Ilmu Pertanian (Agricultural Science)
http://journal.ugm.ac.id/jip
Vol. 10 No. 1 April, 2025: 105–113| DOI: doi.org/10.22146/ipas.108285

Analysis of factors affecting differences in potassium buffering capacity in several soil orders

Permata Harty Noor Fajarini, Eko Hanudin*, Benito Heru Purwanto

Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada
Jl. Flora, Bulaksumur, 55281, Sleman, Yogyakarta, Indonesia
*Corresponding author: ekohanudin@ugm.ac.id

Article Info

Received : 23rd June 2025
Revised : 21st August 2025
Accepted: 22th August 2025

Keywords:
Andisols, alfisols, inceptisols, potassium buffering capacity, vertisols

Abstract

Each soil order has different reactivity to potassium ion retention capacity, especially potassium buffering capacity. These differences are related to soil characteristics, including clay mineral content and type, cation exchange capacity, and soil texture class. This study compared the potassium buffering capacity (PBCk) of Andisols, Alfisols, Inceptisols, and Vertisols. The PBCk experiment reacted 2.5 grams of air-dried soil (passing a 0.5 mm sieve) and 25 ml of KCl solution with a series of concentrations of 0, 25, 50, 75, 125, 150, 175, 200, 225, and 250 ppm. Then, it was shaken for 24 hours to reach equilibrium conditions. The next day, the solution was centrifuged to obtain a clear solution. The remaining K content in the equilibrium solution was measured using a flame photometer. The amount of K read was calculated to obtain the Q/I factor and PBCk value from the gapon equation. The Q/I relationship was used to estimate PBCk values for each soil order with changes in K in the solution or Q (ΔK) as the X axis and the intensity of K or I (CRk) as the Y axis. Then, the K intensity data were connected to the PBCk results to determine the buffer capacity of the four soil orders. Vertisols showed the highest PBCk (1.099 cmol kg^{-1}/mol $L^{-1})^{0.5}$, followed by Andisols, Alfisols, and Inceptisols. The determining factors include clay minerals in the form of smectite (2:1), high CEC value, and soil texture dominated by clay.

INTRODUCTION

Plants require approximately 1% (~10,000 mg/kg) potassium, which can be absorbed as K^+, and its availability in the soil is essential for maintaining plant productivity. Potassium is essential for enzyme activation, water regulation, protein and starch synthesis, and energy processes in plants (Mas'ud, 1992). Potassium is a nutrient that must be carefully considered during plant growth and development. The application of potassium can meet the plant's nutrient requirements, but its absence can disrupt plant growth and lead to potassium deficiency. Symptoms of potassium deficiency are evident in mature leaves, particularly at the tips, where burned-like areas may appear (Mia, 2015).

The availability of potassium in the soil is influenced by the soil's buffering capacity and potassium dynamics. Potassium buffering capacity is the soil's ability to maintain the availability of potassium ions in the soil solution and provide potassium to plants while preventing potassium loss through leaching. Potassium buffering capacity has a mutually influential relationship with potassium quantity and intensity factors. According to Nihn et al. (2009), potassium intensity (I) is the amount of potassium competing with other cations in the soil solution, while potassium quantity (Q) is the fraction of labile potassium adsorbed by the soil. Based on the relationship between quantity and intensity (Q/I), potassium buffering potential (PBCK) can be determined, which is the soil's ability to maintain the available potassium content in the

How to cite: Fajarini, P. H. N., Hanudin, E., Purwanto, B. H.(2025). Analysis of factors affecting differences in potassium buffering capacity in several soil orders. Ilmu Pertanian (Agricultural Science), 10(2), pp. 105–113.

ISSN 0126-4214 (print) ISSN 2527-7162 (online)

soil against potassium reduction and addition (Shengxiang, 1998).

Potassium buffering capacity (PBCk) is determined from quantity/intensity (Q/I) relationships, which describe the equilibrium between the amount of exchangeable potassium and its activity in soil solution. This capacity is strongly influenced by soil properties, such as mineralogy, particle surface area, surface charge, cation exchange capacity, and the type of clay minerals, which together regulate potassium availability through adsorption–desorption processes (Shaviv et al., 1985). Cation Exchange Capacity (CEC) reflects the soil's ability to retain and exchange cations on the surface of soil particles, particularly in clay minerals and organic matter. Soils with high CEC tend to retain potassium longer and reduce its loss through leaching, thereby extending potassium availability for plants. However, the extent to which CEC and other soil properties influence potassium buffering capacity (PBCk) can vary among soil types. This study aimed to compare PBCk across four major Indonesian soil orders and identify the key soil properties governing potassium retention capacity, providing insights for targeted soil fertility management.

