e-ISSN 3050-9602
p-ISSN 2795-4340

GPH - JOURNAL OF AGRICULTURE & RESEARCH

10.5281/ZENODO.18145277 VOLUME 08 ISSUE 10 OCTOBER - 2025 ARTICLE ID: #02199

THE EFFECT OF SOIL AMENDMENTS AND N, P, K FERTILIZERS ON POTENTIAL K, EXCHANGEABLE K, K-UPTAKE, AND YIELD OF LOWLAND RICE ON INCEPTISOL SOILS

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Abstract:

The decline in soil quality caused by the intensive use of inorganic fertilizers is a major obstacle in lowland rice cultivation on Inceptisol soils. These soils have low natural fertility, particularly limited potassium availability. Low potential and exchangeable potassium reduce potassium uptake by plants and rice productivity. Continuous cultivation without organic matter input accelerates potassium depletion and soil degradation. This study aimed to analyze the effect of a combination of soil amendments with N, P, and K fertilizers on potential potassium, exchangeable kalium, plant potassium uptake, and lowland rice yield on Inceptisol soils. The experiment was conducted from June to November 2025 using a randomized block design with nine treatments and three replications: control; recommended N, P, and K fertilizers; 1 soil amendment; ¼ soil amendment + 1 dose of N, P, and K fertilizers; ½ soil amendment + 1 dose of N, P, and K fertilizers; ¾ soil amendment + 1 dose of N, P, and K fertilizers; 1 soil amendment + ½ dose of N, P, and K fertilizer; 1 soil amendment + ¾ dose of N, P, and K fertilizer; and 1 soil amendment + 1 dose of N, P, and K fertilizer. The soil amendments used consisted of water hyacinth compost, rice straw biochar, and humic acid. The experimental results showed that the H treatment (1 soil amendment + ¾ dose of N, P, and K fertilizer) significantly increased potential potassium, exchangeable potassium, plant potassium uptake, and rice yield components (number of grains per panicle, percentage of filled grains per panicle, 1,000-grain dry weight, and dry milled grain yield) on Inceptisol soil from Jatinangor.

Keywords:

Soil Amendments, Inorganic Fertilizer, Potassium, Lowland Rice, Inceptisol.

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INTRODUCTION

The intensive use of chemical fertilizers in conventional agricultural systems aims to increase crop productivity, but in the long term, it can negatively impact soil quality. Unbalanced fertilization practices are known to cause degradation of the physical, chemical, and biological properties of the soil, as well as a gradual decrease in soil fertility (Sukriming et al., 2019; Nurnawati et al., 2022). This situation demands a sustainable land management strategy to maintain agricultural productivity while preserving the quality of land resources.

One approach that can be implemented is balanced fertilization combined with the use of soil conditioners. Soil amendments play a role in improving soil quality, thereby increasing the availability and absorption of nutrients by plants (Abdillah and Budi, 2021). Soil amendments can be derived from natural or synthetic materials, both organic and mineral, which function to stabilize soil aggregates, increase the soil's water-holding capacity, and increase the cation exchange capacity (CEC), thus improving the soil's ability to retain nutrients (Luta et al., 2020). Organic materials such as compost, biochar, and humic acid are known to be effective in improving the physical, chemical, and biological properties of soil and supporting the activity of soil microorganisms that are beneficial for plant growth (Shinde et al., 2019; Singh et al., 2022).

Compost from organic waste is a potential soil amendment to increase soil fertility. Water hyacinth (*Eichhornia crassipes*) waste, abundantly available and often causing environmental problems, can be used as a compost raw material. Ismayanti et al. (2020) reported that water hyacinth contains relatively high levels of macronutrients and organic matter, thus potentially increasing the soil's ability to retain water and provide nutrients. Several experiments have also shown that the application of water hyacinth compost can support plant growth and increase rice yields in lowland rice (Yusnaweti, 2018; Remona et al., 2020).

Rice straw biochar has high porosity, high organic carbon content, and good cation exchange capacity, thus increasing water retention and soil nutrient availability (Prasetiyo et al., 2020; Setiawan et al., 2021; Shah et al., 2021). The application of biochar has been reported to increase soil pH, phosphorus availability, cation exchange capacity, and soil potassium potential (Surianti et al., 2021).

