International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(3): 573-578
www.biochemjournal.com
Received: 15-12-2023
Accepted: 19-01-2024

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Quantity-intensity characteristics of potassium in coastal alluvial soils of Udupi district, under paddy land use cover

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DOI: https://doi.org/10.33545/26174693.2024.v8.i3g.776

Abstract
The concepts of quantity-intensity and buffering capacity help describe and measure the potassium-supplying power of soils. The intensity factor (I) measures K in soil solution, i.e., immediately available for plant absorption, varies with the amount of labile form of this element (quantity). Quantitatively, the buffering capacity is expressed as the ratio ΔQ/ΔI. The wider the ratio of ΔQ/ΔI, the more buffered the soil. So, quantity-intensity characteristics of potassium were studied to quantify the potassium availability in coastal alluvial soils under the paddy cover of the Udupi district. The investigation results indicated that the specifically bound potassium (K_X), a part of labile K, and the K retained by nonspecific sites ($-\Delta K^o$) were deficient. Hence, these soil's labile potassium (K_L) appeared to be low. The low values of PBC^K (14.39, 07.00, 09.00 cmol (p+) kg^{-1}) indicated that the soils had meager potassium buffering capacity (PBC^K), probably due to their low clay content.

Keywords: Quantity-intensity, buffering capacity, potassium availability

Introduction

Potassium supplying ability of soil to a crop depends on its immediate availability and also on the ability of the soil to replenish against K depletion, which is dependent on the quantity-intensity relationship of the labile K. The power of the given soil to supply any particular nutrient is characterized by the total amount of labile nutrient present (quantity) and the energy level (intensity) at which it is held in solution. The relationship between these two parameters may be determined by the quantity-intensity technique, which is based on thermodynamic principles and applies to all soils. In some cases, even though the soil contains a considerable amount of total K, the availability to plants is negligible. This refers to the availability of K to plants which depends not only on its availability but also on its dynamics, *viz*., intensity, capacity, and renewal rate in soils. It is, therefore, essential to know the magnitude of different quantity-intensity parameters of K to ensure the K availability at different K status such as low, medium, and high potassium status in soils. Finally, knowing the equilibrium constants is essential for predicting the status and supply of K for plants (Lindsay, 1979) [8]; misunderstanding these dynamics leads to mismanagement of soil fertility.

In this case, the activity ratio AReK or $aK/\sqrt{a(Ca+Mg)/2}$ described by Beckett (1964) [2] is one of the satisfactory measures of the K dynamics and its availability because it measures both the chemical potential of labile K present to the chemical potential of labile (Ca+Mg) in the same soil. At the same time different soils having the same AReK values may not possess the capacity for maintaining AReK when soil K is depleted. The PBCK characterizes soil's capacity to resist changes in available potassium under the impact of natural and anthropogenic factors (Zharikova, 2004) [16].

The forms and dynamics of soil potassium are greatly influenced by changes in land use, which often involve changes in vegetative cover and biomass production. Since K is mainly required for paddy (*Oryza sativa*) crops next to nitrogen, major paddy-growing alluvial soils of the Udupi district were selected to measure the potassium dynamics in relation to K availability. With this background, an attempt was made to relate the potassium availability parameters to the quantity-intensity characteristics under paddy cover in alluvial soils of the Udupi district.

Study area and sample collection
Material and Methods

The study was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Shivamogga, UAHS, Shivamogga, from 2014 to 2016.

For the investigation, one sixty five surface (0-15cm) soil samples of paddy land use cover, were collected from nine hoblis under Udupi district, Karnataka. Udupi, a Karnataka state coastal district is located on the west coast, peninsular India. The district lies between 13^o 04' and 13^o 59' North latitude and 74^o 35' and 75^o 12' East longitude, covering an area of 3575 sq km. It is about 88 km in length and 80 km in widest part. Udupi district consists of three taluks namely Udupi, Karkala, and Kundapur, and nine hoblies *viz*., Udupi, Kota, Kapu, Bramhavara, Byndoor, Vandse, Kundapura, Karkala, and Ajekaru as shown in Fig. 1.

