Jammu Kashmir J. Agri., 03 (03) 2023. 311-318 DOI: 10.56810/jkjagri.003.03.0125

Faculty of Agriculture, University of Poonch Rawalakot
Jammu Kashmir Journal of Agriculture
ISSN: 2958-3756 (Online), 2958-3748 (Print)
https://jkjagri.com/index.php/journal

POTASSIUM FRACTIONATION AND ITS RELATIONSHIP WITH OTHER SOIL CHARACTERISTICS IN THE UPLANDS OF BALOCHISTAN

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ABSTRACT

Potassium (K) stands as a vital nutrient for plant growth and reproduction, ranking second only to nitrogen in importance among essential plant nutrients. Often heralded as the cornerstone of quality nutrition for plants, its significance extends to influencing various attributes such as plant shape, size, color, taste, and overall health. Plants primarily uptake potassium in its ionic form, K+. In the pursuit of high crop yields and superior agricultural produce, achieving a balanced and sufficient mineral nutrition, including potassium, is paramount. However, in many rain-fed regions of developing countries, imbalances in potassium nutrition have emerged as a significant impediment to optimal crop production. This study aimed to assess the potassium status in diverse soils across the uplands of Balochistan and elucidate the relationship between potassium fractions and other soil characteristics. Various soil profiles were meticulously examined, and samples were systematically collected, processed, and subjected to comprehensive analysis. The findings indicate that soils in the Quetta district exhibit higher levels of water-soluble, exchangeable, and non-exchangeable potassium compared to soils in the Pishin and Mastung regions. The readily available (water-soluble + exchangeable) and non-exchangeable potassium fractions constituted 0.02-0.07% and 0.1-0.9% of the total potassium content in soils, respectively. Mineral potassium accounted for approximately 92-97% of the total potassium, with concentrations ranging between 27.6-54.5 cmol/kg. The maximum soluble potassium content was recorded in Beleli location (0.039 cmol/kg), while the minimum was observed in Yaro location (0.015 cmol/kg). These variations in potassium levels were primarily attributed to the presence of potassium-rich minerals within the soil. The study concluded that a variability of potassium fractions exists across different soil profiles, with soils in Quetta district exhibiting higher levels compared to Pishin and Mastung regions.

Keywords: Quetta; K Fraction; Potassium; Soil Analysis; Upland Balochistan

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Article history
Received: November 2nd, 2023
Revised: December 14th, 2023
Accepted: December 17th, 2023

INTRODUCTION

Potassium (K) stands out as a crucial nutrient among others, renowned for its pivotal role in crop growth and its behavior within soil ecosystems. K is acknowledged for its beneficial impact on plant growth (Johnson et al., 2022). In soil, K exists in distinct forms: immediately available, readily available, slowly available, and relatively unavailable K, also referred to as water-soluble, exchangeable, non-exchangeable, and mineral K, respectively (Panda et al., 2022). The response of crops to K fertilization is primarily associated with the redistribution among different forms of K rather than the sheer quantity present in the labile pool. Accurate assessment of K status necessitates integrating measurements describing K dynamics in soil systems into routine soil testing protocols, upon which fertilizer recommendations should be based. Soil profile characteristics, influenced by various factors and soil formation processes, significantly impact soil fertility and crop productivity (Alkharabsheh et al., 2021). Investigating different K fractions is crucial for maximizing the effective use of K fertilizers.

Potassium serves numerous functions among major plant nutrients in soil, including enzyme activation, water regulation, energy relations, assimilate translocation, photosynthesis, and protein and starch synthesis, supporting agricultural productivity and sustainability (Hasanuzzaman et al., 2018). Soil K availability to plants is governed by dynamic interactions among its various chemical forms (Wang et al., 2004). The amount of K in soils varies based on parent material, weathering extent, fertilization, and losses during crop removal, leaching, and erosion. Different forms of K, such as mineral, solution, exchangeable, and non-exchangeable, exhibit varying mobility and availability to plants, with soil solution K being the most mobile and prone to leaching. Understanding the dynamics of potassium in soils is essential for sustainable crop production.

In recent years, studies have highlighted the critical role of potassium in cereal yield and grain weight (Wani et al., 2014). Applications of potassium fertilizer have been shown to promote wheat grain filling and enhance overall crop productivity (Cakmak, 2023). Furthermore, potassium plays vital roles in enzyme activation, water regulation, energy relations, assimilate translocation, photosynthesis, and protein synthesis, underscoring its importance in sustaining agricultural productivity (Wakeel, 2013).

