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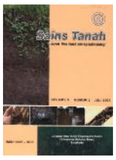

Utilization of cattle manure and potassium fertilizer on soil potassium availability and yield of cowpea (*Vigna unguiculata* L. Walp) in rainfed rice

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ABSTRACT

Cowpea (*Vigna unguiculata* L. Walp), a botanical protein source, exhibits resilience in the face of drought-induced stress on rainfed rice fields, especially in dry season crop patterns. Cowpea growth depends on the availability of nutrients in the soil, including potassium (K). In fact, low K availability (exchangeable K is ≤ 0.04 cmol$_{(+)}$ kg^{-1}) is one of the obstacles in rainfed rice fields, especially in increasing crop yields, including cowpea. Therefore, K supplies from various sources are needed to improve soil and cowpea productivity, such as K fertilizer and manure. This study was carried out to determine the response of nutrient management to increase cowpeas' yield and exchangeable potassium on rainfed rice fields. The field experiment used a randomized block design, with six replications and six fertilizer management treatments, specifically to control composted cattle manure (CCM), Nitrogen Phosphate Fertilizer (NP), CCM+NP, NPK Fertilizer, and CCM+NPK. The parameters observed include plant height, yield components, seed yield, and exchangeable K. Fertilizer management affects the cowpea yield, yield components, K-Uptake, and exchangeable potassium, with the best treatment depicted as CCM+NPK treatment. Compared to the control, CCM by itself and in combination with inorganic fertilizer increases the kernel yield of cowpea by as much as 54-104%, K uptake as much as 40.9-68.2 kg K ha^{-1}, and exchangeable K in soil ranging from 37.8-101.3%. It is indicated that the CCM could supply nutrients, including potassium, to overcome potassium deficiency in rainfed rice fields. Furthermore, applying CCM and cultivating cowpeas in rainfed rice fields during the dry season, with water as a limiting factor, is an appropriate option to enlarge the plant yield.

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1. INTRODUCTION

One of the leguminous crops, Cowpea (*Vigna unguiculata* L. Walp), is a primary source of botanical protein. Originating from Africa, cowpea has been extensively grown in Africa, Latin America, North America, and Southeast Asia. This plant has turned out to be a crucial commodity to cover nutrition and feed needs, especially in a tropical country (Owade et al., 2020). Cowpeas are widely planted in Indonesia, albeit not as extensively as others, such as peanuts, soybeans, and mung beans. Even though cowpea data is not available officially in Indonesia, in 2012, cowpea yield was fairly high, around 494,506 tons (Papa et al., 2020).

Cowpeas is a potential and favorable plant that can be an alternative to manufactured products from soybeans and mung beans. Cowpea tempeh contains 0.67% fat and 59.6% antioxidant; it is higher than soybean tempeh which has 8.20% fat and 56.66% antioxidant activity (Fadillah et al., 2020). Moreover, cowpea biomass could be utilized as soil ameliorant (Boateng, 2007). Cowpea is also an adaptable plant for facing climate change effects, including drought stress, increasing temperatures with low precipitation, and low soil nutrient fertility as rainfed land. Cowpea are roundly more drought-resistant in comparison to other legumes (Ezin et al., 2021; Mekonnen et al., 2022).

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Rainfed rice fields in Indonesia are quite extensive, covering around 2,195,699 hectares (Mulyani et al., 2022); the majority are in Sumatra, Java, and Sulawesi. Several challenges in managing rainfed rice fields for food crops are low water availability, low soil fertility, especially low available potassium (K) in soil due to drought stress with the low input and poor management (Al Viandari et al., 2022; Dianga et al., 2021; Kasno et al., 2020; Rashid et al., 2004). Lengthy, without any technology application, it will constantly enhance land degradation.

Various crop patterns generally used by the farmers in rainfed rice fields are paddy-paddy-fallow and paddy-paddy-secondary crops such as maize and legumes, which depend on rainfall availability. Whereas the rainfed rice fields are often influenced by climate change (Arifah et al., 2022). In the dry season, particularly in the third crop season, rainfed rice fields are left fallow after being used for first and second cultivation. Therefore, cowpeas, adaptable to drought stress, can be practically used in this season. Certainly, appropriate management must be taken during cowpea cultivation in light of the constraints of the rainfed rice field.

