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Assessing five different soil nutrient extraction techniques on Cambisols for a practical evaluation of potassium and phosphorus availability in chili cultivation

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Abstract

Phosphorus (P) and potassium (K) are essential nutrients for plant growth and development. Plants will achieve optimum biomass and production if phosphorus and potassium needs are met through fertilization. Determining the availability of phosphorus and potassium in the soil is essential because it is related to deciding phosphorus and potassium fertilizer rate recommendations. In this study, we evaluated five common phosphorus and potassium extraction methods by correlating the indicated soil nutrient levels to the relative dry-weight biomass of chili plants. The phosphorus and potassium extraction methods were Mehlich–1, Bray–1, Morgan–Wolf, Ammonium acetate, and HCl–25%. Mean Root Error (MRE) and Root Mean Square Error (RMSE) were used to determine the precision of the linear regression equation model in predicting the relationship between phosphorus and potassium soil extraction methods and the relative dry-weight biomass of chili plants. The correlation of the soil extraction methods of Cambisols with relative dry-weight biomass of chili was highly significant and very strong ($r > 0.75$), suggesting that the best soil-phosphorus extraction method for determining concentrations for optimal growth of chili was Morgan–Wolf ($r = 0.96$) with MRE = 0.21 and RMSE = 6.87. The Mehlich-1 with $r = 0.91$, MRE = 0.91, and RMSE = 5.60 was the best Cambisols potassium-extraction method.

1. Introduction

Each soil type has a different nutrient composition because the availability of nutrients in the soil is diverse and flexible. Soil structure, texture, and the activity of soil microbes also affect the formation of nutrients in the rhizosphere near root plants (Husnain et al., 2021; Lal, 2017; Paul, 2015). The chemical and biological properties of the soil also play a role in the level of nutrient availability. Al–P and Fe–P bonds in acid soils result in low P availability (Weil et al., 2017). Phosphorus in the soil matrix is typically present in the form of phosphate. This ion interacts with aluminium and iron oxides in acid soils, forming surface-bound or adsorbed complexes. Adsorbed phosphate reduces phosphorus availability to the plant (Channarayappa et al., 2019). The availability of potassium for plants is also limited. Approximately 90–98% of the total potassium in the soil, is slowly even not available to plants. K bound in the primary mineral structure is very difficult for plants to absorb. Available potassium is generally in the form of soil solution or cation exchange area, about 1–2% of the total potassium in the soil (Marschner, 2012).

The Cambisols based on WRB Classification are mainland Indonesia's most widely distributed soil order (Hati et al., 2016). An important factor in cultivating vegetables on Cambisols land is identifying nutrient availability. Management of the wrong nutrients through poor cultivation techniques will affect and limit their availability so that crop production will decrease (Chowdhury et al., 2019). Most Cambisols in Indonesian have a clay content of between 18–78%, are acidic a soil pH of 4.6–6.8, have a low to medium C/N ratio, P–potential from low to high, K-potential (very low-moderate), cation exchange capacity (medium-high) and base saturation (low-high) (Izhar et al., 2013). Under these conditions, it requires high input, both in the form of inorganic materials (N, P, and K fertilization) and organic materials (compost, manure, or green manure) (Gunawan et al., 2019; Yuniarti et al., 2019). Amisnaipa et al. (2014) found that the nutrient content of phosphorus and potassium in Cambisols was low and varied. Therefore, proper fertilization techniques are needed, including determining the dosage of phosphorus and potassium fertilizers.