MATERIALS AND METHODS

Sample preparation

This study used four types of soil, namely Andisols, Alfisols, Inceptisols, and Vertisols. Soil sampling was conducted at various locations depending on the soil type. Vertisols were collected in Panjatan, Kulon Progo, Yogyakarta (S 7°54'9", E 110°9'44") on October 30, 2023. Alfisols were collected in Naungan 1, Selopamioro, Imogiri, Bantul, Yogyakarta (S 7°57'50", E 110°24'26") on November 3, 2023. Inceptisols were collected in Bulak Salak, Cangkringan, Sleman, Yogyakarta (S 7°57'50", E 110°24'26") on November 17, 2023. Andisols were collected on Telaga Warna Street, Kejajar, Dieng, Central Java (S 7°12' 5.2", E 109°54'24.1") on December 7, 2023. At each sampling point, a profile was created in the form of a 60 x 60 x 60 cm mini pit. Samples were taken at a depth of 60 cm and composited for each soil horizon. The soil was then dried and sieved using 2 mm and 0.5 mm sieves for laboratory analysis.

Analysis of soil characteristics

The physical and chemical properties of the soil were analyzed using standard methods (Soil Chemistry Technical Guidelines, 2023). Soil texture was determined using the sieve method. Soil pH (H_2O, KCl, and NaF) was measured at a soil and solution ratio of 1:2.5 after 30 minutes of equilibration using a pH meter calibrated with standard buffer solutions (pH 4.0 and 7.0) for calibration. Cation exchange capacity (CEC) was determined using the ammonium acetate method (1 M NH_4OAc, pH 7), and exchangeable base cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) were measured using atomic absorption spectrophotometry (AAS) and flame photometer after extraction. Base saturation was calculated from the number of exchangeable bases relative to CEC. Organic carbon was measured using the Walkley and Black method, while the Muffle Furnace method was performed at 550°C for 4 hours in a combustion furnace. Total potassium was determined through digestion with HNO_3 and $HClO_4$, while water-soluble potassium was extracted with distilled water and measured using a flame photometer. Clay mineralogy was identified using X-ray diffraction (XRD). All tests were performed with blanks and standards to ensure data quality.

Buffer capacity experiments

The adsorption experiment was conducted by adding 2.5 g of air-dried soil (<0.5 mm, dried at room temperature) to 25 mL of background electrolyte solution (0.01 $mol \cdot L^{-1}$ $CaCl_2$) containing KCl at concentrations of 0, 25, 50, 125, 150, 175, 200, 225, and 250 $mg \cdot L^{-1}$. The suspension was placed in a shaker bottle and shaken using a shaker at a speed of 250 rpm for 24 hours at room temperature until equilibrium was reached. The pH of the suspension was monitored but not adjusted. The use of 0.01 $mol \cdot L^{-1}$ $CaCl_2$ as the background electrolyte aimed to maintain constant ionic strength and minimize dispersion. After reaching equilibrium, the samples were centrifuged at 8000 rpm for 10 minutes, and the supernatant was analyzed for potassium concentration using a flame photometer. All treatments were performed in duplicate to ensure reproducibility.

Potassium buffer capacity model

The potassium buffering capacity of each soil type can be calculated using the following formulas:

$$\Delta K = (CK_i - CK_f)\ (v/w) \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

to determine the change in K (ΔK) in the solution, where CK_i and CK_f are the initial concentrations (concentration of K added) and the final concentration of K in the solution, and v and w are the volume of the solution and the mass of each soil, respectively. Then, the potassium concentration ratio (CR) was calculated to describe the intensity of K in the presence of Ca and Mg in the final equilibrium solution. Calcium and magnesium concentrations were determined using atomic absorption spectrophotometry (AAS). Instrument calibration was performed with multi-element standard solutions covering the full concentration range of the samples. Blanks, duplicate samples, and certified reference materials were included for quality assurance and quality control. The potassium concentration ratio (CR) is calculated to describe the intensity of K in the presence of Ca and Mg (in the final equilibrium solution) as follows:

$$CR = CK_f / (Ca_f + Mg_f)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where Caf and Mgf are the concentrations of Ca and Mg in the final equilibrium solution, respectively (Wang et al., 1988).

The concept of PBCK can basically be summarized from a simple exchange reaction involving calcium (Ca^{2+}) and K^+, which is related to the Gapon exchange equation. According to Beckett (1964), the potential buffering capacity of soil is based on the assumption that the linear portion of the Q/I curve corresponds to the Gapon exchange equation. This equation results in KG, which indicates cation adsorption affinity. The Gapon selectivity coefficient (KG) for this exchange reaction is defined as follows:

$$KG = \{(K_{ex}/Ca_{ex}) \text{ x } \{((Ca)^{1/2})/((K))\}\} \ldots\ldots\ldots\ldots (3)$$

where Caex and Kex are interchangeable K and Ca (cmol kg^{-1}), and (Ca) and (K) are the activities of Ca and K in the solution phase, respectively. After calculating the gapon selectivity coefficient (KG), the potassium buffering capacity of each soil can be calculated using the following formula:

$$PBCK = K_{ex}/CRk = KG \times Ca_{ex} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

RESULTS AND DISCUSSION

Characteristics of soil physical and chemical properties

The physical and chemical properties of the four soil orders vary greatly, with some characteristics affecting their potassium buffering capacity (PBCk). The results of soil characterization are presented in Table 1. Clear differences are observed between soil orders, with Vertisols showing higher clay content, smectite minerals, and CEC, indicating greater potassium retention potential, while Inceptisols, with a sandy texture and lower CEC, show more limited

