Effect of cropping rotation patterns on rice productivity in irrigated rice fields

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Abstract. Crop rotation has an important role in increasing soil fertility (chemical, physical and biological), production, and sustainable land use. The aim of this study to determine the variables affecting rice productivity in irrigated rice fields in several crop rotation patterns. The fieldwork was taken place in irrigated rice fields, Imogiri District - Bantul, Yogyakarta, Indonesia. The experimental design used in this study was Oversite design, on four irrigated rice fields that applied four different crop rotation patterns: rice-rice-corn (RRM), rice-rice-soybean (RRS), rice-rice-rice (CCR), and rice-rice-rice grown organically (COR). The rice variety Impari 23 was grown during wet season (February - May 2018) while during dry season (June – September 2018), the rice variety Mentik Wangi was planted. The data were analyzed by ANOVA at 5% level, and continued with HSD level 5% using SAS 9.1.3. portable, while the correlation analysis used SPSS. The results showed that the highest production of MDG was obtained from CCR cropping pattern while the lowest production from RRM cropping pattern. The Impari 23 grown in wet season produced higher MDG (6,092 kg ha⁻¹) than Mentik Wangi which grown in dry season (5,110 kg ha⁻¹). The production of MDG has a positive correlation with plant height, dry weight of grain and weight of 1.000 grains. Since the irrigated rice fields used in this study had a moderate level of fertility, the results showed that differences in crop rotation patterns and rice cultivation techniques in irrigated rice fields that have moderate soil fertility did not affect crop productivity. The productivity have more influenced by the choice of rice varieties planted in each planting period.

1. Introduction

Rice (Oryza sativa L.) is the main food commodity in Indonesia and has an important role in economic development. Rice is a strategic commodity of Indonesia because as a staple food, it is very arduous to replace by other commodities. It is consumed by approximately 90% of the total population of Indonesia for daily staple food [1].

The availability of nutrients plays a role in the productivity of rice, especially the primary macro nutrients, such as nitrogen, phosphorus, and potassium. The availability of these nutrients is determined by two factors, congenital factors and dynamic factors. The congenital factor is the main soil parent material, which is related to the soil order. Dynamic factors are changing factors, including soil tillage, irrigation, fertilization (organic and anorganic fertilizer) and return of plant residues after harvesting. Several factors can contribute to the decline in rice productivity, such as improper fertilization dose, availability of quality seeds, sources of funding, rice business incentives, attacks by pests and diseases, floods or drought, efficiency of water use [2]. The use of superior rice varieties that
have high yield and the improving good farming practices such as soil tillage, fertilization and planting methods have involved in going up rice productivity [3].

Paddy rice cultivation that reflects local-wisdom techniques such as the application of crop rotation, adjustments to climatic characteristics and the distribution of annual rainfall have also increase the rice productivity. Rice-rice-soybean crop rotation was the most ideal cropping rotation pattern in paddy fields. Rice was grown in the second planting period (February/March - July/August) while soybean planting was carried out in the first planting season (September/October — December/January. In this case, soybean could increase the production of rice because soybean farming at the end of the dry season could increase soil fertility, facilitate soil cultivation, reduce weeds and reduce the risk of pest attacks [4].

The application of crop rotation has important roles in several aspects, such as agronomy, economy and the environment. Since crop rotation can increase soil organic matter, improve soil structure, reduce soil degradation, and increase crop yields so that system in the long term can increase the agricultural benefits [5]. The increase of rice productivity contributed more to the success of increasing rice production by 56.1% than the harvested area which only contributed 26.3%. Meanwhile, the interaction between rice productivity with harvested area contributed 17.5% in the 1971 - 2006 period [6]. The aim of the study was to investigate the effect of different crop rotation patterns on the yield and productivity of paddy rice.