In Pakistan, where nitrogen and phosphorus are traditionally emphasized for wheat production, the role of potassium has been relatively understated. However, increasing evidence suggests that potassium is essential for optimizing wheat yields and ensuring sustainable production (Kochian et al., 2023). As such, understanding soil potassium dynamics is becoming increasingly crucial for agricultural sustainability in the region (Hasanuzzaman et al., 2018). Consequently, this research endeavors to evaluate the present potassium levels in upland Balochistan soils with the intention of refining fertilizer application for improved crop yield.

MATERIALS AND METHODS

Soil sampling

Various soil profiles were carefully selected from three districts: Quetta, Pishin, and Mastung, based on the heterogeneous nature of the soil concerning morphological features, crop growth patterns, and yield variability. Furthermore, different soil horizons within each soil profile were differentiated based on variations associated with soil color, texture, structure, root density, effervescence, and consistency. Soil samples were collected from each horizon and processed for further analysis. The preparation of soil samples was conducted at the Soil and Water Testing Laboratory, ARI, Quetta. The soil samples underwent various processes including air drying, crushing with a pestle and mortar, sieving through a 2 mm sieve of a soil grinder, and washing and drying. Prepared samples were stored in plastic bags for subsequent laboratory analysis.

Soil analysis

Soil samples underwent comprehensive analysis for various parameters including soil pH, organic matter, electrical conductivity (EC), texture, and potassium (K) tractions using standard procedures. All analytical work was carried out in the laboratory of Soil and Water Testing, ARI, Quetta. The procedures used for analysis included measuring soil pH by mixing 50 grams of air-dried soil with 50 ml of distilled water and measuring with a calibrated pH meter (McLean et al., 1982). Soil texture was determined by mixing 40 grams of soil with a solution of one percent Na-hexa-metaphosphate and sodium carbonate, and liquid density was recorded using a hydrometer at regular intervals (Bouyoucos, 1927). Electrical conductivity was measured by mixing soil with deionized water, stirring the suspension, and recording readings using a calibrated conductivity meter (Rhoades, 1996).

Soil potassium content was evaluated by extracting potassium using ammonium acetate solution, filtering the suspension, and determining potassium concentration using a flame photometer. Soluble potassium was obtained from a water extract of soil suspension, and exchangeable potassium was calculated as the difference between extractable and soluble potassium. Non-exchangeable potassium was estimated by treating soil with nitric acid and determining potassium concentration using a flame photometer. Total potassium was evaluated through digestion of soil samples in Teflon tubes with hydrofluoric acid and aqua regia, followed by potassium measurement using a flame photometer. Mineral potassium was determined by subtracting total soil potassium from the sum of all other forms of potassium.

Statistical analysis

Upon acquiring the data from these analyses, descriptive statistics were employed to examine the standard deviation, minimum, maximum, and mean values of all parameters. The relationship between different forms of potassium (K) and soil properties will be assessed using linear regression and Pearson’s correlation analysis, facilitated by Statistix 8.1 software.

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RESULTS AND DISCUSSION

Physico-chemical properties of soil

The physicochemical characteristics of soil samples collected from various locations are mentioned in Table 1. Across the sampled sites, soil texture ranged from light to medium, while pH readings indicated a range from neutral to alkaline, specifically falling between pH 7.3 and 8.3. Analysis of electrical conductivity (EC) values suggested low salt content, with readings ranging from 16 ds/ms to 25 ds/ms. Bulk density measurements exhibited variability across sites, with the highest recorded in City-I area of Pishin district (average: 1.26 g/cm3) and the lowest in the Hanna site of the Quetta district (average: 1.02 g/cm3). Organic carbon content was also assessed at each site, with the highest recorded at the ARI site of Quetta district (average: 0.86%) and the lowest at the Yaro site of Pishin district (average: 0.42%). Moreover, percentages of sand, silt, and clay were documented and presented in Table 1. These variations among sites could be attributed to differences in annual rainfall and cropping patterns.

Table 1. Selected Physico-chemical properties of soils in different agro-ecological locations of Quetta Zone, Balochistan.

