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The effect of dosage of inorganic fertilizer and straw compost on P-available, pH, P-uptake, and rice yield in ultisol soil

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Abstract
Ultisols is soil that has a high soil acidity with a pH of 4.50, low macronutrients especially P nutrient, and low organic matter content. Application of rice straw compost and N, P, K, Si is believed to be able to increase Ultisol's fertility and increase the yield of rice crops. This research was conducted to determine the effect of rice straw compost application and inorganic fertilizer (N, P, K, Si) on P-available, pH, P-Uptake, and yield of lowland rice in Ultisols and to determine the dosage of rice straw compost and inorganic fertilizer doses (N, P, K, Si) were the best for increasing P-available, pH, P-uptake, and rice yield in Ultisols. The research was carried out from August 2022–January 2023 at the Soil Chemistry and Plant Nutrition Experimental Field, Faculty of Agriculture, Padjadjaran University, Jatinangor, Sumedang Regency with an altitude of ± 752 masl. Soil analysis was carried out at the Laboratory of Soil Chemistry and Plant Nutrition, Faculty of Agriculture, University of Padjadjaran. This research was carried out using a randomized block design (RBD), which consisted of 10 treatments with 3 replications. The results showed the dose of straw compost 10 t ha^{-1} + 1 N, P, K, Si (250 kg ha^{-1} Urea, 100 kg ha^{-1} SP-36, 100 kg ha^{-1} KCl, and 1 nano silica L ha^{-1}) gave the best results in increasing pH (5,3), P-available, P-uptake, and rice yield.

Keywords: nano silica, nitrogen, nutrient, phosphorus, potassium

Introduction

Ultisols are one of the most widespread soil orders in Indonesia, covering an area of 45,794,000 ha or around 25% of the total area of Indonesia, so becomes an opportunity for agricultural progress in Indonesia (Prasetyo & Suriadikarta, 2006) [21]. Some common constraints on Ultisols are high soil acidity pH 4.50, high Al saturation, low CEC, low macronutrients, especially P, K, Ca, and Mg, and low organic matter content (Sujana & Pura, 2015) [30].

Ultisols in Indonesia are generally not utilized optimally, especially at the scale of small farmers because they do not allow them to be managed properly (Agusni & Satriawan, 2012) [1]. Utilization of Ultisols is important in the context of optimizing existing land in Indonesia, especially with an increase in population and increased food needs. Based on data from the Central Statistics Agency (BPS) the population in Indonesia has increased, especially in 2020 with a population of 270,203,900 people and has increased until 2022 to 275,773,800 people. Consumption per capita has also increased, namely 1.379 kg per capita per week and continues to increase to 1.451 kg per capita per week in 2021. According to Syahputra *et al*. (2015) [32], Ultisols have the potential to expand agricultural land in Indonesia if in practice they pay attention to the constraints encountered such as soil chemical properties, soil physics, and proper plant and soil management.

One of the commodities that have the potential to be planted in Ultisols is the Ciherang rice variety, which is a superior rice variety with high adaptability or adaptability to the environment (Runtak *et al*., 2016). Rice is a very important food crop almost half of the world's population depends on rice plants as a source of food, as well as in Indonesia most rice is a primary need because it is the staple food for daily energy sources (Utama, 2015) [32], but over time rice production has decreased. Based on the results of the Area Sampling Framework (KSA) survey by the Central Bureau of Statistics (BPS) the need for national rice per year in 2021 will reach 30.03 million tons with rice production of around 31.36 million tons higher than the national rice demand, but this production figure it can be said that it has decreased by 233.91 thousand tons or 0.43% compared to 2020. One of the causes of this decrease in rice production is the decrease in the area of rice fields itself since 2020 by 20.61 thousand ha (0.19%) compared to 2019 and a decrease in 2021 of 245.47 thousand ha or 2.30% compared to the paddy harvested area in 2020.

