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Research Article

Macronutrients (NPK) balance in rice field and dryland maize cropping systems

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Abstract

Fertilizers, especially those containing NPK nutrients, have become a necessity in farming both rice fields and dry land. Most of the application of fertilizers is based on plant commodities and less based on the nature of the diversity of the soil or growing media. This study aimed to determine the balance of NPK nutrients and the nutrient elements that became the limiting factor in the rice and dryland maize cropping systems. The study was conducted at a rice field in Jember District and on dry land in Bogor District with maize plants. The fertilizer used is organic fertilizer. Nutrient balance is obtained by calculating the difference between the total input of nutrients N, P, and K given and the total output of nutrients N, P, and K transported by plants. The results showed that the combination of fertilizing treatment with biochar (50%), fish waste (25%), and chicken manure (25%) up to 10 t/ha on rice field soil at the experimental location in Jember had to limit factors for plant growth: low organic matter content, trace elements essential nutrients N and P are also low. Likewise, the combination of inorganic NPK fertilizer treatment with organic fertilizer up to 600 kg/ha on dry land in Bogor has not been able to improve its fertility status with limiting factors: low organic matter content, low N-total, and low exchangeable K.

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Introduction

The need for productive agricultural lands in Indonesia continues to increase. According to Mulyani and Agus (2017), 5.3 million hectares of agricultural land are for rice, shallots, and sugar cane, and about 10.3 million hectares for upland rice, maize, soybeans, peanuts, green beans, sugar cane, shallots, cassava, and sweet potato. All of them are directed to meet the self-sufficiency target of food by 2045. Many sub-optimal lands have been used for agriculture (extensification) but based on the same expert evaluation. It shows that of the 29.8 million hectares of abandoned land, only about 7.9 million hectares are potentially available for agricultural extensification in the future. On the other hand, agricultural intensification lands that are already under management show a continuous decline in soil fertility or can be said to experience degradation, especially chemical and biological aspects, which ultimately have a negative impact on the environment or ecosystem (Logan, 1990; Alam, 2014; Ammurabi et al., 2020; Dragović and Vulević, 2020). Intensified land increasingly requires high inputs; as shown by

Widowati et al. (2011), the application of urea (N) fertilizer at the farmer level in Kediri has reached 400 to 500 kg/ha and even up to 600 kg/ha in rice fields. Another case in Wonosobo was also presented in which potato plants were given 800 to 1000 kg/ha. The amount of N fertilizer is not balanced with the provision of other macronutrients, namely P and K, thus adding to the imbalance of plant nutrients

Fertilizers, especially those containing N, P, and K nutrients, have become a necessity in farming both rice fields and dry land. This condition is also found in various countries in Asia and Africa (Kotschi, 2015). In Germany, a wheat harvest of 8 t/ha absorbs as much as 180 kg N, 37 kg P, and 124 kg K from the soil. Of these, the plants took 64% N, 41% P, and 18% K from the previously applied fertilizer or crop residues. The amount of NPK absorbed by these plants will vary depending on the plant. Until now, most of the application of fertilizers is based on plant commodities and less based on the nature of the diversity of the soil or growing media.

The humid and hot tropical humic country causes the process of degradation or destruction to be faster or higher. Evaporation of N and erosion that carry nutrients. Therefore, in general, the limiting factor apart from plant nutrients is also soil organic matter or C content (Winarso et al., 2020; Voltr et al., 2021). In general, the efficiency of N fertilization can reach 50%, but Jalpa et al. (2020) researched the efficiency of N fertilization on sandy soils, getting the highest yields of only 12.05% (spring) and 32.38% (fall). The results of research by Widowati et al. (2011) in Andisol Wonosobo and Kopeng soils, Central Java, on potato plants showed a very high variation in the efficiency of N fertilizer, which varied between 4-30% and Kopeng 11-67%. High variation and loss of N through runoff and downward movement (leaching) and erosion (Feng et al., 2019). Results of research that has been carried out by Damar et al. (2021) to obtain optimal and long-term profitable management through the P balance showed that organic P sources were better (varied 65-610 kg P/ha) than inorganic (varied 54-446 kg P/ha).

