N, P and K fertilization response on maize in Vertisols in Central Java, Indonesia

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Abstract. One of the key factors for the success of maize production is nutrient adequacy through efficient fertilization. To determine the effectiveness of fertilization, a study was conducted to determine the response of maize to N, P, K fertilization on Vertisols. The research was conducted during 3 seasons (2014-2016) in Central Java. The study used omission plots with 5 replications. The fertilizers used for the study were N 200, P2O5 30 to 35, and K2O 75 to 100 kg ha-1. The observed data consisted of climate, soil and yield, and were analyzed descriptively. Vertisols soil in the research location has a heavy clay texture, alkaline pH, low soil organic C and N, high content of Ca, Mg and bases saturation, and cracked in the dry season. The results showed that the average yield from the plot -N (1.8), -P (8.5), -K (8.9), and +NPK (10.0) t ha-1. Based on the data, maize has the highest response to N fertilizer, followed by P and K. The response of maize to N, P, K fertilizers in Vertisols respectively N (8.1), P2O5 (1.5) and K2O (1.0) t ha-1. The agronomic efficiency of N and P fertilization was 41 and 44 kg kg-1, while K was 11 kg kg-1.

1. Introduction

Grobogan Regency is one of the biggest lowland maize producing regions in Central Java Province. At this location, maize became the main source of income for farmers after rice. Maize as a strategic food commodity requires more attention to be able to maintain and even increase yields. One of the key success factors in the production of maize yields is the adequacy level of plant nutrients to achieve optimal results through adequate, balanced and site-specific fertilization.

The concept of balanced and site-specific nutrient management is to consider the capacity of the soil to provide natural nutrients from soil and water, as well as the number of nutrients added through fertilization in previous seasons [1-3]. Since 2002, the concept of site-specific nutrient management has begun to be used in maize plants in the Nebraska United States with a focus on yield potential and yield gaps as a determinant of site-specific fertilizer recommendations [4]. Site-specific nutrient management is an approach to providing appropriate nutrients (dosage, type and time of application) taking into account the needs of plants and soil capacity from the supply of natural nutrients [5].

Maize requires nutrients such as N, P and K more than others, therefore it is often found symptoms of deficiency of these 3 elements. Low fertilization efficiency, inadequate fertilization recommendations at this time, and ignorance of nutrients other than N, P, and K can limit crop production [6]. In addition, low plant productivity can be caused by less intensive maintenance, environmental factors and fertility levels [7]. To improve the effectiveness and efficiency of fertilization in maize, it is necessary to know the reference of fertilizer response. In Africa the relative response of maize to N-P-K fertilizer tends to decrease with soil quality improvement. Soil type greatly affects all aspects of and on the soil surface.
[8]. Soil diversity affects the efficient use of resources mainly through the effect on the efficiency of resource capture. Clear recovery efficiency varies between 0 and 70% for N, 0 and 15% for P, and 0 to 52% for K [9, 10]. Based on the above considerations, a study was conducted in Central Java to determine the effectiveness of N, P and K fertilization on vertisol soil in paddy fields.

2. Methods
The study was conducted during 3 growing seasons (2014-2016) in irrigated rice fields in Toroh and Purwodadi Districts, Grobogan District, Central Java Province. Fertilization response research on maize was conducted in the dry season (June-October) after rice. Water requirements for maize plants at the study site generally depend on the remnants of rainfall with the addition of irrigation from the remnants of water in irrigation channels or rivers using pumps.

Soil characteristics in this study site are dominated by Vertisol soil type with heavy clay texture [11], soil pH 7-8, low organic carbon (C) and nitrogen (N) soil content, high Ca content, Mg and high base saturation. One of the unique and specific characteristics of vertisol is the cracking of soil that occurs during the dry season. Soil sampling was conducted by fusing of a composite from 5 omission plot locations.

The research method of fertilizer response test on maize plants uses an omission plot model with 5 replications implemented in 5 places (farmers). The fertilizing treatment practiced in this study consisted of (1) minus N (+PK); (2) minus K (+NP); (3) minus P (+NK); (4) complete (+NPK). Treatment measures of fertilization in the study of the response of fertilization to maize during 3 growing seasons are presented in Table 1.

Table 1. List of fertilizers dosage in the lowland vertisols of Grobogan District, Central Java

| Fertilizers Rate | 1st season | 2nd season | 3rd season |
|------------------|------------|------------|------------|
| N (kg ha⁻¹)      | 200        | 200        | 200        |
| P₂O₅ (kg ha⁻¹)   | 30         | 35         | 35         |
| K₂O (kg ha⁻¹)    | 75         | 100        | 100        |

Data observations were made for local climatic conditions (rainfall & solar radiation), physical and chemical properties of the soil, maize yields, yield responses to fertilizer applications and agronomic efficiency. Data analysis was carried out using a simple descriptive statistical model, concerning site-specific nutrition management (SSNM) guidelines [12,13].

