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The Effect of N, P, K, and Si Fertilizers on pH, P-available, P-uptake and Black Rice Yield (*Oryza sativa* L. indica) on Dryland Inceptisols

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Abstract: Black rice is a type of rice variety found in Indonesia and is well-known as a functional food with a high anthocyanin content which beneficial for those who consume it. Dryland has the potential to support growth of black rice plants, because it has a wide distribution in Indonesia, but has problems with soil fertility such as soil pH and low availability of P nutrients. The problem in dryland requires proper handling, one of which is by using N, P, K, and Si fertilizers. This study aims to determine the effect of N, P, K, and Si fertilizers on pH, P-available, P uptake, and yield of black rice (Oryza sativa L. indica) on dryland Inceptisols. This research was conducted from November 2020 to March 2021 at Soil Fertility and Plant Nutrition Research Area, Faculty of Agriculture, Padjadjaran University, Sumedang district, West Java and the analysis process at the Laboratory of Soil Chemistry and Plant Nutrition, Department of Soil and Land Resources Sciences, Faculty of Agriculture, Padjadjaran University. The experimental design was carried out using a randomized block design consisting of eight treatments with four replications. The doses of N, P, K fertilizers used were ¾ and 1 (Urea 300 kg ha^{-1}, SP-36 50 kg ha^{-1}, and KCl 50 kg ha^{-1}) and the doses of silica fertilizer used were 2, 1½, and 1 (2 mL L^{-1}). The results showed that the combination of fertilizer with a dose of 1 N, P, K followed by 1 silica gave the highest yield of black rice on dryland as much as 77.78 g $plant^{-1}$ or equivalent to 10.58 t ha^{-1}.

Keywords: Black Rice, Dryland, Inceptisols, N, P, K Fertilizer, Silica Fertilizer

1. Introduction

Attempts to increase food production can be done by expanding the planting area and or increasing soil productivity. Currently, the expansion of the planting area is only possible on marginal soils, including dry land Inceptisols [1]. The area of dry land throughout Indonesia reaches 144.47 million ha or 76.20% of Indonesia's land area [2]. Inceptisols are the main agricultural land in Indonesia, especially for dryland agriculture. Inceptisols in Indonesia for agricultural land has an area of about 70.52 million ha or 40% of the land area of Indonesia. The distribution of Inceptisols in Indonesia is quite wide, one of which is in West Java, which is around 2.119 million ha [3].

The problems found in Inceptisols include the rapidly decreasing soil organic matter content, low N nutrients ~~and~~ easily leached N elements, soil pH is acidic to slightly acidic (pH 4.5-5.8), P-available low which can be caused by the solubility of Al, Fe, or Mn in soil is in high so that it forms bonds with phosphate ions, and the content of K ions is relatively low [4]. Productivity on dry land can be optimized with fertilizer and organic matter management technology [5]. Fertilization strongly supports efforts to preserve land productivity and maintain the availability of nutrients in the soil [6]. Nitrogen (N), phosphorus (P), and potassium (K) are the main elements needed for plant growth [7].

Indonesia has many varieties of rice, one of which is black rice (*Oryza sativa* L. indica). Black rice is a type of rice that is currently gaining popularity among the public and is consumed as a functional food that is beneficial for health because it contains many nutrients such as amino acids, K, Mg, Ca, iron, anthocyanin pigments, and flavonoids so that it can increase body resistance [8]. Rice-is one of the silica (Si) accumulator plants, so it requires large amounts of silica to support its growth [9].

The element Si can reduce abiotic stresses, such as temperature, light radiation, wind, water, and drought, as well as increase plant resistance to biotic stresses, such as disease and pest attacks [10]. Fertilization of Si elements can also inceasing the availability of other nutrients such as P. Adequate Si in the soil can suppress Al, Fe, or Mn compounds in the soil so that P can be available to plants [11].

Application of organic Si fertilizer with N, P, K fertilizers in increasing P and Si in Inceptisols Jatinagor against the response of hanjeli (*Coix lacryma* Jobi L.), the results obtained were 1 N, P, K + 1 colloidal nano-silica showed the highest P content of 52.99 mg/100 g and gave the highest yield of hanjeli (*Coix lacryma* Jobi L.) at 18.00 g [12]. The combination treatment of 1 N, P, K fertilizer (urea 300 kg/ha, SP-36 50 kg/ha, and KCl 50 kg/ha) + 1 nano-silica (2 ml L^{-1}) gave the best yield of plant N uptake of 2.03 g/plant and dry milled grain yield of 82.20 g/plant or equivalent to 11.18 t/ha on Inceptisols from Jatinangor [13].