Potassium (K) is a crucial plant nutrient for photosynthesis and plant growth. Sufficient K availability in the soil will stimulate nutrient uptake and photosynthetic assimilation and maintain the fall and dried leaves due to turgor control (Bulawa et al., 2022; Sardans & Peñuelas, 2021; Thornburg et al., 2020). Potassium also plays a crucial role in managing stomata opening, admitting gasses and water fluxes (Bulawa et al., 2022). In addition, the K^+ concentration in chloroplasts is required to create a well-structured stromal lamella (Sardans & Peñuelas, 2021). K^+ is crucial in controlling water and nutrients from the roots to the other plant organs and tissues. It also controls turgor, pH, cell osmosis, and the movement of organic molecules (Sardans & Peñuelas, 2021).

Potassium nutrient availability input not only impact on the plant yields but also the grade of the harvested yield component (Bulawa et al., 2022). In contrast, plants with potassium-deficient symptoms are more susceptible to several constraints, including water shortage, drought threats, and unstable parameters. Symptoms of K deficiency in rice plants are shown by plants growing stunted with smaller, shorter leaves, less hard stems, easy to fall, hampered carbohydrate translocation, and reduced uptake of other nutrients (Thornburg et al., 2020; Wihardjaka, 2016). Reducing K^+ in soil is caused by several factors, including nutrient transport during harvest, intensive farming activities, modern rice varieties application, and reduced K input or being without K input (Wihardjaka et al., 2022).

Several forms of K are exchangeable K, non-exchangeable K, solution K, and mineral (Kaur, 2019; Volf et al., 2021). Its availability depends on the K concentration and exchangeable K in the soil solution. Available K in the soil is the premier source of K in total, which is around 0.1%-0.2% of the total soil K (Dhillon et al., 2019), while the exchangeable K forms around 1%-2% of the total soil (Dhillon et al., 2019; Sattar et al., 2019). However, around 96%-99% of K in soil is unavailable to plants (Dhillon et al., 2019). Increasing K in soil can be obtained from K synthetic and organic fertilizers. It can also be a problem-solving tool in rainfed rice fields to optimize plant growth and increase plant grain yield.

Wihardjaka (2016) mentioned that applying potassium fertilizer into rainfed rice fields can improve yields by 0.93-1.39 t-ha^{-1} rice, particularly in potassium-deficient cases in soil. Moreover, to promote the improvement of the physical and biological properties of soil, organic materials such as livestock manure provide nutrient needs, including potassium. Rakshit et al. (2017) reported that cattle manure is one of the potassium sources with a K content of around 0.5-2.0%. As well, Sharma et al. (2022) have stated that cow manures have 0.66% of K and 7.83 of pH. Besides, other manures such as goat manure and poultry manure also could be the best option as the source of K as much as 0.85% K and 0.67% K, respectively. Even though, the difference in K contents, it is always preferable to look over the K content in manures to get the best dosage and optimum gain.

More studies are required to identify the effect of applying CCM on the cowpea yield parameters and its supporting parameter such as plant height, yield components (number of empty pods, number of filled pods, weight of 100-grains), kernels yield, biomass weight, particularly in rainfed fields. In-depth study about increasing cowpea yield, to be specific in rainfed paddy field, have not been ascertained intensively. BPS (2020) have not reported cowpea yield yet. Connected with the farmer in rainfed fields that rarely cultivating cowpea and applying farmyard manure in the third cropping pattern. It is indicated the cowpea has not cultivated extensively whereas the farmers could have a great probability to increase plant grain yield amidst lacked water and nutrient availability. Whereas Rakshit et al. (2017) mentioned that cowpea leaf compost contents 3.2-3.5% of K. It is higher compared than various manures and could be the potential compost that can be applied in the next cultivation in rainfed fields, which is paddy cultivation that also need high K. The main objective of this study is to discover the effect of the cattle manure and potassium fertilizer on grain yield of cowpea and soil potassium particularly potassium uptake and exchangeable potassium in rainfed rice fields, especially in the dry season.

2. MATERIAL AND METHODS

The field experiment was carried out in rainfed rice fields in Sidomukti Village, Jaken Sub-district, Pati District, Central Java, from June to September 2021, during the dry season. The experiment was located at 111°10' E and 6°45' S with an altitude of 15 m above sea level (Fig. 1), with average monthly weather factors in June, July, and August 2021 as shown in Table 1. The soil type in the experimental site was typic Endoaquepts, which is dominated by sand and silt at 0–20 cm depth (48% sand, 47% silt, and 5% clay), with pH H_2O 5.0 (acid reaction), low C content (3.5 g kg^{-1}), low N-total content (0.5 g kg^{-1}), 50.7 mg kg^{-1} of available P, and low cation exchangeable capacity (5.74 cmol$_{(+)}$ kg^{-1}), with exchangeable cations of Ca, Mg, K, and Na as high as 2.93, 0.45, 0.04, and 0.05 cmol$_{(+)}$ kg^{-1}, respectively. Soil analysis was conducted at Indonesian Agricultural Environment Instrument Standard Testing Institute (IAESTI), Pati Central Java. The testing method for soil is shown at Table 2.

