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CHEMICAL PROPERTIES OF ULTISOLS AND RICE YIELDS APPLIED WITH INORGANIC NANO-SILICA AT DIFFERENT DOSES

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ABSTRACT

The addition of N, P, K, Nano-silica, and Straw Compost proves to be beneficial in providing both macro and micronutrients for paddy rice plants. In lowland rice cultivation, nutrient deficiencies are often encountered, particularly in growing media or soils characterized by high acidity, such as Ultisols. To enhance CEC, pH, P absorption, and yield of lowland rice on Ultisols, this study investigates the fertilization of N, P, K, Nano-silica, and Straw Compost. Conducted at the Padjadjaran University Faculty of Agriculture's Chemistry and Plant Nutrition Experimental Field in Jatinangor, Sumedang, West Java, situated at an elevation of 723 meters above sea level, the field trial comprised ten treatments with three replications each. The treatments included Control (Without N, P, K, Si, and Straw Compost); Straw Compost (5 tons per hectare) + ½ N, P, K, Si; Straw Compost (5 tons per hectare) + 1 N, P, K, Si; Straw Compost (5 tons per hectare) + 1½ N, P, K, Si; Straw Compost (10 tons per hectare) + ½ N, P, K, Si; Straw Compost (10 tons per hectare) + 1 N, P, K, Si; Straw Compost (10 tons per hectare) + 1½ N, P, K, Si; Straw Compost (15 tons per hectare) + ½ N, P, K, Si; Straw Compost (15 tons per hectare) + 1 N, P, K, Si; Straw Compost (15 tons per hectare) + 1½ N, P, K, Si. The results indicate that the combination of fertilizer doses comprising 1 N, P, K, Nano-silica, and 10 tons/ha of Straw Compost yielded the highest rice yield, with a harvested dry grain weight of 11.00 g.plants-1.

Keywords: Ultisols, Phosphorus, lowland rice, organic fertilizer, inorganic fertilizer.

1. INTRODUCTION

In Indonesia, Ultisols represent the predominant soil type, covering a substantial land area of 45,794,000 hectares, which accounts for nearly 25% of the country's total geographical expanse. Kalimantan has the largest distribution with 21,938,000 hectares, followed by Sumatra (9,469,000 hectares), Maluku and Papua (8,859,000 hectares), Sulawesi (4,303,000 hectares), Java (1,172,000 hectares), and Nusa Tenggara (53,000 hectares) (Subagyo et al., 2004). Despite its widespread distribution, Ultisols face challenges related to fertility, soil acidity, inadequate organic matter, deficiencies in macronutrients, and extremely low phosphorus (P) availability (Fitriatin et al., 2014).

Addressing the macro- and micronutrient needs of Ultisols requires the application of well-balanced inorganic and organic fertilizers at appropriate doses and timings. The supplementation of macro- and micronutrients to plants contributes to heightened resistance, increased production levels, and enhanced tolerance against pests and diseases. Makarim (2007) emphasizes the crucial role of silica (Si) addition in supporting the growth of national rice production. This is particularly relevant as more agricultural lands are being used sub-optimally, facing endemic issues related to pests and diseases, and employing high doses of nitrogen (N) in current farming practices. The biological, chemical, and physical properties of soil can all be enhanced by adding organic matter. Fertilization efficiency declines because more fertilizer will be lost by washing, fixation, or evaporation in soils with insufficient organic matter to sustain inorganic fertilizers. Lowland rice cultivation is still experiencing many obstacles, such as frequent and increasing amounts of land being converted into non-agricultural land, low productivity, pest and disease disturbances, frequent droughts, and land degradation due to inappropriate cultivation practices.

