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Research Article
Determination of Potassium (K) Fertilizer Requirement for Pepper (*Capsicum annuum* L.) on Inceptisols Soil

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Abstract

Background and Objective: Research on soil test calibration has been conducted through field experiment on pepper responses to potassium (K) fertilization at various K soil nutrient status. The objectives of this study were to determine class of K soil nutrient availability and calculate recommended K fertilizer for pepper cultivation on inceptisols soil. **Methodology:** This study used single location approach, where the treatment were randomized according to split-plot design with three replications and conducted in SP-1 Prafi Manokwari from December, 2012 to July, 2013. The treatment of the main plot is prepare K soil nutrient status through K fertilizer application with 5 doses, namely: 0 X (Very low), 1/4 X (low), 1/2 X (medium), 3/4 X (high) and X (very high). Dose X is application of K fertilizer as much as 367.54 kg K ha^{-1} to achieve very high K content in the soil. Treatment on subplot is the dose of K fertilizer, namely: 0, 40, 80, 160 and 320 kg K_2O ha^{-1}. **Results:** The results showed that K fertilization on soil with very low-medium K soil status has significant effect on the growth and yield of pepper, while high and very high K soil status has not significant effect. Class of K soil nutrient availability based on two extractors for very low, low, medium, high and very high, respectively are as follows: Morgan Vanema (<114, 114 to <228, 228 to <460, = 460 and >460 ppm K) and HCl 25% (<5960, 5960 to <6645, 6645 to <8100, = 8100 and >8100 ppm K). **Conclusion:** The maximum dose of K fertilizer recommended for pepper cultivation on inceptisols with K nutrient availability very low, low and moderate are: 165.00, 148.50 and 127.50 kg K_2O ha^{-1}, respectively, while high-very high class of K nutrient availability does not require fertilization.

Key words: Calibration, potassium, fertilization, inceptisols, pepper

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Red pepper (*Capsicum annuum* L.) is an important vegetable commodity and has high economic value with the widest planting area (19.12%) compared with other vegetables[1]. However, this large planting area has not been accompanied by high productivity. This is because red chili has become staple for daily need. Increasing population number and industries that use pepper as raw materials must be accompanied with increasing pepper need. Chili production average of the last 5 years is 5,501 t ha^{-1}, whereas the production potential of chili can reach 15-20 t ha^{-1}. Lack of chili production led the government must import red chili where each year an increasing number of imports. The average production of pepper during the last 5 years is 1.831.768 t (Export and import statistics 2008-2012, the data is processed). Average consumption of red chili from the last 5 years data is 1,550 kg per capita, higher than the other pepper (chili 1,329 kg per capita and green chili 0246 kg per capita)[2]. Indonesian chili imports mostly from Japan, Hong Kong, Korea, China, Thailand, Singapore, Malaysia and India.

Production of pepper can be increased through planting area expansion, especially in outside of Java. Dryland widespread outside of Java reached 132.88 million hectares which potential to be used for expansion of pepper planting area. However, around 30.78% of the area (40.90 million hectares) is acidic inceptisols soils scattered in Sumatra, Kalimantan, Sulawesi, Maluku and Papua[3,4]. Such soils type generally has low natural fertility and fertilizer is needed to improve the fertility. Fertilization is intended to supply unavailable nutrients to meet plant needs.

Low K nutrient availability is one of limiting factors for plants growth which commonly found in acid soils including inceptisols[3]. Farmers often use high doses fertilizer to meet the nutrient requirements. Each planting seasons, farmers use K fertilizer as much as 150-180 kg ha^{-1} K_2O or KCl 250-300 kg ha^{-1} [5,6]. Continuously high application of chemical fertilizers causing decrease in productivity, land resources quality and environmental pollution. Nutrients excess that not utilized by plants can turn into pollutants and lead to nutrient imbalances and in turn declining plants response[7].

Appropriate fertilizer doses according to plant requirement and soil nutrient availability is key factors for improving the productivity of agricultural lands. Calibration of K soil test is a stage to determine class of nutrients availability and fertilizers recommendation[8]. Calibration of soil test done through field experiments on plant response to fertilization at various soil nutrient status ranging from the lowest to the highest. Thus, K fertilizers can be supplied in the right quantities and specific to each class of K nutrient availability for pepper cultivation.