The availability of phosphorus and potassium nutrients in the soil is essential for the growth and development of plants, including chili (Aprianto et al., 2020; Hossain et al., 2017). Phosphorus is used to form roots (Jones, 2012) and stems, whereas potassium helps develop flowers and fruit (Mitra, 2015; Widyanti et al., 2015). Potassium availability in the soil is strongly influenced by the cations adsorbed on the soil fraction. Soil-nutrient extraction methods are used to determine the availability of nutrients in the soil (Koralage et al., 2015; Panda et al., 2018; Spargo, 2016). By knowing precisely the availability of phosphorus and potassium in the soil, we can determine the precise fertilization dosage for plants, including chili plants. Precision fertilization will provide the right amount of fertilizer for the growth and development of chili plants to produce maximum yield. Thus, farmers will not be wasteful in providing fertilizer so that they can harvest chilies optimally while increasing the efficiency of fertilizing costs.

A correlation test was first carried out to determine which phosphorus and potassium extraction method produced a high correlation between extracted available phosphorus and potassium chili plant growth, represented by the weight of relatively dry chili plants. The high correlation coefficient value ($r > 0.70$) indicates that the extraction method can extract available phosphorus and potassium more accurately so that plants can absorb these nutrients. The nutrients absorbed and utilized in plant metabolism can be seen in the relative value of the dry weight of the biomass.

An appropriate soil phosphorus and potassium extraction method will accurately describe the phosphorus and potassium nutrient content in the context of plant growth. This information is vital in determining accurate fertilizer rate recommendations for each soil and crop type, including chili. A correlation test was performed to select the proper phosphorus and potassium extraction methods for certain soil types and vegetables (Culman et al., 2019). The extraction method correlation test will not give a significant value if it is not related to the agronomic variables of the plant (Widyanti et al., 2015).

In Indonesia, soil analysis laboratories use the Bray–1, Olsen, HCl–25%, and Ammonium acetate methods to test soil phosphorus and potassium for all types of soil to determine fertilizer doses for all plant species. Several laboratories have used Morgan–Wolf and Mehlich–1 to analyze the availability of phosphorus and potassium content in the soil. In fact, for optimal results, each type of soil should have its own soil extraction method to find out every nutrient available in that soil (Koralage et al., 2015). However, which extraction method is best for each soil type and plant is not yet known. In this research, the correlation test will provide an overview of the closeness and direction of the relationship between soil Phosphorus and potassium-extraction methods and the relative dry weight of chili and help us to determine the best phosphorus and potassium extraction method in Cambisols for chili cultivation.

2. Materials and methods

The research was conducted from February to June 2021 at the Experimental Farm of the Center for Tropical Horticultural Studies (PKHT), IPB University at Tajur, Bogor. Fifthy Cambisols samples were collected from a location near Margamulya Village, Pangalengan Regency, Indonesia, 7°10'00.4"S 107°34'14.2"E. Soil sampling is based on the diagonal method (Dari et al., 2019) on the 250 m^2 research area. With this method, there are 25 sample points with a distance of about 1 m between sample points on each diagonal.

The first Cambisols activity began with taking Cambisols samples, which were carried out using the diagonal method (Dari et al., 2019). Soil samples were collected by spade, taken 25–30 cm from the top of the soil, and then homogenized by mixing them for 10 minutes. Soil tests to characterize the soil were performed at the Soil Chemistry and Fertility Laboratory, Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University. The laboratory tested the phosphorus and potassium content of the soil samples using five extraction methods (Mehlich–1, Bray–1, Morgan–Wolf, Ammonium acetate, and HCl–25%) (Adesanwo et al., 2013; Amisnaipa et al., 2014; Brown, 1987; Gunawan et al., 2019; Lumbanraja et al., 2017; Morgan et al., 2010; Westerman, 1990). The results of these tests for the homogenized soil samples are summarised in (Table 1).