The objective of this research was to investigate the effect of N, P, K, and Si fertilizer applications on pH, P-Available, P uptake and yield of black rice on Dryland Inceptisols.

2. Materials and Methods

2.1. Site Description

A field experiment was conducted in November 2020 to March 2021 at the Jatinangor Soil Fertility and Plant Nutrition Research Area, Universitas Padjadjaran. Initial soil analysis results showed that the characteristics of Inceptisols in the experimental field included pH 5.17, P_2O_5 1.7 ppm, and P_2O_5 HCl 25% 14, 27 mg 100 g^{-1}.

2.2. Experimental Design

The study arranged in a Randomized Block Design consisted of 8 treatments and 4 replicates. The treatments were are followed: A = Control (without N, P, K, and Si Fertilizer); B = 1 N, P, K; C = 1 N, P, K + 1 Silica; D = 1 N, P, K + 1½ Silica; E = 1 N, P, K + 2 Silica; F = ¾ N, P, K + 1 Silica; G = ¾ N, P, K + 1½ Silica; H = ¾ N, P, K + 2 Silica. The size of the planting distance used is 25 × 25 cm with the number of one seed for one planting hole.

The recommended dosage of inorganic fertilizer used in this study was 300 kg ha^{-1} urea, 50 kg ha^{-1} SP-36, and 50 kg ha^{-1} KCl. Urea fertilizer had given 3 times at 14, 42, and 55 days after planting with 1/3 dose in each application. Phosphate (SP-36) and Potassium (KCl) fertilizers had given once at the time of planting. Silica fertilizer had given as many as 4 times application with dipped into the roots of plants before transplanting and at 35, 56, and 70 days after planting by spraying the leaves of plants at a dose of 1 L ha^{-1} (2 ml L^{-1}). Organic fertilizer in the form of compost is used as basic fertilizer with a dose of 10 t ha^{-1} (74 g/plant) given once at the beginning of planting

2.3. Soil and Plant Sampling and Analysis

Soil sampling for pH and available P on soil analysis was carried out during the maximum vegetative phase at 84 days after planting by taking soil around plant roots, then drained, homogenized, and mashed. The fine soil samples are then filtered and further analyzed in the laboratory by the parameters to be tested. Plant sampling for P uptake analysis was carried out in the vegetative phase taken by cutting the whole stover of rice plants which were then cut into small pieces, dried and mashed for further analysis in the laboratory. Determination of soil pH is carried out using a pH-meter electrode, P-available on soil was analyzed using Bray and Olsen method, and P uptake count with multiply dry weight and plant content of P. Plant Content of P plants was analyzed using extracting $HClO_4$ 60% and HNO_3 65%. Black rice was harvested 110 days after planting and counted Dry Harvest Grain Weights and Milled Dry Grain Weights.

2.4. Data Analysis

Observation data were analyzed using the SPSS software version 26 with an F test at a 5% level, and if there were significant differences in average treatment, the test was continued with Duncan's multiple range test (DMRT) at 5% significance level. The parameters observed consisted of pH, P-available, P uptake, and yield of black rice (*Oryza sativa* L. Indica).

3. Result and Discussion

3.1. pH

The results of the analysis of variance showed that the application of N, P, K, and silica fertilizers gave results that had a significant effect on soil pH.

The data in Table 1 shows that the 1 N, P, K + 1 silica treatment gave a greater tendency to increase compared to other treatments, which had an average pH value of 6.32. It can be seen in Duncan's multiple range test at a 5% significance level that the Control treatment was significantly different from other treatments given the addition of N, P, K, and Si fertilizers with the lowest average pH value of 5.55 with acid criteria. The application of N, P, K, and Si fertilizers seemed to affect increasing the pH in each treatment compared to the Control treatment which did not add fertilizer at all.

Si fertilization can increase soil pH due to the hydrolysis of water by given sodium silicate to produce silicic acid with OH^- ions [14]. The addition of Si can also increase soil pH due to changes in soil reactions from Fe^{3+} (Ferry) to Fe^{2+} (Ferro) which in the process occurs H^+ consumption [15]. The effect of P fertilizer on increasing soil pH was due to the release of OH^- due to the adsorption of some of the phosphate anion ($H_2PO_4^-$) by the hydrates of Al and Fe so that the soil pH increased. KCl fertilizer liberates K^+ ions as basic cations. K^+ ions will exchange Al^{3+} ions which are a source of soil acidity so that soil pH will increase [16].