Humic acid is a fraction of organic matter that plays a crucial role in increasing fertilizer efficiency and nutrient availability. Humic acid can form complexes with nutrients, temporarily retaining them in the soil and gradually releasing them as needed by plants (Ismillayli et al., 2019). Furthermore, humic acid has also been reported to increase nutrient availability in sandy soils and reduce phosphorus fixation by aluminum and iron, making phosphorus more available to plants (Hardjowigeno, 2010; Rahayu et al., 2021).

The use of soil amendments is crucial for soils with low fertility, one of which is Inceptisols. Inceptisols are the most widely distributed soil order in Indonesia and have significant potential for agricultural development (Center for Soil and Agroclimate Research, 2000; Fitriatin et al., 2022). However, Inceptisols generally have moderate to low fertility levels, thus requiring proper management through the application of balanced soil amendments and inorganic fertilization (Parapat et al., 2023).

Potassium (K) is an essential macronutrient for rice plants because it plays a role in enzyme activation, starch formation, stomatal regulation, and increasing plant resistance to biotic and abiotic stresses (Pratiwa, 2014; Rahmah et al., 2023). In the soil, potassium is available in the form of exchangeable potassium (K-dd) and potential potassium as a reserve, so its availability is greatly influenced by the balance of these two forms (Suwarno & Leiwakabessy, 2003; Nursyamsi, 2012).

Rice (*Oryza sativa* L.) is a major food commodity that plays a strategic role in national food security. One effort to increase rice productivity is through the use of superior varieties such as Inpari 32 HDB, which has high yield potential and resistance to major rice diseases (Arianti et al., 2020; Nurwahyuni & Arianti, 2022). However, achieving the potential yield of superior varieties is highly dependent on soil quality and nutrient availability, making soil management through soil amendments and N, P, and K fertilization key factors in sustainable lowland rice cultivation systems.

The objective of this study was to analyze the effect of a combination of soil amendments and N, P, and K fertilizers on potential K, exchangeable K, plant K uptake, and lowland rice yield in inceptisol soils.

MATERIALS AND METHODS

This experiment was conducted from June to November 2025 at the Soil Chemistry and Plant Nutrition Laboratory Research Site, Faculty of Agriculture, Padjadjaran University, in Jatinangor District, Sumedang Regency. Soil and plant analyses were conducted at the Soil Chemistry and Plant Nutrition Laboratory, Department of Soil Science and Land Resources, Faculty of Agriculture, Padjadjaran University. The materials used included Inceptisol paddy soil, Inpari 32 HDB rice seeds, water hyacinth compost, rice straw biochar, humic acid, and inorganic fertilizers containing N, P, and K. Initial analyses were conducted on the Inceptisol soil and the soil amendment combinations used in the experiment.

The experiment used a Completely Randomized Block Design (CRBD) with nine treatments and three replications, resulting in 27 experimental units. The treatment combinations are as follows:

A = Control
B = Recommended N, P, K
C = 1 soil amendment
D = ¼ soil amendment + 1 dose of N, P, K
E = ½ soil amendment + 1 dose of N, P, K
F = ¾ soil amendment + 1 dose of N, P, K
G = 1 soil amendment + ½ dose of N, P, K
H = 1 soil amendment + ¾ dose of N, P, K
I = 1 soil amendment + 1 dose of N, P, K

Observations included initial Inceptisol soil analysis, soil amendment content, potential K content, exchangeable K, plant K uptake, and rice yield components, including the number of grains per panicle, the percentage of filled grains per panicle, 1.000-grain weight, and dry milled grain yield (GKG).

The data obtained were analyzed using analysis of variance at a significance level of 5%, and if it showed a significant effect, it was continued with Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

1. Initial Soil Analysis

The soil used in this experiment is an Inceptisol from Jatinangor, which is slightly acidic (pH 5.7 H_2O) with a relatively low initial fertility level. This condition is indicated by a low organic carbon content (1.45%), moderate total nitrogen content (0.22%), and a low C/N ratio (7). Potassium nutrient status is also low, with a potential potassium content of 19.44 mg/100 g soil and exchangeable potassium (EC-K) of 0.11 cmol kg^{-1}, while the cation exchange capacity is moderate (19.53 cmol kg^{-1}) with a base saturation of 50.68%. The total P_2O_5 content is very high, but the available P_2O_5 content is low, so phosphorus availability to plants is still limited. These characteristics align with the report by Sudirja et al. (2019) states that Inceptisol Jatinangor generally has low to moderate fertility with a slightly acidic soil reaction, so it is necessary to apply a combination of soil conditioners and appropriate N, P, and K fertilization to increase nutrient availability and support plant productivity.