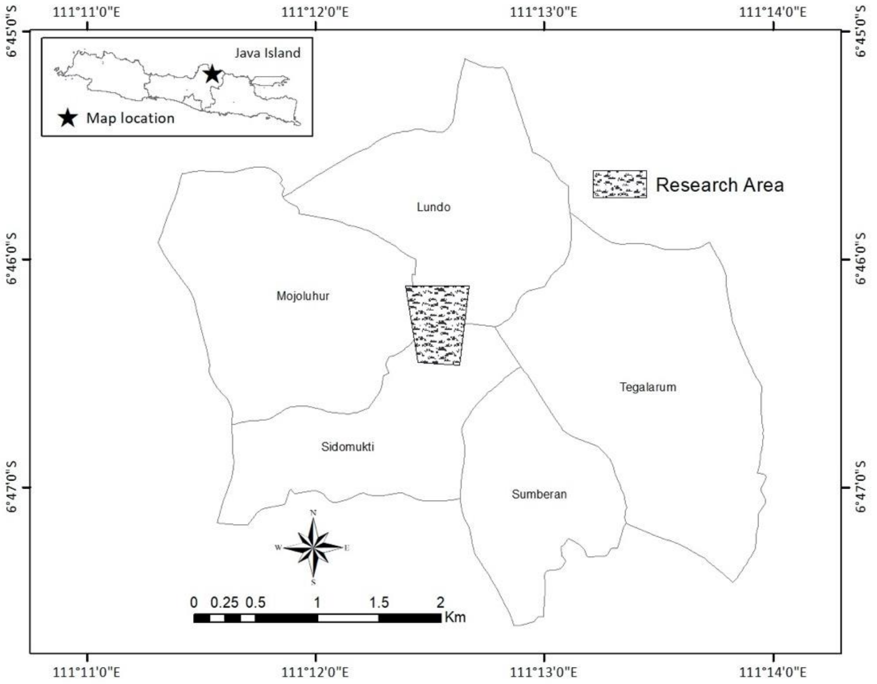

Figure 1. The map of research area located in Pati Regency, Central Java.

Table 1. Averaged monthly weather factors in June, July, and August 2021 in the experimental site

Weather factors	June	July	August
Maximum temperature (°C)	32.7	32.6	33.1
Minimum temperature (°C)	22.5	21.6	21.4
Relative humidity (%)	79.6	76.0	76.0
Solar radiation (cal cm^{-2})	398	415	444
Evaporation (mm)	4.7	5.6	6.6
Wind velocity (m sec^{-1})	1.24	1.48	1.81

Source: Observation from field weather station

Cowpea is planted after the second rice harvest in a general planting pattern: monsoon rice rain is followed by rice before the dry season and followed by secondary crops (including cowpea).

The experiment used a randomized block design with six replications and six treatments: control, composted cattle manure (CCM), NP, CCM+NP, NPK, and CCM+NPK. The experiment used an experimental unit measuring 3 m x 5 m. Composted cattle manure was obtained from Jakenan experimental station in Pati, Central Java. CCM contained 4.5 g kg^{-1} N, 1.0 g kg^{-1} P, and 5.5 g kg^{-1} K.

Field experiment area was 912.64 m^2, with 24.8 m-width and 36.8 m-length. The local variety Cowpea of KT9 was seeded using dibble, 2 seeds per dibbling hole in each plot with the spacing of 30 cm x 20 cm, on June 3, 2021. The seeds grew on June 9, 2021. Organic and inorganic fertilizers were given according to the treatment, where the dosage for N, P, and K fertilizer was 25 kg N, 10 kg P, and 40 kg K per hectare, respectively, while the dosage for cattle manure compost was 5 t ha^{-1}. These dosages refer to the Ministry of Agriculture about fertilizer dosage recommendations for legumes. Plant maintenance is carried out intensively, including cleaning weeds and controlling plant pest organisms. Cowpea was harvested on August 18, 2021. Irrigation depends on the availability of rainfall during cowpea growth, where the distribution of rainfall during cowpea growth is shown in Figure 2.