Table 1. Results of analysis of physical and chemical properties of Andisols, Alfisols, Inceptisols, and Vertisols

Parameters	Andisols	Alfisols	Inceptisols	Vertisols
Clay (%)	24.46	59.97	2.07	67.96
Sand (%)	42.76	19.26	90.10	4.53
Silt (%)	32.78	20.95	7.82	27.51
Textural Class	Loam	Clay	Sandy	Clay
pH				
H_2O	5.28	5.39	5.85	7.30
KCl	3.93	4.55	5.13	6.15
NaF	11.39	-	9.42	-
CEC (NH_4OAc/NH_4Cl) (cmol.kg^{-1})	22.87^{M}	25.13^{H}	14.41^{L}	45.40^{VH}
Exchangeable cations (cmol.kg^{-1})				
K^+	0.10^{VL}	0.14^{L}	0.31^{L}	0.24^{L}
Na^+	0.02^{VL}	0.05^{VL}	0.04^{VL}	0.23^{L}
Ca^{++}	1.44^{VL}	4.87^{L}	2.27^{L}	18.03^{H}
Mg^{++}	0.28^{VL}	0.18^{VL}	0.33^{VL}	0.27^{VL}
Base saturation (%)	8.04^{VL}	20.85^{L}	20.47^{L}	41.34^{M}
Organic C (%)	57.30^{VH}	0.03^{VL}	0.01^{VL}	0.05^{VL}
K-water soluble (%me)	0.001	0.003	0.001	0.011
K-non exchangable (mg.kg^{-1})	1.39	1.84	0.50	5.96
K-Total (mg.kg^{-1})	7.13^{VL}	9.46^{VL}	2.19^{VL}	30.26^{VH}

Description : Juknis Kimia Tanah, 2023; (VL) Very low ; (L) Low; (M) Medium; (H) High; (VH) Very high

Table 2. Results of clay mineral types determined by XRD analysis

Soil Type	Dickite	Kaolinite	Smectite	Amorphous
Andisols	-	+	-	+++
Alfisols	++	+++	-	-
Inceptisols	-	+++	-	+
Vertisols	++	-	+++	-

Notes : +++ = dominant phase (> 50%); ++ = major phase (20-50%); + = minor phase (5-20%); tr = trace (< 5%) (Misskire et al., (2019)

Table 3. Calculation results for the levels of alophane, ferrihydrite, and silica in oxalate extracts from Andisols and Inceptisols

Soil Type	Alophane	Ferrihydrite	Silica	% Alo + 0,5 %Feo
Andisols	4.94	5.57	0.70	7.81
Inceptisols	1.33	5.08	0.19	3.87

potassium retention capacity. These contrasting properties highlight the influence of soil texture, clay mineral type, and CEC on potassium buffering capacity.

Types of soil clay minerals

In this experiment, analysis was conducted using an XRD (X-ray Diffraction) instrument to identify the clay minerals present in each soil type, followed by data processing using Profex software. The results of the clay mineral analysis are presented in Table 2 and Figure 1. Based on Figure 1 part (a), it can be seen that Andisols have a fairly low peak. This indicates that the soil is dominated by amorphous minerals, such as allophane and imogilite, which are listed in Table 2, but cannot be detected by XRD because they are non-crystalline minerals. This can also be seen in Table 3 regarding the calculation of amorphous minerals.

Andisols have higher values than Inceptisols (Table 3). This indicates that Andisols are dominated by amorphous minerals, particularly Al and Fe. According to the Soil Survey Staff (2014), Andisols have andic properties, which means that the soil must have an Al-Oxalate + 0.5 Fe-Oxalate percentage more than 2%. Mineralogical analysis (selective dissolution) using chemical soil methods confirms that Andisols in Wonosobo meet one of the andic properties criteria, namely a percentage of Al-Oxalate + 0.5 Fe-Oxalate exceeding 2%. Additionally, the diffraction pattern in Figure 1 (a) shows a broad hump diffraction signal at 2θ in the range of 15- 30°. This pattern has low intensity and does not show sharp peaks. This phenomenon indicates the presence of an amorphous phase or volcanic glass material, which is commonly found in Andisol soils resulting from volcanic ash weathering.

Despite being dominated by low peaks, Andisols still contain clay minerals (Table 2). The clay mineral detected in this soil is kaolinite (1:1), which is quite dominant after the amorphous mineral. The X-ray diffraction pattern shows the dominant presence of kaolinite clay minerals at around 70.04%, characterized by sharp peaks at 2θ in the range of 12.2°, 20.2°, and 35°. These results are consistent with the research by Nursyamsi & Suprihati (2005), which stated that the Andisols in their study contained kaolinite and cristobalite (oxide) clay minerals.