The research's objective are to: (1) Determine class of K soil nutrient availability for pepper on inceptisols and (2) Calculate the need for K fertilizer recommended for pepper cultivation on inceptisols.

MATERIALS AND METHODS

Study area and time: Making the soil K status was conducted from January-April, 2013 in farmer's fields SP-1 Prafi Manokwari. Study on K soil test calibration was carried out from May-August, 2013 in the same land. Soil analysis conducted at the Laboratory of Soil Research Institute, Jalan H. Juanda Bogor. Chemical properties of inceptisols soil for this study is as follows: pH 4.68 (water: Soil = 1: 5), C/N ratio 8:26 (Kjeldahl), P available 3.02 ppm P (Bray-I), K-exchangable 0.13 cmol kg^{-1} (CH_3COONH_4 1 M, pH 7) and CEC 11:25 cmol kg^{-1} (CH_3COONH_4 1 M, pH 7).

Materials and tools: The materials required are: Pepper seed F1-horizon varieties, KCl (60% K_2O), urea (46% N) and SP-36 (35% P_2O_5), plastic bags, sacks and rapia ropes, composted chicken manure, pesticides and fungicides used in case of pests and diseases outbreaks.

Tools used from nursery to field planting are include seedlings trey, hoes, shovels, buckets, yells, wangkil, machete, hand-sprayer capacity 15 L, weighing 10 kg and ruler with a length of 1 m.

Research methods: The study use single location approach, namely create an artificial soil nutrient status from very low to very high and construct fertilizing experiment on each nutrient status. Placement of treatment is using split-plot design with three replications. Treatment on the main plots is K soil nutrient status, namely K fertilizer application with 5 doses: 0 X (for K status is very low), 1/4 X (low), 1/2 X (medium), 3/4 X (high) and X (very high). Dose X is the number of K as much as 367.54 kg K ha^{-1} or equivalent with 1478.613 kg KCl ha^{-1}, to achieve very high K levels, namely 0.6 g 100 K with NH_4O Ac pH 7.0 as extractors[9].

Treatment on subplot is K fertilizer dose, namely 0, 40, 80, 160 and 320 kg K_2O ha^{-1}. This study consisted of 25 treatment combinations and repeated 3 times so that there are 75 experimental units. Additive linear model of this experimental design is as follows[10]:

$$Yijk = \mu+\rho_k+\alpha_i+\delta_{ik}+\beta_j+(\alpha\beta)_{ij}+\epsilon_{ijk}$$

Where:

Y_{ijk} = Observation value for K soil status ith and K fertilizer dose jth on replication kth
μ = Nilai rata-rata
ρ_k = Effect of replication kth
α_i = Effect of K soil status ith
β_j = Effect of K dose jth
$(\alpha\beta)_{ij}$ = Interaction effect of K soil status ith and P dose jth
δ_{ik} = Random effect of K soil status ith at replication kth
ϵ_{ijk} = Random effect of K soil status ith, P dose jth and replication kth
i = 1, 2,..., 5
j = 1, 2,..., 5
k = 1, 2, 3

Making K soil nutrient status: The land cleared and prepared twice using hand tractor. After second land preparation, two beds were constructed by size: 1.5 m wide, 25 m long and 0.4 m high as experimental plots. Different K soil status created by the addition of KCl fertilizer with a dose every plot, namely: 0, 1.109, 2.218, 3.327 and 4.436 kg per plot. Each dose of the treatment was dissolved in water to reach a volume of 20 L and watered evenly throughout the beds surface. To obtain stable K soil nutrient status where all the K derived from K fertilizers has been turned into the soil, then soil was incubated for 4 months. During the incubation period, every 2 weeks, the soil is stirred to make KCl evenly mixed and grass allowed to grow to accelerate changing in K fertilizer to K soil.

Treatment of K fertilizer dose: After the main plot incubated for 4 months, then split into subplot, 1.5 m width, 5 m long and 0.4 m high. Potassium (K) fertilizers used are KCl with 60% K_2O (laboratory test results). The KCl fertilizer needs for every plots for each dose of K is as follows: 0, 40, 80, 160 and 320 g of KCl per plot. Treatment of K dosage on the subplot carried out a week before the seeds are planted, by broadcasting on soil surface and mix evenly.