Table 1. *Application N, P, K + Silica on pH.*

Code	Treatments	pH
A	Control	5.55a
B	1 N, P, K	5.89b
C	1 N, P, K + 1 Silica	6.32c
D	1 N, P, K + 1½ Silica	6.18bc
E	1 N, P, K + 2 Silica	6.05bc
F	¾ N, P, K + 1 Silica	5.97b
G	¾ N, P, K + 1½ Silica	5.94b
H	¾ N, P, K + 2 Silica	6.11bc

Note: The numbers followed by the same letters in each column are not significantly different according to Duncan's Multiple Range Test at 5% level

3.2. P-Available

The results of analysis of variance showed that the application of fertilizers N, P, K, and silica gave significantly different effects on the available P-available soil. Table 2 shows the results of Duncan's multiple range test at a 5% significance level for P-available in the soil.

Table 2. *Application N, P, K + Silica on P-Available.*

Code	Treatments	P-Available (mg kg^{-1})
A	Control	4.45a
B	1 N, P, K	7.57ab
C	1 N, P, K + 1 Silica	14.59c
D	1 N, P, K + 1½ Silica	7.99b
E	1 N, P, K + 2 Silica	6.79ab
F	¾ N, P, K + 1 Silica	6.59ab
G	¾ N, P, K + 1½ Silica	6.09ab
H	¾ N, P, K + 2 Silica	8.31b

Note: The numbers followed by the same letters in each column are not significantly different according to Duncan's Multiple Range Test at 5% level

Based on the data in Table 2, it can be seen that each treatment has an effect on P-available in Inceptisols Jatinangor dry land. The treatment value of 1 N, P, K + 1 silica produced P-available which was significantly higher than the other treatments with an average P-available of 14.59 mg kg^{-1}. The available P-value of the soil is included in the high category based on the criteria for assessing the chemical properties of the soil.

P-available soil increased for all treatments in the application of N, P, K, and Si fertilizers because Si was able to liberate P bound by soil components through anion exchange between P and Si [17]. The addition of Si to the soil will go through two processes. The first process, namely increasing the concentration of monosilicate acid in the soil will result in the conversion of insoluble P to P available for plants. This is because SiO_4^{4-} has a greater electronegativity than PO_4^{3-} so that SiO_4^{4-} can replace the bound PO_4^{3-}. The second process is that Si can bind P so that P leaching is reduced by about 40-90% [18].

The addition of P fertilizer can increase the level of available P in the soil through the mechanism of P release from the adsorption complex. The application of P fertilizer can also affect the reduction in retention because the adsorption site is saturated with phosphate, so that the availability of P elements increases. K fertilizers can indirectly increase available P, because KCl fertilizer applied to the soil will liberate K^+ ions as basic cations so that P will be released from the bonds of Al-P, Fe-P, or Mn-P compounds so that it can be available in the soil. soil solution [19].

The control treatment showed the lowest available P-Available with an average of 4.45 mg kg^{-1}. Based on the criteria for assessing the chemical properties of the soil, the P-Available of the soil is in the very low category. The control treatment had a low P-Available because the treatment was not given the addition of N, P, K, and silica fertilizers so that P was bound by Al, Fe, or Mn in the soil. The availability of P in the soil for plants is influenced by soil acidity. Optimum availability of nutrient P for plants was obtained at pH 6.0–7.0. Under acidic pH conditions, some elements such as Fe, Mn, and Al can convert P to become unavailable to plants [20].

3.3. P Uptake

The results of the analysis of variance showed that the application of N, P, K, and silica fertilizers affected the P uptake of black rice plants. The result of Duncan's multiple range test at a 5% significance level on P uptake of black rice are presented in Table 3.

Table 3. *Application N, P, K + Silica on P Uptake.*

Code	Treatments	P Uptake (g/plant)
A	Control	0.27a
B	1 N, P, K	0.41b
C	1 N, P, K + 1 Silica	0.71c
D	1 N, P, K + 1½ Silica	0.47b
E	1 N, P, K + 2 Silica	0.48b
F	¾ N, P, K + 1 Silica	0.43b
G	¾ N, P, K + 1½ Silica	0.42b
H	¾ N, P, K + 2 Silica	0.44b

Note: The numbers followed by the same letters in each column are not significantly different according to Duncan's Multiple Range Test at 5% level

Based on Duncan's multiple range test at a 5% significance level, Table 3 shows that the P uptake of plants in the 1 N, P, K + 1 silica treatment had the highest P uptake value, which was significantly different from the other treatments, which was 0.71 g/plant. The lowest plant P uptake was found in the control treatment with a plant P uptake value of 0.27 g/plant.

The treatment of N, P, K, and Si fertilizers caused differences in the P content in plant tissues. Administration of Si accompanied by P can increase plant absorption and use of P in plant roots, increase P content and accumulation, increase dry matter, and improve chlorophyll content and photosynthesis rate in leaves [21]. Elemental silica can increase P translocation to panicles so that the role of P is more optimal for plants [22].

