. The data were subjected to analysis of variance. The comparison of treatment means was performed using the honestly significant difference (Tukey) test at p ≤ 0.05 using Statistical Tool for Agricultural Research (STAR) version 2.0.1.

3. Results and Discussion

3.1. Morphological and physiological parameters

Plant height was affected by fertilizer treatment, in average each treatment showed a significantly different in plant height at 70 and 100 DAT (Table 3). The average plant height in each phase showed a significant increase (Figure 1). The application of fertilizer increased plant height from 35 to 70 DAT by 44% - 77%, meanwhile 35 DAT to 100 DAT by 56% - 94% (Figure 1). However the application of different fertilizer recommendation was not significantly affected on plant height at 35 DAT, with the mean plant height of rice plant ranging from 44.7 cm to 57.6 cm (Table 3 and 4).

This recent study was similar to the one observed by [17] found that the different doses of inorganic fertilizer showed significant variation on rice plant height. In this study, at the last generative phase, the longest plant (90 cm) was observed from KATAM and the lowest (84.12 cm) was found from farmer’s practice (Table 4). However, this traits were similar for another fertilizer treatments. Increase in plant height in response to recommendation of fertilizer might be primarily due to the improved vegetative growth and supplementary contribution of nitrogen [18]. Chemical fertilizer offers nutrients which are readily soluble in soil solution and hence instantaneously available to plants.
Figure 1. Plant height of IR-64 rice variety at 35 – 100 DAP.

Table 3. Calculated value of F observed for morphological and physiological parameter under different fertilizer traits at irrigated lowland, Sukabumi, West Java, DS 2019.

| Parameters                      | Source of variance | Block  | Treatments |
|---------------------------------|--------------------|--------|------------|
| Plant height at 35 DAT          |                    | 59,09ns| 84,39ns    |
| Plant height at 70 DAT          |                    | 0,95ns | 18,97**    |
| Plant height at 100 DAT         |                    | 6,57ns | 21,67**    |
| Number of tillers per hill at 35 DAT |          | 1,16ns | 5,18**    |
| Number of tillers per hill at 70 DAT |            | 8,81ns | 9,83**    |
| Number of tillers per hill at 100 DAT |            | 8,80ns | 6,63**   |
| Chlorophyll Content 35 DAT      |                    | 1,25ns | 3,00**    |
| Chlorophyll Content 70 DAT      |                    | 0,31ns | 1,59ns    |

Remarks:***: Significant differences at p ≤ 0.001, **: Significant differences at p ≤ 0.01, *: Significant differences at p ≤ 0.05, ns: not significant.

Table 4. Mean of several Morphological and Chlorophyll Content at different Fertilizer Treatment (tukey).

| Treatments                     | Plant height at 70 DAT | Plant height at 100 DAT | Number of Tiller 35 DAT | Chlorophyll Content 35 DAT |
|--------------------------------|------------------------|-------------------------|-------------------------|---------------------------|
| Urea only (A)                  | 78,53 c                | 85,85 ab                | 30,83 ab                | 39,56 a                   |
| LKP (B)                        | 80,88 abc              | 88,30 ab                | 31,67 b                 | 39,06 a                   |
| Factory’s recommendation (C)   | 82,57 abc              | 89,17 a                 | 31,83 b                 | 39,15 a                   |
| PUTS (D)                       | 83,62 a                | 89,47 a                 | 31,67 b                 | 39,64 a                   |
| KATAM (E)                      | 82,88 ab               | 90,00 a                 | 32,00 a                 | 39,27 a                   |
| Farmer’s practice (F)          | 78,78 bc               | 84,12 b                 | 25,17 c                 | 37,28 b                   |

Remarks: Mean values within a row followed by the same letters are not significantly different at p ≤ 0.05 according to HSD (Tukey).