Alfisols is dominated by 1:1 clay mineral, namely kaolinite (Table 2 and Figure 1). Based on XRD analysis, kaolinite (1:1) clay minerals dominate at around 70%. The diffraction peak patterns at 2θ in the range of 12.4° and 24.8° indicate the presence of kaolinite structures. Kaolinite is one of the dominant clay minerals in Alfisols, along with illite or mica. Kaolinite is formed through the weathering of primary minerals such as feldspar and mica (Basu & Mookherjee, 2021). Kaolinite remains stable under acidic to neutral pH conditions, which is a characteristic of Alfisols.

Additionally, the presence of dickite was detected in this soil, as shown in Table 2, indicating that this mineral is part of the major phase. The presence of dickite in Alfisol soil is approximately 21%. Dickite acts as a polymorph of kaolinite, supporting the indication of stable and prolonged formation conditions in a humid tropical climate. Kaolinite and dickite have the same chemical formula, ($Al_2Si_2O_5(OH)_4$).

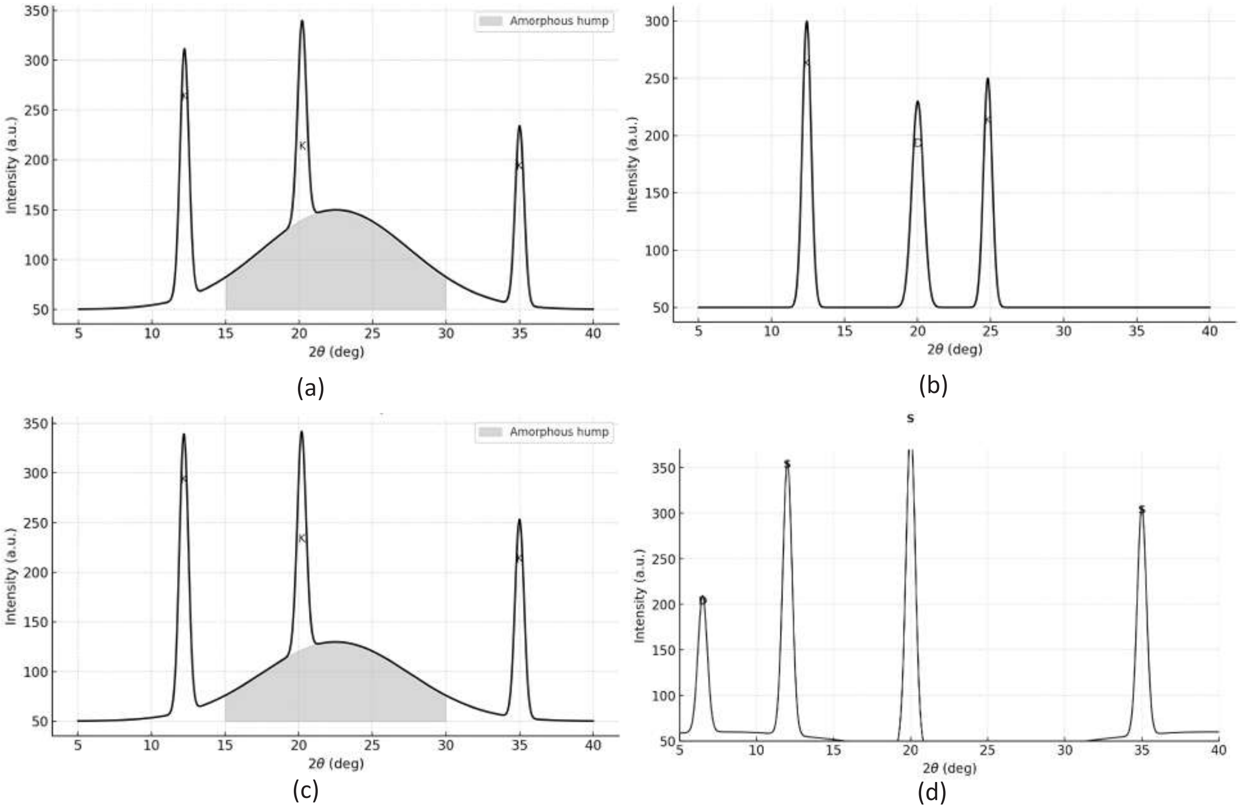

Figure 1. X-ray Diffraction results of clay minerals in Andisols (a), Alfisols (b), Inceptisols (c), and Vertisols (d) soil.

According to Ehrenberg et al. (1993), their structure consists of aluminum atom planes coordinated in an octahedral arrangement with hydroxide ions, which are bound to silicon atom planes coordinated in a tetrahedral arrangement with oxygen.

Kaolinite and dickite exhibit two different types of OH groups. The inner OH groups are located within the octahedral sheets, while three non-equivalent inner-surface-OH groups are located above the octahedral sheets (Wu et al., 2022). In kaolinite, empty octahedral sites occur at the same relative position in each subsequent layer. In dickite, however, empty sites alternate between positions from one layer to the next. Thus, kaolinite has one (1:1) layer per unit cell, while two (1:1) layers are required to define the dickite unit cell.