2. Materials and Methods

2.1. Research Site, Soil Analysis dan Plant Analysis

The research was conducted in irrigated rice fields using technical irrigation with water sources from the Candan Kiri dam from the Opak River in Imogiri District, Bantul Regency – Yogyakarta, Indonesia. This study was arranged in an oversite design using two factors. The first factor is crop rotation patterns (4 patterns): RRM (rice-rice-corn), RRS (rice-rice-soybean), CCR (rice-rice-rice), and COR (rice-rice-rice, grown organically without the addition of chemical fertilizers, the dose of manure is 10 t ha⁻¹ season⁻¹. Organic fertilizer was applied three times: before transplanting day (when plowing the fields and rice stubble was incorporated in the top soil), 15 and 30 days after transplanting. The second factor is planting season (2 planting periods): wet season (WS) (February - May 2018) and dry season (DS) (June - September 2018). The average annual rainfall in Bantul Regency for 10 years was 1,613 mm / year, with the largest rainfall of 321.5 mm in February. While the smallest rainfall is 0 mm in August. The average wet month was 5.7 months, the average humid month was 0.6 months and the average dry month was 5.8 months. The monthly average temperature was around 26.1 °C. Rice variety Inpari 23 was used in wet season and rice variety Mentik Wangi was grown in dry season. The selection of rice varieties follows the experiences of the farmers at the research location.

Research location that represent the RRM crop rotation pattern was in Ndemen Village and RRS crop rotation pattern was in Miri Village, these locations do not get enough irrigation water for the growth of rice plants during the dry season. Meanwhile, COR and CCR crop rotation patterns were in Kebon Agung Village has always had enough water throughout the year for the growth of rice plants. The management of rice cultivation follows the experiences of the farmers. The distance between rows and plants in the rows of the rice plants was 20 x 20 cm while the experimental plot size used was 5 m x 6 m. Plant and soil samples taken from each experimental plot were 5 plants or 5 points per treatment plot. The observed parameters were plant height, number of tillers, number of panicles, weight of 1,000 grains, grain dry weight, and milled dry grain (MDG) production. Soil samples were taken on pH, organic carbon, cation exchange capacity, N- NH₄ (NH₄ form is a form of N which is more common in anaerobic soils such as rice fields), P₂O₅, Ca and Mg were carried out at harvest in WS and DS.

2.2. Data Analysis

In order to compare the effect of each treatment, the data obtained were analyzed by analysis of variance (ANOVA), and continued with the Honestly Significant Differences (HSD) test of 5%. Data analysis was performed using SAS 9.1.3. Portable. Meanwhile, correlation analysis was performed using SPSS.
3. Results and Discussion

3.1. The physical and chemical soil properties of paddy soil

The main constituent of soil formation in the study area is dominated by alluvial deposits from the Opak - Imogiri river and volcanic deposits from Young Merapi Mount. This alluvial deposit becomes soil material, but due to time factors, the soil genesis has not yet developed, thus forming the soil order Inceptisols [7,8], with an altitude of 74 - 114 m asl. Inceptisol soil in all study areas has the same soil texture, was sandy clay loam (Table 1).

Based on the results of the preliminary analysis of irrigated paddy soil, on each crop rotation pattern again soil chemical properties parameters such as: the value of CEC, organic C content, P₂O₅ and K₂O were analyzed (Table 1). It is visible that irrigated paddy soil in all crop rotation patterns has a moderate level of fertility. The determination of moderate value was based on the high value of the CEC and P₂O₅, but it had low levels of organic C and very low K₂O content [9]. Soil fertility is the ability of the soil to produce the desired plant products in the environment where the soil is located. Plant products include fruit, seeds, leaves, flowers, root sap, biomass, stems and so on.