The material plants used in this study were Bonita IPB chili seeds, urea, superphosphate, and potassium chloride. The pots used were 25 × 30 cm, digital scales and calipers, and an oven. A total of 6 kg of soil was put into a pot in a plastic house. The pots are arranged using a randomized complete block design (RCBD), which is repeated five times. Chili seeds were sown using a mixture of cocopeat and roasted husks with a ratio of 1:1 (w/w). Chili seeds that are 21 days after sowing are replanted into pots. Watering the plants is done using an automatic fertigation machine. The fertigation machine flushes 3 times a day at 07.00 am, 1.00 pm, and 4.00 pm. The volume of watering is

Table 1
Characteristic of the studied Cambisols from Pangalengan, Indonesia

Soil type	Soil analysis[a)]				
	pH	C-organic (%)	N-total (%)	Available nutrient (mg kg^{-1})	
				Phosphorus (P_2O_5)	Potassium (K_2O)
Cambisols, Pangalengan	6.21	3.57	0.52	12.83	260.77
Method	pH meter	Walkley and Black	Kjeldahl	Mehlich–1	Mehlich–1

250 mL per pot. Chili fertilization uses 1.3 g pot^{-1} of urea, 1.4 g pot^{-1} of superphosphate, and 0.9 g pot^{-1} of potassium chloride. The phosphate correlation test only used urea and potassium chloride, while in the K-correlation test, fertilization only used urea and superphosphate. Chili plants are harvested entirely or removed from the pot after 40 days after planting.

The variable observed in chili plants is relative dry biomass weight (DBW). Chili plants were placed in an oven at 70°C for three days. The ratio between the dry weight of biomass for specific nutrient treatments and the maximum dry weight of biomass for phosphorus and potassium correlation test. The calculation refers to Gunawan (2019) with the formula:

$$\text{Relative dry biomass weight (DBW)} = \frac{Y_i}{Y_{\max}} \times 100\% \qquad (1)$$

Description: Y_i = dry weight of biomass in the phosphorus and potassium treatments; Y_{max} = maximum dry weight of biomass at phosphorus and potassium treatments. The magnitude of the error model of the linear regression equation with the formula:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \quad \text{and} \quad \text{MRE} = \frac{\sum_{t=1}^{n}|x_i - y_i|}{n\ x\ x_i} \qquad (2)$$

Description: x_i = actual measurement; y_i = prediction measurement; RMSE = Root Mean Square Error; MRE = Mean Relative Error.

3. Results

3.1. Soil properties of Cambisols, Pangalengan, Indonesia

The characteristics of the studied Cambisols from Pangalengan, Indonesia soils are shown in Table 1. Based on the soil analysis procedure by Hazelton et al. (2016), the Cambisols taken from research sites in Pangalengan have high C–organic and total N–content, but at pH = 6.21 was slightly acidic.

3.2. Cambisols phosphorus and potassium-soil extraction methods for chili

The best Cambisols phosphorus and potassium-soil extraction methods for chili plants were determined by considering the correlation coefficient (r), coefficient of determination (R^2), significance, RMSE, and MRE values. The results showed that all the phosphorus-soil extraction methods for Cambisols were positively correlated to the increase in the relative dry weight of chili plants with high determination correlation ($R^2 \geq 0.8$) (Fig. 1).

For the phosphorus correlation with dry weight, the Morgan–Wolf extraction method showed a positive slope and the highest closeness relationship to the relative dry weight of chili plants (r = 0.96) (Table 2). Based on the values of r and R^2, the largest to the most negligible relationship is Morgan–Wolf >