Improving fertilizer recommendations for smallholders is critical to improving the food security of smallholder landscapes. Currently, comprehensive recommendations are provided across agroecological zones, although fertilizer response and plant nutrient use efficiency vary spatially (Ichami et al., 2019). The results of research in Indonesia show that: i). The new NPK fertilizer affects the growth and yield of rice plants, ii). The dose of fertilizer that gives the best response to vegetative and generative growth of rice plants is 250 kg/ha new NPK fertilizer + 300 kg/ha Urea. This is supported by the relative value of agronomic effectiveness (RAE) of 101%, and economic feasibility (R/C) of 1.88). The new NPK fertilizer can be effectively used as an alternative to Phonska's NPK fertilizer (Irawan et al., 2020). Although nitrogen (N) is an essential plant nutrient, its use as fertilizer shows high losses (Dimkpa et al., 2020). Such losses pollute the environment and increase the production of greenhouse gases and other environmental events associated with high ammonia evaporation and nitrous oxide emissions. In addition, the leaching process and soil nitrate runoff will contaminate surface and underground water, with implications for human health. Thus, it is necessary to determine the limiting factors and calculate the nutrient balance to increase crop production through proper fertilization management.

This study aimed to determine the balance of NPK nutrients that become the limiting factor in the rice and dryland maize cropping systems.

Materials and Methods

The study was conducted in 2021 in the rice field of Sucopangepok Village, Jember District, and in the dry land of Bojong Village, Bogor District, with maize plants. Soil samples collected from the areas were air dried and analysed to determine their pH (by pH meter), organic C content (by Walkley and Black method), total N (by Kjeldahl method), total P, and total K contents (by wet ashing with HNO_3 and $HClO_4$), available P content (by Bray I and Olsen methods), available K content (by Morgan Wolf), exchangeable Ca, Mg, K, and N (by NH_4O_{Ac} 1M, pH 7 extraction method), cation exchange capacity (by NH_4O_{Ac} 1M, pH 7 extraction method), and exchangeable Al and H (NH_4O_{Ac} 1M, pH 7 titration methods). The results of the analysis of the soils before treatment and planting are presented in Table 1.

The rice field Sucopangepok Village, Jember District, is dominated by Alfisols with the application of terrace conservation and has good irrigation. The soil has a neutral pH of 7.47. Soil organic matter has a low content, indicated by an organic C content of 1.33%, Likewise with a low total soil N content of 0.12%. The available P content in the soil is 0.19 ppm or very low, while the exchangeable K was very high or 1.20% or 468 ppm. The soil has a moderate value of cation exchange capacity (CEC) of 17.48 me/100 g. This is because the soil has a loam texture (41% sand, 33% silt, and 26% clay) and a soil pH of 7. Based on the results of the analysis, the limiting factors of the soil before treatment are the levels of organic matter and essential nutrients of N and P. The soil is classified into poor/infertile soil based on the criteria for soil fertility status developed by the Soil Research Institute (2009).

The dry land in Bojong Village, Bogor District, is dry land that has been routinely used for cultivating annual crops, such as maize and vegetables. The soil is dominated by Inceptisols with volcanic parent material because it is located not far from Mount Salak, which is still listed as an active volcano. The pH of the soil is classified as acidic (4.4) with Al^{3+} value of 3.50

cmol$_c$/kg. Likewise, the soil had low organic matter (1.81%), low total N (677 ppm), and low exchangeable K (58 ppm), while P was very high (677 ppm). Data presented in Table 1 show that the dry land soil has a low pH and a high Al^{3+}, while the rice field soil has a neutral pH value with low organic C and total N contents. The fertilizer commonly used for the soils is organic fertilizer.