| Parameter | Unit | RRM cropping pattern | RRS cropping pattern |
|-----------|------|----------------------|----------------------|
| Texture:  |      |                      |                      |
| Sand      | g 100g⁻¹ | 33.47                | 31.15                |
| Silt      | g 100g⁻¹ | 41.58                | sandy clay loam      |
| Clay      | g 100g⁻¹ | 24.95                | 24.43                |
| pH        |      | 6.09                 | 6.19                 |
| organic C| g 100g⁻¹ | 1.10                 | low                  |
| CEC       | c mol¹⁺kg⁻¹ | 53.55                | 64.90                | very high |
| N-NH₄     | mg kg⁻¹ | 34.84                | very high            | very high |
| P₂O₅      | mg kg⁻¹ | 33.06                | 17.91                | very high |
| K₂O       | c mol¹⁺kg⁻¹ | 0.02                | 0.02                 | very low  |
| Ca        | c mol¹⁺kg⁻¹ | 4.62                 | rendah               |
| Mg        | c mol¹⁺kg⁻¹ | 1.94                 | moderate             |
| Texture:  |      |                      |                      |
| Sand      | g 100g⁻¹ | 40.66                | 37.82                |
| Silt      | g 100g⁻¹ | 28.64                | sandy clay loam      |
| Clay      | g 100g⁻¹ | 30.69                | 29.02                |
| pH        |      | 5.82                 | 5.71                 |
| organic C| g 100g⁻¹ | 1.66                 | low                  |
| CEC       | c mol¹⁺kg⁻¹ | 39.12                | 63.93                | very high |
| N-NH₄     | mg kg⁻¹ | 27.58                | very high            | very high |
| P₂O₅      | mg kg⁻¹ | 50.18                | 24.36                | very high |
| K₂O       | c mol¹⁺kg⁻¹ | 0.02                | 0.02                 | very low  |
| Ca        | c mol¹⁺kg⁻¹ | 5.02                 | low                  |
| Mg        | c mol¹⁺kg⁻¹ | 1.85                 | moderate             |

*(Balittanah, 2005)*

Table 1. The physical and chemical properties of the initial soil conditions
The low organic C level becomes the limiting factor in managing the paddy soil. Carbon is a food source for soil microorganisms; thus, the presence of organic C will stimulate microorganisms which will accelerate the decomposition process and reactions that require microorganisms activity such as P dissolving and N fixation. Other research stated that low organic C content is an indicator of the low availability of soil organic materials [10]. Moreover, added that the organic C content must be maintained at no less than 2% to keep soil fertility [11]. Hence, organic materials restoration or addition (such as manure, green manure, compost, etc.) is needed.

3.2. Growth of the rice plant in various crop rotation patterns in irrigated rice fields
Observations show that Inpari 23 planted in wet season and Mentik Wangi planted in dry season has moderate growth parameter (Table 2) with plant height of 90 - 125 cm [12]. The moderate growth parameter tend to be more tolerant to falling down caused by wind or other cultivation factors compare to higher posture plant [13].

The result shows that the planting season has significantly affect plant height, number of tillers, and number of panicles. The plant height is higher in wet season while number of tillers and panicles is higher in dry season. However, the implementation of crop rotation patterns is not significantly affect these growth parameters (Table 2). Plant height is the most important agronomic parameter that can directly affect crop yields in which higher rice plant may produce higher yield. Therefore, plant height achievement to a certain height is the basis consideration for breeding of superior rice varieties [14, 15, 16].

Table 2. The paddy growth parameters for two planting seasons in irrigated rice field in several crop rotation application

| Parameter | Plant Height (cm) | Number of tillers |
|-----------|------------------|------------------|
|           | Rotation         |                  |                  |
|           | WS               | DS               | Average          | WS | DS | Average |
| RRM       | 123.40           | 96.73            | 110.07 a         | 14.10 | 23.20 | 18.65 a |
| RRS       | 120.77           | 114.33           | 117.55 a         | 19.33 | 19.33 | 19.33 a |
| COR       | 126.00           | 110.90           | 118.45 a         | 17.47 | 22.23 | 19.85 a |
| CCR       | 124.33           | 121.57           | 122.95 a         | 18.57 | 20.90 | 19.73 a |
| Average   | 123.62 a         | 110.88 b         | 117.25 (-)       | 17.37 b | 21.42 a | 19.39 (-) |
| CV (%)    |                  |                  | 8.54             |     |     | 19.23    |

