

Unveiling novel insights into potassium extractability in rubber-growing soils: A comparative analysis using single extraction and a sequential extraction process

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ABSTRACT: Potassium (K) is a limiting element for rubber trees grown in southern Thailand. The availability of soil K depends on the K fractionation. The aims of this study were to explore K fractionation distribution, to assess the correlation between K fractionation and soil properties, and to compare K fractionation received by single extraction (SE) and a sequential extraction process (SEP). Coarse, medium, and fine soils were collected (0–30 cm) from rubber plantations for K fractionation analysis. The results showed that soil K was high in fine > medium > coarse soil textural categories. K fractionation using SEP was increased in residue K > exchangeable K > K bound to Fe-Mn oxide > K bound to organic matter > K bound to carbonate, whereas K fractionation using SE was increased in mineral K > fixed-K > exchangeable K > water soluble K. Available K received by SE and SEP was positively correlated with organic matter, cation exchange capacity, and clay content. It was lower than the optimal soil K level for rubber plantations. The combination of potash and organic fertiliser to support K for plant uptake is essential in this region. Soil K fractionation received by SE and SEP was highly correlated. Therefore, SEP may be a viable alternative for K fractionation analysis in rubber-growing soil. Rubber soil K management by increasing the solubility of mineral K or residual K combined with SEP monitoring soil K fractionation would be useful for sustaining crop yield and soil K fertility.

KEYWORDS: K fractionation, K status, soil characteristics, fertiliser management

INTRODUCTION

The rubber tree (*Hevea brasiliensis*), renowned for its natural rubber production, is a vital commercial crop in numerous countries, including Thailand, Indonesia, Vietnam, China, and Malaysia [1]. In 2023, Thailand's rubber plantations covered a substantial 3.53 million hectares, predominantly in the southern region [1]. The soil in Thailand presents unique challenges, characterised by low pH, limited cation exchange capacity, and a scarcity of essential nutrients, particularly potassium (K), crucial for the optimal growth and yield of rubber trees [2]. Elevated levels of aluminium and iron oxides, coupled with a predominance of low-activity clay minerals [3] due to the country's tropical location, influence the soil processes that impact K availability. Notably, 42% of Thai soils are extremely weathered and can be classified as Ultisols [4].

Rubber trees in Thailand thrive in diverse soil textures, ranging from coarse to fine [5, 6]. Generally, fine soil textures exhibit higher bioavailable K and total K content than coarse textures [7]. The conventional single extraction (SE) method is a one-step extraction approach emphasising soil K fractionation [7, 8]. This method evaluates water-soluble K, exchangeable-K, fixed-K, and mineral-K as chemical fractions indicative of bioavailability [7, 9], employing ammonium acetate (1 M NH₄OAc, pH 7.0) for assessing plant-available

K [10]. While straightforward, SE encounters limitations due to its inability to consider environmental factors influencing metal fractionation in soil.

To address these limitations, this study employs the sequential extraction process (SEP) [11], initially designed for heavy metal analysis and subsequently applied to assess the bioavailability of various elements (e.g., Zn [12], Mg [13], Ca [14], Fe [15], and P [16]). This research stands at the forefront of innovation in exploring K dynamics in rubber-growing soils, introducing ground-breaking methodologies and uncovering unprecedented insights. Unlike conventional approaches, which often employ SE for soil K assessment, this study pioneers the use of the SEP. The SEP method provides a novel and nuanced perspective, elucidating the solubility, availability, and precipitation of metals, thus offering a more reliable evaluation of K elements in the soil. A significant gap in the current literature is addressed by this study, which marks the first attempt to compare and classify K fractionation obtained through SE and SEP. This novel undertaking examines readily available, slowly available, and unavailable K fractionation for bioavailability. The research objectives were 1) to explore K fractionation distribution, 2) to assess the correlation between K fractionation, using SE and SEP, and soil properties, and 3) to compare K fractionation received by SE and SEP methods for increasing knowledge regarding the

complex soil K fractionation analysis in rubber growing soils.

MATERIALS AND METHODS

Soil sampling and treatment application

Soil profiles for the rubber-growing plantations in southern Thailand were selected with different textural soil groups as follows: Coarse textural soil group (Kho Hong (Kh), Bacho (Bc), Khlong Thom (Km), and Na Thawi (Nat) soil series); medium textural soil group (Fang Daeng (Fd), Sai Buri (Bu), Lamphu La (Ll), and Hat Yai (Hy)); and fine textural soil group (Ao Luek (Ak), Na Thon (Ntn), Ruso (Ro), and Phattalung (PtI)) (Table S1). Soil samples were collected from the top layer of the plant circumference by a soil auger (0–30 cm) in agricultural zoning areas; they were collected from 9 points and mixed for a composite sample. Twelve soil samples were air-dried, ground, and passed through 2 mm and 0.5 mm sieves.