The nutrient balance was obtained by calculating the difference between the total input of N, P, and K nutrients given and the total output of N, P, and K nutrients of the harvested plants. The limiting factor was based on the status or value of the analysis of soil chemical parameters (Soil Research Institute, 2009).

The design used in the experiment was a completely randomized block design with several treatment combinations and three replications. The treatments in rice fields were doses of organic fertilizer derived from combinations of biochar, chicken manure, and fish waste (2:1:1) consisting of 5 levels, namely: D0: 0 t/ha equivalent to 0 g/plant, D1: 2.5 t/ha equivalent to 3.3 g/plant, D2: 5 t/ha equivalent to 6.6 g/plant, D3: 7.5 t/ha equivalent to 9.9 g/plant, D4: 10 t/ha equivalent to 13.2 g/plant. Each treatment combination was repeated three times. The fertilizer was applied three times at 21, 35, and 45 days after planting. The combination of treatments on dry land were solid organic fertilizer and inorganic fertilizer recommendations (solid organic fertilizer + urea + SP36 + KCl) kg/ha consisting of 6 treatments, namely: (1) 0+0+0+0, (2) 0+360+200+200, (3) 400+0+0+0, (4) 200+360+200+200, (5) 400+360+200+200, and (6) 600+360+200+200.

Solid organic fertilizer was applied during soil tillage so that it was evenly distributed and the day before planting maize seeds, while inorganic fertilizers of urea (N fertilizer), SP36 (K fertilizer), and KCl (K fertilizer) were applied twice, namely on maize plants aged 10 and 30 days. The fertilizer dose was based on general recommendations, i.e. 360 kg urea/ha + 200 kg SP36/ha, and + 200 kg KCl/ha. Organic fertilizer used in rice fields was a combination of biochar (50%), fish waste (25%), and chicken manure (25%) that contained 27.83% C, 1.46% N, 0.85% P, and 1.71% K. The solid organic fertilizer used in dryland contained 22.99% C, 1.69% N, 6.69% P, and 3.52% K. Determination of the inhibiting factors of soil characteristics in determining soil fertility or quality was based on the criteria for assessing soil chemical properties and soil fertility at low and very low status (Soil Research Institute, 2009).

The calculation of the nutrient balance was based on the difference between the input and output of nutrients in one cropping season. The input was based on the availability level in the soil and fertilizer addition, while the output was based on the nutrient uptake from the crop (rice and stover or maize and stover).

Table 1. Results of preliminary soil analysis before treatment.

Soil Chemical Parameters	**Dryland, Kemang, Bogor**	**Rice Field, Sucopangepok, Jember**	**Status[*)]**
pH H_2O	4.4	7.47	Vary Acid/Neutral
Organic C (%)	1.81	1.33	Low
C/N	11	11.08	Moderate
Total N (%)	0.15	0.12	Low
P_2O_5 Bray 1[a]/Olsen[b] (ppm)	677	1900	Very low /Very High
K_2O Morgan/NH_4-Acetate (ppm)	58	468	Low/Very high
Cation Exchange Capacity (CEC) (cmol$_c$/kg)	19.57	17.48	Moderate
Base Saturation (BS) (%)	17		Very Low/Moderate
Al^{3+} (KCl 1 N) (cmol$_c$/kg)	3.50		-
H^+ (KCl 1 N) (cmol$_c$/kg)	0.89		-

Notes: [*)]Soil Research Institute (2009); [a]Dryland, Kemang Bogor; [b]Rice Field, Sucopangepok Jember.