In average, the number of tillers per hill ware increased from 35 DAT to 70 DAT (Figure 2). The number of tillers at 35 DAT increased to 70 DAT by 2 – 19%, while at 70 to 100 DAT the number of tillers remain the same. As an important aspect for rice growth improvement, tillering becomes a crucial trait for grain production. Different recommendation of fertilizer showed significant variation on number of tillers per hill (Table 3). This study confirmed earlier reports that fertilizer increased number of tillers per hill thus affecting grain yield [17-[20].
However, the response of tillers number to fertilizer treatment was only significant at 35 DAT (Table 3) with the mean number of tillers of rice ranging from 25 to 32 tillers/hill (Table 4). Maximum number of tillers were produced from KATAM meanwhile minimum number of tillers were observed from farmer’s practice (Table 4). According to [21] tillers number affected by NPK fertilizer, applying improper N fertilizer could be decreased tillering numbers as shown in farmer’s practice treatment which was only produced 25 tillers per hill.

![Figure 2. Number of tillers of IR-64 rice variety at 35 – 100 DAT.](image)

The SPAD chlorophyll meter (SPAD) has been widely used as an indirect measure of leaf chlorophyll content, leaf N status and photosynthetic capacity in rice plants [22-26]. Therefore, by doing so monitoring N status and guiding fertilizer-N timing on irrigated rice becomes easier than before [27, 28]. In the current study the mean SPAD values ranged from 37 to 39, suggesting significant variation in leaf chlorophyll content or photosynthetic capacity due to fertilizer treatment at 35 DAT. However, the mean SPAD values were not significant at 70 DAT (Table 3). The lowest SPAD values were observed from farmer’s practice treatment compared to another treatments. Meanwhile, the mean SPAD meter between the rests of fertilizer recommendation showed similar values (Table 4). The reduction in mean SPAD values in farmer’s practice treatment are in support of earlier work which reported reduction in chlorophyll content due to lack of N fertilizer [22]. [29] Revealed that one of the key factor which could be limiting rice growth in many production systems is nitrogen deficiency causing serious nutritional disorder in rice. During pre-heading and ripening stage of rice, nitrogen contributes to carbohydrate accumulation in clumps and leaf sheaths at those phases [29].

### 3.2 Yield and Yield Components

Different fertilizer recommendation showed significant variation on grain yield of rice (Table 5). The highest grain yield was obtained from KATAM treatment and was not significantly different form PUTS treatment, meanwhile urea only and farmer’s practice had the lowest grain yield and LKP and factory’s recommendation showed no significant variation among the traits (Table 6). However, yield components varied among the traits for panicle number, number of filled and unfilled grains per hill, total number of grains per hill and % empty grains (Table 5).

Different doses of fertilizer had significant effect on panicle number of rice (Table 5). The highest panicle number (31.56) was found from application of KATAM fertilizer recommendation and the lowest (24.19) was observed from farmer’s practice treatment. This might be due to the balanced supply of nutrients from compound fertilizer which enhanced panicle number. KATAM treatment had higher panicle number might be due to it had higher tiller number. This recent finding was in line with
the earlier worked by [30] claimed that tillering is responsible and crucial element for panicle development in rice plants. Moreover, [31] stated that fertilizer application affects rice tillering capacity. The number of filled grain is the substantial yield component of rice plant [32]. The number filled, unfilled grains per hill and total number of grains per hill was significantly influenced by different fertilizer recommendation (Table 5). The highest number of filled grains (2497.75 grains/hill) was found from KATAM fertilizer recommendation (Table 6). Potential grains’ filled was influenced by the status of nutritional of rice plant [33]. This recent study indicated that KATAM fertilizer recommendation had sufficient nutrient during rice plant growth and development. The number of unfilled grains per hill was significantly influenced by different fertilizer recommendation (Table 5). The highest unfilled grains was found from KATAM treatment and the lowest unfilled grains was observed from framer’s practice treatment. Similar pattern was found for % empty grains parameter. Even though farmer’s practice had the lowest unfilled grains and % empty grains per hill, it had due to the lowest total number of grains per hill in which statistically similar with other treatments (Table 6).