Physicochemical property analysis

Soil physicochemical properties were assessed using the standard method for soil analysis [10]. Soil pH and electrical conductivity (EC) were measured in 1:5 soil:DI water. Organic matter (OM) was determined by the Walkley and Black method. Extractable Ca and Mg was obtained using 1 M NH_4OAc at pH 7.0. Cation exchange capacity (CEC) was measured by 1 M NH_4OAc extraction. Available phosphorus (Avai. P) was determined using the Bray II technique, and the Kjeldahl method was used for total nitrogen (total N). Hydrometers were used to measure the particle size distribution [17]. The analysis of each parameter is presented herein as the mean values of 3 replications.

Single extraction (SE)

The Helmke and Sparks approach [18] was used for the SE technique. Water-soluble K (Sol-K) was determined by extracting 5 g of soil in 50 ml DI water and shaking for 30 min. To determine the amount of available K ($\text{NH}_4\text{OAc-K}$), which consists of exchangeable K (Exch-K) and Sol-K, 1 M NH_4OAc at pH 7.0 was used. Using 1 M nitric acid (HNO_3), 0.5 g of soil was boiled for 25 min at 113 °C to determine $\text{HNO}_3\text{-K}$. The concentration of $\text{HNO}_3\text{-K}$ consisted of Sol-K, Exch-K, and Fixed-K. Therefore, Fixed-K was established as the difference between $\text{HNO}_3\text{-K}$ and $\text{NH}_4\text{OAc-K}$. The total K was digested in a Teflon beaker with concentrated hydrogen fluoride (HF) and a combination of HNO_3 and HCl (1:3 v/v) while boiling at 110 °C for 180 min. Mineral-K (Min-K) was defined as the difference between total-K and $\text{HNO}_3\text{-K}$.

Sequential extraction process (SEP)

The approach from Tessier et al [11] was used for the SEP technique. One gram of soil was extracted in 5 steps for Exch-K, K bound to carbonate (Car-K), K

bound to Fe-Mn oxides (Oxide-K), K bound to organic matter (OM-K), and residue K (Res-K) (Table S2). The supernatant from each suspension was decanted and passed through Whatman No. 5 filter paper after centrifugation at 2,500 rpm. Before the subsequent K fractionation extraction, the soil sample was rinsed with DI water, centrifuged, and discarded. To extract Res-K, soil particles were transferred to a Teflon beaker and digested at 105 °C with concentrated HClO_4 and HF until the soil particles turned white. For pseudo-total-K ($\text{total-K}_{\text{pseudo}}$), the sum of all K fractionation was determined.

Measurement of K concentration

An atomic absorption spectrophotometer (AAS; ICE 3500, Thermo Fisher Scientific, UK) was utilised to determine the K fractionation concentration in the supernatant. The recovery test verified $\text{Total-K}_{\text{pseudo}}$ produced by SEP with the analytical findings preferred for validation method between SE and SEP [19] and was accepted within a 15% error range in this investigation.

Statistical analysis

SPSS software was applied for statistical analysis. The concentration of K fractionation in the various soil textural groups is shown as the mean of 3 replicates. Moreover, Pearson correlation analysis was utilised to examine the correlations between K fractionation and soil characteristics at $p \leq 0.05$ and 0.01. The percentages of K fractionation distribution and K fractionation were calculated.

RESULTS

Soil characterisation

The soil pH ranged from strongly acid to slightly acid (5.15–6.54) and had low EC values (0.01 dS/m) in the 3 soil textural groups that planted rubber trees (Table S3). The fine textural group had a higher OM content (21.12 g/kg) than those of the medium (13.68 g/kg) and coarse (8.67 g/kg) textural groups. Furthermore, the extractable Ca and Mg concentrations were high in the fine-textural groups. The total N and CEC concentrations were high in the fine, medium, and coarse-textural groups, respectively.