Results and Discussion

Chemical characteristic

The rice field soil (Sucopangepok, Jember), after the addition of organic fertilizer and rice cultivation, showed a decrease in the total N content, the exchangeable K was relatively constant, and on the other hand, the available P increased (Figure 1). The status of the soil NPK content was the same as before the treatment, where N and P remained the limiting factors for the next planting period. The combination of treatments with the addition of organic matter up to 600 kg/ha on maize tended to reduce the organic C content of the soil (varied between 1.4 to 1.57%) and N (varied from 0.12 to 0.13%) and P, which was classified as still very high (512-620 me/100 g P_2O_5) and very low K (5-88 me/100 g K_2O). This shows that the combination of treatment with the addition of organic matter in only one planting (seasonal) has reduced organic matter and NPK nutrients present in the previous soil (Figure 2). In just one planting season, the organic C, N, P, and K contents decreased even though fertilization had been carried out. This indicates nutrient depletion during planting, especially C, N, and K for Bojong dry land, and remains a limiting factor for farming. The Bojong location has high rainfall with an annual average of 3,000-3,500 mm, so the washing process for bases is high. The exchangeable K content of the soil is very low, the pH is low, the base saturation is low, and Al has started to rise (Table 2). This reduction in nutrients is discussed in more detail in the nutrient balance section. On the other hand, the combination of treatments increased the pH of the soil by 0.1 to 0.3 units.

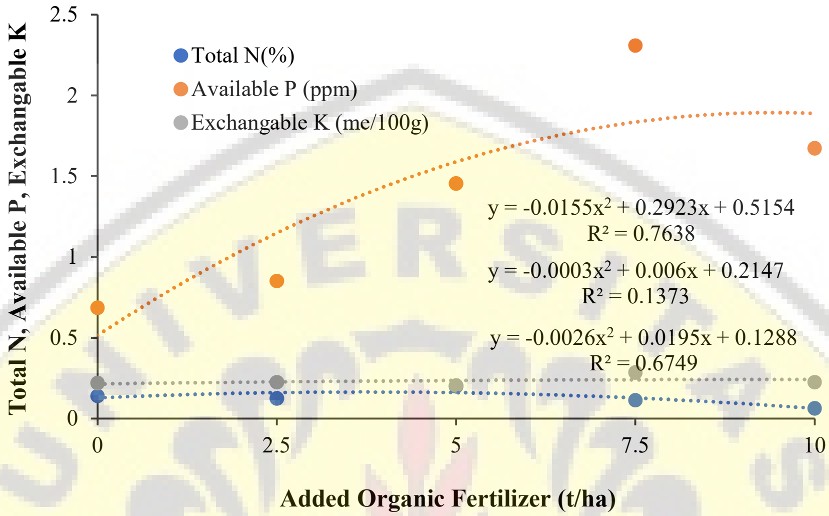

Figure 1. Total N, available P, and exchangeable K contents in the soil after treatment and rice planting (rice field, Jember).

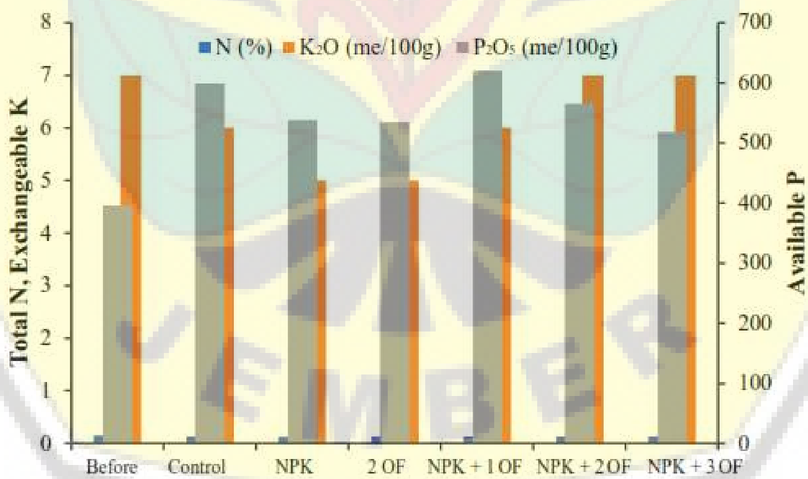

Figure 2. Total N, available P, and exchangeable K contents in the soil after treatment and planting of maize (Dryland, Bogor). Note: OF is organic fertilizer.