District	Location	pH	EC (ds/m)	Bulk Density (g/cm^3)	Organic Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Texture
	ARI	7.8	0.23	1.16	0.86	36.8	32.1	29.8	Loam
	Beleli	7.6	0.21	1.06	0.66	29.6	33.5	36.9	Loam
Quetta	Hanna	7.4	0.25	1.02	0.72	45.2	30.8	26.8	SandyLoan
	Qambrani	7.9	0.26	1.11	0.52	43.9	32.9	28.4	Sandy Loam
	Nowsar	7.7	0.16	1.03	0.59	31.7	29.4	33.7	Clay Loam
	Yaro	7.8	0.20	1.16	0.42	24.1	21.9	43.8	Clay Loam
	Manzaki	8.1	0.19	1.18	0.69	36.9	28.7	32.9	Loam
Pishin	Karbala	7.8	0.12	1.16	0.55	26.8	33.7	41.2	Clay Loam
	City 1	7.3	0.25	1.26	0.62	34.5	26.9	35.7	SandyClay Loam
	Torasha	7.9	0.22	1.15	0.78	36.1	30.1	32.8	Sandy Loam
	Mastung	7.5	0.16	1.20	0.61	35.9	34.9	28.5	Loam
	Kanak	7.4	0.26	1.21	0.82	27.5	29.8	32.9	Loam
Mastung	Bashaan	7.8	0.18	1.19	0.74	25.4	32.6	33.7	Clay Loam
	Dringarh	8.2	0.23	1.12	0.64	36.8	31.8	29.9	Sandy Loam
	Sorghaz	8.3	0.21	1.09	0.63	30.2	29.9	33.8	Loam

Comparing these findings with previous studies, it is evident that they align with the observations made by Sharif et al. (2019). For instance, Sharif et al. (2019) and Agha et al. (2020) also noted similar trends in pH levels across different regions. Specifically, Agha et al. (2020) reported higher pH levels in Panjpai and Quetta, whereas lower pH levels were observed in Khanozai and Pishin. This consistency in findings suggests robustness in the observed patterns and reinforces the influence of geographical and environmental factors on soil characteristics.

Water soluble potassium

The water-soluble potassium levels varied from 0.015 cmol/kg in the Yaro location of Pishin District to 0.039 cmol/kg in the Beleli location of Quetta District. In comparison to Mastung and Pishin districts, all locations in Quetta district exhibited the highest soluble potassium content (Figure 1). The elevated levels of water-soluble potassium in Quetta district may be attributed to the accumulation of salts in the mountains of Quetta district, as indicated by relatively higher electrical conductivity (EC) values. These findings align with those of Benipal et al. (2009) and Ahmad et al. (2023), who also noted high levels of water-soluble potassium in regions adjacent to mountains. Additionally, a significant correlation was observed between soil EC and water-soluble potassium content in the soils (Table 2). Ghiri and Abtahi (2011) similarly discovered that water-soluble K tended to be higher in soils with elevated EC, as potassium is a cation that contributes to soil salinity alongside calcium and magnesium.