K fractionation by SE

The highest K fractionation was found in $\text{Min-K} > \text{Fixed-K} > \text{Exch-K} > \text{Sol-K}$ (Table 1). The Sol-K and Exch-K concentrations were high in the fine > medium and coarse-textural groups, with levels ranging from 5.22 to 21.40 mg/kg for Sol-K and 7.22 to 37.89 mg/kg for Exch-K. $\text{NH}_4\text{OAc-K}$ dominated in the fine textural group (59.30 mg/kg) compared to the medium (28.07 mg/kg) and coarse (12.44 mg/kg) textural groups, as Fixed-K, Min-K, and Total-K were higher in the fine > medium > coarse-textural groups. The

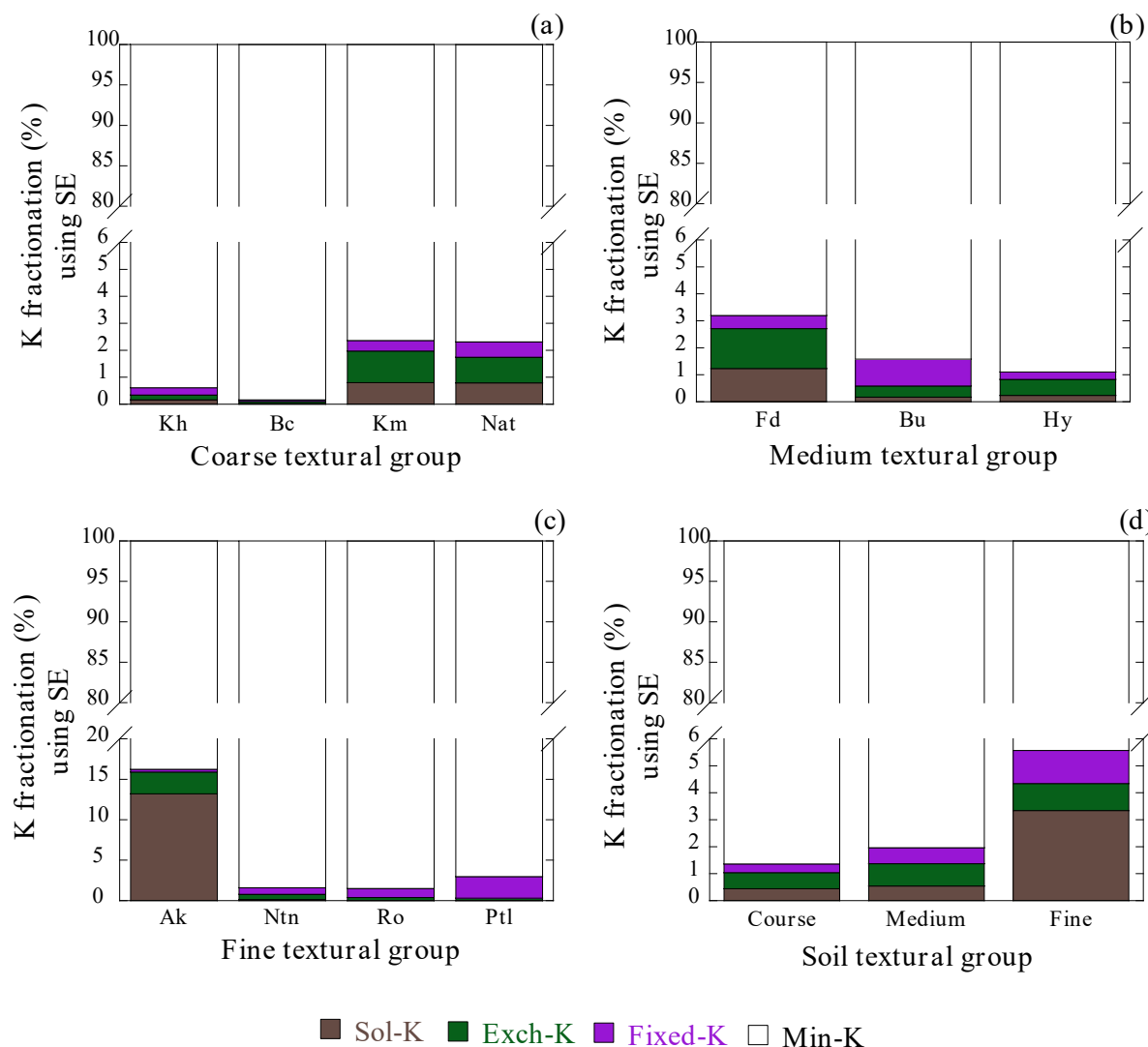


Fig. 1 K fractionation by SE in coarse (a), medium (b), and fine (c) textural groups and the average of K fractionation based on soil textural group (d). Note: Coarse textural soil group: Kh, Bc, Km, and Nat; medium textural soil group: Fd, Bu, Ll, and Hy; and fine textural soil group: Ak, Ntn, Ro, and Ptl.

Table 1 K fractionation using SE.