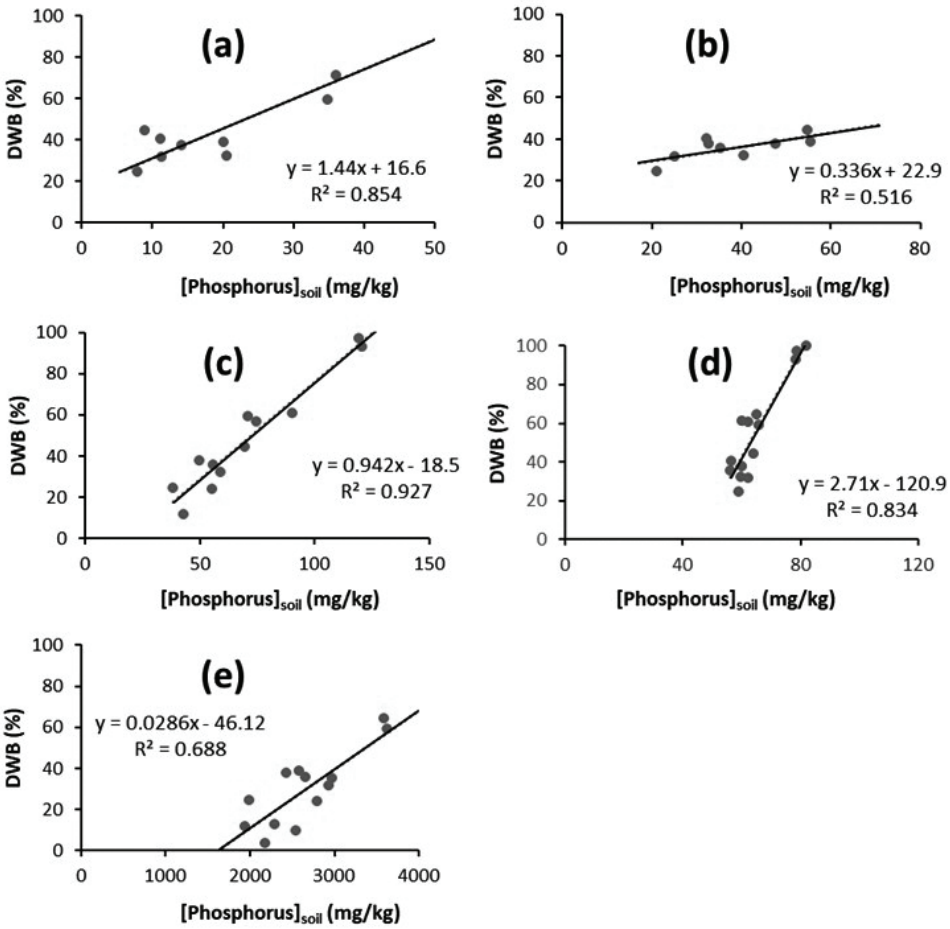

Fig. 1. Linear correlation between P-soil extraction methods and dry biomass weight (DBW) of chili in Cambisols. (a) Mehlich–1; (b) Bray–1; (c) Morgan–Wolf; (d) Ammonium acetate; (e) HCl–25%

Table 2
Relationship between the phosphorus extraction methods and the relative dry weight of chili plants as determined using a Linear Regression Model

Phosphorus-soil Extraction Methods	Regression Equations	r	MRE	RMSE	p-value
Mehlich–1	Y = 1.440x + 16.65	0.92	0.16	8.26	0.00**
Bray–1	Y = 0.336x + 22.93	0.72	0.09	3.76	0.02*
Morgan–Wolf	**Y = 0.942x – 18.52**	**0.96**	**0.21**	**6.87**	**0.00****
Ammonium acetate	Y = 2.713x – 120.85	0.91	0.20	9.99	0.00**
HCl–25%	Y = 0.029x – 46.20	0.83	0.65	9.86	0.00**

Note: Y is response or dependent variable and X is predictor or independent variable.

Mehlich–1 > Ammonium acetate > HCl–25% > Bray–1. To validate the linear regression equation model P (Y = 0.942x – 18.52) correlation test on Morgan-Wolf, the MRE = 0.21 and RMSE = 6.87 values were obtained.

In the potassium-correlation test, the Mehlich-1 extraction method showed a positive slope and the highest closeness relationship to the relative dry weight of chili plants (Fig. 2). The Mehlich–1 had the highest correlation coefficient value (r = 0.91) (Table 3). Based on the values of r and R^2, the strength of this relationship from highest to lowest was Mehlich–1 > Morgan–Wolf > Bray–1 > Ammonium acetate > HCl–25%. The MRE = 0.24 and RMSE=5.60 in the Mehlich–1 linear regression equation (Y = 0.061x + 3.06) model was smaller than in other extraction methods. The smallest MRE and RMSE values suggest that the Morgan–Wolf and Mehlich–1 linear regression equation model is precise.