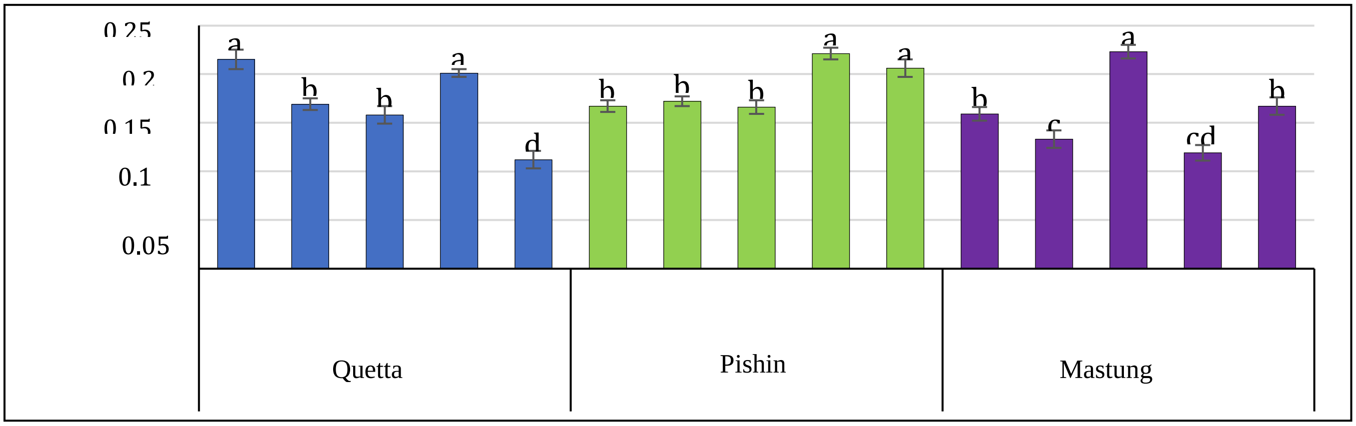

Figure 1: Mean soluble potassium (*K*) in different agro-ecological locations of QuettaZone, Balochistan.

Exchangeable potassium

The range of exchangeable potassium in the soils varied from 0.112 cmol/kg in Nowsar soils (Quetta) to 0.223 cmol/kg in Bashaan soils (Mastung). These values accounted for approximately 0.21% to 0.46% of the total potassium content, respectively (Figure 3). The highest levels of exchangeable potassium were observed in soils of Pishin district, averaging 0.186 cmol/kg, followed by Quetta district (average of 0.171 cmol/kg) and Mastung district (average of 0.162 cmol/kg). These findings are consistent with those reported (Ahmed et al., 2019). Exchangeable potassium demonstrated a positive correlation with both electrical conductivity (EC) and organic carbon, similar to the relationship observed between soluble potassium and EC (Table 2).

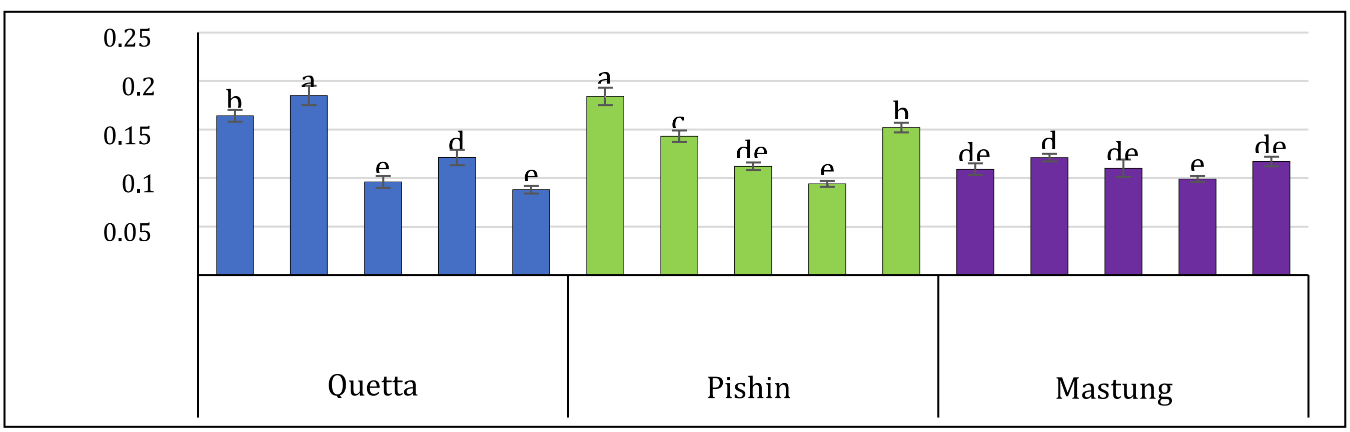

Figure 2: Mean available potassium (*K*) in different agro-ecological locations of Quetta Zone, Balochistan.

The notable correlation with organic carbon content in soils can be explained by the increased availability of exchange surfaces for positively charged potassium ions. While exchangeable potassium exhibited positive

 DOI: 10.56810/jkjagri.003.03.0125

correlations with clay content and negative correlations with sand content, these relationships were not statistically significant. This observation aligns with findings reported by Kochian et al. (2023). Generally, higher levels of water-soluble and exchangeable potassium were found in the southwestern alluvial plain regions. This distribution pattern may be attributed to higher rainfall in northern regions, potentially leading to leaching. Additionally, the presence of $CaCO^3$ and the release of occluded potassium during the breakdown of $CaCO^3$ could contribute to this pattern. The trend observed in available potassium, which comprises both exchangeable and water-soluble potassium, followed a similar pattern to that of exchangeable potassium.