The high P uptake by plants is influenced by the high content of P-available nutrients in the soil, the high availability of P in the soil is also influenced by the pH and organic matter content, the higher the pH of the soil towards neutral, the heavy metals will be chelated so that P nutrients are available for use. plants [23].

The addition of Si elements can cause plant roots stronger so that nutrient absorption becomes more intensive. The supply of Si can increase P translocation to the panicle so that the role of P is more optimal for plants. Si can also increasing root oxidizing power, namely reducing excess Fe, Al, and Mn which often inhibit root development so that root absorption of nutrients can be better [8, 10, 24].

3.4. The Yield of Black Rice

The results of the analysis of variance showed that the application of N, P, K, and Si fertilizers had an effect on the weight of dry grain harvested and the weight of a milled dry grain of black rice plants.

Table 4. *Application N, P, K + Silica on The Yield of Black Rice.*

Code	Treatments	HDG (g/plant)	MDG (g/plant)
A	Control	13.63a	7.68a
B	1 N, P, K	34.23b	31.95b
C	1 N, P, K + 1 Silica	81.70d	77.78e
D	1 N, P, K + 1½ Silica	57.43c	48.55cd
E	1 N, P, K + 2 Silica	56.33c	46.80c
F	¾ N, P, K + 1 Silica	57.95c	50.70cd
G	¾ N, P, K + 1½ Silica	66.70c	63.30d
H	¾ N, P, K + 2 Silica	59.38c	52.13cd

Note: The numbers followed by the same letters in each column are not significantly different according to Duncan's Multiple Range Test at 5% level

Duncan's multiple range test at a 5% significance level, Table 4, shows that the weight of harvested dry grain and milled dry grain (MDG) in the 1 N, P, K + 1 silica treatment has the heaviest weight and is significantly different from other treatments. The weight of harvested dry grain (HDG) in the treatment of 1 N, P, K + 1 silica had an average weight of 81.70 g/plant and the weight of milled dry grain (MDG) in the treatment of 1 N, P, K + 1 silica had the average weight is 77.78 g $plant^{-1}$ or equivalent to 10.58 t ha^{-1}.

The increase in harvested dry grain weight and milled dry grain weight could be caused by an improvement in the growth of black rice plants during the vegetative and generative phases. Increasing soil pH and availability of P will increase P uptake so that its levels in plant tissues increase. This will increase photosynthesis because P is needed as energy in the process. The increasing in the photosynthesis process will be followed by an increase in the number of grains [25]. The addition of Si that accumulate in rice leaves can make black rice plant leaves stand upright so that it helps catch sunlight in the photosynthesis process and translocate CO_2 to panicles so that the role of P elements is more optimal so that the production of black rice can be optimal [26]. Plants that have a high chlorophyll content are expected to be efficient in the use of solar radiation energy to carry out the photosynthesis process. Plants that can utilize solar energy properly can increase plant biomass and also crop seed yields [27].

Silica is abundant in the epidermal layer of leaves, leaf midribs, and stems. The addition of silica in rice plants can increase the weight of plant grain. A thick layer of silica gel makes the leaves stronger, stronger, and stretch well so that the absorption of sunlight becomes more optimal and the rate of photosynthesis can increase. The rigidity of rice leaves due to the administration of Si can increase photosynthesis by 10% higher than rice plants that are not given Si. Increasing the rate of photosynthesis will increase the uptake of nutrients from the soil so that it can spur plant growth [8, 28].

The control treatment gave the lowest yield of harvested dry grain and milled dry grain compared to other treatments. The average weight of dry grain harvested from the control treatment was 13.63 g/plant and the average weight of milled dry grain from the control treatment was 7.68 g/plant or equivalent to 1.04 tons/ha. Control treatment can produce the lowest weight of harvested dry grain and milled due to the absence of addition of fertilizers that can increase the availability of nutrients in the soil.

4. Conclusion

The study shows the application of N, P, K, and Si fertilizers affect increasing pH, P-available, P uptake, and yield of black rice on dry land. Combination doses of 1 fertilizer N, P, K (Urea 300 kg ha^{-1}, SP-36 50 kg ha^{-1}, and KCl 50 kg ha^{-1}) and 1 dose silica (2 mL L^{-1}) yielded black rice highest on dry land as much as 77.78 g $plant^{-1}$ or equivalent to 10.58 t ha^{-1}.

5. Recommendations

1) It is necessary to conduct further research in the field regarding the effect of application of N, P, K, and Si fertilizers with fertilizers containing higher SiO_2 to obtain better black rice yields and to improve soil fertility by using effective and efficient fertilizers. so that it can be applied by farmers in the field.
2) In further research, it is better to present Si fertilizer by different applications.

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