2. Soil Amendements Combination

The organic soil amendement applied in this experiment was a combination of three main ingredients: water hyacinth compost, rice straw biochar, and humic acid. Based on analysis, the soil amendment combination in the experiment contained 21.56% organic carbon, a 1.12% C/N ratio, a C/N ratio of 19.25, a pH of 9.4, and a heavy metal content of 19,785.60 ppm. These characteristics indicate that the soil amendment used in this experiment met the minimum technical requirements stipulated in the Decree of the Minister of Agriculture of the Republic of Indonesia Number 261/Kpts/SR.310/M/4/2019.

The water hyacinth compost used comes from fresh water hyacinth and contains 25.12% organic C; 1.13% total N, C/N ratio of 23.17; 0.62% P_2O_5 and 0.78% K_2O, which shows its potential as a source of organic matter and nutrients. The humic acid used has a humic acid content of 91.44% with a pH of 4.6 and heavy metal content below the maximum limit, and plays a role in improving the physical, chemical, and biological properties of the soil and increasing nutrient availability. Rice straw biochar, as another soil amendment component, has a content of 15.99% organic C; 1.04% total N; C/N ratio; 2.16% total K, and a pH of 11.16, which is alkaline and has the potential to increase the pH and cation exchange capacity of the soil, thereby supporting increased nutrient availability for plants.

3. Potential K and Exchangeable K Levels in Soil

The results of the analysis of variance showed that the combination of soil amendment and N, P, and K fertilizer significantly affected soil potential K and exchangeable K. The soil potential K and exchangeable K values for each treatment are presented in Table 1.

Table 1. The Effect of Soil Amendment and N, P, and K Fertilizer Combinations on Soil Potential K and Exchangeable K

Code	Treatment Combination	Potential K (mg/100 g)	Exchangeable K (cmol/kg)
A	Control	6,32 a	0,11 ab
B	N, P, K recommendations	6,06 a	0,07 a
C	1 soil amendment	21,35 e	0,2 b
D	¼ soil amendment + 1 dose of N, P, K	7,83 b	0,13 ab
E	½ soil amendment + 1 dose of N, P, K	7,56 b	0,1 ab
F	¾ soil amendment + 1 dose of N, P, K	18,97 d	1,19 d
G	1 soil amendment + ½ dose of N, P, K	12,4 c	0,64 c
H	1 soil amendment + ¾ dose of N, P, K	20,8 e	1,4 e
I	1 soil amendment + 1 dose of N, P, K	18,27 d	1,13 d

Note: Numbers followed by the same letter do not indicate a significant difference according to Duncan's Multiple Range Test at the 5% level.

The lowest K-potential values were obtained in the control treatment and the N, P, and K fertilization treatment without soil amendment, indicating that inorganic fertilization alone was not able to increase soil potassium reserves. The treatment of one dose of soil amendment (C) and the combination of one dose of soil amendment with ¾ dose of N, P, and K fertilizer (H) produced the highest K-potential values, indicating the important role of soil amendments in enriching the K reserve fraction. Potassium potential is the fraction of soil K in the form of fixed K and mineral K that is not directly available to plants but functions as a long-term nutrient reserve through gradual release due to mineral weathering and cation exchange processes (Mulyani et al., 2017).

The increase in K-potential in the treatment with soil amendment indicates that the combination of water hyacinth compost, rice straw biochar, and humic acid contributes to increasing the soil's K storage capacity. Water hyacinth compost increases organic matter content and cation exchange capacity, so that more K is adsorbed in the organo-mineral complex. Rice straw biochar with a porous structure and high negative charge increases K retention and suppresses losses due to leaching, while humic acid strengthens the soil's negative charge and the stability of the K-adsorption complex. The synergy of these three materials encourages K accumulation in the K-potential fraction, thereby strengthening sustainable soil potassium reserves to support lowland rice growth (Wulandari et al., 2016; Oktaviani et al., 2018; Rini & Sugiyanta, 2019).