Table 2. Correlation of various potassium (K) forms with soil properties.

	Soluble	Available	Exchangeable	Non-exchangeable	Mineral	Total
pH	-0.32525	-0.25504	0.202305	0.598559	-0.02365	0.044625
EC *(ds/m)*	0.078554	0.058803	0.18658	0.089447	-0.12256	-0.10811
Bulk Density *(g/cm^3)*	-0.43837	0.025326	0.443989	0.593625	-0.43441	-0.35546
Organic Carban	0.43667	0.024731	0.202656	0.362688	0.434584	0.470249
Sand (%)	0.325192	-0.26228	0.082663	-0.31765	-0.18858	-0.22206
Silt (%)	0.692652	-0.2406	0.022431	-0.03182	0.107055	0.100989

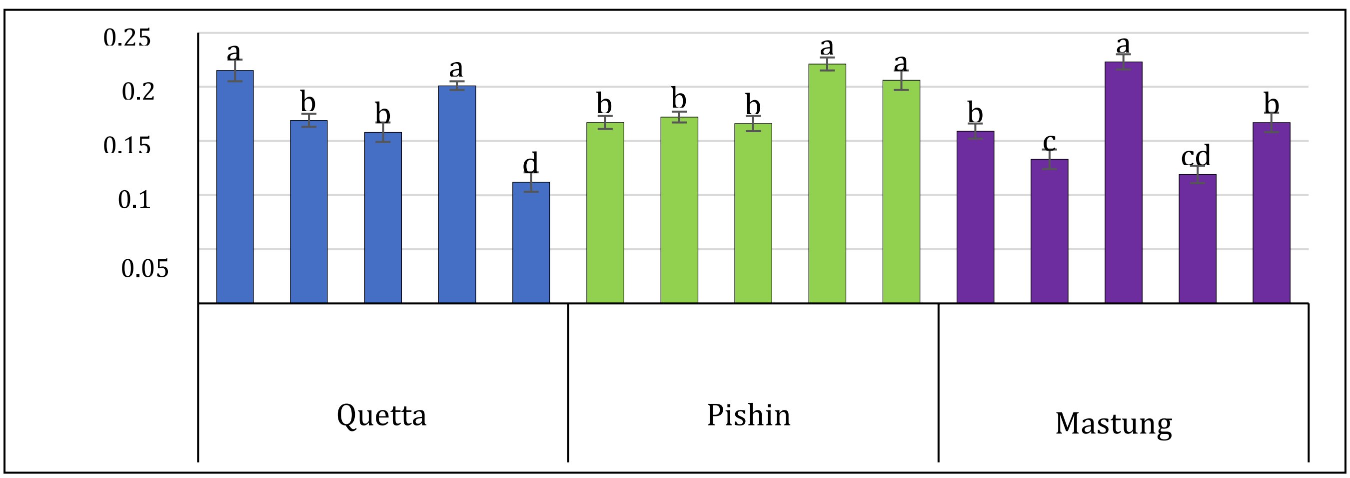

Figure 3. Mean exchangeable potassium (*K*) in different agro-ecological locations of Quetta Zone, Balochistan.

Non-exchangeable potassium

The non-exchangeable potassium content in the soils varies from 0.984 cmol/kg at the Hanna location in Quetta district to 2.691 cmol/kg at the Kanak location in Mastung district (Figure 4). The proportion of non-exchangeable potassium to the total potassium ranges from 1.92% to 4.8% at the Hanna (Quetta) and Kanak (Mastung) locations, respectively. Non-exchangeable potassium is recognized as the primary source of potassium supply to plants (Benipal et al., 2009). According to Sharma et al. (2006), fixed potassium typically constitutes around 2-4% of the total potassium content in various landforms. A significant positive correlation was observed between non-exchangeable potassium and clay content (Table 2), likely due to the high illite content in the soils (Abou-Taleb et al., 2010). The findings indicate that soils in the Pishin district exhibit high levels of both readily available (water-soluble and exchangeable) and slowly available potassium forms.

Mineral potassium

Mineral potassium, also known as lattice potassium, exhibits a range from 39.70 cmol/kg at City I location in the Pishin district to 54.62 cmol/kg at the ARI location in the Quetta district (Figure 5). The mean values were determined to be 50.05 cmol/kg, 47.48 cmol/kg, and 48.55 cmol/kg in the Quetta, Pishin, and Mastung districts, respectively.