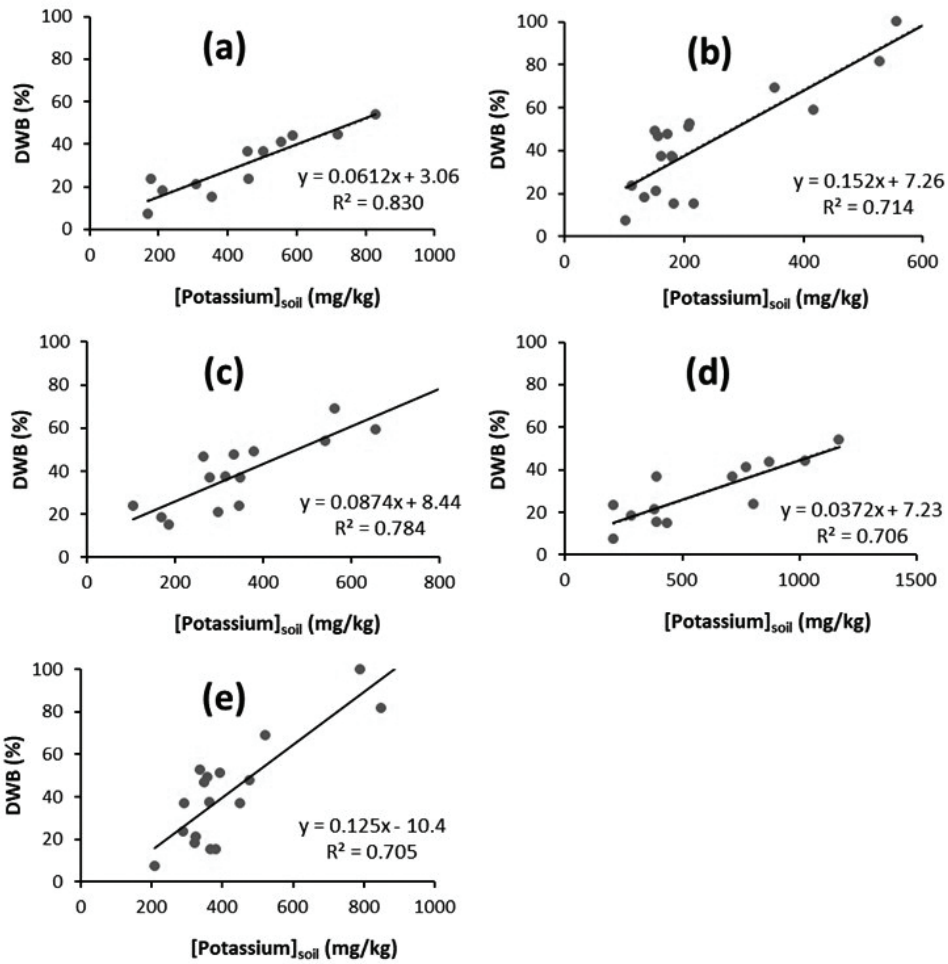

Fig. 2. Linear correlation between potassium-soil extraction methods and dry biomass weight (DBW) of chilis grown in Cambisols. (a) Mehlich–1; (b) Bray–1; (c) Morgan–Wolf; (d) Ammonium acetate; (e) HCl–25%

Table 3
Relationship between the potassium-Inceptisols extraction methods and the relative dry weight of chili plants as determined using a Linear Regression Model

Potassium-soil Extraction Methods	Regression Equations	r	MRE	RMSE	p-value
Mehlich–1	**Y = 0.061x + 3.06**	**0.91**	**0.24**	**5.60**	**0.00****
Bray–1	Y = 0.152x + 7.26	0.85	0.47	12.79	0.00**
Morgan–Wolf	Y = 0.087x + 8.44	0.89	0.25	8.75	0.00**
Ammonium acetate	Y = 0.037x + 7.23	0.84	0.30	7.40	0.00**
HCl–25%	Y = 0.125x – 10.41	0.84	0.33	13.19	0.00**

Note: Y (response/dependent variable) and X (predictor/independent variable).