Utilization of Ultisols is a solution that can be done to expand the area and progress of agriculture in Indonesia. Soil engineering according to existing constraints can be carried out by fertilizing straw compost and inorganic fertilizers. Straw compost is an organic material that has been proven to increase soil fertility and overcome problems in Ultisols with its ability to increase pH and P-available content (Bimasri *et al*., 2020) [5].

Low P nutrients in Ultisols are closely related to high soil acidity. According to Nurwati & Sudjudi (2002) [17], P-available in the soil is influenced by many factors, but the most influential is soil pH. This is because pH greatly influences the ease with which element P becomes available, especially for plants. In acidic conditions, soils are generally dominated by Al and Fe elements which will bind P in the form of Al-P and Fe-P so that the availability of P nutrients is low (Siswanto, 2019) [28].

Inorganic fertilizers N, P, and K are absolute nutrients needed by rice plants to support the growth and development of rice plants (Dewanto *et al*., 2017) [6], as well as silica (Si) which is a nutrient that is no less important for cereal crops, especially rice plants because rice plants are needed in large quantities (Husnain, 2009) [9], even the composition of rice straw consists of 70.8% silica (Purwaningsih *et al*., 2012) [23]. Silica also has very good benefits, especially for planting rice on Ultisols because it can reduce the toxicity of nutrients such as Al, minimize biotic and abiotic stress, and can reduce the level of pest and disease attacks (Sugiyanta *et al*., 2018) [29].

Based on these descriptions and problems, the combination of straw compost and inorganic fertilizer needs to be studied further by determining the best dosage for rice cultivation in Ultisols, so this study examines whether the treatment of various doses of rice straw compost and inorganic fertilizer doses (N, P, K, Si) has an effect on on the increase in P-available, pH, P-uptake, and lowland rice yields on Ultisols and which dose of straw compost and inorganic fertilizer doses gave the best results for increasing P-available, pH, P-uptake, and lowland rice yields on Ultisols.

The aims of this study were (1) to determine the effect of various doses of rice straw compost and inorganic fertilizers (N, P, K, Si) on P-available, pH, P-uptake, and yield of lowland rice in Ultisols, (2) to obtain doses Rice straw compost and inorganic fertilizer doses (N, P, K, Si) were the best for increasing P-available, pH, P-uptake, and yield of lowland rice in Ultisols.

Material and methods

This research was conducted at the Experimental Field of Soil Chemistry and Plant Nutrition, Faculty of Agriculture, Padjadjaran University, Jatinangor, Sumedang Regency with an altitude of ±752 masl. Soil analysis was carried out at the Laboratory of Soil Chemistry and Plant Nutrition, Department of Soil Science and Land Resources, Faculty of Agriculture, University of Padjadjaran. The experiment was carried out in September 2022–January 2023.

The design used was a randomized block design (RBD), which consisted of ten treatments with three replications. In this study, there were two experimental units, one unit for observation of plants until the maximum vegetative phase and the second unit for observation until the harvest phase.

Table 1: Arrangement of straw compost and N, P, K, Si fertilizer treatment.

Treatment	Information
A	Control (without straw compost and N, P, K, Si)
B	Straw compost 5 t ha^{-1} + ½ N, P, K, Si
C	Straw compost 5 t ha^{-1} + 1 N, P, K, Si
D	Straw compost 5 t ha^{-1} + 1½ N, P, K, Si
E	Straw compost 10 t ha^{-1} + ½ N, P, K, Si
F	Straw compost 10 t ha^{-1} + 1 N, P, K, Si
G	Straw compost 10 t ha^{-1} + 1½ N, P, K, Si
H	Straw compost 15 t ha^{-1} + ½ N, P, K, Si
I	Straw compost 15 t ha^{-1} + 1 N, P, K, Si
J	Straw compost 15 t ha^{-1} + 1½ N, P, K, Si.