Soil textural group	K fractionation based on SE (mg/kg)						Total-K
	Sol-K	Exch-K	NH ₄ OAc-K	Fixed-K	HNO ₃ -K	Min-K	
Coarse (n=4)	5.22	7.22	12.44	5.63	18.07	2776.54	2794.60
SD	2.79	2.18	4.93	3.70	7.10	839.33	836.50
Medium (n=4)	9.13	18.94	28.07	26.07	54.14	3463.75	3517.89
SD	1.92	8.41	9.80	14.79	24.11	938.70	981.00
Fine (n=4)	21.40	37.89	59.30	143.79	203.08	8187.35	8390.43
SD	12.26	12.28	15.35	78.03	69.37	812.51	1156.02

Note: SD = standard deviation.

Sol-K, Exch-K, and Fixed-K fractions were all less than 6% (Fig. 1a–c), whereas the highest K fraction was detected in Min-K, accounting for more than 94% of total-K (Fig. 1d). The percentage of K fraction in Min-K was the greatest, ranging from 95 to 99% of total-K, whereas the sum of Sol-K, Exch-K, and Fixed-K fraction was less than 1–5% in all soils.

K fractionation using the SEP

All K fractionation tended to be increased in coarse, medium, and fine-textural groups, respectively (Table 2). The highest K fractionation was found in Res-K > Exch-K > Oxide-K > OM-K > Car-K (Fig. 2a–c). All soil texture groups had low Car-K, Oxide-K, and OM-K contents and were high in fine > medium > coarse textural soil groups. In all soils, Res-K accounted for over 95% of total K fractionation (Fig. 2d). The summation of Exch-K, Car-K, Oxide-K, and OM-K fractionation was lower than 1–5% in all soils, whereas Res-K fractionation ranged from 95–99% of Total-K (Fig. 2a–c).

Correlation between K fractionation and soil properties

The correlation coefficient (r) between K fractionation based on the SE method and soil properties found that Exch-K and $\text{NH}_4\text{OAc-K}$ was positively correlated with OM and CEC (Table 3). Moreover, $\text{NH}_4\text{OAc-K}$ and the percentage of clay particles were highly and positively correlated. $\text{HNO}_3\text{-K}$ showed a positive correlation with the percentage of clay particles.

Meanwhile, K fractionation based on the SEP method indicated that Exch-K was strongly correlated with OM, CEC, and the percentage of clay particles. The Car-K had a significant correlation with soil pH and Extr. Ca. Similarly, OM-K had a significant correlation with soil pH and silt (Table 4).

Correlation between K fractionation using SE and SEP

The correlation between each K fractionation extracted in SE or SEP was high in itself (Table 5 and Table S4). Based on the SE scheme, $\text{NH}_4\text{OAc-K}$ was highly correlated with Sol-K and Exch-K. While, based on SEP scheme, the summation of Exch-K and Car-K was highly correlated with $\text{NH}_4\text{OAc-K}$ (Table S4). Moreover, the summation of Oxide-K and OM-K was highly correlated and showed high coefficient of determination with Fixed-K, while Res-K was highly correlated with Min-K.

DISCUSSION

Min-K (Fig. 1d) contained almost 95% of total soil K. Min-K mainly comprises K-bearing minerals that are soil parent materials [7]. Min-K is not directly bioavailable but may be readily available after weathering

[7, 20]. This environmental process is gradual. However, the solubilising of bacteria can exudate organic acids to dissolve K-containing minerals and release K into the soil solution [20]. The fine textural group had higher K content and bioavailable K than those of the medium and coarse groups (Table 1). However, the long-term absence of K fertiliser application in rubber-growing soil may lead to low available K concentration in fine textural soil like coarse textural soil [6].

Clay particles affect dynamic equilibrium of soil K by releasing and fixing soil K by the soil process [7]. Soil K fractionation balances Water-K, Exch-K, Fixed-K, and Min-K [8]. Fixed-K is the K ion trapped and held in the inner lattice of secondary minerals, which can be transformed into bioavailable K [8]. Moreover, some plant species, such as elephant grass [7], ryegrass [20], maize, pak choi, alfalfa [21], and rubber tree [22], are not only efficient in the absorption of available K but also exude root exudates releasing organic acid (chelation process) that can be released Fixed-K and make it bioavailable [20].

$\text{NH}_4\text{OAc-K}$ based on SE is the K species readily available for plant uptake [7, 8, 20]. This species includes both Sol-K and Exch-K [18]. The Exch-K is around 90% in $\text{NH}_4\text{OAc-K}$ [7]. Exch. K is referred to as K^+ adsorbed on the surfaces of negatively charged clay particles and humic substances due mainly to electrostatic force interaction [8]. This fractionation of K^+ can be leached from soils via exchangeable cations such as NH_4^+ , Ca^{2+} , H^+ , and others [20] in the soil after fertiliser application or other soil processing.