The parameters measured include plant height, yield components (number of filled pods, number of empty pods, weight of 100 grains), kernels yield, biomass weight, K uptake, and soil exchangeable K content. Plant height was measured randomly from 10 plant samples. Yield components were measured randomly from 5 plant samples. Seed and biomass samples from the 5 plant samples were dried and ground for analysis of total K content, following the procedures in Eviati et al. (2023). The weight of kernels and biomass were determined from the area harvest of 1.8 m x 3.8 m. Analysis of total K in plant tissue was used to compute K uptake, shown in Equation 1.

$$K\ uptake = [Ck \times Wk] + [Cb \times Wb] \text{............................} [1]$$

where Ck = K concentration in kernels (%), Wk = kernels yield (kg ha^{-1}), Cb = K concentration in biomass (%), Wb = biomass weight (kg ha^{-1})

Soil samples were taken at two depths (0-15 cm, and 16-30 cm) for exchangeable K analysis. Soil samples were taken three times, namely 20 DAG, flowering growth phase (40-45 DAG), and maturity growth phase (70 DAG). From each plot, five soil subsamples were taken diagonally and composited. Exchangeable K was analyzed using the 1N ammonium acetate saturation method according to the procedure in Eviati et al. (2023).

The collected data has been analyzed statistically by calculating analysis of variance (ANOVA) using Minitab v19 application. The Tukey post-hoc test at 5% level was used to determine the differences between treatments.

3. RESULTS

3.1. Cowpea Yields

Derived from statistical analysis, the management of organic and inorganic fertilizers has a significant impact on the growth and yield of cowpea in rainfed rice fields. Specifically, the variables of plant height ($p<0.01$), number of filled pods ($p<0.01$), dry kernels yield ($p<0.05$), and weight dry biomass ($p<0.01$). On the plant height, the combination of CCM+NP and CCM+NPK treatment have higher plant height compared to the others, about 30.9 cm and 30.3 cm, consecutively (Table 3). Whereas on CCM, NP, and NPK treatment oneself, even the treatments gave significant effect on plant height by statistical hypothesis test, they have not given the optimum plant height. Application of farmyard manure such as CCM significantly increases the number of filled pods, particularly when combined with inorganic fertilizers NPK, around 6.8 pods per crop. The treatments of CCM, CCM+NP, and CCM+NPK result by 16.7%, 33.3%, and 41.7% increase in the number of filled pods, respectively, compared to the control.

Providing inorganic and organic fertilizers leads to a significant increase in cowpea kernel yield, particularly in CCM+NPK treatments, increasing by 104%, while applying CCM oneself didn't give significant effect compared to NP, CCM+NP, NPK treatment. It is indicated that CCM could be a potential input in rainfed fields, especially on cowpea cultivation. CCM plays a crucial role in enhancing the yield of cowpea seeds, specifically in environments with limited rainfall for irrigation. However, by combining CCM and fertilizers containing potassium resulting in higher cowpea seed yields. The true impact of CCM combining with inorganic fertilizer is clear in the biomass yields, as the combination of inorganic fertilizer with CCM application, both with NP and NPK, produces higher biomass compared to treatments without CCM.

3.2. Potassium Uptake

This study depicts different results as regards the potassium uptake in the cowpea. The quantity of K nutrients transported in plant tissues has a direct impact on cowpea seed yield and biomass. The uptake of K by cowpea was significantly influenced by fertilizer management ($p<0.01$).

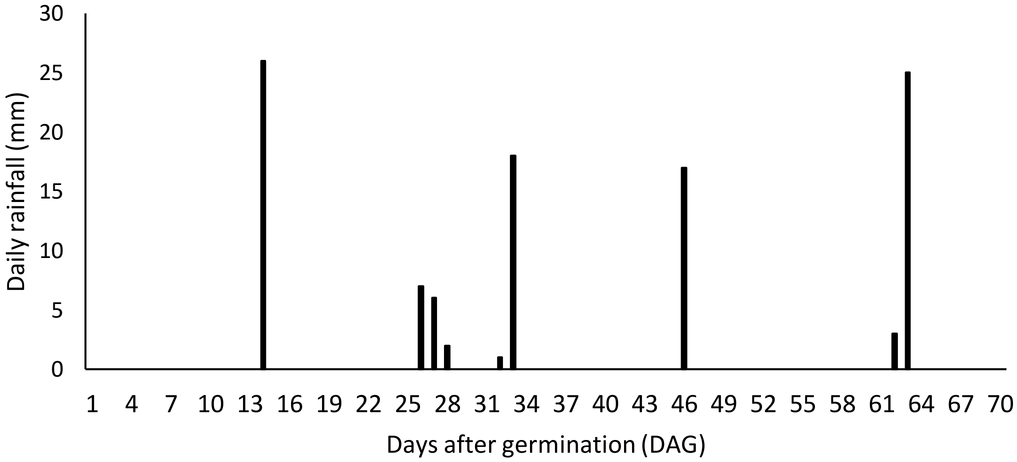

Figure 2. Daily rainfall distribution during cowpea growth in rainfed rice fields, 2021