| Parameter | Number of Panic |
|-----------|----------------|
|           | Rotation        |                  |
|           | WS              | DS               | Average          |
| RRM       | 13.57           | 22.67            | 18.12 a          |
| RRS       | 17.57           | 19.33            | 18.45 a          |
| COR       | 16.67           | 21.67            | 19.17 a          |
| CCR       | 17.77           | 19.67            | 18.72 a          |
| Average   | 16.39 b         | 20.83 a          | 18.61 (-)        |
| CV (%)    |                  |                  | 17.60            |

Remarks: (-) there is no interaction among the factors tested; (+) there is an interaction among the factors tested. The numbers in the same column followed by the same letter are not significantly different in the HSD level of 5%. WS = wet season; DS = dry season; RRM = rice-rice-maize; RRS = rice-rice-soybean; COR = rice-rice-rice, grown organically; CCR = rice-rice-rice.
The pH in irrigated rice fields that applied the COR rotation pattern in dry season was 7.06 (neutral), while the CCR crop rotation pattern in wet season was 6.09 (slight acidic). Irrigated rice fields in all crop rotation patterns have a neutral soil pH at dry season (Table 4). Likewise, the highest organic C content was found in the COR and CCR crop rotation pattern in dry season which is 2.65 - 2.87 g 100g$^{-1}$ (moderate) (Table 3). Meanwhile, the irrigated rice fields that apply the RRM and RRS crop rotation patterns have low levels of organic C in both seasons.

Figure 1. Rice plant height growth in irrigated rice fields in several application of crop rotation during wet season (top) and dry season II (bottom)

*Inpari* 23 and *Mentik Wangi* are aromatic rice varieties with higher yield potential. Rice plant growth can be visually observed from the appearance of plant height and number of tillers, which can be used to measure the effect of environmental or treatment applied [17]. The elongation of plant cells is regulated by internal and external factors, and the regulation of endogenous hormones in plants leads an important role in this process. For example, the hormones auxin (IAA), gibberellin (GA), brassinolide (BR) and ethylene (ETH) which manage cell elongation and interactions between hormone sources directly or indirectly regulate cell elongation [18].

The plant height of *Inpari* 23 planted in wet season experience the fastest growth after the 20 DAS phase to grain filling and then slowdown or constant growth in grain ripening or harvest phase. Meanwhile, the *Mentik Wangi* planted in dry season experience the fastest growth after 20 DAS until it reach the vegetative phase (tillers multiplication), then slowdown until harvest time (Figure 1). A high posture of rice plants tends to show a longer plant age [19].

3.3. The effect of crop rotation and planting season to irrigated rice soil fertility

The application of crop rotation and planting season were positively related to soil pH and Organic C values.
Table 3. The chemical properties of paddy soil for 2 planting seasons in irrigated rice fields in several crop rotation applications

| Parameter | pH | Organic Carbon (g 100g⁻¹) |
|-----------|----|---------------------------|
|           | Rotation | WS | DS | Average | WS | DS | Average |
| RRM       | 6.65 abc | 6.54 bcd | 6.59 | 1.56 bc | 1.76 bc | 1.66 |
| RRS       | 6.42 cd | 6.99 ab | 6.70 | 1.32 c | 1.76 bc | 1.54 |
| COR       | 6.39 cd | 7.06 a | 6.72 | 2.23 ab | 2.87 a | 2.55 |
| CCR       | 6.09 d | 6.96 ab | 6.52 | 1.23 c | 2.65 a | 1.94 |
| Average   | 6.39 | 6.89 | 6.64 (+) | 1.58 | 2.26 | 1.92 (+) |
| CV (%)    | 1.64 | 13.01 |