Water-soluble K is generally referred to as soil-soluble K [18]. In this study, the concentration of $\text{NH}_4\text{OAc-K}$ in the coarse and medium textural soil groups was lower than the optimal level (40–80 mg/kg) for rubber tree cultivation [23]; it was at a suitable level in the fine textural soil group (Table 1). Similarly, previous reports showed that the soil for rubber cultivation in southern Thailand had low available K in both monocrop [13] and intercrop rubber-based plantation areas [24].

K fractionation concentration increased in coarse, medium, and fine textural soil groups, respectively, and was found to be high in Res-K > Exch-K > Oxide-K > OM-K > Car-K. Positively charged K^+ can be adsorbed onto negatively charged soil constituents, and exchange fractionation can influence the environmental sorption-desorption processes [11]. The available K extracted by SEP extraction (Exch-K) was lower than that extracted by SE extraction ($\text{NH}_4\text{OAc-K}$). The direct effect was that NH_4^+ in the ammonium acetate solution (NH_4OAc) gained an advantage by exchanging with K^+ because the presence of the hydrated NH_4^+ has an ionic radius more similar to K^+ [10]. Moreover, NH_4OAc extracted not only Water-K and Exch-K but also the carbonate [25]. Therefore, metal bound to carbonate species is broadly considered bioavailable [25]. The