Planting and maintenance: Healthy pepper seed planted as many as 1 seed per planting hole, with double row spacing 40×60 cm, so that each plot contained 26 plants. In order to support the growth, basic fertilizer applied namely N and P with a dose of 200 kg N ha^{-1} and 150 kg P_2O_5 ha^{-1} or the equivalent 326.1 g of urea per plot and SP-36 321 428 g per plot. Fertilizer application is done twice, which is 50% urea+100% KCl fertilizer given the day before planting and the remaining 50% of urea given 4 weeks after planting. During the growth, maintenance performed for watering, weeding and pest and disease control.

Observations variable:

- **K soil analysis:** Soil that had been incubated with KCl taken from each plot for K soil analyze using the best K extractors for inceptisols, i.e., Morgan Vanema and HCl 25%
- **Plant height (cm):** Measurements were made from ground level to the top of the highest branch
- **Crown and root dry weight (g):** The plant is cut at the base of the stem to separate the crown and root. Crown and roots dried, then put into oven at 70°C for 2-4 days
- **Content of K in crown (%):** Crown (leaves and stems) that has been dried in oven is milled using blender to form a powder, then analyzed for K content in laboratory
- **Number of fruits harvested per plant:** Harvesting is done when 50% of the fruits surface has changed color to red. The amount of fruit harvested is calculated cumulatively until the last harvest
- **Weight of harvested fruit per plant (g):** Weighing is carried out for all harvested fruit, then calculated cumulatively until the last harvest
- **Weight per fruit (g):** Calculated from the weight of harvested fruit divided by the number of harvested fruit

Data analysis: Effect of K fertilization treatment on pepper response is known through the analysis of variance. If the treatment shows significant difference, then followed with orthogonal polynomials test to determine the responses pattern. Determination of K soil nutrient availability class is refers to Kidder[11], which classify into five classes namely: Very low (<50%), low (50-75%), medium (75-100%), high (100%) and very high (<100%). Critical limit to differentiate K extracted value from each class was determined by regression equation of calibration curve that connecting the value of extractable K (X) with yield (Y) as in the following Fig. 1.

Calculation of K fertilizer is using regression analysis of the yield response curve for each class of K soil nutrient availability. Regression equation is:

$$Y = a+bX+cX^2$$

Where:

a, b, c = Regression coefficient
X = Dose of K fertilizer (K_2O kg ha^{-1})
Y = Maximum yield (%). The maximum dose (K fertilizer requirement to achieve maximum yield) was calculated by assuming that the maximum yield is achieved at 100% yield

Table 1: Response of pepper height to K fertilization in different K soil status

K dose (kg K_2O ha^{-1})	K soil status with addition of K fertilizer (kg K ha^{-1}) 0 (0 X)	91.89 (1/4 X)	183.77 (1/2 X)	275.66 (3/4 X)	367.54 (X)
Plant height at 4 MST (cm)					
0	32.8	33.8	35.2	45.7	45.3
40	33.4	36.1	37.8	46.2	45.8
80	37.5	40.1	40.9	46.9	46.3
160	44.4	46.2	47.4	47.1	46.5
320	48.1	47.9	48.4	47.2	46.7
F-value	33.45**	25.32**	22.42**	0.21^{ns}	0.19^{ns}
Response pattern	L**	L**	L**	-	-
Plant height at 8 MST (cm)					
0	58.3	60.2	62.7	81.6	80.9
40	59.3	64.3	67.3	82.4	83.5
80	66.8	71.5	77.6	87.3	86.5
160	79.2	82.4	86.9	85.8	85.3
320	85.8	85.5	84.7	84.2	84.9
F-value	33.64**	25.53**	8.34**	0.16^{ns}	0.29^{ns}
Response pattern	L**	L**	Q**	-	-

Significant at p<0.01, ns: Not significance, L: Linear response pattern, Q**: Quadratic response pattern

