Effect of P, Zn and crop residue return on grain yield and P uptake of direct seeded rice

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Abstract. Climate change greatly impacts on agricultural cultivation, including in rainfed rice fields. Improving rice crop performance and productivity in rainfed fields could be done by adaptation in dealing with climate change. This study aims to determine the effect of providing P, Zn and Crop Residue Return (CRR) on direct seeded rice. This study was conducted at the Jakenan Experimental Station, Pati, Central Java, Indonesia from September 2012 to January 2013. A randomized block design was used, and these treatments consisted of various doses of P fertilizer (0P, ½P, P), providing Zn, and incorporation of crop residue. The observed parameters were plant height, maximum tillers per hill, productive tillers per hill, filled grain per panicle, grain yield, weight of dry straw, P-uptake. The results of this study indicated that providing P, Zn, and CRR have positive effects to plants growth and rice yield component. The treatment of ½P+ CRR + Zn took the best effect on plant growth and rice yield component. Applying of CRR and Zn could be a adaptation techniques and sustainable tools in the field that has beneficial impact for plant growth and rice yield component.

1. Introduction

Agriculture is one of the primary sectors of Indonesia with the main crop such as rice, oil palm and others. Like other Asian countries, rice is the important staple food and a principal source of livelihood in Indonesia. Rice is one of the most climate-dependent crops and its growth is influenced by climate factors such as temperature, rainfall, atmospheric CO₂ and solar radiation [1]. Physiological characteristics such as relative water content (RWC%), membrane stability index (MSI), chlorophyll content, photosynthetic rate and TSS content were raised over the increased CO₂ but inversely proportional with increased temperature [2]. Improving CO₂ level from 340 to 680 mg L⁻¹ could also improve the plants yield specifically in C3 plants such as rice [3, 4].

Recently, we have a big challenge even though climate change is not a new issue. It’s been a long time since human activities in industrial revolution have led to increasing gas emissions causing climate change. The average temperature is expected to increase up to 4°C in the 21st century [5] and have significant impacts on water resource, wind velocity, rainfall and snow rate (precipitation), and solar radiation [6].

Climate change also greatly influences on agricultural cultivation, including rainfed rice. Changing hydrological cycle, such as water scarcity, runoff, evapotranspiration, drought, and flood also attacks soil health and fertility to supply nutrient and optimum environment for the plant growth [7, 8].
Increasing soil temperature and CO₂ levels are among the results of climate change [9]. Soil temperature change has an impact on soil moisture, root growth, and nutrients availability for plant growth [10]. Furthermore, dry and rainfed areas have a poor soil health and cause disrupted plant growth [11]. Nutrients deficiency and low organic matter content also cause the lower productivity in these areas [12].

In the coming years, adapting to the climate change has been widely known as a primary response to encounter the climate change [13]. Plant adaptability strategy can be done by crop-management techniques that have the capability to rectify crop development under various environmental pressure [14]. One of the techniques is incorporation of crop residue into the soils. Moreover, rice is very residue-producing crop in Asia. In a long-established practice, harvested rice straws have been used as cattle feed and other uses in Indonesia. Nowadays, most farmers have been heaping the straw around and burning in a large quantity in the field directly in the mechanized harvesting areas. The rice straw burning has an impact on soil and environment [15] which causes large losses up to 80% N, 25% P, 21% K and 4–60% S.

Crop residue return (CRR) has the potential ability to increase fertilizer efficiency due to its high organic and nutrient contents required by plants [16] and contains cellulose, lignin, Nitrogen Free Extract, Si, P, K, Ca, Mg, and S essential nutrients for plants [17]. Crop residue releases P in the form of orthophosphate that can be directly absorbed by plants. Phosphorus (P) from crop residues has the potential to supply a proportion of a crop plant's total P requirement [18]. Application of crop residue (millet straw) and mineral fertilizer (NPK) for five years have increased the P uptake and other nutrients [19]. Crop residue return contributes to support the availability of P where the large quantities in CRR with comparatively a large P added to soil. Providing CRR with low concentration of P does not significantly contribute to availability of soil P both in short and long-term applications [20].