The application of rice straw compost is known to contain nitrogen nutrients at 0.83% (Sintia, 2011). In more detail, straw compost contains 0.27% P, 0.47% K, 0.27% Na, 0.05% Ca, and 0.034% Mg (Gunarto et al., 2002). Organic fertilizers including organic matter contribute to soil fertility by delivering macronutrients like N, P, K, Ca, Mg, and S, as well as micronutrients like Zn, Cu, Mo, Co, B, Mn, and Fe, as well as enhancing soil cation exchange capacity (CEC) and generating metal ions (Mn, Fe, and Al). The NPK inorganic compound fertilizer and N, P, K single fertilizer significantly affected plant height, thousand seed weight, and plant yield. Based on the study's findings, it was determined that the government advised applying N, P, and K fertilizers in quantities of 90–120 kg of urea, 30–60 kg of SP36, and 30–50 kg of KCl per hectare (Taslim, 1993). Ultisols have nutrient-poor soil properties, so a higher dose of fertilizer is needed than this dose. The Agricultural Research and Development Agency (2020), recommends a single N, P, K fertilizer for rice plants in paddy fields, Jasinga District, Bogor Regency with 250 kg Urea, 100 kg SP-36, and 100 kg KCl per hectare.

The application of straw compost at a dose of 10 tons per hectare, according to research by Cut Salbiah et al. (2015), shows that applications of straw compost are effective in increasing plant height because they can contribute to the N nutrients needed by paddy rice plants. Fertilizer treatment with the concept of balanced fertilization to achieve balanced and optimal essential nutrient status in the soil to increase yields, maintain soil fertility and environmental health and optimize agricultural yield (Balittanah, 2013). The Republic of Indonesia's Ministry of Agriculture has recommended N, P, and K fertilization in paddy rice in conjunction with the use of both inorganic and organic fertilizers in Permen No.40/Permentan/OT.140/2007. In the hopes of improving the CEC and P-uptake capacity, pH level, and yield of lowland rice plants on Ultisols, this research examined the effects of composting straw along with inorganic N, P, K, and Nano-silica.

2. RESEARCH METHOD

Research Location

This study took place at an elevation of 750 meters above sea level (masl) in the Soil Fertility and Plant Nutrition Experimental Field and the Laboratory of Soil Chemistry and Plant Nutrition, Department of Soil Science and Land Resources, Faculty of Agriculture, Universitas Padjadjaran, Sumedang, West Java. This location served as the setting for conducting both soil and plant chemical analyses. The Ultisols utilized in this study originated from Jasinga, Bogor Regency, where they were transformed into paddy fields. The soil was then planted with Ciherang Variety Rice, using buckets measuring 30 x 30 cm and filled with 1 kg of soil.

Experimental Design and Implementation

In this study, inorganic fertilizers were applied at the recommended rate of 250 kg of N-urea, 100 kg of SP-36, and 100 kg of KCl per hectare. Urea fertilizer was applied three times, with ten dosages each, at 7, 21, and 42 days following planting. Fertilizers containing phosphorus (SP-36) and potassium (KCl) were applied once for seven days after planting. Nano Silica Fertilizer was applied three times: on the 15th and 30th days after planting, 1 L/ha of the fertilizer was sprayed onto the leaves, and once into the roots of the plants before transplanting (3.90 mL $plant^{-1}$). Basic fertilizer was applied at a rate of 10 tons per hectare (78 kg) of organic fertilizer in the form of compost. Soil and plant sampling were conducted 67 days after planting, during the final vegetative period, and dry grain (GKP). Laboratory analysis included determining the pH of bray and olsen, assessing cation exchange capacity using the distillation method, and measuring P-Uptake through wet ashing or wet destruction using concentrated acids HNO3 and HCLO4.

The Ultisol soil used for the initial soil analysis exhibited a pH H2O of 4.3 (very acidic), available P of 4.9 ppm (very low), CEC of 23.54 cmol kg^{-1}, N-total of 0.09% (very low), and Al saturation of 47% (very high). The soil texture was dominated by 36% clay (Balittanah, 2009).