Inceptisols are almost entirely dominated by kaolinite clay minerals, as indicated by the sharp reflection peaks at 2θ in the range of 12.2°, 20.2°, and 35° in Figure 1 (c). The predominance of kaolinite (1:1 clay) together with the sandy texture results in low cation exchange capacity (CEC), which in turn limits the potassium buffering capacity (PBCk). Although a broad diffraction signal in the range of 15–30° 2θ suggests the possible presence of amorphous material, its proportion is minor and not sufficient to compensate for the low reactivity of kaolinite. These results are in agreement with the findings of Nursyamsi & Suprihati (2005), reporting that Inceptisols formed from volcanic tuff are generally dominated by kaolinite.

Vertisols in this study are dominated by smectite clay minerals (2:1), which accounted for nearly 78% of the mineral composition, with dickite (kaolin group) present in smaller amounts (22%). The sharp XRD reflections at 2θ in the range of 12°, 20°, and 35° confirm the crystallinity of smectite, while field observations of wide shrink–swell cracks further support its dominance. This occurred in this study when soil samples were taken from Vertisols, which exhibited fairly large cracks in dry land. According to Garcia et al. (2021), smectite resembles the structure of mica and vermiculite, where one smectite crystal unit consists of one Al-octahedral plate sandwiched between two Si-tetrahedral plates

Generally, from other studies, Vertisols tend to always contain smectite minerals. According to Nursyamsi (2011), soils containing smectite clay minerals are typically found in the Vertisols order and other orders within the Vertic subgroup. One characteristic of Vertic soils is their swelling and shrinking properties. When soil swells (expands) when wet, cations such

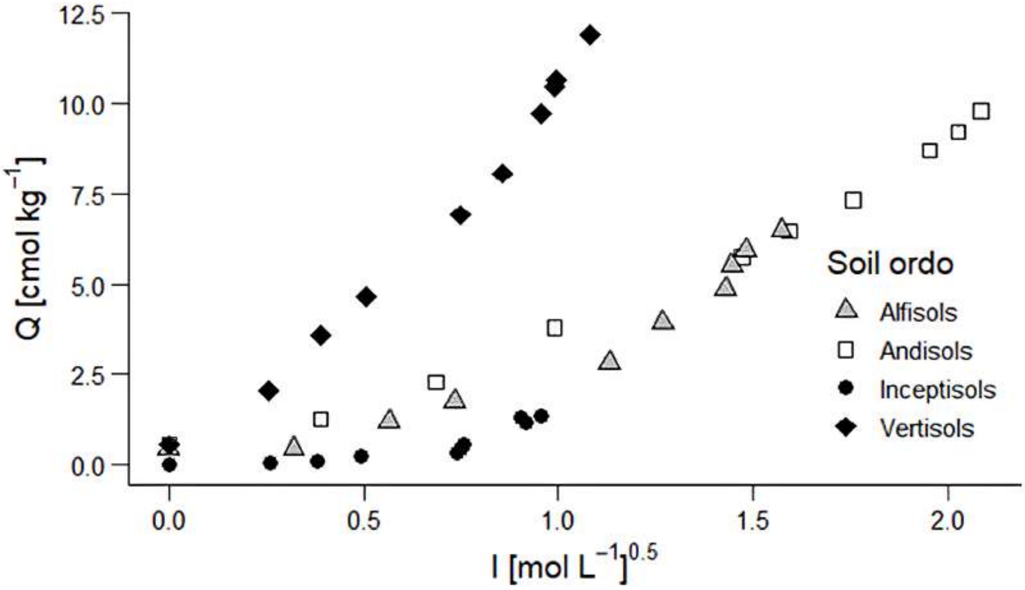

Figure 2. Q/I curves for Andisols, Alfisols, Inceptisols, and Vertisols

as K^+, NH_4^+, Na^+, Ca^{2+}, Mg^{2+}, and others enter the interlayer spaces of the clay. When the soil shrinks (contracts) when dry, the water in the interlayer spaces exits, causing the previously water-filled spaces to be replaced by air and resulting in cracks. The swelling and shrinking process is related to the content of 2:1 type clay mineral (smectite) (Borchardt, 1989).

Potassium buffering capacity

One factor that influences potassium buffering capacity is the Q/I factor. This factor helps describe the stability of soil in maintaining potassium availability. Each soil type has different stability capabilities. These capabilities can be seen in the Q/I curve for each soil type in Figure 2. In the context of potassium, Q represents the amount of potassium that can be exchanged from the soil colloid complex, while I describes the concentration of potassium in the soil solution that is directly available to plants. Quantitatively, potassium buffering capacity is often expressed as the slope of the Q/I curve, also known as the “Slope of Q/I curve” or PBCK (Potassium Buffering Capacity) (Moss & Herlihy, 1970). The steeper the slope of the curve, the higher the potassium buffering capacity of the soil.