Table 5. Calculated value of F observed for yield components at different Fertilizer traits, Sukabumi, West Java, DS 2019.

| Parameters                         | Source of variance |
|------------------------------------|---------------------|
|                                    | Block               | Treatments        |
|                                    | 10.6635<sup>ns</sup> | 71.58<sup>ns</sup> |
| Biomass (g)                        |                     |                   |
| Panicle number                     | 6.9271<sup>ns</sup> | 40.31***          |
| Panicle length (cm)                | 0.9193*             | 0.18<sup>ns</sup> |
| Number of filled grains/ hill      | 51380.15<sup>ns</sup> | 303145.92**      |
| Number of unfilled grains/ hill    | 1036.66<sup>ns</sup> | 61925.03***      |
| Total number of grains/hill        | 95759.21<sup>ns</sup> | 828288.82***     |
| Number of grains/ panicle          | 99.53<sup>ns</sup>  | 54.98<sup>ns</sup> |
| Empty grains (%)                   | 7.90<sup>ns</sup>   | 43.89***          |
| 1000 grain weight (g)              | 0.51<sup>ns</sup>   | 0.94<sup>ns</sup> |
| Grain Yield (t/ha)                 | 4.102<sup>ns</sup>  | 3.325*            |

Remarks: ***: Significant differences at p ≤ 0.001, **: Significant differences at p ≤ 0.01, *: Significant differences at p ≤ 0.05, ns: not significant.

Table 6. Mean of several yield components under Fertilizer Treatment (tukey).

| Treatments                  | Panicle Number | Number of filled grains / hill | Number of unfilled grains / hill | Number of grains / hill | Empty grains (%) | Grain Yield (t/ha) |
|-----------------------------|----------------|-------------------------------|---------------------------------|------------------------|------------------|-------------------|
| Urea only (A)               | 23.38 b        | 1879.25 b                     | 212.81 cd                      | 2092.06 b              | 10.19 b         | 8.30 c            |
| LKP (B)                     | 25.38 b        | 1855.19 b                     | 365.19 b                       | 2220.38 b              | 16.55 a         | 8.99 b            |
| Factory’s recommendation (C)| 26.25 b        | 2135.06 ab                    | 337.94 bc                      | 2473.00 ab             | 13.62 ab        | 9.01 b            |
| PUTS (D)                    | 22.88 b        | 1742.75 b                     | 260.12 bcd                     | 2002.88 b              | 13.08 ab        | 9.69 a            |
| KATAM (E)                   | 31.56 a        | 2497.75 a                     | 525.44 a                       | 3023.19 a              | 17.24 a         | 9.73 a            |
| Farmer’s practice (F)       | 24.19 b        | 1894.12 b                     | 186.06 d                       | 2080.19 b              | 8.95 b          | 7.87 c            |

Remarks: Mean values within a row followed by the same letters are not significantly different at p ≤ 0.05 according to HSD (Tukey).

3.3. Financial Analysis

Production cost was calculated based on the fertilization cost regarding the other cost are constant. The fertilization cost depend on the use of dosage for each treatment. Based on cost analysis for each treatments, the highest fertilizer cost were found in farmers’ practice which is Rp 1,912,500/ha/season and the lowest fertilizer cost were found in urea only treatment which is Rp 360,000/ha/season. If we
compared with farmer’s practice treatment, the fertilization cost for urea only treatment was 81.18% lower than that. The amount and cost of fertilizer for each treatment can be seen in Table 7.

### Table 7. Amount and cost of fertilizer for each treatment, 2019.

| Treatments               | Urea (kg/ha/season) | Phonska (kg/ha/season) | KCl (kg/ha/season) | TSP (kg/ha/season) | Total Fertilizer Price (Rp 000/ha/season) | The delta if compared with Farmer’s Practice (F) |
|--------------------------|----------------------|------------------------|--------------------|-------------------|------------------------------------------|-----------------------------------------------|
| Urea only (A)            | 200                  | 360                    | -                  | -                 | -                                        | 360                                           |
| LKP (B)                  | 200                  | 360                    | 150                | 375               | -                                        | 735                                           |
| Factory’s recommendation (C) | 200                | 360                    | 300                | 750               | -                                        | 1,110                                         |
| PUTS (D)                 | 170                  | 306                    | 250                | 625               | -                                        | 1,211                                         |
| KATAM (E)                | 125                  | 225                    | -                  | -                 | 125                                      | 1,912.5                                       |

Information:
- Price of urea: Rp 1,800/kg; Price of phonska: Rp 2,500/kg; Price of KCl for PUTS: Rp 7,000/kg
- Price of KCl for farmers Rp 3,500/kg; Price of TSP: Rp 10,000/kg

From revenue analysis, the highest grain yield showed in KATAM treatment which is 9.73 ton grain yield/ha and the lowest grain yield were found in farmer’s practice which is 7.9 ton GKG/ha. The grain yield in the KATAM treatment was 1.86 ton grain yield/ha or 23.7% higher than farmer’s practice. If we assumed the grain yield price is Rp 5,070/kg [34], so the revenue difference for KATAM treatment is Rp 9,232,151/ha/season. The grain yield and revenue for each treatments can be seen in Table 8.