4. Discussion

The soil's acidity causes the availability of nutrients, especially phosphorus and potassium, to disrupt plants (Barker et al., 2015). Under acidic conditions (pH < 7), phosphorus and potassium will be bound by Al and Fe. The low availability of phosphorus and potassium in Cambisols has also been reported previously (Izhar et al., 2012). Root growth will be hampered, and plant roots will be shortened in more severe conditions. As a result, this will disrupt nutrient transport, resulting in plants experiencing nutrient deficiencies in plant tissues such as stems and leaves. Therefore, when planting in Cambisols, it is necessary to apply phosphorus and potassium fertilization to overcome these limitations (Hati et al., 2016; Widyanti et al., 2015).

In the regression equation model, it can be seen that there is a negative intercept on the phosphorus and potassium correlation. This shows that the range of values of the independent variable (the value of the extraction method) does not include zero as one of the observed values, but the range value is outside the data (extrapolation). Therefore, the intercept value cannot be interpreted. Only when x = 0 is within the range of the extraction method values in the sample and is a practical value will it have a meaningful interpretation (Mendenhall et al., 1996). The five phosphorus and potassium extraction methods responded differently to the relative dry weight of chili in Cambisols. A different relationship was obtained when correlated with the relative dry weight of the chili collected from each of the respective treatments.

The result shows that each phosphorus and potassium extraction method works specifically and differently. Based on the values of r, R^2, MRE, and RMSE, it can be concluded that the best phosphorus and potassium extraction methods in Cambisols for chili cultivation were Morgan–Wolf and Mehlich–1. This is caused by the ability of the different solutions in each extraction method to extract phosphorus and potassium. In addition, the pH of the constituent solutions also reacts differently to Cambisols. These two things are the main factors for the differences in phosphorus and potassium availability in each extraction method. Previous research conducted on Andisols soil, found that the Morgan-Wolf and Ammonium acetate methods had high correlation values between P and K concentration in soils with chili plant biomass (Dermawan et al., 2022).

The Morgan–Wolf constituent solution is sodium acetate (NaOAc) and acetic acid (CH_3COOH). Sodium acetate solution is the basic salt of acetic acid, which functions as a buffer solution to maintain the stability of the pH of the solution at pH 4–6. The pH of the Morgan–Wolf solution is 4.8. Even though it is a weak acid, it can dissolve polar compounds such as salt and sugar, as well as non-polar compounds (such as oil) and also elements (such as iodine and sulfur). Mehlich–1 is composed of two acids, HCl and sulfuric acid (also called double acid extraction or North Carolina extraction), so that it can extract nutrients better and more precisely on acidic soils such as Cambisols, fast, easy, and cheap extraction method (Ferrando et al., 2020; Shahandeh et al., 2017; Zhu et al., 2016).

5. Conclusions

The correlation of the soil extraction methods of Cambisols with relative dry-weight biomass of chili was highly significant and very strong (r > 0.75), suggesting that the best soil-phosphorus extraction method for determining concentrations for optimal growth of chili was Morgan–Wolf (r = 0.96) with MRE = 0.21 and RMSE = 6.87. Meanwhile, Mehlich–1, with r = 0.91, MRE = 0.91, and RMSE = 5.60, was the best method for Cambisols potassium extraction. The two methods above can be used as a reference in determining the dose of P and K fertilizer, especially in Cambisols of Pangalengan, Indonesia.

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