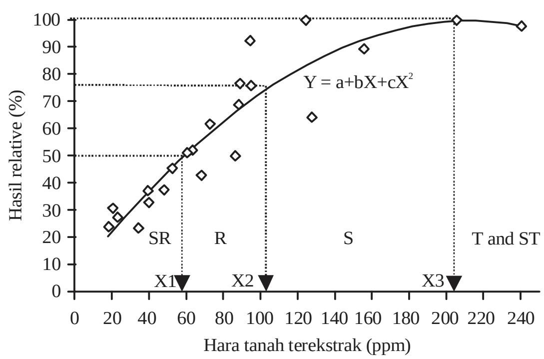

Fig. 1: Calibration curve to determine the critical limit value of K extractable

RESULTS AND DISCUSSION

Plant response on K fertilization

Plant height: Plant height response on K fertilizer is determined by K soil status. The K fertilization on very low (0 X) to medium (1/2 X) K soil nutrient status has significant effect on pepper height, while high (3/4 X) and very high (X) nutrient status has not significant effect on plant height (Table 1). This finding is closely related to K availability at each soil nutrient status. In general, results of K soil analysis indicate that K extracted value on very low to moderate nutrient status lower than high and very high. Lower K availability causes K fertilization provide significant response to pepper height. In contrast, high K availability in the soil causing K fertilization does not provide significant response to the height of pepper.

Increasing K fertilizer doses on soils with very low and low K status will increase plant height linearly, while on medium status show quadratic pattern. Meanwhile, increasing K doses on soils with high-very high K status has not significant effect on plant height. This indicated that pepper plants on soil with very low to medium K soil nutrient status depends more on K fertilization, while high and very high K soil status does not depend on K fertilization because of its availability in the soil has been fulfilled. In soils with low K availability status need potassium to provide optimum plant growth[12].

Biomass dry weight: Results of analysis of variance showed significant interaction between treatment of K soil status and K fertilization on the dry weight of roots and crown. At very low K soil status (0 X) and low (1/4 X), K fertilization dosages up to 320 kg K_2O ha^{-1} will improve crown and root dry weight in linear manner (Table 2). While on medium K soil status (1/2 X) and crown dry weight has quadratic pattern to K fertilization. The K fertilization up to 160 kg K_2O ha^{-1} is still increasing crown and root dry weight, but at higher dose will reduce the dry weight of roots and crown.

At high (3/4 X) and very high (X) K soil status, K fertilization did not significantly affect the dry weight of roots and crown. Even without K fertilization, the growth of pepper looks very well and no different from plants treated with K fertilizer. The K soil availability seems to be sufficient, so that K fertilization did not provide significant response to the growth of roots and crown. As one of the essential nutrients, potassium availability in the soil is an

Table 2: Response of biomass dry weight of pepper to K fertilization at different K soil status

	K soil status with addition of K fertilizer (kg K ha^{-1})				
K dose (kg K_2O ha^{-1})	0 (0 X)	91.89 (1/4 X)	183.77 (1/2 X)	275.66 (3/4 X)	367.54 (X)
Root dry weight (g per plant)					
0	5.4	5.7	6.3	9.9	10.3
40	6.5	6.7	6.6	10.7	11.1
80	7.9	8.5	8.9	11.1	10.7
160	9.5	10.5	11.2	11.3	12.1
320	11.0	12.6	10.9	11.2	11.8
F-value	39.96**	63.11**	10.32**	1.36^{ns}	2.86^{ns}
Response pattern	L**	L**	Q**	-	-
Crown dry weight (g per plant)					
0	22.51	23.95	26.43	40.91	42.29
40	27.05	27.97	27.29	44.04	45.32
80	32.20	35.14	36.74	44.10	44.90
160	39.31	43.30	45.94	46.52	49.55
320	44.44	51.52	44.56	46.12	48.34
F-value	39.64**	65.07**	10.56**	1.69^{ns}	2.84^{ns}
Response pattern	L**	L**	Q**	-	-

Significant at p<0.01, ns: Not significance, L: Linear response pattern, Q**: Quadratic response pattern