Table 2. Initial soil analysis before establishing experiment

Characteristics	Methods	Value
pH H_2O	pH Meter (1:5)	5.02
Organic C (g kg^{-1})	Walkey and Black	3.5
Total N g kg^{-1})	N Kjeldahl, H_2SO_4 extract	0.5
P_2O_5 (mg kg^{-1})	Bray 1	50.7
CEC (cmol(+) kg^{-1})	Ammonium Acetate Percolation	5.74
Exchangeable K (cmol$_{(+)}$ kg^{-1})	Ammonium Acetate Percolation	0.04
Exchangeable Na (cmol$_{(+)}$ kg^{-1})	Ammonium Acetate Percolation	0.05
Exchangeable Ca (cmol$_{(+)}$ kg^{-1})	Ammonium Acetate Percolation	2.93
Exchangeable Mg (cmol$_{(+)}$ kg^{-1})	Ammonium Acetate Percolation	0.45
Texture:	pipette methods	
Sand (%)		48
Silt (%)		47
Clay (%)		5

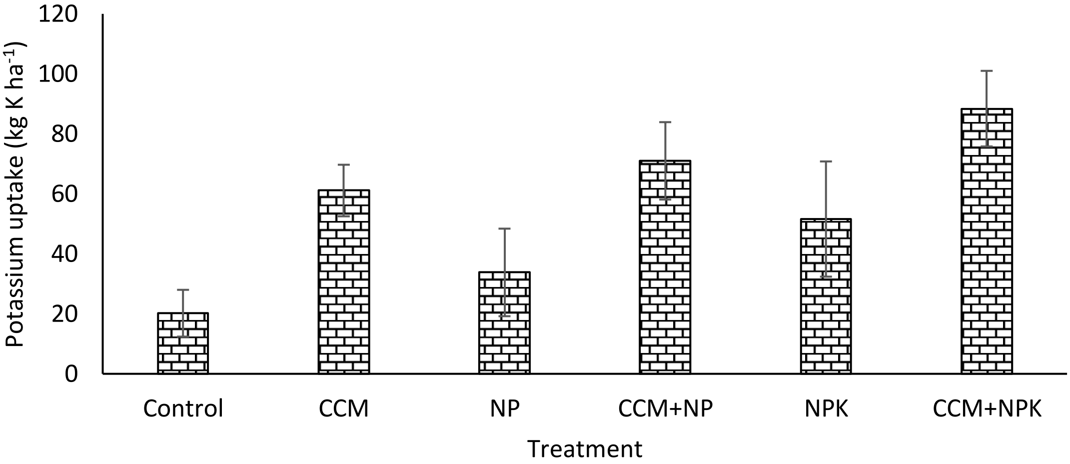

Figure 3. Potassium uptake in cowpeas on different nutrient inputs (CCM: compost of cattle manure)

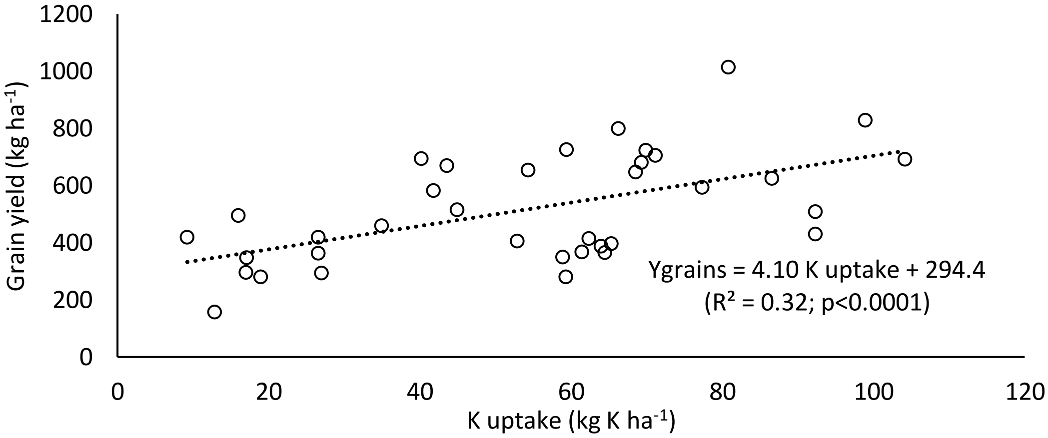

Figure 4. K uptake and cowpea seed yield regression model in fertilizer management in rainfed rice fields