The planting medium used was Ultisols from Jasinga, Bogor. Soil characteristics used included: C-organic content 1.21% (low), H2O pH 4.3 (very acidic) N-total 0.09% (very low), P_2O_5 4.9 ppm (very low), and K_2O 0.17 cmol kg^{-1} (low). The seeds used were the seeds of the Ciherang variety which had been tested for germination and were selected by soaking the rice seeds for 6–12 hours to check the integrity of the seeds (Perdana, 2015) [19]. The quality of a seed greatly affects its ability to grow seeds and can be seen from the mass of the seeds through soaking. Seeds that sink when soaked in water are called seeds that are pithy and have great potential to grow (Siregar, 2013) [27].

Fertilization using urea, SP-36, KCl, and nano-silica liquid fertilizer in stages. Urea fertilizer was given in three times, namely ⅓ dose of treatment at 7 days after planting (HST), ⅓ dose of treatment at 21 HST, and ⅓ dose of treatment at 42 HST which was done by sowing. SP-36 and KCl fertilizers were given at 7 HST with doses according to treatment. Silica nano was given three applications, namely the application of fertilizer doses according to the treatment at the start of planting, at the age of 15 and 30 HST (Sugiyanta *et al*., 2018) [29]. How to fertilize using foliar application technique with a concentration of 2 $mL.L^{-1}$.

Soil sampling for analysis was carried out during the maximum vegetative phase of the plant. Soil samples were taken for each treatment by separating the soil from the roots, then drying, homogenizing, pulverizing, filtering, and further testing in the laboratory according to the parameters tested.

Plant sampling was carried out by cutting the plant on the part of the stem that was above the ground at the maximum vegetative phase. Samples that have been taken are dried, chopped, baked, weighed, and mashed for further analysis in the laboratory.

Observational data begins with a normality test to determine whether the distribution of data is normal or not. If the data is not normally distributed, a data transformation is performed, then data that is normally distributed is analyzed for a variance to determine the effect of the treatment on the response as measured at the 5% level of significance. Treatments that had a significant effect were carried out by Duncan's multiple range test to determine differences in the average response values between treatments.

Results and discussion

Soil acidity (pH)

Based on the results of the analysis of variance, it was shown that the addition of straw compost, N, P, K, and Si made a significant difference in the pH of Ultisols. Table 1 shows the results of Duncan's multiple range test with a significance level of 5% in soil pH parameters.

Table 2. Effect of dosage of inorganic fertilizer and straw compost on pH in ultisols.

Treatment	pH
A	4,8 a
B	5,33 bc
C	5,25 bc
D	5,47 c
E	5,18 b
F	5,3 bc
G	5,31 bc
H	5,23 bc
I	5,21 bc
J	5,35 bc

Note: Mean followed by the same lowercase alphabet in the same column is not significantly different based on Duncan's multiple range test at the level of 5%.

The average soil pH value in this study was still in the acidic category, but when compared with the initial soil pH (4.3), the overall pH value after treatment increased including treatment without straw compost and N, P, K, Si. The increase in pH in the treatment without straw compost and N, P, K, and Si occurred due to soil flooding. According to Hartatik *et al*. (2006) [8], flooding can increase soil pH due to the reaction of reducing protons from aluminum and iron present in the soil into complex compounds that produce OH^- so that the pH increases.

There were no best results from the effect of various doses of straw compost and N, P, K, Si given in increasing the pH because overall the treatment given straw compost and N, P, K, Si did not show a significant difference, but if we compare the treatments which were given straw compost and N, P, K, Si had significantly different pH values higher than the treatment without straw compost and N, P, K, Si. This shows that the application of straw compost and N, P, K, and Si can increase soil pH. According to Anwar *et al*. (2006) [2], a high pH value in straw compost can increase soil pH. The content of organic acids in straw compost can also chelate Al ions which inhibit Al hydrolysis which will produce H^+ ions so that the soil pH increases.

Overall, the pH value of the soil does not meet the requirements for optimal rice plant growth at a pH range of 5.5–6.5 (Hermit, 2022). This is due to the high Al ions in Ultisols so that the organic acids in the straw compost cannot chelate Al ions optimally, resulting in hydrolysis of Al^{3+} which produces H^+ so that the soil pH cannot reach optimal for rice plants (Lisdiyanti *et al*., 2018) [14].