Table 3: Pepper yield response to K fertilization at different K soil status

	K soil status with addition of K fertilizer (kg K ha^{-1})				
K dose (kg K_2O ha^{-1})	0 (0 X)	91.89 (1/4 X)	183.77 (1/2 X)	275.66 (3/4 X)	367.54 (X)
Number of fruits (fruit per plant)					
0	23.9	25.5	28.2	43.6	45.0
40	28.8	31.8	29.0	46.9	48.2
80	34.3	36.1	39.1	49.1	48.5
160	40.5	43.4	48.9	49.2	52.7
320	45.2	49.2	47.4	46.9	51.5
F-value	33.95**	41.21**	11.25**	0.35^{ns}	2.91^{ns}
Response pattern	L**	L**	Q**	-	-
Weight per fruits (g)					
0	9.62	9.90	9.92	11.04	11.39
40	10.41	10.44	10.52	11.41	11.98
80	11.11	10.89	12.22	12.20	12.19
160	11.58	11.56	12.88	12.18	11.77
320	12.25	12.36	11.91	12.07	11.76
F-value	24.72**	24.22**	23.92**	3.33^{ns}	0.01^{ns}
Response pattern	L**	L**	Q**	-	-
Weight of harvested fruits (g per plant)					
0	267.10	284.08	313.81	487.53	504.18
40	321.97	349.18	324.69	524.94	540.52
80	384.11	411.73	437.58	549.82	533.36
160	436.77	485.83	547.95	550.66	577.53
320	505.75	550.63	531.70	525.64	576.46
F-value	29.90**	37.75**	10.28**	0.31^{ns}	2.57^{ns}
Response pattern	L**	L**	Q**	-	-

Significant at p<0.01, ns: Not significance, L: Linear response pattern, Q**: Quadratic response pattern

important factor affecting the growth of roots and crown of pepper. This relates to the function of potassium to increases root growth thereby increasing the absorption of water and nutrients[13].

Yield: Statistical analysis showed that pepper response to K fertilization is affected by K soil status. The K fertilization on very low to moderate K status has significant effect to some components of yield, while for high and very high K status, K fertilization did not have significant effect on some components of yield (Table 3). This suggests that K soil nutrient status will determine plant responses to K fertilizer. Higher K soil nutrient status, the lower plant responses to K fertilization. The K fertilization on higher K soil nutrient status

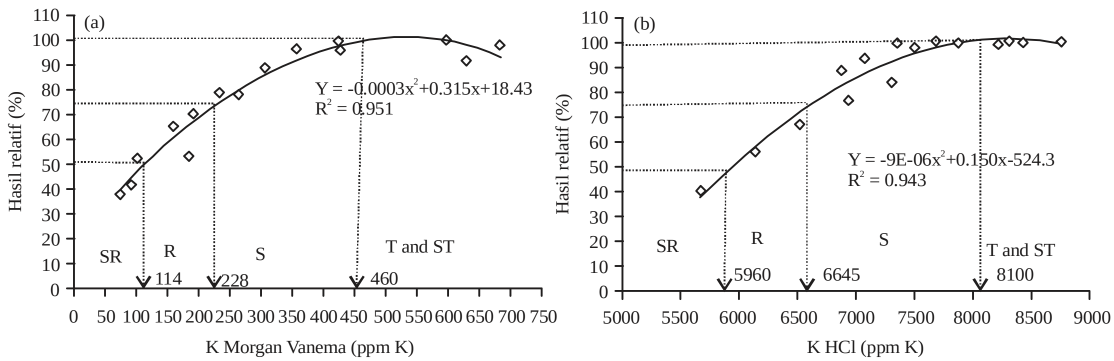

Fig. 2(a-b): Critical limits value of K extracted on pepper yield (a) Morgan Vanema and (b) 25% HCl

Table 4: Class of K nutrient availability for pepper on inceptisols soils

		Interval value of K extracted (ppm K)	
Class of K nutrient availability	Relative yield (%)	Morgan Vanema	HCl (25%)
Very low (SR)	<50	<114	<5960
Low (R)	50-<75	114-<228	5960-<6645
Medium (S)	75-<100	228-<460	6645-<8100
High (T)	= 100	= 460	= 8100
Very high (ST)	<100	>460	>8100

resulted in lower increase on some yield components, such as the number of fruits, weight per fruit and the weight of harvested fruit. For example, the percentage increase in the maximum weight of harvested fruit in very low to moderate status reach 63-94%, while high and very high only reached 8-14%.