### Table 8. Grain yield and revenue for each treatments, 2019.

| Treatments       | Grain Yield (ton/ha) | Price (Rp/kg) | Total Revenue (Rp/Ha/Season) | The delta if compared with Farmer’s Practice (F) |
|------------------|----------------------|---------------|------------------------------|-----------------------------------------------|
| Urea only (A)    | 8.30                 | 5,070         | 42,052.650                  | 2,313.936                                     |
| LKP (B)          | 8.99                 | 5,070         | 45,319.683                  | 5,580.969                                     |
| Factory’s        | 9.01                 | 5,070         | 47,158.032                  | 7,419.318                                     |
| recommendation (C) |                    |               |                              |                                               |
| PUTS (D)         | 9.69                 | 5,070         | 48,479.338                  | 8,740.624                                     |
| KATAM (E)        | 9.73                 | 5,070         | 48,970.865                  | 9,232.151                                     |
| Farmer’s practice (F) | 7.87               | 5,070         | 39,738.714                  |                                               |

Further analysis with calculated the delta from difference in the percentage of costs and farm revenue showed that treatment with urea only is the most profitable treatment in this research. However, it has the lowest yield amongst the traits. Meanwhile, LKP treatment showed higher the delta of difference in the percentage costs and farm revenue, which means that cost production required could provide higher revenue by 75.61% compared to other treatments. This treatment can reduce fertilizer cost by 61.57% and can increase revenue 14.04%. By utilizing LKP, farmers can earn profit of Rp. Rp.5,580,969. The ratio from difference in the percentage of costs and farm revenue from each treatments compared with farmer’s practice can be seen in Table 9.
Table 9. The ratio from difference in the percentage of costs and farm revenue from each treatments compared with farmer’s practice.

| Treatments                  | Cost difference (Rp) | Percentage (%) | Revenue difference (Rp) | Percentage (%) | Delta (E-C) (%) |
|-----------------------------|----------------------|----------------|--------------------------|----------------|-----------------|
| Urea only (A)               | 1,552,000            | 81.18          | 2,313,936                | 5,82           | 87.00           |
| LKP (B)                     | 1,177,500            | 61.57          | 5,580,969                | 14.04          | 75.61           |
| Factory’s recommendation (C)| 802,500              | 41.96          | 7,419,318                | 18.67          | 60.63           |
| PUTS (D)                    | 841,500              | 44.00          | 8,740,624                | 22.00          | 66.00           |
| KATAM (E)                   | 962,500              | 50.33          | 9,232,151                | 23.23          | 73.56           |
| Farmer’s practice (F)       |                      |                |                          |                |                 |

4. Conclusion
Fertilizer recommendation significantly affected morphological, physiological parameters and grain yield of rice plant. PUTS and KATAM resulted higher grain yield (9.7 t/ha) compared to the rest of treatments. There was a large variation for fertilizer response to plant height, tillers number and chlorophyll content. Applying fertilizer increased the number of tillers by 2 – 9% at 70 DAT. The application of fertilizer increased plant height from 35 to 70 DAT by 44% - 77%, meanwhile 35 to 100 DAT by 56% - 94%. Fertilizer by farmer’s practice and urea only tended lower in morphological and physiological responses compared to other fertilizer recommendation. Similar pattern showed for yield components such as panicle number, grains number and % empty grain were also affected by fertilizer recommendation. Based on the financial analysis that treatment with LKP fertilizer recommendation had higher profit (75.61%) if compared with farmer’s practice. That treatment can reduce fertilizer costs by 61.57%, can increase revenue by 14.04% and give a profit of Rp 5,580,969.

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