The results of this experiment show that Vertisols have a fairly steep curve slope, meaning that this soil type can be considered fairly stable in maintaining potassium availability. Vertisols are capable of withstanding changes in potassium concentration in the soil solution despite potassium uptake by plants or loss through leaching. This is supported by the research of Awgchew et al. (2024), stating that Vertisols have better dynamic equilibrium (adsorption and desorption) than other soil types. In Figure 2, it can be seen that all soil samples have very low CRk or Intensity (I) values. This is because the conditions in each soil type have very low exchangeable potassium levels, as shown in Table 1, which directly affects the I factor.

The CRk value for each soil type ranges from 1 to 2 $(mol\ L^{-1})^{0.5}$, as shown in Table 4. This value is considered quite low due to competition between K^+ ions and Ca^{2+} and Mg^{2+} ions. Vertisols have very high to moderate exchangeable Ca content, which allows competition to occur, resulting in very low exchangeable K. Although the Ca^{2+} and Mg^{2+} content in Andisols, Alfisols, and Inceptisols is very low, competition between cations at the exchange site is still possible, as both ions have a stronger affinity (double charge) compared to K^+ ions. According to Wang et al. (2004), there are two important parameters, namely the equilibrium concentration ratio (CRk), obtained from measuring K intensity in the $CaCl_2$ soil system, and the potential equilibrium buffering capacity (PBCK), which serves as an indicator of soil buffering capacity estimated from the least squares regression equation describing the partitioned Q/I

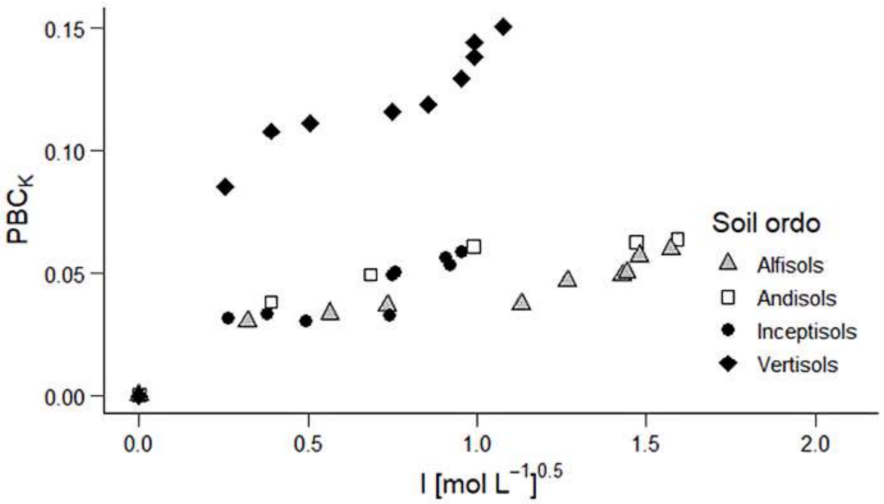

Figure 3. Relationships curves between PBCK and CRk (I) in Andisols, Alfisols, Inceptisols, and Vertisols

Table 4. Calculation results of ΔK (Quantity), CRk (Intensity), and PBCK on Andisols, Alfisols, Inceptisols, and Vertisols

KCl concentration (ppm)	Soil Type											
	Andisols			Alfisols			Inceptisols			Vertisols		
	ΔK (cmol kg^{-1})	CRk (mol L^{-1})^{0,5}	PBCk (cmol kg-1/mol L^{-1})^{0,5}	ΔK (cmol kg^{-1})	CRk (mol L^{-1})^{0,5}	PBCk (cmol kg^{-1}/mol L^{-1})^{0,5}	ΔK (cmol kg^{-1})	CRk (mol L^{-1})^{0,5}	PBCk (cmol kg^{-1}/mol L^{-1})^{0,5}	ΔK (cmol kg^{-1})	CRk (mol L^{-1})^{0,5}	PBCk (cmol kg^{-1}/mol L^{-1})^{0,5}
0	0	0	0	0	0	0	0	0	0	0	0	0
25	1.258	0.390	0.038	0.457	0.320	0.030	0.059	0.262	0.031	2.058	0.254	0.085
50	2.271	0.685	0.049	1.179	0.565	0.033	0.087	0.379	0.033	3.582	0.390	0.108
75	3.794	0.989	0.061	1.756	0.734	0.037	0.210	0.493	0.031	4.668	0.506	0.111
125	5.749	1.471	0.062	2.837	1.130	0.037	0.311	0.740	0.033	6.913	0.747	0.115
150	6.471	1.592	0.064	3.923	1.268	0.046	0.415	0.747	0.049	8.073	0.856	0.119
175	7.339	1.755	0.065	4.864	1.429	0.049	0.535	0.758	0.050	9.741	0.955	0.129
200	8.717	1.951	0.066	5.513	1.444	0.050	1.140	0.918	0.054	10.682	0.990	0.138
225	9.221	2.025	0.068	5.945	1.481	0.057	1.291	0.905	0.056	10.458	0.992	0.144
250	9.797	2.084	0.081	6.521	1.572	0.059	1.352	0.953	0.059	11.909	1.078	0.150

curve. This statement can be interpreted in Figure 3 and Table 4.