Exchangeable K is the fraction of potassium that is weakly adsorbed in the soil sorption complex and is in equilibrium with the soil solution, making it easily released and absorbed by plants (Oklima et al., 2024). Therefore, the exchangeable K value reflects the actual availability of K nutrients for rice plants and is influenced by organic matter content, cation exchange capacity, and the amount of negative charge in soil colloids. In this study, the pattern of changes in exchangeable K is consistent with potential K, indicating a relationship between soil K reserves and the fraction of K available to plants.

The low exchangeable K values in the control treatment, the recommended dose of N, P, K fertilizer treatment, and the low dose soil conditioner combination treatment indicate that without adequate soil absorption capacity support, increasing K from inorganic fertilizers has not been able to significantly increase the exchangeable K fraction. On the other hand, increasing the dose of soil conditioner significantly increased the soil exchangeable K, with the highest value obtained in the combination treatment of one dose of soil amendment with ¾ dose of N, P, and K fertilizer. This increase is related to the increasing concentration of K^+ ions from KCl fertilizer, which are then adsorbed on negatively charged soil colloids, thereby increasing the exchangeable K fraction. The synergy of water hyacinth compost, rice straw biochar, and humic acid increases organic matter, provides additional adsorption surfaces, and stimulates the activity of potassium-solubilizing microorganisms, thereby increasing the efficiency of K fertilization and its availability for rice plants (Al Mu'min et al., 2016; Ihsan et al., 2020; Marjenah & Simolon, 2021; Sihotang et al., 2018).

4. Plant K Uptake

The results of the analysis of variance showed that the combination of soil amendment and N, P, and K fertilizer significantly affected K uptake by plants. The K uptake values for each treatment are presented in Table 2.

Table 2. The Effect of Soil Amendment and N, P, and K Fertilizer Combinations on Plant K Uptake

Code	Treatment Combination	Plant K Uptake (mg plant^{-1})
A	Control	0,79 a
B	N, P, K recommendations	1,47 bc
C	1 soil amendment	1,18 b
D	¼ soil amendment + 1 dose of N, P, K	1,41 bc
E	½ soil amendment + 1 dose of N, P, K	1,62 c
F	¾ soil amendment + 1 dose of N, P, K	2,34 d
G	1 soil amendment + ½ dose of N, P, K	2,13 d
H	1 soil amendment + ¾ dose of N, P, K	**2,91 e**
I	1 soil amendment + 1 dose of N, P, K	2,03 d

Note: Numbers followed by the same letter do not indicate a significant difference according to Duncan's Multiple Range Test at the 5% level.

Table 2 shows that the control treatment produced the lowest K uptake value, indicating limited potassium availability due to the absence of fertilizer or soil amendment additions. The treatment of N, P, and K fertilizers at recommended doses and a combination of low-dose soil amendment showed an increase in K uptake, but the value was still lower than the treatment with a higher dose of soil conditioner. The highest K uptake value was obtained in the treatment of one dose of soil amendment combined with ¾ doses of N, P, and K fertilizers, which was significantly different from all other treatments. This pattern indicates that the increase in plant K uptake is more determined by the presence of adequate amounts of soil conditioners than by a full increase in the dose of inorganic fertilizers.

The increase in K uptake by plants in the combination treatment is related to the increased availability and retention of K in the soil. KCl fertilizer increases the concentration of K^+ ions in the soil solution, thereby widening the diffusion gradient towards the roots and supporting the process of K uptake by plants. Soil amendments play a role in retaining K by increasing organic matter and the negative charge of soil colloids, providing K through the mineralization of organic matter, and suppressing K loss due to leaching and fixation. The synergy between fertilizers and soil amendments increases fertilization efficiency and allows K to be more stably available for absorption by rice plants (Mashavira et al., 2015; Mohapatra et al., 2025).

4. Crop Yield Components

The results of the analysis of variance indicate that the combination of soil amendment and N, P, and K fertilizer significantly affected the components of rice yield. The results of the rice yield components for each treatment are presented in Table 3.