As lack of nutrients content in rainfed lowlands, providing nutrients such phosphorus (P) are also needed to support plant growth but its cycle in rainfed lowlands is unpredictable. In the long dry season, soil is dry and rice straw grazed and it disturbs the rice growth [21]. Phosphorus is one of the essential nutrients and play main role in plant growth especially in yield, by storing and transporting the energies from end process of photosynthesis [22]. Phosphorus transformation is dynamically process [23]. Phosphorus has specific characteristics as slowly diffuse and easily fixed nutrient. Low soil P nutrient is that caused by water stress since the plant availability of P is responsive on water regime [24]. Application of inorganic P fertilizer is expected to overcome the lack of P-availability in soils.

Increasing plant growth can also be done by adding zinc (Zn) into the soil. Zn is a micronutrient needed by plants to help metabolize carbohydrates, fats, proteins, and the synthesis and degradation of nucleic acids. Zinc deficiency can affect plants such as stunting growth, chlorotics, and smaller leaves, increasing crop maturity period, decreasing the number of tillers, spikelet sterility, and inferior quality of harvested products [25]. Long-term applications of crop residue along with Zn impact on biomass yield, physical properties, increasing the soil organic matter content, crop yield, and availability and uptake of micronutrients in soils over mineral fertilizer alone [26]. This study aims were to determine the effect of providing P, Zn, and Crop Residue Return (CRR) on direct-seeded rice.

**2. Materials and methods**

**2.1 Experimental site condition**

This study was conducted at the Jakenan Experimental Station in Pati, Central Java, Indonesia from September 2012 to January 2013 in rainfed condition. The soil classification is silt loam Aeric Endoaquepts, with the topsoil characteristics of pH 5.7, 34% sand, 56% silt, 10% clay, 0.18% organic C, 0.05% total N, C/N ratio of 3.39, 108.3 mg kg⁻¹ total P, 319.1 mg kg⁻¹ total K, 8.69 c mol kg⁻¹ CEC, 0.06% Fe, 0.51% Ca and 0.04% Mg.
2.2. Experimental design, treatment and cultivation details

Ciherrang rice variety was planted by spacing of 20 cm x 20 cm. The treatments consisted of various doses of P fertilizer, providing Zn, and incorporation of crop residue arranged in a randomized block design. Organic fertilizer was given about 3 ton ha\(^{-1}\) and applied during or after tillage. Each plot of the experimental fields was supplied with N and K\(_2\)O of 120 and 90 kg ha\(^{-1}\). Various doses of P\(_2\)O\(_5\) namely no P fertilizer, ½ doses of P, and full dose (60 kg) of P\(_2\)O\(_5\) were given as the treatment. The N fertilizer was given three times, namely 1/3 of N at transplanting time, 2/3 N at tillering stage and the last 1/3 N at panicle initiation stage. The K fertilizer was given twice at the transplanting time and tillering stage. The ZnSO\(_4\) fertilizer of 50 kg ha\(^{-1}\) was applied in each plot. The pests, diseases, and weeds were properly controlled.

2.3. Growth and yield parameters

Growth parameter as plant height, number of maximum and productive tillers per hill, filled grain per panicle, rice yield, weight of dry straw, P-uptake in soil and straw were observed. Panicle and straw were harvested manually at physiological maturity stage. The 14% moisture contents of rice and straw yields were measured from 6 m\(^2\) sampling plots in each block.

2.4. Statistical analysis

The observed data were analyzed using the GenStat 64-bit Release 20.1 (PC/Windows 8-10) to find the variance from the various parameters. The significant treatments were determined by using the Tukey test to know the interaction effect to estimate least significant differences (LSD) at 5% level of significant.