Vertisols have the highest PBCK value compared to the other three soil types. This is because Vertisols have a predominantly clay texture and contain a 2:1 clay mineral, namely smectite. This mineral can have a very high CEC value. A very high CEC value in soil will enable the soil to store large amounts of potassium (K^+) in its exchange complex. According to Nursyamsi et al. (2007), the negative charge originating from the permanent charge on smectite significantly contributes to the soil's cation exchange capacity (CEC). This charge arises from isomorphous substitution, which results in an excess of negative charge on both the Si-tetrahedral and Al-octahedral layers.

Furthermore, smectite is a clay mineral that has a significant influence on potassium dynamics. This can be observed in Vertisols, which has the highest PBCK compared to the other three soil types. Figure 3 shows that Vertisols have the highest and steepest curve. The ability of smectite to dynamically absorb and release potassium ions between its layers enables soils dominated by smectite minerals to maintain higher potassium concentrations in soil solutions, even when changes occur due to plant uptake or leaching processes. If the soil solution loses potassium, such as through plant uptake, smectite can quickly release potassium reserves from the exchange sites to maintain equilibrium. Conversely, if there is an excess of potassium, this mineral can absorb the extra potassium into its structure.

Soils dominated by kaolinite clay minerals (1:1), such as Andisol, Alfisol, and Inceptisol, consistently show lower PBCk values than Vertisol soils rich in smectite. Mineralogical analysis indicates that these soils are almost entirely composed of kaolinite, a low-activity clay with stable layers that do not swell and strong interlayer bonds. As a result, their cation exchange capacity is low, and they lack the interlayer sites necessary for K fixation. This structural limitation explains why potassium in these soils is more susceptible to leaching and less available for long-term retention compared to smectite-rich soils (Shakeri, 2018).

Additionally, the Alfisols and Vertisols in this study also contain dickite clay minerals. These minerals account for approximately 20% of each soil type. Dickite belongs to the kaolin (1:1) group, which has a more ordered structure and higher crystallinity. This more ordered structure results in a more limited active surface area and charge. It also leads to lower potassium retention capacity compared to kaolinite and smectite.

Amorphous minerals also play a role in potassium buffering capacity. An example of this is found in this experiment, namely Andisols, which have a fairly steep curve in Figure 3. Amorphous minerals such as allophane and imogilite have large specific surfaces, enabling them to absorb and release cations such as potassium more effectively. According to Takahashi et al. (2001), this surface provides additional adsorption sites that can enhance the soil's ability to withstand changes in potassium concentration in solution. This is also supported by the research of Carneiro et al. (2013), stating that amorphous minerals can have high buffering capacity due to their unique structural properties and the presence of various cations, including potassium. Its mechanical strength and ion exchange capacity make it suitable for applications requiring strong potassium buffering.

The high cation exchange capacity value directly contributes to the increase in potassium buffering capacity (PBCK) in the soil. Alfisols and Vertisols have very high CEC values, as shown in Table 1. Soils with high CEC have more negatively charged sites capable of adsorbing and retaining potassium ions (K^+), thereby mitigating fluctuations in potassium concentration in the soil solution caused by plant uptake or leaching. High CEC values also have a significant positive correlation with clay content, as indicated by the research of Nursyamsi & Sutriadi (2005), so clay texture also influences this. CEC is one of the important factors in determining the PBCK of a soil.

If the soil is dominated by sandy fractions, it produces a fairly low PBCK value, and Figure 3 shows that Inceptisols have the lowest value compared to the other three soil types. Inceptisols are dominated by sand, as shown in Table 1. The sand fraction consists of large particles, so it has a smaller specific surface area than clay and silt. This small surface area results in a low negative charge to retain cations (including potassium). Sandy soils generally have low cation exchange capacity (CEC) (Riaz & Marschner, 2020). This means that only a small amount of potassium (K^+) can be bound, and most of the potassium remains in the soil solution. These conditions limit the ability of sandy soil to absorb and retain potassium ions, making potassium availability in the soil solution more fluctuating and susceptible to leaching.

CONCLUSIONS

PBCk in the four soil types ranged from 0 to 0.150 $cmol{\cdot}kg^{-1}/(mol{\cdot}L^{-1})^{0.5}$, with the highest value found in Vertisols and the lowest in Inceptisols. Vertisols and Andisols are more reactive than the other two soil types. High clay content, 2:1 mineral dominance (smectite), and synergistic increase in CEC synergistically increase PBCk. The more dominant the clay texture, especially the 2:1 clay mineral in a soil type, the greater the potential potassium buffering capacity. 2:1 clay mineral is more reactive than 1:1 clay mineral. Additionally, the higher the CEC value of a soil, the higher its potassium buffering capacity. Vertisols have a dominant clay texture of approximately 67.96%, contain (2:1) clay minerals such as smectite, and have a very high CEC value of approximately 45.40 cmol kg^{-1}, resulting in a high potassium buffering capacity, with a value of 1.099 (cmol kg^{-1}/mol $L^{-1})^{0,5}$. These findings suggest that managing clay mineralogy and CEC through soil amendments can improve K retention in low PBCk soils.