The K fertilization at a dose of 320 kg K_2O ha^{-1} produce the highest number of fruits, weight per fruit and yield weight on very low and low K status. On medium K soil status, the highest yield achieved by K fertilization at 160 kg K_2O ha^{-1}. While for high and very high K soil status, K fertilization did not significantly affect yield. This shows that soil contribution to provide nutrients for plants must be considered. At very low to moderate K soil status, contribution derived from fertilizer application. Instead, at high and very high K soil status, greater contribution comes from soil.

Class of K soil nutrient availability: The K extracted value of the selected method does not have agronomic meaning prior to calibrate with yield response. Calibration test provides information on adequacy of nutrient availability class for plants, so it can be used as a basis in determining fertilizer requirement. Kidder[11] classified the class of nutrient availability into 5 categories based on relative yield response, namely: (1) Very low, if the relative yield <50%, (2) Low, 50-75%, (3) Medium, 75-100%, (4) High = 100% and (5) Very high <100%. Each nutrient availability class is limited by critical values determined by calibration curve (Fig. 2). For Morgan Vanema extractors, K critical limit value which distinguishes class availability for very low, low and moderate are 114, 228 and 460 ppm K, respectively. Meanwhile, for HCL 25%, K critical limit values are 5960, 6645 and 8100 ppm K, respectively.

According to predetermined critical limit value, it can be constructed K extracted interval value for each availability class, as shown in Table 4. Criteria of K extracted using Morgan Vanema for each nutrient availability class is: (1) Relatively very low, if the value of K extracted <114 ppm K, (2) Low, 114 to <228 ppm K, (3) Medium, 228 to <460 ppm K, (4) High, = 460 ppm K and (5) Very high, >460 ppm K. Meanwhile, criteria for K extracted using HCl 25% are: (1) Relatively very low, if the value of K extracted <5960 ppm K, (2) Low, 5960 to <6645 ppm K, (3) Medium, 6645 to <8100 ppm K, (4) High, = 8100 ppm K and (5) Very high, >8100 ppm K. The difference of critical limit of the two methods indicates that criteria for assessing nutrient conditions will be different when use different extractors.

Requirement of K fertilizer: Determination of K fertilizer requirement can use generalized curve of K fertilization for each class of K soil nutrient availability. Fertilizer requirement is specified as the maximum dose to achieve 100% relative yield according to regression equation in yield response