In general, the addition of both CCM by oneself and in combination with inorganic fertilizer led to an increase in K uptake, ranging from 40.9-68.2 kg K ha^{-1} compared to the control. In the absence of CCM, the use of inorganic fertilizer increased K uptake, ranging from 13.6-31.4 kg K ha^{-1} compared to the control. The application of potassium resulted in a 52.7% increase in K uptake (Fig. 3).

3.3. Exchangeable Potassium

The application of fertilizer actually increased exchangeable K compared to the control, particularly at a depth of 0-15 cm during 20 DAG, the flowering phase, and before harvest (Fig. 5). However, the pattern of exchangeable K at a depth of 16-30 cm differed from that at 0-15 cm, possibly due to various factors, such as evaporation rate, which transports K to the upper soil layer. At a depth of 16-30 cm, the NP, NPK, and CCM+NP treatments exhibited relatively high levels of exchangeable K. The exchangeable K content in the 16-30 cm soil layer applied CCM+NP was relatively the same as that applied NPK, especially at 20 DAG and harvest time was 9 and 13.7 kg K ha^{-1} (Assuming a bulk density of 1.61 g cm^{-3}, respectively. The relatively high exchangeable K in the CCM+NP treatment suggests that CCM may contribute to the increase in exchangeable K in the soil.

4. DISCUSSION

The low availability of K in soil on rainfed rice fields can be overcome by supplying external K with both inorganic and organic fertilizers. In this research, it could be highlighted that the combination of CCM and NPK has a significant effect on various parameters. Plant yields are influenced by several factors, particularly in the availability of soil nutrients and plant nutrient uptake (Chandini et al., 2019; Durán-Lara et al., 2020; Papa et al., 2020; Shambhavi et al., 2017). The nutrient K influences photosynthesis and root formation, which of course influences K uptake in plants and affects grain yield and biomass.

CCM aids in the more efficient absorption of nutrients from inorganic fertilizers, especially in limited soil moisture conditions. This is thought to be closely related to the bacterial population in the soil. Applying organic material which might boost the quantity and activity of bacteria in the soil (Peng et al., 2021). Some soil microorganisms have the capability to dissolve phosphate and potassium, which would otherwise be insoluble (Iftikhar et al., 2024). Several group of microbes both rhizobacteria and fungi can be embroiled on solubilization of K minerals in the soil system. The rhizobacteria group including *Pseudomonas sp.*, *Agrobacterium tumefaciens*, *Acidithiobacillus ferrooxidans*, *B. mucilaginosus*, *Bacillus edaphicus*, *B. circulans*, *Burkholderia* *sp., B. megaterium, Paenibacillus sp., Rhizobium pusense).* Whereas the group of fungi including *G. intraradices, Glomas mosseae, A. terreus, Aspergillus niger,* and *Penicillium sp.* (Wihardjaka et al., 2022). It is assumed that the availability of nutrients, as the effect of microbial activity from CCM, can enhance the nutrients uptake thereby influencing the growth of plants. Thus, CCM application may offer an option for alternative solution to limited rainfed fields condition.

Beside CCM is one of the sources of K, as in this study using CCM with high K content compared to other nutrients such as N and P itself about around 5.5 g kg^{-1}, another positive effect of CCM because farmyard manure stimulated the availability of K by delivering organic colloids with higher cation exchange sites thereby attracting K from non-exchangeable sources and applying K which ultimately supports plant growth and higher biomass accumulation through increased K uptake (Majumdar et al., 2007). This finding aligns with the research results depicted in Figure 4, CCM treatment whether given by oneself, with NP, and NPK gave higher results in layers 0-15 cm, where this area is the rhizosphere zone.