REFERENCES

Awgchew, H., S. Beyene, and A. Kifilu. (2024). Potassium adsorption capacity and desorption kinetics in soils of qenberenaweti sub-watershed, Central Highlands of Ethiopia. Heliyon 10(10).

Basu, A., and M. Mookherjee. (2021). Intercalation of water in kaolinite ($Al_2Si_2O_5(OH)_4$) at subduction zone conditions: insights from Raman spectroscopy. ACS Earth and Space Chemistry 5(4): 834-848.

Beckett, P.H.T. (1964). The "immediate" Q/I relations of labile potassium in the soil. J. Soil Sci. 15: 9–23.

Borchardt, G. (1989). Smectites. Minerals in Soil Environments. Second Edition. Soil Science Society of America Madison, Wisconsin, USA.

Carneiro, F. G., C. N. Keim, D. Acosta-Avalos, and M. Farina. (2013). Elemental composition of biomineralized amorphous mineral granules isolated from ants: Correlation with ingested mineral particles from the soil. Micron 44: 120-124.

Ehrenberg, S. N., P. Aagaard, M. J. Wilson, A. R. Fraser, and D. M. L. Duthie. (1993). Depth-dependent transformation of kaolinite to dickite in sandstones of the Norwegian continental shelf. Clay minerals 28(3): 325-352.

García R. E., A. Lorenzo, A. V. García, J. Morales, J. R. García, and M Suárez. (2021). On the structural formula of smectites: a review and new data on the influence of exchangeable cations. Applied Crystallography 54(1), 251-262.

Juknis Kimia Tanah. (2023). Kementerian Pertanian Republik Indonesia, Bogor.

Mas'ud, P. (1992). Telaah Kesuburan Tanah. Angkasa: Bandung

Mia, M. A. B. (2015). Nutrition of Crop Plants. Nova Publishers: New York

Misskire, Y., T. Mamo, A. M. Taddesse, and U. Yermiyahu (2019). Potassium adsorption and release characteristics on vertisols of North Western Ethiopian Highlands. Communications in soil science and plant analysis 50(9): 1132-1147.

Moss, P., and M. Herlihy. (1970). Availability of soil potassium to ryegrass: 2. Potassium buffering capacity. Irish Journal of Agricultural Research 109-117.

Nihn, H. T., H. T. T. Hoa, P. Q. Ha, and J. E. Dufey. (2009). Potassium buffering capacity of sandy soils from Thua Thien Hue Province, Central Vietnam, as related to soil properties. Communications in soil science and plant analysis 40(21-22): 3294-3307.

Nursyamsi, D. (2011). Mekanisme pelepasan K terfiksasi menjadi tersedia bagi pertumbuhan tanaman pada tanah-tanah yang didominasi Smektit. Jurnal Sumberdaya Lahan 5(2): 61-74.

Nursyamsi, D., dan Sutriadi. (2005). Sifat-sifat kimia dan mineralogi tanah serta kaitannya dengan kebutuhan pupuk untuk padi (*Oryza sativa*), Jagung (*Zea mays*), dan kedelai (*Glycine max*). Jurnal Agronomi Indonesia 33(3).

Nursyamsi, D., K. Idris, S. Sabiham, D. A. Rachim, dan A. Sofyan. (2007). Sifat-sifat tanah dominan yang berpengaruh terhadap K tersedia pada tanah-tanah yang didominasi smektit. Jurnal Tanah dan Iklim 26: 13-28.

Riaz, M., and P. Marschner. (2020). Sandy soil amended with clay soil: effect of clay soil properties on soil respiration, microbial biomass, and water extractable organic C. Journal of Soil Science and Plant Nutrition 20(4): 2465-2470.

Shakeri, S. (2018). Effect of soil buffering capacity and clay minerals on the rate coefficient of non-exchangeable potassium release. Malaysian Journal of Soil Science 22.

Shaviv, A., S. V. Mattigod, P. F. Prat, and H. Joseph. (1985). Potassium exchange in five southern California soils with high potassium fixation capacity. Soil Science Society of America Journal 49: 33 -1128.

Soil Survey Staff. (2014). Keys to Soil Taxonomy Twelfth Edition Natural Resources Conservation Service-United States Department of Agriculture. Washington DC.

Takahashi, M., T. Sakata, and K. Ishizuka. (2001). Chemical characteristics and acid buffering capacity of surface soils in Japanese forests. Water, Air, and Soil Pollution 130: 727-732.

Wang, J. J., D. L. Harrell, and P. F. Bell. (2004). Potassium buffering characteristics of three soils low in exchangeable potassium. Soil Science Society of America Journal 68(2): 654-661.

Wang, J., R.E. Farrell, and A.D. Scott. (1988). Potentiometric determination of potassium Q/I relationships. Soil Sci. Soc. Am. J. 52: 657–662.

Wu, S., M. He, M. Yang, and B. Peng. (2022). Near-Infrared spectroscopic study of OH stretching modes in kaolinite and dickite. Crystals 12(7): 907.