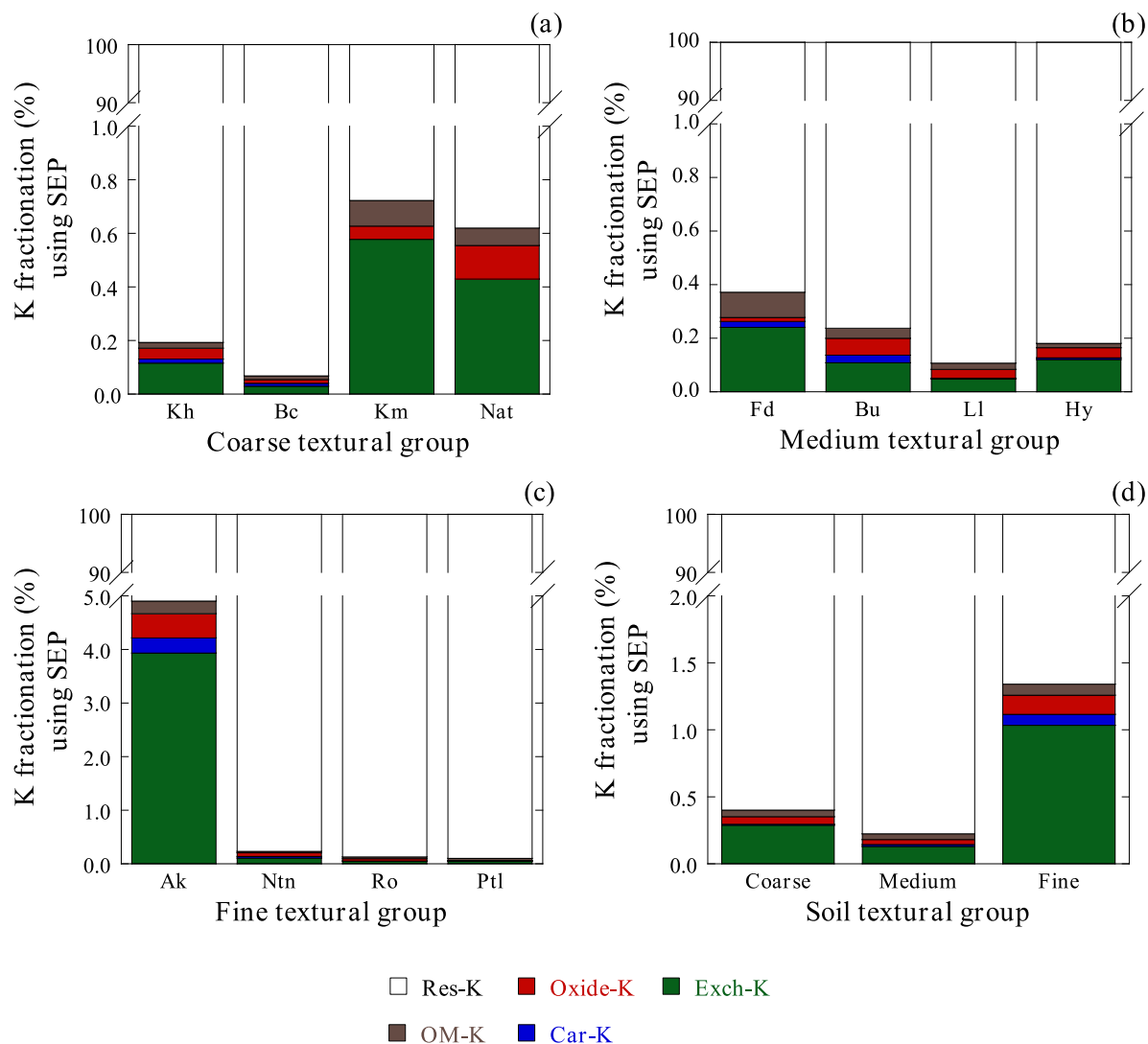


Fig. 2 K fractionation by SEP in coarse (a), medium (b), and fine (c) textural groups and the average of K fractionation based on soil textural group (d). Note: Coarse textural soil group: Kh, Bc, Km, and Nat; medium textural soil group: Fd, Bu, Ll, and Hy; and fine textural soil group: Ak, Ntn, Ro, and Ptl.

Table 2 K fractionation using SEP

Soil textural group	K fractionation based on SEP (mg/kg)					
	Exch-K	Car-K	Oxide-K	OM-K	Res-K	Total _{pseudo} -K
Coarse (n=4)	3.62	0.29	0.97	0.73	2747.64	2753.25
SD	1.41	0.14	0.45	0.12	783.56	983.31
Medium (n=4)	5.59	0.72	2.95	2.06	3360.07	3371.38
SD	1.10	0.12	0.73	0.73	730.18	737.21
Fine (n=4)	10.18	1.65	3.66	3.41	8346.77	8365.66
SD	5.16	1.53	3.05	2.28	711.36	1711.04

Note: SD = standard deviation (n=4).

Table 3 Correlation coefficient (*r*) between K fractionation based on SE and soil properties.

Soil property	K fractionation based on SE method (<i>n</i> =12)						
	Sol-K	Exch-K	NH ₄ OAc-K	Fixed-K	HNO ₃ -K	Min-K	Total-K
pH	-0.175	0.820**	0.468	0.477	0.531	0.326	0.331
EC	0.610*	-0.211	0.287	-0.319	-0.238	-0.386	-0.385
OM	0.504	0.649*	0.834**	0.363	0.498	0.360	0.364
CEC	0.482	0.695*	0.852**	0.433	0.566	0.176	0.184
Total N	0.402	0.725**	0.816**	0.299	0.436	0.312	0.316
Avail. P	0.547	0.164	0.514	-0.348	-0.220	-0.132	-0.135
Extr. Ca	0.334	0.689*	0.740**	-0.02	0.127	0.031	0.033
Extr. Mg	0.970**	0.330	0.724**	-0.162	-0.007	-0.143	-0.142
Sand (%)	-0.423	-0.648*	-0.775**	-0.597*	-0.702*	-0.238	-0.247
Silt (%)	-0.179	0.703*	0.380	0.614*	0.549	0.397	0.403
Clay (%)	0.680*	0.438	0.808**	0.424	0.640*	0.075	0.083

Note: ** and *: Correlation is significant at the $p \leq 0.01$ and 0.05 levels, respectively.

Table 4 Correlation coefficient (*r*) between K fractionation based on SEP and soil properties.

Soil property	K fractionation based on SEP method (<i>n</i> =12)					
	Exch-K	Car-K	Oxide-K	OM-K	Res-K	Total K _{pseudo}
pH	0.344	0.749**	0.674*	0.632*	0.552	0.553
EC	0.275	-0.154	-0.289	-0.395	-0.445	-0.445
OM	0.778**	0.555	0.648*	0.553	0.435	0.436
CEC	0.735**	0.554	0.406	0.499	0.339	0.339
Total N	0.690*	0.592*	0.686*	0.489	0.403	0.403
Avail. P	0.494	0.416	0.284	-0.272	-0.183	-0.182
Extr. Ca	0.640*	0.760**	0.659*	0.125	0.154	0.155
Extr. Mg	0.822**	0.236	0.136	-0.12	-0.195	-0.194
Sand (%)	-0.669*	-0.491	-0.301	-0.647*	-0.396	-0.374
Silt (%)	0.214	0.475	0.465	0.740**	0.569	0.182
Clay (%)	0.768**	0.368	0.119	0.414	0.182	0.569

Note: ** and *: Correlation is significant at the $p \leq 0.01$ and 0.05 levels, respectively.

carbonate fraction is a loosely bound phase; it can easily be altered under low soil pH [26]. In tropical soil, acidic soil has a low Car-K fraction. In this study, it was below 0.015% in all soil groups (Fig. 2). Meanwhile, calcareous soil was higher in carbonate fraction

content than acidic soil [13]. K bonded to Fe and Mn atoms and coated soil particles with oxygen atoms [7]. K bound to Fe-Mn oxide was low (0.01–0.45%) in relative distributions for all soil groups (Fig. 2), but fine textural soil diversity was the greatest owing to Ak

Table 5 Correlation coefficient (*r*) between K fractionation extracted using SE and SEP (*n* = 12).