P-available

Based on the results of the analysis of variance, it was shown that the application of straw compost, N, P, K, and Si had a significant difference to the P-available of Ultisols. Table 2 shows the results of Duncan's multiple range test with a significance level of 5% on the P-available soil parameter.

The average value of P-available showed an increase in all treatments including the treatment without straw compost and N, P, K, Si when compared to P-available in the initial soil analysis. There was an increase in P-available even in the treatment without straw compost and this N, P, K, Si was associated with an increase in pH due to flooding. The Al element in the soil due to flooding will form $Al(OH)_3$ compounds which liberate P from $AlPO_4$ compounds so that P-available increases (Hartatik *et al*., 2006) [8].

Table 3: Effect of dosage of inorganic fertilizer and straw compost on P-available in ultisols

Treatment	P-Available (ppm)
A	5,87 a
B	7,14 ab
C	7,25 ab
D	7,51 ab
E	7,85 ab
F	9,70 bc
G	10,68 c
H	8,79 abc
I	10,69 c
J	15,02 d

Note: Mean followed by the same lowercase alphabet in the same column is not significantly different based on Duncan's multiple range test at the level of 5%.

Straw compost treatment F (10 t ha^{-1} + 1 N, P, K, Si), G (10 t ha^{-1} straw compost + 1½ N, P, K, Si), I (15 t ha^{-1} straw compost) + 1 N, P, K, Si), and J (15 t ha^{-1} straw compost + 1½ N, P, K, Si) showed significantly different values from treatment A (without straw compost and N, P, K, Si) and has been able to provide P in moderate to high criteria. Meanwhile, treatment B (straw compost 5 t ha-1 + ½ N, P, K, Si), C (straw compost 5 t ha^{-1} + 1 N, P, K, Si), D (straw compost 5 t ha^{-1} + 1½ N, P, K, Si), E (10 t ha^{-1} straw compost + ½ N, P, K, Si), and H (15 t ha^{-1} straw compost + ½ N, P, K, Si) was not significantly different from treatment A (without straw compost and N, P, K, Si) and provided P was still in the low criteria. This shows that the dose of straw compost at a dose of 5 t ha^{-1} is not sufficient to meet the needs in providing P nutrients in Ultisols even though it is combined with a dose of 1½ N, P, K, Si, this is because a dose of 5 tons is not enough to chelate Al. in Ultisols so that P is still bound in the Al-P form and is not available to plants. Meanwhile, the E (10 t ha^{-1} + ½ N, P, K, Si) and H (15 t ha^{-1} + ½ N, P, K, Si) treatments were not significantly different from the control and were still in the low category related to administration of a given dose of ½ N, P, K, Si. This shows that the dose of ½ N, P, K, Si given has not met the need to provide P in Ultisols. The 10t ha^{-1} and 15 t ha^{-1} treatments combined with doses of 1 and 1½ N, P, K, Si showed differences with the control and were able to provide P in the moderate to high category. This shows that treatment with 10 t ha^{-1} and 15 t ha^{-1} was able to chelate Al better than 5 t ha^{-1} provided that the N, P, K, and Si elements were given.

Straw compost J treatment (15 t ha^{-1} + 1½ N, P, K, Si) showed a significant difference in all treatments with an average value of 15.02 ppm. This was because the fertilization in the straw compost treatment with a dose of 15 t ha^{-1} + 1½ N, P, K, Si provided greater P elements in the soil than the other treatments. According to Azomy *et al*. (2014) [4], straw compost contains the nutrient P so the direct application of straw compost can increase P-available in the soil. The results of Wahyudi's research (2012) [33] also explained that the application of straw compost at a dose of 5–46 t ha^{-1} was directly proportional to the increase in P-available for plants. This is due to the direct contribution of P from the straw compost used. The application of N, P, K, Si was quite high in the straw compost treatment 15 t ha^{-1} + 1½ N, P, K, Si also affected the high P-available value. According to Asfiant *et al*. (2016) [3], N, P, and K have a significant effect on increasing P-available levels because the P content in fertilizers can be directly available to plants.