Balance of N, P, and K

Plant essential nutrients, especially N, P, and K in lowland rice, are often a limiting factor for the growth and production of lowland rice plants on intensified lands. The application of N-source fertilizers, especially urea, continues to increase from year to year, and after an evaluation of the NPK levels of the soil after seasonal planting, there is a decrease in the levels of N and P (Figure 1). This indicates that there has been depletion in the planting, so it requires a higher dose of fertilizer which must be added or improved in its management so that fertilization efficiency increases. The results of the evaluation of the calculation of the total input and output of N nutrients in lowland rice cultivation with various treatments of organic fertilizer application up to 10 t/ha are presented in Table 3.

The calculation results show that the N absorbed by plants or transported at harvest (N in stover and N in rice) is higher than the input (N in soil and N from added organic fertilizer). The smaller the input, the higher the treatment with the addition of high organic matter (Table 3). This indicates that during the planting of rice plants, there has been a depletion of N in the soil, so the demand for inputs is higher. The high N depletion during rice planting is closely related to low soil organic C content (0.57-0.78%) and is also strengthened by the results of Wibowo and Kasno (2021), which showed a very strong relationship between organic C and total N in soils of Java, Indonesia.

Table 2. Input and output of N in rice planting on various treatments of organic fertilizer application.

Treatment of Organic Fertilizer (t/ha)	N Input (kg/ha)	N Output (kg/ha)	N Balance (input-output) (kg/ha)
0	26.636	101.521	-74.885
2.5	24.571	110.971	-86.400
5	27.656	105.498	-77.842
7.5	29.382	162.240	-132.857
10	36.023	178.672	-142.649

Notes: The input is fertilizer and soil, while the output is stover and rice.

Based on Table 3, unfertilized soil decreased soil N by 74,885 kg N/ha. This decrease was even higher if the soil was treated with the addition of organic fertilizer, which decreased by 4,926 kg N/ha for each ton addition and varied from 11,514 kg N/ha for the addition of 1 t/ha to 6.7 t N/ha in the addition of organic fertilizer The imbalance between input and output N during seasonal rice cultivation is very high, which follows the equation y = -4294.8x2 + 7570.5x – 78395 with R^2 = 0.86**. If this condition occurs continuously, it will cause an equilibrium of total N in the soil at a low to a very low status like most of the current intensification soils (Patrick et al., 2013; Wibowo and Kasno, 2021).

The balance of N in solid organic fertilizer for maize on dry land in Bojong Village, Bogor Regency, showed the same pattern as in rice fields. The balance was negative, or the input (N from fertilizer and soil) was lower than the output (N of stover and cobs), as presented in Table 3. Based on Table 3, the P and K nutrient balance had different patterns. Previously, it was explained that the combination treatment of adding organic fertilizers up to 600 kg/ha in maize cultivation could increase the pH of acid soils (from 4.4 to 4.7), but even so, this did not increase the status or value of C, N, and K which were the limiting factors. Based on these conditions, the balance was calculated after one maize planting.

The calculation of the N, P, and K nutrient balance was the same as that carried out in lowland rice cultivation, which used a simple calculation where the total N, P, and K at the input (fertilizer or treatment and soil) given are reduced by the total nutrients N, P, K at the output (nutrients absorbed by plants). Based on these calculations, it shows that all treatments combined with organic and inorganic fertilizers and controls have a negative N nutrient balance; this means that the input of N fertilizer is lower than the output. This negative result may be caused by the lack of input of fertilizer dosage or the low efficiency of fertilizer use.