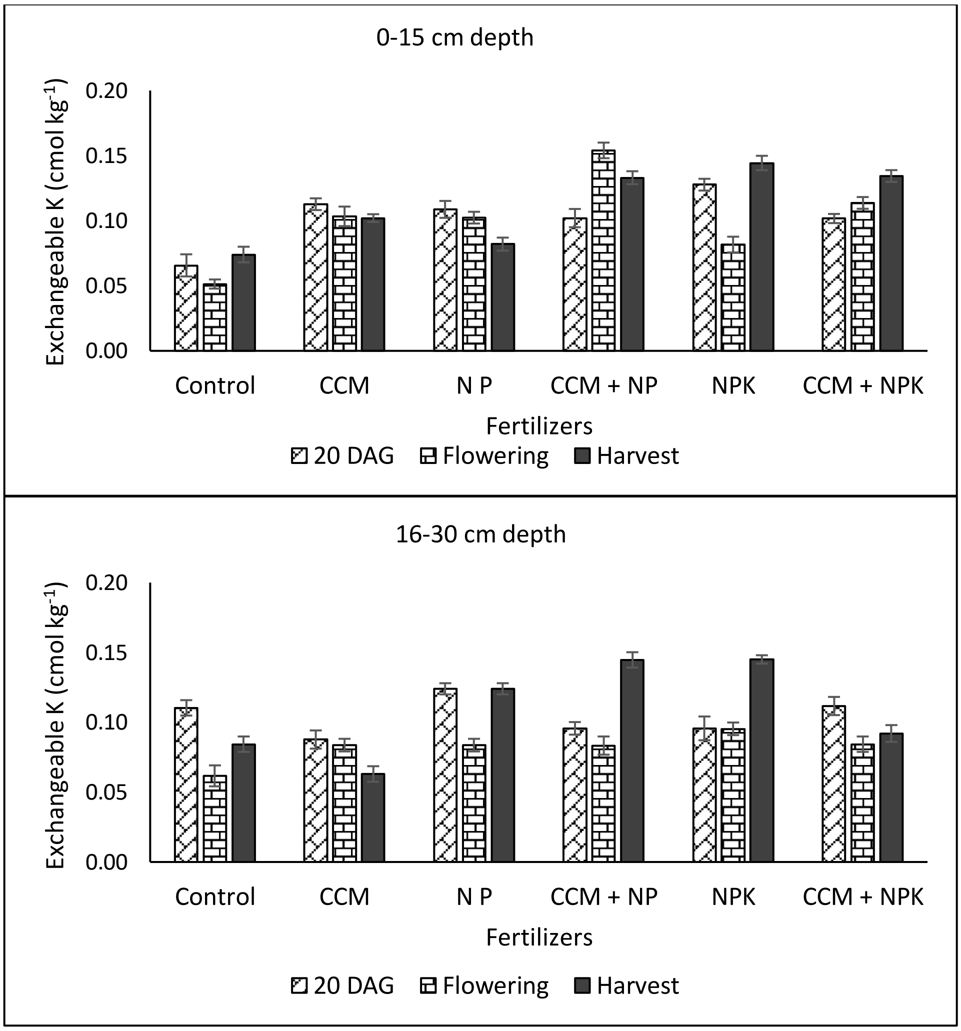

Figure 5. Exchangeable potassium on 0-15 and 16 – 30 depths influenced by various fertilizer management in rainfed rice fields.

Table 3. Yield component and cowpea yield from fertilizer management in rainfed rice fields

Fertilizer management	Plant height (cm)	Filled pods per crop	Empty pods per crop	Weight of 100-kernels (g)	Dry kernels yield (kg ha^{-1})	Dry biomass weight (kg ha^{-1})
Control	21.1± 1.1 a	4.8±0.6 a	0.5+0.2 a	5.39±0.48 a	323±100 a	1610±305 a
CCM	26.2± 3.1 bc	5.6±1.1 ab	0.6±0.3a	5.35±0.20 a	524±164 ab	3532±616 bc
NP	25.3± 1.7 ab	5.6±1.0 ab	0.6±0.2 a	5.56±0.46 a	498±125 ab	2700±694 ab
CCM+NP	30.9± 1.8 d	6.4±1.1 ab	0.4±0.3 a	5.35±0.13 a	522±271 ab	4110±670 c
NPK	27.3± 1.1 bcd	6.0±0.9 ab	0.6±0.4 a	5.45±0.51 a	576±203 ab	2625±940 ab
CCM+NPK	30.3± 1.6 cd	6.8±1.3 b	0.7±0.3 a	5.58±0.25 a	659±110 b	4157±648 c
p-values	**	**	ns	ns	*	**

Remarks: Means in the same column followed by the same letter are not significantly different at 5% Tukey test, * significant at p<0.05, ** significant at p<0.01, ns: not significant, CCM: compost of cattle manure

Additionally, the use of CCM also enhances exchangeable K during the flowering period in 0-15 cm depth. The research results of Wihardjaka et al. (2022) also showed that applying rice straw compost to rice plants increased the exchangeable K content in rainfed rice fields. Soil exchangeable K which is relatively the same in the CCM+NP and NPK treatments means that composted cattle manure can replace inorganic K fertilizer. With a high exchangeable K content during crucial periods such as flowering, it determines the K nutrient uptake which affects the yields.