Statistical Analysis

This study was arranged in a Randomized Block Design (RBD) consisting of ten treatments and three replications. The treatments were as follows: Control (no N, P, K, Si, or straw compost); B = Straw Compost (5 tons per hectare) + ½ N, P, K, Si; C = Straw Compost (5 tons per hectare) + 1 N, P, K, Si; D = Straw Compost (5 tons per hectare) + 1½ N, P, K, Si; E = Straw Compost (10 tons per hectare) + ½ N, P, K, Si; F = Straw Compost (10 tons per hectare) + 1 N, P, K, Si; G = Straw Compost (10 tons per hectare) + 1½ N, P, K, Si; H = Straw Compost (15 tons per hectare) + ½ N, P, K, Si; I = Straw Compost (15 tons per hectare) + 1 N, P, K, Si; J = Straw Compost (15 tons per hectare) + 1½ N, P, K, Si. Observational data were examined using a test of variance (ANOVA) at a significant level of 5%. If there was a significant difference, Duncan's distance test was performed at a 5% significance level (Gomez Ead et al., 1984).

3. RESULT

The result of Cation Exchange Capacity

The results of various analyses showed that the application of N, P, K, Nano-silica, and straw compost fertilizers gave significantly different results on the Cation Exchange Capacity of Ultisols soil. Table 1 shows the results of Duncan's Multiple Distance follow-up tests with a real level of 5% on the CEC variable of rice paddy plants on Ultisols soil.

Tabel.1 Effect of Straw Compost and N, P, K, Nano-silica Fertilizer Application of CEC on Ultisols.

Treatment	CEC (cmol.kg^{-1})
Control (without N, P, K, Si, and straw compost	12,05 a
Straw Compost (5 tons per hectare) + ½ N, P, K, Si	21,43 c
Straw Compost (5 tons per hectare) + 1 N, P, K, Si	25,09 cd
Straw Compost (5 tons per hectare) + 1½ N, P, K, Si	27,07 d
Straw Compost (10 tons per hectare) + ½ N, P, K, Si	16,74 b
Straw Compost (10 tons per hectare) + 1 N, P, K, Si	21,42 c
Straw Compost (10 tons per hectare) + 1½ N, P, K, Si	23,53 cd
Straw Compost (15 tons per hectare) + ½ N, P, K, Si	22,06 c
Straw Compost (15 tons per hectare) + 1 N, P, K, Si	22,68 c
Straw Compost (15 tons per hectare) + 1½ N, P, K, Si	21,60 c

Notes: The results of the analysis of variance showed that the tested treatment has a significant effect on the response. This can be seen from the Sig 0.000 <0.05 based on the analysis of variance at the 5% level of significance.

The cation exchange occurring in the soil is influenced by both soil texture and acidity. Table 2 indicates that treatment D (Straw Compost - 5 tons per hectare + 1½ N, P, K, S) has a pH of 5.47 (slightly acidic), while treatment A (Control - without N, P, K, Si, and straw compost) has a pH of 4.8 (acidic). Notably, a pH value close to neutral corresponds to higher cation exchangeability compared to a pH near acidity.

In alignment with Hardjowigeno's (2002) research, soils with low pH exhibit a permanent charge primarily from clay and some charges of organic colloids, capable of holding ions that can be replaced through cation exchange. Consequently, soils with low pH exhibit relatively low CEC values, whereas soils with high clay content have a higher CEC than those with low organic matter levels or sandy soils. The decomposition of organic matter contributes to organic acids, providing a negative charge to soil colloids and enhancing cation trapping.

Table 1 demonstrates that the application of inorganic and organic fertilizers in different doses influences CEC values. Compostrol treatment, lacking N, P, K, Nano-silica, and Straw Compost, exhibits low CEC due to the absence of additional nutrients and nutrient leaching. Organic matter, sourced from colloidal humus, can increase CEC by 20-70%, thereby enhancing the negative charge and overall CEC (Pratama, 2022).