Overall, the assessment criteria for the results of the P-available soil analysis included in this study included the low to high categories. The low availability of P is due to the high Al-dd in Ultisols which reduces the amount of P-available in the soil because it is bound in the form of Al-P (Siswanto, 2019) [28]. Low available phosphorus also occurs due to a decrease in P concentration as a result of being absorbed by plants so that what remains in the soil is residual P, as well as high P availability, apart from being caused by the fertilization process given, it can also be caused by these nutrients not being absorbed optimally by plants. (Yuniarti *et al*., 2020) [34]. These nutrients that have not been absorbed can occur due to an imbalance in P-dissolved and P-absorbed which when P in the soil solution increases compared to P-adsorbed, P will soon be absorbed by the soil colloid into a form that is temporarily unavailable (Nursyamsi *et al*., 2011) [16].

P-uptake

Based on the results of the analysis of variance, it was shown that the application of straw compost, N, P, K, and Si had a significant difference in P-uptake. Table 3 shows the results of Duncan's multiple range test with a significant level of 5% on plant P-uptake parameters.

Table 4: Effect of dosage of inorganic fertilizer and straw compost on P-uptake in ultisols

Treatment	P-Uptake (mg plant^{-1})
A	0,35 a
B	4,05 b
C	4,03 b
D	3,89 b
E	2,26 b
F	7,60 c
G	3,83 b
H	4,18 b
I	6,61 c
J	2,89 b

Note: Mean followed by the same lowercase alphabet in the same column is not significantly different based on Duncan's multiple range test at the level of 5%.

All treatments given straw compost and N, P, K, Si had significant differences with no straw compost and N, P, K, Si. Treatment F (straw compost 10 t ha^{-1} + 1 N, P, K, Si) showed the highest average P absorption with a value of 7.6 mg plant^{-1}, but not significantly different from treatment I (straw compost 15 t ha^{-1} +1 N, P, K, Si) with a value of 6.61 mg plant^{-1}. Based on nutrient efficiency, treatment F (straw compost 10 t ha^{-1} + 1 N, P, K, Si) is the best treatment for increasing P-uptake. According to Kaya (2018) [12], applying straw compost can improve soil structure and promote good root growth, making it easier for the roots to absorb the given P nutrients, besides that the binding of Al ions into a form that is not available to plants by organic acids in straw compost can reduce Al toxicity in Ultisols thereby encouraging the growth and development of plant root hairs, the more the spread of roots, the potential for plants to absorb more P nutrients is enormous (Zulputra & Nelvia, 2018) [35]. Meanwhile, the application of N, P, K, and Si will also be more optimal because straw compost can increase fertilization efficiency and retain nutrients provided in a form available to plants (Hartatik *et al*., 2015) [7]. Inorganic fertilization can also increase P-uptake because inorganic fertilizers in the form of P nutrient compounds will be released more slowly, this is because P nutrients must first be decomposed from these compounds so that the binding of P elements by other elements such as Al is less and nutrient P to be absorbed by more plants (Nuryani *et al*., 2010) [18]

Treatment F (straw compost 10 t ha^{-1} + 1 N, P, K, Si) showed the highest average P absorption with a value of 7.6 mg plant^{-1}, but not significantly different from treatment I (straw compost 15 t ha^{-1} +1 N, P, K, Si) with a value of 6.61 mg plant^{-1}. If based on nutrient efficiency, the F treatment (straw compost 10 t ha^{-1} + 1 N, P, K, Si) is the best treatment to increase P-uptake. High fertilization does not always guarantee high P-uptake, this is due to the possibility of P fixation through precipitation with Al and Fe (Kasifah, 2014) [11], accumulation of P in the soil due to an imbalance of dissolved and adsorbed P (Nursyamsi *et al*., 2011) [16], and decreased plant response to too high P fertilization (Sukmasari *et al*., 2016) [31].