3. Results and discussion

3.1. Effect of Providing P, Zn and CRR on Plant Growth

Table 1 shows that the average maximum plant height of 64.87 cm was observed at maximum tillering treated with ½ P + CRR + Zn, and the lowest one of 56.32 cm at 0P treatment. Even though various treatments give various results in plant height, but it did not significantly differ each other.

| Treatments | Plant height at max. tillering (cm) | Plant height at harvested (cm) | Number of Tiller per hill |
|------------|-------------------------------------|--------------------------------|--------------------------|
| 0P         | 56.32 ± 3.79\(^a\)                 | 96.90 ± 4.39\(^a\)             | 28.44 ± 1.47\(^ab\)      |
| 0P + Zn    | 59.61 ± 1.64\(^a\)                 | 96.96 ± 3.53\(^a\)             | 32.69 ± 0.83\(^bcde\)    |
| 0P + CRR   | 59.50 ± 3.82\(^a\)                 | 99.94 ± 2.77\(^ab\)             | 30.72 ± 1.43\(^abcde\)  |
| 0P + CRR + Zn | 62.15 ± 4.05\(^a\)            | 101.48 ± 2.91\(^ab\)              | 33.57 ± 1.96\(^de\)     |
| 1/2P       | 57.97 ± 4.42\(^a\)                 | 96.55 ± 4.68 \(^a\)             | 28.73 ± 2.55\(^ab\)       |
| 1/2P + Zn  | 59.41 ± 2.94\(^a\)                 | 102.45 ± 2.99\(^ab\)             | 30.30 ± 3.14\(^abcd\)    |
| 1/2P + CRR | 62.38 ± 3.93\(^a\)                 | 102.95 ± 2.99\(^ab\)              | 29.60 ± 2.40\(^abc\)     |
| 1/2P + CRR + Zn | 64.87 ± 2.49\(^a\)          | 104.20 ± 2.68\(^ab\)              | 31.40 ± 2.22\(^abcd\)    |
| P          | 58.93 ± 3.55\(^a\)                 | 96.73 ± 3.13\(^a\)             | 27.20 ± 1.56\(^ab\)      |
| P + Zn     | 58.97 ± 0.75\(^a\)                 | 99.07 ± 1.17\(^ab\)             | 29.30 ± 3.63\(^abc\)     |
| P + CRR    | 62.07 ± 3.73\(^a\)                 | 99.83 ± 5.27\(^ab\)             | 35.07 ± 1.67\(^de\)      |
| P + CRR + Zn | 63.93 ± 2.15\(^a\)              | 101.03 ± 1.53\(^ab\)              | 35.30 ± 3.37\(^a\)     |

Note: The numbers followed by the same letter in the same column showed no significantly different in the Tukey test of 5%. - Data source: primary research

Plant height also observed before harvested. The average maximum plant height of 104.2 cm was observed on the plants treated with ½ P + CRR + Zn, and the lowest one of 96.5 cm in ½ P treatment.
The observation measurement values in \( \frac{1}{2} P + \text{CRR} + \text{Zn} \) treatment were detected significantly difference with those in \( \frac{1}{2} P, P, 0P \), and \( 0P + \text{Zn} \) treatments. Providing CRR and Zn fertilizer along with \( \frac{1}{2} P \) fertilizer affected plant height and efficiency of P fertilizer usage.

The highest number of tillers was observed in the \( P + \text{CRR} + \text{Zn} \) treated plot and the lowest one in the \( P \) fertilizer treatment. The additions of CRR and Zn fertilizer showed a significant difference in the number of tillers, as in \( P \) treatment compared with \( 0P + \text{Zn}, 0P + \text{CRR} + \text{Zn}, P + \text{CRR}, \) and \( P + \text{CRR} + \text{Zn} \) treatments. In addition, \( 0P \) and \( \frac{1}{2} P \) treatments also significantly differed with \( 0P + \text{CRR} + \text{Zn}, P + \text{CRR}, \) and \( P + \text{CRR} + \text{Zn} \) treatments. Providing P, CRR, and Zn fertilizers could significantly increase the number of tillers. The addition of CRR and Zn fertilizer at various doses (0P, \( \frac{1}{2} P, \) and P) fertilizers showed that one dose of P fertilizer had a higher number of tillers than zero and half-doses of P fertilizer but not significantly different.