Moreover, research by Siregar et al. (2017) asserts that CEC increases with the addition of decomposed organic matter, producing humic compounds that contribute to interchangeable colloids. This increase in CEC facilitates the absorption and delivery of nutrients, preventing their easy loss to leaching by water. Consequently, treatments resulting in high CEC values may absorb and deliver nutrients more effectively than soils with low CEC.

Soil pH and P-Uptake.

Table 2. Effect of Straw Compost and N, P, K, Nano-silica Fertilizer Application on pH and P-Uptake of Rice Lowland on Ultisols.

Treatment	pH	P-Upatake
Control (without N, P, K, Si, and straw compost	4,80 a	0,35 a
Straw Compost (5 tons per hectare) + ½ N, P, K, Si	5,33 bc	4,05 b
Straw Compost (5 tons per hectare) + 1 N, P, K, Si	5,25 bc	4,03 b
Straw Compost (5 tons per hectare) + 1½ N, P, K, Si	5,47 c	3,89 b
Straw Compost (10 tons per hectare) + ½ N, P, K, Si	5,18 b	2,26 b
Straw Compost (10 tons per hectare) + 1 N, P, K, Si	5,30 bc	7,60 c
Straw Compost (10 tons per hectare) + 1½ N, P, K, Si	5,31 bc	3,83 b
Straw Compost (15 tons per hectare) + ½ N, P, K, Si	5,23 bc	4,18 b
Straw Compost (15 tons per hectare) + 1 N, P, K, Si	5,21 bc	6,61 c
Straw Compost (15 tons per hectare) + 1½ N, P, K, Si	5,35 bc	2,89 b

Notes: The results of the analysis of variance showed that the tested treatment has a significant effect on the response. This can be seen from the Sig 0.000 <0.05 based on the analysis of variance at the 5% level of significance.

The analysis of Ultisols revealed a significant impact of the application of N, P, K, Nano-silica, and straw compost fertilizers on both pH and phosphorus (P) uptake in Ultisols soil. The results are presented in Table 2, which displays the outcomes of Duncan's Multiple Distance follow-up tests at a significance level of 5%. These tests were conducted on the variables of pH and P uptake in rice plants grown in Ultisols soil.

Soil pH

Treatment A as a control (without N, P, K, Si, and straw compost) gave the lowest results because no inorganic or organic fertilization was applied which was 4.80 (very acidic). Based on Table 2 soil pH in treatment B (Straw Compost (5 tons per hectare) + ½ N, P, K, Si), C (Straw Compost (5 tons per hectare) + 1 N, P, K, Si), E (Straw Compost (10 tons per hectare) + ½ N, P, K, Si), F (Straw Compost (10 tons per hectare) + 1 N, P, K, Si), G (Straw Compost (10 tons per hectare) + 1½ N, P, K, Si), H (Straw Compost (15 tons per hectare) + ½ N, P, K, Si), I (Straw Compost (15 tons per hectare) + 1 N, P, K, Si), and J (Straw Compost (15 tons per hectare) + 1½ N, P, K, Si) did not differ markedly from the respective values of 5.33, 5.25, 5.18, 5.30, 5.31, 5.23, 5.21, and 5.35, but still increased from treatment A (Control) which was not given any nutrients.

According to Hardjowigeno (2005), inundation carried out on saving soil resulted in soil pH close to neutral (6.5-7.0), except on clear soils with pH or soils with low $Fe\ 2^+$ content. This shows that the application of N, P, K, Nano-silica, and straw compost fertilizers has no real effect in increasing soil pH, but overall tends to increase from the results of Ultisols soil analysis with a value of 4.3 (very acidic). Organic matter contained in straw compost which is humus can increase OH^-, so that it can increase soil pH. Based on Atmojo's research (2003), states that organic matter will bind hydrogen (OH^-), so that the active groups in the soil turn into positive

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charges (-$COOH^{2+}$ and $\pm OH^{2+}$). Soil acidity that increases due to the application of organic matter depends on the level of maturity, if the application of organic matter is still immature then the process of decomposition of organic matter will be slow and organic matter has not been able to release organic acids (Atmojo, 2003).