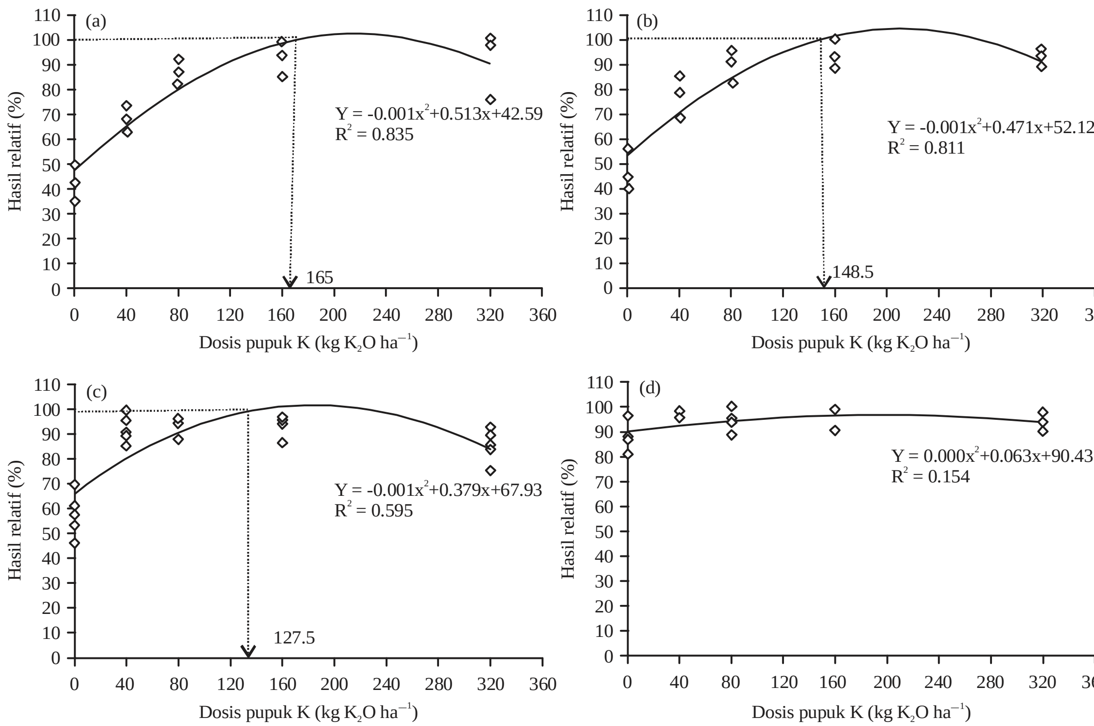

Fig. 3(a-d): Response of relative yield to K fertilizer application on pepper on different classes of K availability on inceptisols, Kelas ketersediaan hara (a) K sangat rendah, (b) K rendah, (c) K sedang and (d) K tinggi dan s. tinggi

Table 5: K fertilizer recommendation for pepper in various classes of K availability on inceptisols

Classes of K availability	Regression equation	R^2	Maximum dose K_2O (kg ha^{-1})	Maximum dose KCl (kg ha^{-1})
Very low	$Y = 42.59+0.513X-0.001X^2$	0.835	165.00	275.00
Low	$Y = 52.12+0.471X-0.001X^2$	0.811	148.50	247.50
Medium	$Y = 67.93+0.379X-0.001X^2$	0.595	127.50	212.50

curve (Fig. 3). Based on the curve, the calculation of K fertilizer requirement is only can be done for very low, low and medium class. Meanwhile, for high and very high class of K nutrient availability is not necessary because the plants did not respond to fertilization.

From the response curve, it can be seen that the recommended K dose on very low nutrient availability is higher than low and medium. Such difference shows that the higher K soil concentration, the higher nutrients available to plants so that fertilizer requirement will be reduced.

Pepper yield response show quadratic pattern on K fertilizer application. Addition of K fertilizer dose to a sufficient nutrients level can improve crop yield, but if the dose exceeds adequacy then crop yields begin to decline. Quadratic equation show maximum dose of K fertilizer for each class of K soil nutrient availability.

The maximum dose of K fertilizer required to achieve maximum yield (yield 100%) was showed by very low K availability, then decreased to the lowest in medium availability. The regression model that describes yield-dose response pattern to calculate K fertilizers requirement in various class of K soil nutrient availability is shown at Table 5.

The K fertilizer recommendation for pepper on inceptisols organized into three classes of K soil nutrient availability. In very low class, the maximum recommended dose is 165.00 kg ha^{-1} K_2O or equivalent to KCl 275 kg ha^{-1}, low class is 148.50 kg K_2O ha^{-1} or equivalent to KCl 247.50 kg ha^{-1} and medium is 127.50 kg K_2O ha^{-1} or equivalent to KCl 212.50 kg ha^{-1}.

In high and very high class of K soil nutrient availability, K fertilizer is not necessary because response of harvesting fruit weight showed no significant improvement. This is consistent with the basic philosophy of fertilization using nutrients sufficient levels, namely the addition of fertilizer only when the soil is not capable of supplying nutrients to plants.

CONCLUSION

- The K Fertilization has significant effect on the growth and yield of pepper on inceptisols with K soil status is very low to medium, while the effect on high and very high is not significant
- Criteria of K extracted using Morgan Vanema for each nutrient availability class is: (1) Relatively very low, <114 ppm K, (2) Low, 114 to <228 ppm K, (3) Medium, 228 to <460 ppm K, (4) High, = 460 ppm K and (5) Very high, >460 ppm K. Meanwhile, criteria for K extracted using HCl 25% is: (1) Relatively very low, <5960 ppm K, (2) Low, 5960 to <6645 ppm K, (3) Medium, 6645 to <8100 ppm K, (4) High, = 8100 ppm K and (5) Very high, >8100 ppm K
- The maximum dose of K fertilizer recommended to pepper on inceptisols for very low, low and medium are: 165.00, 148.50 and 127.50 kg K_2O ha^{-1} or equivalent to 275.00, 247.50 and 212.50 kg KCl ha^{-1}, whereas high and very is not required K fertilization

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