Table 4. The level of N-NH₄ and P₂O₅ in irrigated rice field for 2 planting season in several crop rotation application

| Parameter | N-NH₄ (mg kg⁻¹) | P₂O₅ (mg kg⁻¹) |
|-----------|----------------|----------------|
|           | Rotation | WS | DS | Average | WS | DS | Average |
| RRM       | 0.54 | 2.30 | 1.42 b | 20.93 | 14.65 | 17.79 a |
| RRS       | 0.00 | 2.26 | 1.13 b | 17.18 | 11.35 | 14.26 a |
| COR       | 10.07 | 9.05 | 9.56 a | 14.19 | 11.03 | 12.61 a |
| CCR       | 1.35 | 12.73 | 7.04 ab | 7.57 | 7.31 | 7.44 a |
| Average   | 2.99 b | 6.59 a | 6.64 (-) | 14.97 a | 11.08 b | 13.02 (-) |
| CV (%)    | 11.45 | 28.32 |

Remarks: (-) there is no interaction among the factors tested; (+) there is an interaction among the factors tested. The numbers in the same column followed by the same letter are not significantly different in the HSD level of 5%. WS = wet season I; DS = dry season; RRM = rice-rice- maize; RRS = rice-rice-soybean; COR = rice-rice-rice, grown organically; CCR = rice-rice- rice.
The application of crop rotation did not affect the availability of N-NH₄, P₂O₅, Ca and Mg nutrients in irrigated rice fields, while the planting season did. The P₂O₅, Ca and Mg nutrient levels were high, very low, and low respectively. The nutrient level of N-NH₄ increased in dry season to 6.59 mg kg⁻¹ (moderate) (Table 4).

3.4. Relationship between yield and plant growth

The rice farming in wet season produce higher MDG than dry season. Meanwhile, the parameters of dry grain weight per plant and 1000 grain weight were not affected by the planting season and application of crop rotation patterns. The application of CCR crop rotation yield the highest MDG of 7,292 kg ha⁻¹. This yield was much higher than the RRM and RRS crop rotations. Likewise, rice farming in wet season yield higher MDG of 16.12% (equivalent to 6,091.9 kg ha⁻¹) than in dry season (Table 5). Those results were in accordance with the results reported by some studies, that growing rice with the recommended dosage of NPK fertilization (200 kg Urea ha⁻¹, 200 kg SP-36 ha⁻¹, and 100 kg KCl ha⁻¹) planted in technically irrigated rice fields gave the milled dry grain yield of 5.79 t ha⁻¹ [20]. Moreover, it has been reported too that rice cultivation using the Integrated Crop Management approach using a specific fertilizer dosage produced grain 6.62-8.26 t ha⁻¹ [21]. According to [22], the need for rice plant nutrients to produce up to 4 t ha⁻¹ of dry unhusked rice includes 90 kg N, while the loss of N nutrient is 60 kg ha⁻¹. In order to produce an average grain of 6 tons/ha, rice plants need nutrients of 165 kg N ha⁻¹, 19 kg P ha⁻¹, and 112 kg K ha⁻¹ or the equivalent of 350 kg of Urea, 120 kgSP-36, and 225 kg K ha⁻¹ [23].

| Parameter | Grain Dry Weight (g) | Weight of 1,000 grain (g) |
|-----------|----------------------|--------------------------|
| Rotation  | Grain Dry Weight (g) | Weight of 1,000 grain (g) |
| RRM       | 27.37                | 35.96                    | 31.66                    | 22.99 | 22.99 | 22.71 b |
| RRS       | 35.46                | 42.32                    | 38.89                    | 24.33 | 25.24 | 24.78 ab |
| COR       | 52.61                | 50.15                    | 51.37                    | 23.80 | 25.72 | 24.76 ab |
| CCR       | 55.77                | 45.25                    | 50.50                    | 25.88 | 27.59 | 26.74 a |
|平均       | 42.80 a              | 43.42 a                  | 43.11 (-)                | 24.25 a | 25.25 a | 24.75 (-) |
| CV (%)    | 15.20                | 8.58                     |