P-Uptake

The results of P uptake analysis on Ultisols showed that the application of N, P, K, Nano-silica, and straw compost fertilizers had a significant effect on increasing P-uptake compared to no treatment (control). In treatment B (Straw Compost (5 tons per hectare) + ½ N, P, K, Si), C (Straw Compost (5 tons per hectare) + 1 N, P, K, Si), D (Straw Compost (5 tons per hectare) + 1½ N, P, K, Si), E (Straw Compost (10 tons per hectare) + ½ N, P, K, Si), G(Straw Compost (10 tons per hectare) + 1½ N, P, K, Si), H (Straw Compost (15 tons per hectare) + ½ N, P, K, Si), and J (Straw Compost (15 tons per hectare) + 1½ N, P, K, Si) have no real effect between these treatments, it is suspected that the absorption carried out by rice plants has not been maximized. According to Winarso (2005), stated that P absorption in the vegetative phase of rice plants is not more than 10%, while in the generative phase, P nutrient absorption reaches 90%. P nutrients for rice plants function as the formation of cell nuclei and cell walls, the formation of chlorophyll, and the constituents of ADP (Adenosine diphosphate) and ATP (Adenosine triphosphate), and fertilization such as the formation of flowers, fruits, seeds. F (Straw Compost (10 tons per hectare) + 1 N, P, K, Si) and I (Straw Compost (15 tons per hectare) + 1½ N, P, K, Si treatments significantly affected control and other treatments, and showed the highest values in plant P uptake. This is because inorganic fertilizer in the form of SP-36 is added according to the recommended dose as a source of P so that it will be available P in high quantities and easily soluble and then absorbed by plants. In addition, straw compost as organic matter contributes phosphorus by producing humified materials that act as the formation of P-humates that are more easily absorbed by plants and organic matter also produces organic acids that can release P elements bound by Al and Fe (Sutanto, 2005).

Rice Grained Yield

The results of the analysis showed that the application of N, P, K, Nano-silica, and straw compost fertilizers gave significantly different results to the Dry Grain Harvest of rice crops on Ultisols soil. Figure 1. showed the results of Duncan's Multiple Distance follow-up tests with a real level of 5% on the variable Dry Grain Harvest of rice crops on Ultisols soil. In statistical analysis, treatment A as a control (without N, P, K, Si, and straw compost) has the lowest Dry Grain value with a value of 5.67 $g.plants^{-1}$, this is because there is no fertilization carried out, so there is no additional input to macro and micronutrients. In the treatment C (Compost Straw (5 tons per hectare) + 1 N, P, K, Nano-silica), D (Compost Straw (5 tons per hectare) + 1½ N, P, K, Nano-silica), E (Compost Straw (10 tons per hectare) + ½ N, P, K, Nano-silica), and J (Compost Straw (15 tons per hectare) + 1½ N, P, K, Nano-silica) showed no noticeable difference between the treatments. In (Straw Compost (5 tons per hectare) + ½ N, P, K, Nano-silica), G (Straw Compost (10 tons per hectare) + 1½ N, P, K, Nano-silica), and H (Compost Straw (15 tons per hectare) + ½ N, P, K, Nano-silica) were not significantly different.