3. Result and Discussion

3.1. Characteristic of weather in Grobogan District, Central Java
The average climate data (precipitation, relative humidity, temperature, solar radiation) at the research location is presented in Figure 1.

The average annual rainfall at the study site for 3 years (2014-2016) ranged from 1600 to 2500 mm with a monthly average of around 175 mm. Rain distribution for one year is usually divided into 5 wet months (December-April) and 4 to 5 dry months (June-October). The highest intensity of solar radiation generally occurs from June to October. This high solar radiation condition is a climatic condition that is very potential for the growth of maize plants, as long as the water needs can be fulfilled properly.

The cropping pattern at the research location is rice-rice-maize. Usually maize is planted in the dry season (June-October), with irrigation water supply from the remnants of minimum rainfall and adding water from irrigation channels or rivers using pumps. Water supply systems are generally carried out by flowing directly from channels or rivers to the land, or by pouring it into each base of the stem.

3.2. Soil characteristics of irrigated lowland Vertisols in Grobogan District, Central Java
The research location is an irrigated paddy field with Vertisols (Typic Hapluderts) soil type. The soil conditions and characteristics of the study site are presented in table 2.
Figure 1. Data of precipitation, humidity, temperature and solar radiation in Grobogan District, Central Java (2014-2016) [18]

Table 2. Soil properties analysis from omission plot in lowland Vertisols*)

| Soil Properties (0-20 cm of soil surface) | Value |
|------------------------------------------|-------|
| Soil pH (1:2.5 H₂O)                      | 8.3   |
| Soil organic C (g kg⁻¹)                  | 1.18  |
| Total soil N (g kg⁻¹)                    | 0.09  |
| Soil nitrate N (mg kg⁻¹)                 | 80.6  |
| Exchangeable K (cmol c kg⁻¹)             | 0.3   |
| Exchangeable Ca (cmol c kg⁻¹)            | 59.5  |
| Exchangeable Mg (cmol c kg⁻¹)            | 3.4   |
| Capacity of Exchangeable Cation (pH7)    | 24.3  |
| Potential P₂O₅ (HCl 25%) (mg 100g⁻¹)    | 1580  |
| Potential K₂O (HCl 25%) (mg 100g⁻¹)     | 310   |
| Extractable P (Olsen-P, mg kg⁻¹)         | 42    |
| Extractable P (Bray-1, mg kg⁻¹)          | 15    |
| CaCO₃ (%)                                 | 17.6  |
| Texture                                   | clay  |

Based on the data in table 2, it appears that the soil conditions at the study location have specific characteristics such as heavy clay texture with average alkaline soil acidity (pH >8). The soil organic carbon content (C) is low (1.0-2.0%) with very low soil N content (<0.1%). Based on the potential P and K nutrient content (HCl 25%), the nutrient content of P₂O₅ and K₂O is classified as very high, respectively 1,580 mg 100 gr⁻¹ (P₂O₅) and 310 mg 100 gr⁻¹ (K₂O). Meanwhile, the available P nutrient content is also included in the high status, namely >20 ppm for P Olsen and >15 ppm for P Bray. In general, cation exchange capacity (CEC) in Grobogan is moderate (>16 me) which is dominated by cation exchange cations (>20 cmol, kg⁻¹) and Mg (>2.0 cmol kg⁻¹). The dominance of Ca that can be exchanged is shown from the high CaCO₃ content in the soil, which is around 17.6%.
3.3. Grain yield average

The average yield of maize from the omission plots during 3 growing seasons is presented in table 3. Based on the corn yield data as presented in table 3, it can be seen that the average dry shelled maize yield from NPK plots during the 3 growing seasons is around 10.00 t ha⁻¹ (MC, 15.5%). Based on data on the achievement of maize yields from omission plots (-N, -P, -K), the reduction of K fertilizer to 100% (-K plot) shows a decrease in maize yield of 10%. P fertilizer reduction to 100% (-P plots) reduces yields by around 15%. Meanwhile, the reduction of N fertilizer by up to 100% (-N plot) reduces the largest yield by around 82%. These conditions indicate that the response of maize plants to fertilizer N is highest, followed by the response of P fertilizer of 14.9% and K fertilizer. Even according to the result in Uganda [14] maize yields can increase by 120% from maize yields without N fertilization (reduction of N fertilizer to 100%) which is only able to achieve a yield of 1.79 t ha⁻¹.