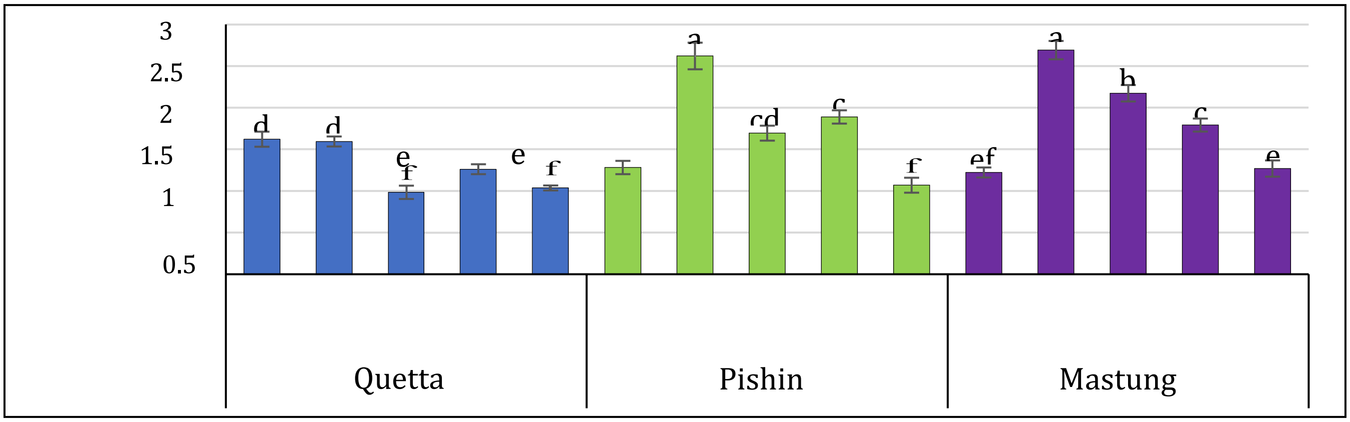

Figure 4. Mean Non-exchangeable potassium (*K*) in different agro-ecologicallocations of Quetta Zone, Balochistan.

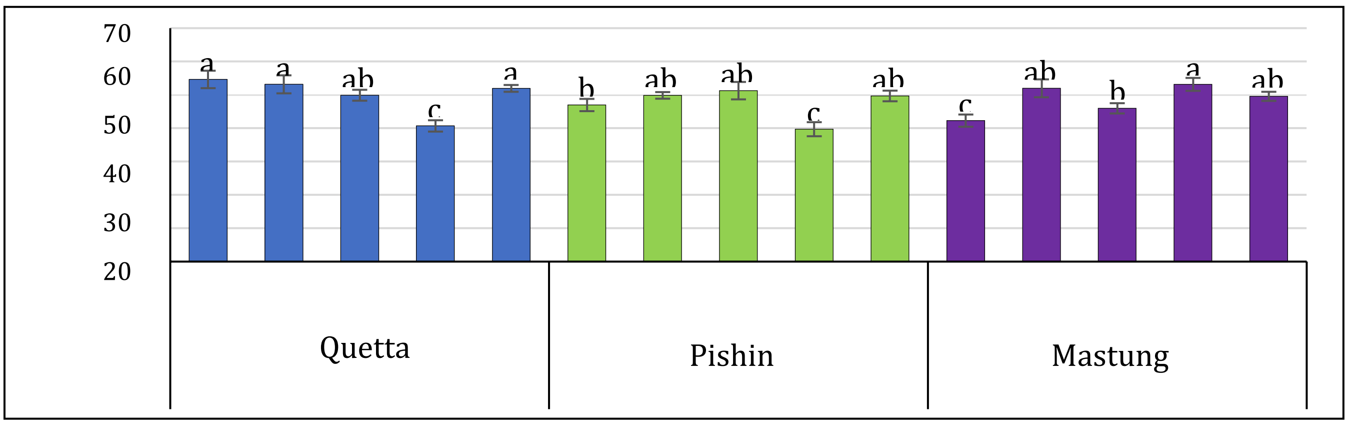

Figure 5. Mean mineral potassium (*K*) in different agro-ecological locations of QuettaZone, Balochistan.