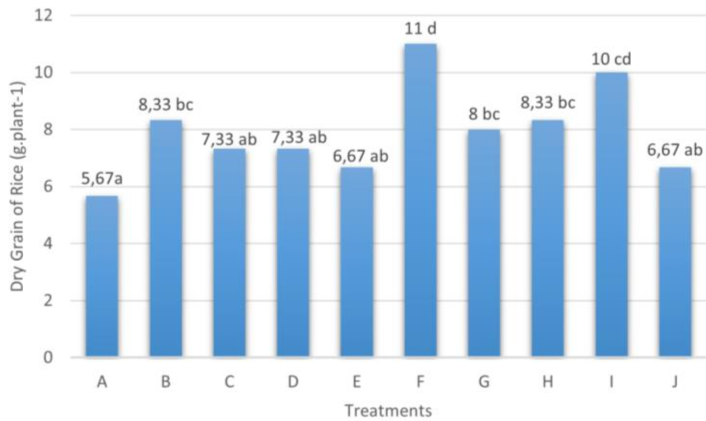

Figure 1. Dry Grain (g.plants^{-1})

Treatment F (Compost Straw (10 tons per hectare) + 1 N, P, K, Nano-silica) has the highest GKP value compared to other treatments, which is an average value of 11.00 g.plants^{-1}. The level of rice yield seen from Dry Grain is caused by inorganic and organic fertilizers applied. One of the nutrients that affect rice grain is phosphorus. When rice plants enter the generative phase, phosphorus plays a role in the process of storing and transferring energy for metabolism by ATP (Adenosine triphosphate), this can arrange phospholipids, nucleoproteins, and phytin in the preparation of rice grain (Syamsiyah, 2009). In addition, the application of nano-sized silica fertilizer can be more easily absorbed by plants because it is relatively small. This fertilizer has an active role in enhancing enzymatic reactions in increasing the number of saplings and their weight thereby expanding the surface of photosynthesis (Al-Juthery et al., 2020). Research conducted by Amalya et al. (2020), shows that the application of nano-silica can increase sunlight absorption so that the photosynthesis process increases and can increase the biomass and grain yield of rice plants. Apply silica fertilizer by spraying directly on plants through leaves called Foliar Application. According to AL-Jutheri et al., (2020), fertilizer with Foliar Application makes absorption more effective than applying fertilizer through the soil so that leaching does not occur.

Provision of sufficient K^+ elements can improve the quality of rice, plants that lack K^+ elements cause easy collapse which can eventually reduce the quantity and quality of yield. K^+ elements can also cause plants to be more resistant to disease attacks, this is because K elements can form phenol compounds that are functional and decrease the content of inorganic N in plant tissues. According to Lakudzala (2013), nutrient K is related to tissues in plants needed for the transportation of water, nutrients, and carbohydrates. Carbohydrates inside the plant that were previously stored inside the stems and leaves are converted into sugars, then transported to the seed tissue and can increase the weight of the plant seeds. If the rice plant lacks element K, the cell will release exudate, and its oxidation ability will decrease. Based on Leibig's Minimum Law, in increasing plant yields, additional fertilizers are needed so that plants get the nutrients needed, and plants have minimum levels so that nutrient needs for photosynthesis are fulfilled. Thus, in the application of this type of dose, there is an optimal amount of input absorbed by rice plants (Mustaqim, 2018)

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The process of photosynthesis has an important role after the stages of flower formation until the formation of grain. Suppose the availability of sufficient K^+ elements in the process of photosynthesis can convert solar energy into chemical energy (ATP). If the plant experiences a nutrient deficiency, then the translocation of carbohydrates from leaves to other organs is inhibited, accumulation of photosynthesis that is not transported decreases the speed of photosynthesis in plants.

4. CONCLUSIONS

The application of N, P, K, Nano-silica, and straw compost, both as inorganic and organic fertilizers, to Ultisols soil is expected to enhance several key factors, including CEC, pH, phosphorus (P) uptake, and rice yield. The dry grain harvest of rice plants reached 11.00 g.plants^{-1} at the specified dose—straw compost (10 tons per hectare) + 1 N, P, K, Nano-silica—reflecting a substantial 94% increase compared to the control, which yielded 5.67 g.plants^{-1}. This indicates a positive impact on crop productivity associated with the applied fertilizers.

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