K fractionation using SE	Sol-K	Exch-K	NH ₄ OAc-K	Fixed-K	HNO ₃ -K	Min-K
Exch-K	-0.044					
NH ₄ OAc-K	0.690*	0.693*				
Fixed-K	-0.191	0.618*	0.310			
HNO ₃ -K	-0.041	0.706*	0.482	0.982**		
Min-K	-0.123	0.514	0.284	0.680*	0.682*	
Total-K	-0.122	0.520	0.289	0.682*	0.691*	1.000**
K fractionation using SEP	Exch-K	Car-K	Oxide-K	OM-K	Res-K	
Car-K	0.634*					
Oxide-K	0.539	0.680*				
OM-K	0.315	0.429	0.450			
Res-K	0.252	0.420	0.623*	0.910**		
Total-K _{pseudo}	0.253	0.421	0.624*	0.910**	1.000**	

Note: ** and *: Correlation is significant at the $p \leq 0.01$ and 0.05 levels, respectively.

soil containing high Fe and Al oxide content. Organic residual and living creatures in soil may decompose to release K for plant absorption [11]. Similarly, a previous report showed that organic matter in soil acts as a slow-release nutrient storehouse [7]. The bulk of residual-K comprises primary and secondary minerals that are unlikely to dissolve [11]. Like the mineral fraction via SE, this fractionation may be easily accessible after weathering, but the environmental process is very slow.

The correlation of available K received by SE and SEP methods was high with OM, CEC, and clay particles due to negatively charged clay particles and OM surface cation adsorption (Table 3 and Table 4). The Sol-K relation to EC due to the saline effect from K fertiliser showed a similar correlation between Sol-K and EC [27]. Fixed-K, HNO_3 -K, and OM-K were negatively correlated with sand particles, while they were positively correlated with silt and clay. Sand particles consist of a single mineral, mainly quartz, which has a low specific surface area and little capacity to hold nutrients [7].

Rubber-growing soils have low available K content (Table 1). Therefore, the combination between potash and organic fertiliser application to enhance K status is essential in this region. Moreover, the amount of potash fertiliser application in rubber grown in coarse textural soil groups should be higher than in fine soil textural groups due to the soil K ability and the K buffering capacity. In soils that were high in Fixed-K, Min-K, or Res-K, the application of K-solubilising bacteria for bio-fertiliser and stimulating the rubber to secrete organic acids (oxalic acid) to change K in the soil from an un-bioavailability to bioavailability fractionation may require fertiliser input saving and cost reduction for precision K management in soils used for growing rubber trees.

CONCLUSION

The K fractionation analyses conducted through SE and SEP not only revealed robust positive correlations with soil properties but also demonstrated a high level of intercorrelation between the K fractionation groups. The amalgamation of Exch-K and Car-K, representing readily available K, exhibited a striking correlation with $\text{NH}_4\text{OAc-K}$ ($r^2 = 0.937$). Similarly, the combined presence of Oxide-K and OM-K, indicative of slowly available K, displayed a strong correlation with Fixed-K ($r^2 = 0.844$). The concentration of unavailable K (Res-K) was notably correlated with Min-K ($r^2 = 0.832$). Therefore, SEP may be an alternative method for K fractionation and K ability in rubber-growing soils. To unravel the intricacies of these processes further, there is a compelling need for additional research, particularly in terms of exploring the application of K solubilising bacteria to augment soil K availability. Additionally, investigating the stimulation of rubber trees

to secrete organic acids, enhancing the bioavailability of soil K fractionation on a larger agricultural scale, is a promising avenue for future inquiry.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at <https://dx.doi.org/10.2306/scienceasia1513-1874.2025.007>.

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Appendix A. Supplementary data

Table S1 Universal Transverse Mercator (UTM) coordinates of the sampling areas.