In contrast to the 16-30 cm depth, the exchangeable K content is lower than the 0-15 cm depth. It indicates that there was minimal nutrient leaching, presumably due to limited rainfall during the study. This characteristic is particularly beneficial for the cultivation process, considering that the cowpea plant has shallow roots. Thus, growing cowpeas in the time of the third crop season is an appropriate option, with accurate fertilizer management in certain. Nevertheless, it is required to conduct studies in multiple season with a specific period, for particular purpose to discover the side effect of using CCM in several parameters such as nutrient availability, plant uptake, and plant yields. Tian et al. (2023) documented that the highest of K nutrient was discovered in the third year of cowpea planting and providing by various organic amendments and fertilizing methods. Furthermore, in-depth study also is required to determine the optimal ratio dosages of CCM and NPK for the optimum plant growth and economic value of cowpea cultivating.

Aside from the input of K fertilizer and manure, the high K uptake by cowpea was predicted due to contribution of the K content in primary minerals, K residues in non-exchangeable form, and the release of K fixed in the clay lattice. K release from the non-exchangeable form may rises plant growth and K uptake (Wihardjaka et al., 2022). The regression model of K uptake and cowpea seed yield in this study can be expounded by the equation $Y= 294.4 + 4.10 X$ ($R^2=0.32$, $n=22$, $p<0.0001$) (Fig. 4), with Y is grain yield and X is K uptake, which was derived from maximum dilution and maximum K accumulation data in rice fields (Wihardjaka et al., 2022). This equation assists to define K uptake in cowpea plants, in light of the maximum dilution or accumulation limit. It was observed that K uptake more than 60 kg K ha^{-1}, but the resulting cowpea seed yields were less than 400 kg ha^{-1}. It indicates that a large amount of K is below the maximum K accumulation limit, by that means It can inhibit the optimal utilization in the photosynthesis process. In contrast, the treatment with K uptake of less than 20 kg ha^{-1} (the control) produced grain yields around 400 kg ha^{-1}. Similarly, in the NP treatment, K uptake of approximately 40 kg K ha^{-1} resulted in grain yields of 600 kg ha^{-1}. These findings indicate that plant roots effectively utilize diluted K in the soil to enhance productivity in the absence of K nutrient input.

In this study, it appears that applying CCM oneself is not significantly affected compared to NP and NPK, but it has a significant effect compared to control. Aside from that, CCM+NPK treatment gives the best effect on several parameters, including K-Uptake. It is indicated that CCM and NPK fertilizer have a positive effect when combining one and another. Mortland and Ellis (1959) reported that when the soil organic matter in soil rise, will also enhance K release from clay lattice and non-exchangeable K. It will increase the exchange interaction between soil organic matter and NH_4^+ and the exchangeable K or interlayer K in clay mineral. By adding K input from fertilizer, it also helps to increase K source in soil. Also, there was a correlation between exchangeable K and K-uptake, especially in 0-15 cm soil depth when the plant was entering the flowering and harvest phase, with correlation coefficients of 0.62 and 0.60, respectively.

5. CONCLUSION

Cowpea cultivation in rainfed rice fields, particularly during the third planting season, has considerable potential for development to increase the yield. Fertilizer management influenced various aspects such as yield, yield components, K-Uptake, and exchangeable potassium. The treatment involving the combination of CCM+NPK has significantly influenced plant height, number of filled pods, dry kernel yields, and dry biomass weight. Additionally, the CCM+NPK treatment also affects K-Uptake. At the same time, CCM+NP treatment is the greatest way to encourage the exchangeable K in rainfed rice fields. The application of CCM by itself and in combination with inorganic fertilizer increased the kernel yield of cowpeas by as much as 54-104%, K uptake by as much as 40.9-68.2 kg K ha^{-1}, and exchangeable K in soil ranging from 37.8-101.3%. This indicates that the CCM application can address the challenges associated with limited rainfed rice fields. Nevertheless, further research is required to collect various observed data for accurate recommendations in the future.

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Declaration of Competing Interest

The authors declare that no competing financial or personal interests may appear to influence the work reported in this paper.

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