Overall P-uptake in rice plants is still relatively low, this is due to the high Al-dd in Ultisols which disrupts P-uptake by plants. According to Prasetyo *et al*. (2008) [22], plant P-uptake will be disrupted if Al-dd in the soil is high, this is due to the deposition of P by Al in the plant roots so that the mobility of P to the top of the plant is small. Meanwhile, according to Sancayaningsih *et al*. (2012) [26], Al can affect the root system because Al can damage the permeability of the root membrane due to the binding of Al with carboxyl groups and phosphate groups on the cell wall and cell membrane which disrupts mechanisms in the cells so that roots cannot absorb nutrients to the fullest.

Rice yield

Based on the results of the analysis of variance, it was shown that the application of straw compost, N, P, K, and Si made a significant difference in harvested dry grain (HDG). Table 5 shows the results of Duncan's multiple range follow-up test with a 5% significance level on the parameter of harvested dry grain (HDG).

Table 5: Effect of dosage of inorganic fertilizer and straw compost on rice yield in ultisols

Treatment	HDG (g)
A	5,67 a
B	8,33 ab
C	7,33 ab
D	7,33 ab
E	6,67 a
F	11,00 c
G	8,00 ab
H	8,33 ab
I	10,00 bc
J	6,67 a

Note: Mean followed by the same lowercase alphabet in the same column is not significantly different based on Duncan's multiple range test at the level of 5%.

The lowest HDG results were in the treatment without straw compost and N, P, K, Si. This is due to the absence of fertilization during the growth period, so that nutrients, especially N, P, K, and Si are not fulfilled which causes low yields. Meanwhile, the highest yield in increasing HDG was in treatment F (straw compost 10 t ha^{-1} + 1 N, P, K, Si) with an average of 11 g clump^{-1}, but not significantly different from treatment I (straw compost 15 t ha^{-1} + 1 N, P, K, Si). This is because the P absorption received in this treatment was higher than in the other treatments. Harvested dry grain correlates with the P-uptake of rice plants which ultimately affects the yield capacity of HDG, any increase in the amount of P-uptake of plants will lead to an increase in the amount of HDG of plants (Noviani & Slamet, 2018) [15]. This is proven by the correlation test which shows that there is a strong correlation ($r = 0.635$) between P-uptake and dry unhulled rice harvest and has a positive correlation, which means that if P-uptake increases, HDG increases. The relationship between P-uptake and HDG is also in line with the statement of Hwang *et al*. (2012) [10] that phosphate is an essential nutrient for rice plants because it plays an active role in the developmental phase as a constituent of the attributes of rice yield components, such as productive tillers, panicle length, and grain filling.

Overall the HDG results in this study are still very low. The yield of rice in this study was seen from the highest average yield in the straw compost treatment of 10 t ha^{-1} + 1 N, P, K, Si, namely 11 g of $clump^{-1}$. This is due to bacterial leaf blight that attacks during the ripening phase resulting in reduced yields. According to Sinartani (2011) [27], when entering the flowering and maturation phases it can cause an incomplete filling process so that the grain is not filled or even empty which can cause yield losses reaching 50-70 percent.

Conclusions and recommendations
Conclusion
Based on the research results, it can be concluded as follows:
1. Application of various doses of straw compost and N, P, K, Si has the effect of increasing pH, P-available, P-uptake, and rice yields in Ultisols.
2. Treatment of straw compost dosage of 10 t ha^{-1} + 1 N, P, K, Si (250 kg ha^{-1} Urea, 100 kg ha^{-1} SP-36, 100 kg ha-^{1} KCl, and nano-silica 1 L ha^{-1}) Is the best dose in increasing pH, P-available, P-uptake and yield of lowland rice in Ultisols.

Suggestion
It is necessary to carry out further research regarding the effect of various types of organic fertilizers or liming before the soil is used as a planting medium considering the very high Al-dd content and very acidic pH in Ultisols. This aims to increase soil productivity by improving soil chemical properties to maximize rice yields on Ultisols.

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