**Table 5.** Productivity parameters of rice for 2 planting seasons in irrigated rice fields in several crop rotation applications

| Parameter | Milled Dry Grain (kg ha⁻¹) |
|-----------|-----------------------------|
| Rotation  | Milled Dry Grain (kg ha⁻¹) |
| RRM       | 4,421.9                     | 2,427.7                    | 3,424.8 c               |
| RRS       | 4,771.9                     | 5,090.6                    | 4,931.2 bc              |
| COR       | 7,122.3                     | 6,389.2                    | 6,755.7 ab              |
| CCR       | 8,051.5                     | 6,532.4                    | 7,292.0 a               |
|平均       | 6,091.9 a                   | 5,110.0 b                  | 5,600.9 (-)             |
| CV (%)    |                             |                            | 8.58                    |

Remarks: (-) there is no interaction among the factors tested; (+) there is an interaction between the factors being tested. The numbers in the same column followed by the same letter are not significantly different in the HSD level of 5%. PS I = planting season I; PS II = planting season II; RRM = rice-rice-maize; RRS = rice-rice-soybean; COR = rice-rice-rice, grown organically; CCR = rice-rice-rice.

The results of the correlation analysis showed that the components of the milled dry grain yield had a positive and very significant correlation with plant height, dry weight of grain, and weight of 1,000 grains, but negatively correlated with P and Mg nutrients (Table 6). So these results indicated that the higher the rice plant, the higher the productivity, which was reflected in the dry weight of grain, the weight of 1,000 grains and the high yield of milled dry grain. The result of other study showed that the weight of 100 grains was related to plant height and plant age. They reported that the high plant posture
tended to denote a longer plant age, so that the grain filling period was also longer which then made the grain weight heavier. A high plant posture indicated that more photosynthesis was produced so that it affected grain weight because it had long panicles and more pithy grain [24].

**Tabel 6.** Results of correlation analysis of MDG components with several other parameters

| Parameter                    | Plant height | Grain Dry Weight | Weight of 1,000 grain | Hara P₂O₅ | Hara Mg |
|------------------------------|--------------|------------------|-----------------------|-----------|--------|
| GKG                          | 0.526**      | 0.715**          | 0.621**               | -0.441*   | -0.451*|

Information: * = correlation has significant effect at the 0.05 level (two-way), ** = highly significant correlation at the 0.05 level (two-way), (-) = negatively correlated

The superior rice varieties produce higher yield, more pests and diseases resistance, short lifespan, and fluffier taste [25] which is reliable to increase productivity. The difference in rice yield is affected by the ability of plants in translocating assimilates during seed filling and accumulating dry matter before heading [26]. The *Mentik Wangi* planted in dry season yield lower than the *Inpari 23* planted in wet season (Table 5). This is also happen due to the occurrence of falling down before the harvest time of *Mentik Wangi*. Thus, the high level of falling down on the *Mentik Wangi* resulted in low yield [27].

4. Conclusion

The highest rice productivity was obtained in the CCR crop rotation (7,292 kg/ha) and the lowest yield was produced by the RRM pattern (3,425 kg/ha). The rice grown in the wet season gave higher yields (6,092 kg/ha) than the rice grown in the dry season (5,110 kg/ha). Milled dry grain yield had a positive correlation with growth and rice production parameters such as plant height, grain dry weight and 1,000 grain weight. Irrigated rice fields in this study had a moderate level of fertility. Those results implied that the differences in crop rotation patterns and rice cultivation techniques in irrigated rice fields that have moderate soil fertility did not affect crop productivity but had had more influenced by the choice of rice varieties planted in each planting period.

Acknowledgement

This article was written as part of the first author's dissertation. We would like to thank the Indonesia Agency for Agricultural Research and Development (IAARD) for funding this research.

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