Table 3. Effect of the Combination of Soil Amendment and N, P, and K Fertilizer on the Components of Lowland Rice Yield

Code	Treatment Combination	Number of Grains per Panicle	Percentage of Filled Grains per Panicle (%)	Weight of 1,000 Dry Grains (g)	Weight of Milled Dry Grain (g)
A	Control	85 a	92,53 a	24,47 a	2,2 a
B	N, P, K recommendations	106,67 b	94,25 ab	28,47 cd	3,29 b
C	1 soil amendment	84,33 a	91,54 a	27,48 bc	2,36 a
D	¼ soil amendment + 1 dose of N, P, K	133,33 de	93,24 ab	26,18 ab	3,38 bcd
E	½ soil amendment + 1 dose of N, P, K	119 c	94,13 ab	27,25 b	3,31 b
F	¾ soil amendment + 1 dose of N, P, K	127 cde	94,26 ab	28,39 cd	**3,79 d**
G	1 soil amendment + ½ dose of N, P, K	129,67 cde	94,03 ab	28,42 cd	3,35 bc
H	1 soil amendment + ¾ dose of N, P, K	**137,67 e**	**96,16 b**	**29,5 e**	3,78 cd
I	1 soil amendment + 1 dose of N, P, K	126 cd	92,57 a	28,64 cd	3,61 bcd

Note: Numbers followed by the same letter do not indicate a significant difference according to Duncan's Multiple Range Test at the 5% level.

The rice yields observed in this study included the number of grains per panicle, the percentage of filled grains per panicle, the weight of 1,000 dry grains, and the weight of dry milled grain (GKG). A summary of the results of the statistical analysis of all these parameters is presented in Table 3, which shows that the application of soil amendment and N, P, and K fertilizers, both singly and in combination, had a significant effect on the components of rice yield. Based on Duncan's further test at the 5% level, the combination treatment provided a significantly different response in most parameters compared to the control treatment and the recommended doses of N, P, and K fertilizers.

For the number of grains per panicle and the percentage of filled grains per panicle, treatment H (1 soil amendment + ¾ dose of N, P, and K) showed the highest yields, at 137.67 grains per panicle and 96.16%, respectively, and significantly different from the control treatment and most other treatments. This increase in the number and percentage of filled grains indicates that the combination of soil conditioner and N, P, and K fertilizers can support optimal panicle formation and filling. The role of humic acid in soil conditioners is thought to contribute to increasing nutrient absorption efficiency, plant physiological activity, and cell division and elongation, thereby supporting panicle formation and reducing the number of empty grains (Rahayu et al., 2021; Sofyan et al., 2024). Conversely, the control treatment showed the lowest values due to limited nutrient availability during the generative phase.

The weight of 1,000 dry grains and the weight of dry milled grain (GKG) were also significantly affected by the treatments. Treatment H produced the highest 1,000 dry grain weight of 29.5 g, while treatment F produced the highest GKG weight at 3.79 g, significantly different from the control treatment. This increase in grain weight is related to the optimal availability of potassium due to the combination of rice straw biochar and N, P, and K fertilizers, which increase the soil's cation exchange capacity and suppress nutrient loss. K plays a crucial role in the translocation of photosynthetic products, grain formation and filling, and the activation of enzymes involved in plant metabolism and energy synthesis (Maryani, 2021; Pan et al., 2025). Furthermore, water hyacinth compost plays a role in gradually providing nutrients and increasing the activity of soil microorganisms, thus creating a synergy between soil conditioners and inorganic fertilizers in increasing the yield components of lowland rice.

CONCLUSION

1. The combined application of soil amendment and N, P, and K fertilizers significantly affected potential K, exchangeable K, and K uptake by plants, as well as the yield of lowland rice on Inceptisols from Jatinangor.
2. The combined treatment of soil amendment at a dose of 8 tons ha^{-1} with ¾ doses of N, P, and K fertilizers (262.5 kg ha^{-1} Urea; 37.5 kg ha^{-1} SP-36; and 37.5 kg ha^{-1} KCl) provided an optimal yield response with an increase in the number of grains per panicle, 1,000 grain weight, and competitive dry milled grain weight, and demonstrated better fertilizer use efficiency compared to the full dose of inorganic fertilizer on lowland rice of the Inpari 32 variety.

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