The control treatment also gave the same effect, namely the negative N balance of -58.09 kg N/ha; While the treatment of inorganic NPK fertilizer according to the recommended dose (360 kg urea/ha + 200 SP36 kg/ha + 200 kg KCl/ha) also gave a negative value but had a lower value of -38.50 kg N/ha. This is also similar to the treatment of adding organic fertilizer, which gives a negative N balance value of up to 3 times the amount compared to control (without fertilizer) with a value of -151.01 kg N/ha. This N nutrient balance pattern is almost the same as that in lowland rice. Furthermore, the combination of organic and inorganic fertilizer treatments was still negative even though there was a decrease. It appears that the application of organic fertilizer alone will deplete the N nutrients in the land where N is the limiting factor. This nutrient depletion will be reduced if the application is combined with organic and inorganic fertilizers. The decrease in the negative value of the N balance in the soil will decrease with the increase in the addition of organic fertilizer combined with inorganic NPK fertilizer by following the equation y = 14,493x2 - 92.212x + 88,193 with R^2 = 0.98**. The pattern of decline in the negative N balance was very large, from -57.30 kg N/ha (1 NPK + 1 OF) to -10.32 kg N/ha for the treatment of 1 NPK + 3 OF. This indicated that the combination showed an increase in N fertilization efficiency and automatically reduced N depletion in the soil. The balance or balance of P and K nutrients on dry land planted with maize and treated with a combination of inorganic fertilizers and organic fertilizers is not the same as for N nutrients, which is positive, or the input is higher than the output, or there is no depletion of P and K nutrients in the soil. When compared with the control (without fertilizer application), the balance remained negative, or there was a depletion of P and K nutrients, namely -5.79 kg

P/ha and -5.19 kg K/ha. The same thing happened to N nutrients. If only NPK fertilizer is given, the balance of P and K nutrients is also positive, and vice versa; if it is fertilized from organic fertilizers, it will be all negative. The interesting thing is the combination of inorganic fertilizers and organic fertilizers, that is, the more organic fertilizers added, the more positive it will be, or the amount of input will increase.

Table 3. Input and output of NPK nutrients in maize cultivation in the dry land studied.

*Treatment	**Input (kg/ha)	Output (kg/ha)	Nutrient Balance (kg/ha)
N, Control	0	58.09	-58.09
1 NPK	165.6	204.10	-38.50
0 NPK + 2 OF	6.76	157.77	-151.01
1 NPK + 1 OF	168.98	226.28	-57.30
1 NPK + 2 OF	172.36	221.85	-49.49
1 NPK + 3 OF	175.74	186.06	-10.32
P, Control	0	5.79	-5.79
1 NPK	31.44	14.17	17.27
0 NPK + 2 OF	11.68	12.89	-1.21
1 NPK + 1 OF	37.28	15.92	21.36
1 NPK + 2 OF	43.12	18.54	24.58
1 NPK + 3 OF	48.96	14.07	34.89
K, Control	0	5.19	-5.19
1 NPK	49.79	18.91	30.88
0 NPK + 2 OF	5.84	15.03	-9.18
1 NPK + 1 OF	52.71	21.14	31.57
1 NPK + 2 OF	55.63	21.66	33.97
1 NPK + 3 OF	58.55	17.26	41.28

** 1 NPK: 360 urea kg/ha, 200 kg SP36/ha, 200 kg KCl/ha, 1 OF (organic fertilizer): 200 kg/ha (3.38 kg N/ha, 5.84 kg P/ha, 2.92 kg K/ha). **Input is fertilizer and soil, while the output is stover and cobs.

Especially for low C, it can be increased by restoring crop yields and will be good in its application as mulch or the form of biochar (Mensah and Frimpong, 2018; Winarso et al., 2021), while for N elements, it is better to focus on increasing its efficiency because so far, its efficiency still low. The combination of N fertilization between mineral and organic N is proven to be better in increasing N efficiency.

Conclusion

There was an imbalance of nutrients in one growing season in rice fields and dry land. In rice cultivation, with the application of organic fertilizer up to 10 t/ha, the N absorbed by plants or transported at harvest was higher than the input. The balance of N in dry land planted with maize with the application of combined inorganic and organic fertilizers, was negative, but the balance of P and K were positive, except for control and treatments with organic fertilizer only. The application of only organic fertilizer in rice fields and dry land depleted N in the soil.

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