Mineral potassium content was notably higher in locations within the Quetta district compared to those in the Pishin and Mastung districts. The proportion of mineral potassium to total potassium varied between 94.7% and 96.5%. The elevated mineral potassium content may be attributed to the increased presence of mica and feldspars in the coarse fractions and illite in the clay fraction. Benipal et al. (2009) noted that over 93% of the total potassium existed in mineral form, suggesting the parent material as the primary potassium source. Mineral potassium exhibited a significant positive correlation with silt and clay content (Table 2), likely due to the presence of potassium-bearing minerals in these fractions.

Total potassium (K)

The overall potassium content varies from 41.92 cmol/kg at the City I location in Pishin district to 56.65 cmol/kg at the ARI location in Quetta district (Figure 6). These elevated total potassium values across different sites primarily result from the presence of significant quantities of potassium-bearing minerals, capable of retaining substantial potassium levels within the soils. These findings align with those documented by Sharma et al. (2006).

Total potassium exhibited a positive correlation with silt and clay content, while showing a negative correlation with sand content (Table 2). The negative association with sand content can be attributed to the prevalence of quartz, which diminishes its potassium retention capacity. Conversely, the positive correlation with clay and silt suggests potassium fixation by these fractions due to their abundant potassium-bearing mineral content Deka et al. (1995).

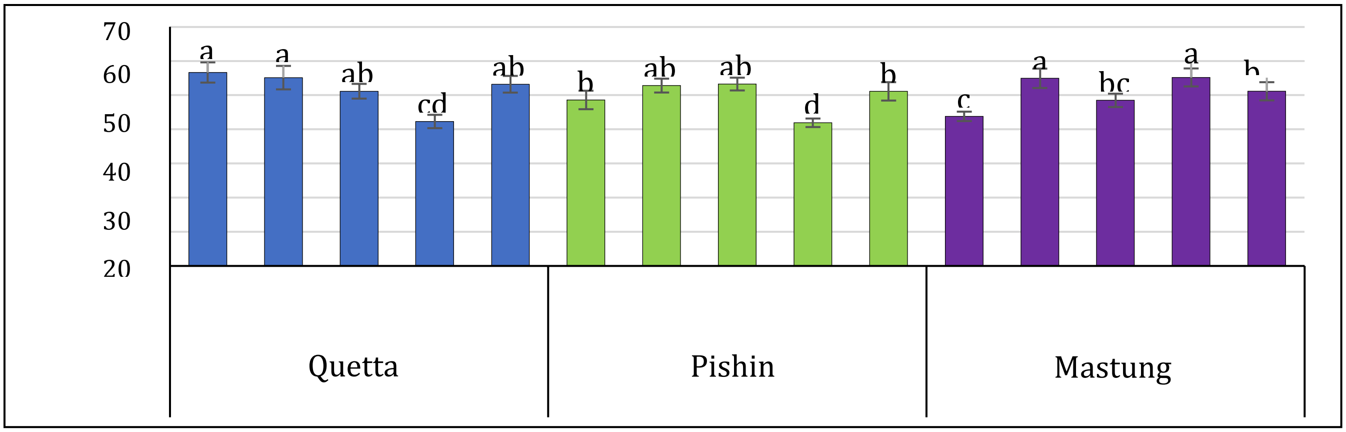

Figure 6. Mean total potassium (*K*) in different agro-ecological locations of QuettaZone, Balochistan.

CONCLUSION

This research concluded the critical importance of potassium (K) in agricultural systems, particularly in upland areas like Balochistan. Neglecting potassium in fertilizer application could lead to imbalanced nutrition, adversely affecting crop yield and quality. The study highlighted the variability of potassium fractions across different soil profiles, with soils in Quetta district exhibiting higher levels compared to Pishin and Mastung regions. The findings emphasized the necessity of monitoring soil potassium reserves to make accurate fertilizer recommendations, considering the dynamic equilibrium between various forms of potassium in the soil. By understanding the relationship between potassium fractions and other soil characteristics, such as mineral content, agricultural practices could be better tailored to optimize potassium utilization, thereby enhancing crop productivity in rain-fed areas and contributing to sustainable agricultural development.

CONFLICT OF INTEREST

There is no conflict of interest.

AUTHOR'S CONTRIBUTION

The writing of this article was assisted and helped by all authors.

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