Soil textural group	Soil series	Soil taxonomy	Coordinate UTM system
Fine	Ao Luek (Ak)	Very-fine, kaolinitic, isohyperthermic Rhodic Kandiodoxs	47P X573536 Y1013713
	Na Thon (Ntn)	Fine, mixed, semiactive, isohyperthermic Typic Hapludults	47N X642331 Y784884
	Ruso (Ro)	Fine-silty, mixed, semiactive, isohyperthermic Typic Paleudults	47N X654353 Y759784
	Phattalung (PtI)	Fine, kaolinitic, isohyperthermic Plinthic Paleaquults	47N X641509 Y783460
Medium	Fang Daeng (Fd)	Fine-loamy, kaolinitic, isohyperthermic Rhodic Kandiodults	47N X634957 Y808358
	Sai Buri (Bu)	Fine-silty, kaolinitic, isohyperthermic Aquic Kandiodults	47N X681592 Y746489
	Lamphu La (Ll)	Fine, mixed, semiactive, isohyperthermic Typic Palehumults	47N X621086 Y815550
	Hat Yai (Hy)	Clayey-skeletal, kaolinitic, isohyperthermic Typic Paleudults	47N X649387 Y783099
Coarse	Kho Hong (Kh)	Coarse-loamy, kaolinitic, isohyperthermic Typic Kandiodults	47N X672121 Y765150
	Bacho (Bc)	Coated, isohyperthermic, Typic Quartzipsamments	47N X685401 Y783772
	Khlong Thom (Km)	Fine-loamy, kaolinitic, isohyperthermic Typic Kandiodults	47N X653006 Y784688
	Na Thawi (Nat)	Coarse-loamy, kaolinitic, isohyperthermic Typic Kandiodults	47N X690435 Y745021

Table S2 Sequential extraction process by Tessier et al's scheme [11].

Step	Form/association	Extraction reagent	Shaking time	Temp. (°C)
1	Exchangeable K (Exch-K)	8 ml of 1 M MgCl ₂ pH 7	1 h	25
2	Carbonate (Car-K)	8 ml of 1 M CH ₃ COONa pH 5 with CH ₃ COOH	6 h	25
3	Fe and Mn oxide (Oxide-K)	20 ml of 0.04 M NH ₂ OH · HCl in 25% (v/v) CH ₃ COOH	10 h in daylight	96
4	Organic matter (OM-K)	3 ml of 0.02 M HNO ₃ and 5 ml of 30% (v/v) H ₂ O ₂ pH 2 with HNO ₃	2 h	85
		A second, 3 ml of 30% (v/v) H ₂ O ₂ pH 2 with HNO ₃	3 h	
		After cooling, 5 ml of 3.2 M NH ₄ OAc in 20% (v/v) HNO ₃	0.5 h	
5	Residual (Res-K)	The residue was digested with HF-HClO ₄ mixture	Heating to near dryness	113

Table S3 Physicochemical properties of soil samples.

Soil textural group	pH (1:5)	EC (dS/m)	OM (g/kg)	Avai.P (mg/kg)	Extr. Ca (mg/kg)	Extr. Mg (mg/kg)	Total N (g/kg)	CEC (cmol _c /kg)	Sand (%)	Silt (%)	Clay (%)
Coarse (n=4)	5.15	0.01	8.67	3.90	30.14	38.96	0.53	1.60	80	8	12
SD	0.11	0.01	2.29	0.63	9.65	7.73	0.23	0.44	9	5	4
Medium (n=4)	5.34	0.01	13.68	3.48	15.25	41.19	0.86	5.33	51	24	25
SD	1.14	0.01	5.16	1.20	7.29	5.61	0.21	1.90	8	10	4
Fine (n=4)	6.54	0.01	21.12	5.48	319.67	265.20	1.27	10.75	20	28	52
SD	1.12	0.01	2.79	2.71	58.30	64.51	0.24	1.19	14	12	19

Note: SD = standard deviation.

Table S4 The correlation coefficient (*r*) between K fractionation based on SE and SEP (n=12).

K fractionation based on SEP	K fractionation based on SE						
	Sol-K	Exch-K	NH ₄ OAc-K	Fixed-K	HNO ₃ -K	Min-K	Total-K
Exch-K	0.808**	0.510	0.953**	0.208	0.379	0.237	0.241
Car-K	0.187	0.827**	0.734**	0.319	0.438	0.260	0.264
Exch-K + Car-K	0.727**	0.612*	0.986**	0.246	0.416	0.257	0.261
Oxide-K	0.109	0.729**	0.607*	0.193	0.297	0.607*	0.605*
Exch-K + Car-K + Oxide-K	0.578*	0.715**	0.935**	0.251	0.415	0.409	0.411
OM-K	-0.146	0.729**	0.423	0.925**	0.960**	0.787**	0.794**
Exch-K + Car-K + Oxide-K + OM-K	0.470	0.800**	0.919**	0.448	0.593*	0.546	0.549
Res-K	-0.215	0.698*	0.351	0.814**	0.819**	0.948**	0.950**
Total-K _{pseudo}	-0.215	0.699	0.352	0.814*	0.819*	0.948**	0.950**

Note: ** and *: Correlation is significant at the $p \leq 0.01$ and 0.05 levels, respectively.