Table 3. Yield average of maize from omission plot in lowland vertisols of Grobogan District Central Java during 3 seasons

| Fertilizer Treatments | Grain Yield (t ha⁻¹) (Moisture Content 15.5%) *) | 1st season | 2nd season | 3rd season | Average |
|-----------------------|-------------------------------------------------|------------|------------|------------|---------|
| Minus N               |                                                 | 2.35       | 1.70       | 1.47       | 1.8     |
| Minus P               |                                                 | 7.45       | 9.05       | 8.96       | 8.5     |
| Minus K               |                                                 | 8.20       | 9.20       | 9.39       | 8.9     |
| + NPK                 |                                                 | 8.65       | 10.45      | 10.81      | 10.00   |

*) The data are the results of an average of 5 cooperator farmer omission plots

Maize plants that were not given P fertilizer in the Vertisols soil of this paddy field only decreased yield of about 1.5 t. In contrast to the results of research in China, where maize plants were not given P fertilizer, yields decreased by up to 4 t ha⁻¹ compared to NPK fertilizer [15]. While the results of research in Kenya, the reduction in P fertilizer decreased yields sharply enough by 50%, and greater than the reduction in N fertilizer which only decreased by about 43% [16].

3.4. Yield response to N, P and K fertilizer application

By calculating and considering yield gaps from NPK plots and omission plots (-N, -P, -K), it can be seen the response of maize yields to the application of certain fertilizers (N, P or K). The average response of maize yields to N, P and K fertilizers during the 3 harvest seasons in Grobogan Regency is presented in table 4. Based on the response data in table 4, it can be seen that the response of maize plants to N fertilization is highest, at 81.5%, followed by the response of P fertilizer of 14.9% and K fertilizer of 10.4%. The response of NPK fertilizer to maize in Vertisol soils in Grobogan Regency, Central Java is lower than the results of research in Uganda where the response of corn plants to N fertilizer can reach 120% [14]. Fertilization of N in soil advertises on maize plants in Africa has only a response of 32%, whereas for P fertilizer does not seem to provide a real response [17]. The response of maize plants to P and K fertilizers is relatively low, presumably due to the relatively high potential of P and K content in the soil.

Table 4. Yield response of maize to NPK fertilizer application in lowland vertisols of Grobogan District Central Java

| Fertilizer Response | Yield Response (t ha⁻¹) *) | 1st season | 2nd season | 3rd season | Average | Yield Response (%) |
|---------------------|----------------------------|------------|------------|------------|---------|--------------------|
| N                   | 6.3                        | 8.8        | 9.3        | 8.13       | 81.5    |                    |
| P                   | 1.2                        | 1.4        | 1.9        | 1.48       | 14.9    |                    |
| K                   | 0.5                        | 1.3        | 1.4        | 1.04       | 10.4    |                    |
| NPK                 | 8.65                       | 10.45      | 10.81      | 10.00      |         |                    |

*) The data is the difference of yield between the +NPK plot and the omission plot
3.5. Agronomic efficiency (AE)
Agronomic efficiency is the amount of increase in yield per unit of fertilizer applied (kg yield per kg of nutrients). By understanding the agronomic efficiency of applying certain fertilizers, the effectiveness of fertilizer application for plants can be predicted more easily. The results of the calculation of agronomic efficiency of N, P and K in maize in Vertisol soil in paddy fields in Grobogan Regency are presented in Table 5.

| Fertilizer | 1st season | 2nd season | 3rd season | Average |
|------------|------------|------------|------------|---------|
| N          | 32         | 44         | 47         | 41      |
| P          | 40         | 40         | 53         | 44      |
| K          | 6          | 13         | 14         | 11      |

Based on the data in Table 6, N and P fertilizers have agronomic efficiency at a moderate level, namely 41 and 44 kg kg⁻¹, respectively. Meanwhile, K fertilizer has a low agronomic efficiency, which is around 11 kg kg⁻¹. Based on the data above, the application of N and P fertilizers has efficient use as a good fertilizer on increasing maize yields in Vertisol soils (Typic Hapluderts) in Grobogan Regency, Central Java. Conversely, the application of K fertilizer on corn has a relatively low use efficiency on Vertisol soil in paddy fields. The low agronomic efficiency of K fertilizer is thought to be caused by interlayer fixation of element K by montmorillonite mineral (type 2:1) which is one of the specific characteristics of Vertisols. The agronomic efficiency of P fertilizer in Kenya is reported to have decreased by 34.4% if there is a reduction in N fertilizer [16].

4. Conclusion
Soil limiting factors of Vertisols in paddy fields in Grobogan, Central Java are high soil pH, low organic C and N soil content, interlayer fixation of K nutrient minerals and cracks in the dry season.

Maize plants in the application of the complete fertilizers (+NPK) in Vertisols soils in Grobogan Regency are able to achieve a yield of around 10 t ha⁻¹ of dry shelled corn, while reducing N fertilizer to 100% has reduced yields by 81.5%, reducing P fertilizers by 100% decreases yield 14.8% and a reduction in 100% K fertilizer decrease the yield of about 10.4%.

The highest response of maize to N fertilizer in Vertisols in paddy fields was around 8.1 t ha⁻¹, followed by the response of P fertilizer about 1.5 t ha⁻¹ and K fertilizer about 1.0 t ha⁻¹. Fertilizer N and P have medium level agronomic efficiency (AE), while K fertilizer has low AE.

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