The problem of direct seeded rice in rainfed lowlands is water resource that impacting the soil properties such as nutrient availability for plant growth. The application of CRR and ZnSO\(_4\) and various doses of P fertilizer on the plant growth and rice yield in this study took various result both in plant growth and rice yield component parameter.

Addition of straw residue on the field produced higher plant growth when compared to that of only P fertilizer treatment. This result indicated that crop residue return gave positive effect on plant growth. The CRR take the effect to C in the soil [27]. CRR contribute soil organic carbon (SOC) formation and SOC increases along with the provision of CRR for several years [28]. SOC contribute to the soil structure, water filtration, supporting living organisms, and give the effect to nutrients availability to the soil so as it is impact to plant growth and yield components [29]. Halvorson et al. [30] reported that returning crop residue to soil in Central Great Plains, USA, followed by increased N rate deliver the increased soil organic level which also support soil quality and productivity. The crop residue of rice cultivation or straw contains macro and micronutrients. Rice crop residue consists of 7% N, 0.23% P and 1.75% K [31] and the rice straw containing 40% N, 30-35% of P, and 80-85% of K easily obtained from rice farmers [32]. Crop residue management positively impacted on soil physical properties such as soil moisture content, temperature, aggregate stabilization, bulk density, soil porosity and hydraulic conductivity.

Table 1 shows that treatment with CRR + Zn treatment also take the highest plant growth. Providing of CRR and Zn to the treatments were expected to produce higher plant growth compared to only providing CRR or fertilization. Decomposed crop residues produced several organic compounds such as humic and fulvic acids, and polysaccharides, complexing with native zinc. Likewise, combination of the organic compounds with the zinc increases the solubility and availability of Zn in wheat [33]. The Zn takes important position in metabolism of plant by stimulating the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome [34]. Application of soil zinc sulphate (ZnSO\(_4\)) also high probably increases several cereals (such as maize and wheat) yields [35, 36].

3.2. Effect of Providing P, Zn and CRR on Rice Yield Component

Effects of providing various doses of fertilizer, ZnSO\(_4\), and CRR on filled grain and rice yield are presented on Table 2. Rice yield expectedly produced the various results due the varying treatment in rainfed condition with direct seeded rice system. Table 2 showed the highest rice yield was observed in the plot of \( \frac{1}{2} P + \text{CRR} + \text{Zn} \) as 7,224 kg ha\(^{-1}\) but it is not significantly difference with the other treatments. Table 2 also presents the other rice yield component parameter, and filled grain per panicle. The result of the various treatments also gave no significant effect on filled grain per panicle. The percentage of filled grain per panicle was around 87 to 90%. Several reasons that might be impacted of adding CRR on the rice yield are varying climatic conditions, various tillage techniques (both type and depth of tillage), irrigation systems, and also soil properties [37].
### Table 2. Effect of the treatment on rice yield component

| Treatments       | Filled grain per panicle (%) | Rice yield (kg ha⁻¹) |
|------------------|------------------------------|----------------------|
| 0P               | 88.76 ± 0.28a                | 6,474 ± 0.72a        |
| 0P + Zn          | 89.79 ± 0.91a                | 6,550 ± 0.47a        |
| 0P + CRR         | 90.17 ± 0.11a                | 6,116 ± 0.57a        |
| 0P + CRR + Zn    | 90.12 ± 2.24a                | 6,111 ± 1.17a        |
| 1/2P             | 88.78 ± 0.66a                | 6,158 ± 0.31a        |
| 1/2P + Zn        | 89.83 ± 3.41a                | 6,417 ± 0.34a        |
| 1/2P + CRR       | 87.35 ± 2.05a                | 7,167 ± 0.86a        |
| 1/2P + CRR + Zn  | 90.33 ± 0.82a                | 7,224 ± 0.13a        |
| P                | 90.67 ± 2.21a                | 6,613 ± 1.01a        |
| P + Zn           | 90.87 ± 2.88a                | 6,886 ± 0.27a        |
| P + CRR          | 89.80 ± 1.62a                | 6,867 ± 0.10a        |
| P + CRR + Zn     | 88.70 ± 0.09a                | 6,884 ± 0.57a        |

Note: The numbers followed by the same letter in the same column showed no significantly different in the Tukey test of 5%. - Data source: primary research

### 3.3. Effect of Providing P, Zn, and CRR on P-Uptake

Increasing P-uptake in this treatment expected that P nutrient was well absorbed by the plant. The effect of providing P, Zn, and CRR on P-uptake are shown on Table 3. The various treatments of this study showed significant effects on P-uptake both in grain and straw. The highest number of P-uptake in grain of 0.2533 mg kg⁻¹ was found on the plot treated by P + Zn and significantly different with other treatments. The treatment was not significantly different on the 0P, 0P+Zn, 0P+CRR, ½ P, and ½ P + Zn treatments. The lowest P-uptake in grain of 0.1878 mgL⁻¹ was shown by the 0P+Zn+CRR treatment.

The P + Zn treatment also the highest number of P-uptake (0.1733 mg kg⁻¹) of straw. The lowest P-uptake of 0.0833 mg kg⁻¹ in straw also occured on 0P+Zn+CRR treatment.

### Table 3. Effect of the treatment on P-uptake

| Treatment          | P uptake in grain (mg kg⁻¹) | P uptake in straw (mg kg⁻¹) |
|--------------------|-----------------------------|----------------------------|
| 0P                 | 0.2044 ± 0.07ab             | 0.0922 ± 0.02ab            |
| 0P + Zn            | 0.2067 ± 0.01ab             | 0.1175 ± 0.01abc           |
| 0P + CRR           | 0.2150 ± 0.01abc            | 0.0967 ± 0.01ab            |
| 0P + CRR + Zn      | 0.1878 ± 0.03a              | 0.0833 ± 0.01a             |
| 1/2P               | 0.2033 ± 0.01ab             | 0.1033 ± 0.00b             |
| 1/2P + Zn          | 0.1967 ± 0.01ab             | 0.0960 ± 0.03ab            |
| 1/2P + CRR         | 0.2150 ± 0.01abc            | 0.1017 ± 0.01ab            |
| 1/2P + CRR + Zn    | 0.2233 ± 0.01abc            | 0.1083 ± 0.01ab            |
| P                  | 0.2200 ± 0.03abc            | 0.1567 ± 0.01cd            |
| P + Zn             | 0.2533 ± 0.01c              | 0.1733 ± 0.02d             |
| P + CRR            | 0.2333 ± 0.01bc             | 0.1333 ± 0.04bcd           |
| P + CRR + Zn       | 0.2167 ± 0.02abc            | 0.1200 ± 0.02bc            |

Note: The numbers followed by the same letter in the same column showed no significantly different in the Tukey test of 5%. - Data source: primary research
Providing P combined with Zn also take significantly higher P-uptake in grain and straw compared with the others. The additions of CRR and Zn fertilizer at various doses of P fertilizer (0P, ½ P, and P) showed that one dose of P fertilizer had a higher number of tillers than zero and half-doses of P fertilizer, but not significantly different.

Phosphorus in the soil is always in low availability but plant needs in high concentrations, so P-uptake becomes a problem to the crop [33]. The characteristic of phosphorus is fixed easily with Al and Fe and very low mobility in the tropical soils, so its P availability relies on the characteristics of soil and landscape level [34]. Maximizing P-uptake depends on the plant root condition and morphology since the root system surface area influences the effectiveness of absorption [35]. The important factors influencing the P-uptake are the high content of P availability in soil. By adding P fertilizer, the P availability and the plant absorption were expected to increase. The P-uptake rates probably increase with the reapplied of P [36]. The P supplying capacity takes the primary controlled by the amount of inorganic and organic P fertilizations, and adsorption capacity of the soil matrix [34].

4. Conclusion
This study showed that providing P, Zn, and CRR have positive effects to plants growth and rice yield component. The treatment of ½P+ CRR + Zn gave the best effect on plant growth and rice yield component. Applying of CRR and Zn could be an option for adaptation techniques to climate change and has beneficial impact for improving plant growth and rice yield component.

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