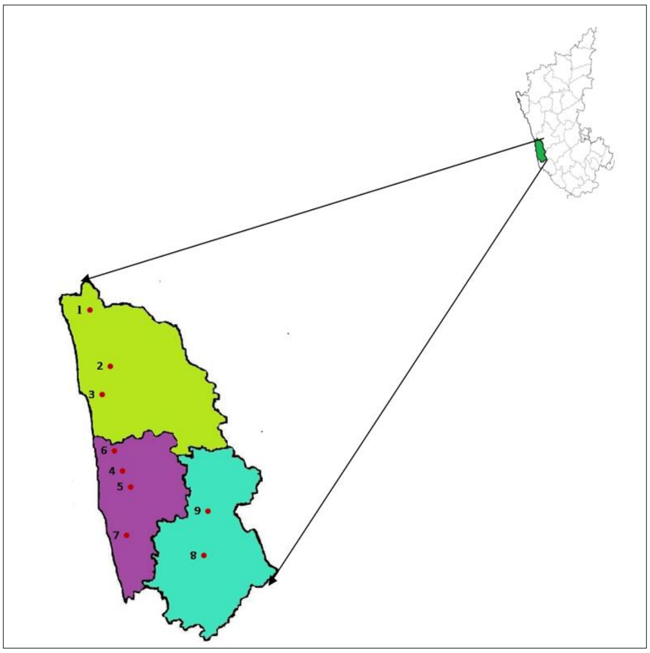

Fig 1: Map showing Udupi district with nine hoblies

Collected representative soil samples were analyzed for pH, EC, Organic carbon, texture, CEC, available potassium status and, Quantity-Intensity of soils using standard methods.

Quantity-Intensity factor determination

The soil samples were selected from the Udupi district of paddy land cover for evaluating the Q/I parameters by following the procedure suggested by Beckett (1964a and 1964b) with some modifications. Five grams each of soil was taken in series of 250 ml conical flasks and impregnated with 50 ml of 0.01 M $CaCl_2$ solution containing graded concentrations of K (0, 0.1, 0.2, 0.3, 0.4, 1, 2, 3, 4 m mol L^{-1}). The suspension was filtered after shaking for one hour allowing them to stand overnight. Potassium in the filtrate was determined using a flame photometer. Calcium plus magnesium contents were determined by the EDTA method (Jackson, 1973) [6].

The quantity factor (ΔK in units of cmol (p^+) kg^{-1}) was computed by taking the difference between the initial and final concentration of K in equilibrium solution and the potassium activity ratio was calculated after determining activity coefficient of the ions from the ionic strength using modified Debye-Huckel equation given below:

$$-\log fi = -\log fi = \frac{A Z_i^2 \sqrt{\mu}}{1+B a_i \sqrt{\mu}}$$

Where,
A is constant (0.512)
Z_i = Valency of ion, i
B = Constant equal to 0.328 at 25 °C
a_i = Ionic size parameter is said to correspond to the closest approach of
cation and anion (3 for K, 6 for calcium)
μ = Ionic strength, given by EC (dSm^{-1}) x 0.013 as suggested by Griffin and Jurinak (1974) [5]
fi = activity coefficient

The Potassium activity ratio was calculated using the formula,

$$AR^K = \frac{{}^aK}{\sqrt{{}^a(Ca+Mg)}}$$

Where,
^aK = Activity of K in mol L^{-1}
$^a(Ca+Mg)$=Activity of (Ca+Mg) in mol L^{-1}

The activity ratio (AR^K) of all the equilibrium K concentrations was plotted against ΔK to obtain the Q/I curve.

Results and Discussion
Soil properties

The soils of the Udupi district were found to be acidic with values ranging from 4.00 to 6.98 (Table 1). Analysis of 165 samples collected from nine hoblies belonging to three taluks of the Udupi district indicated that 9.70, 32.12, 38.18, 15.67, 1.82 percent samples were recorded as extremely, very strongly, strongly, moderately, and slightly acidic soils respectively (Fig. 2). Only 2.42 percent of the samples had a normal range of pH, the pH in Byndoor, Vandse, Kundapur, Brahmavara, Udupi, Kota, Kapu, Karkala, Ajekaru hoblies varied from 4.38-6.86, 4.08-6.26, 4.71-6.17, 4.00-6.98, 4.01-6.85, 4.06-5.97, 4.08-5.86, 4.72-5.98, 4.65-6.64 respectively.

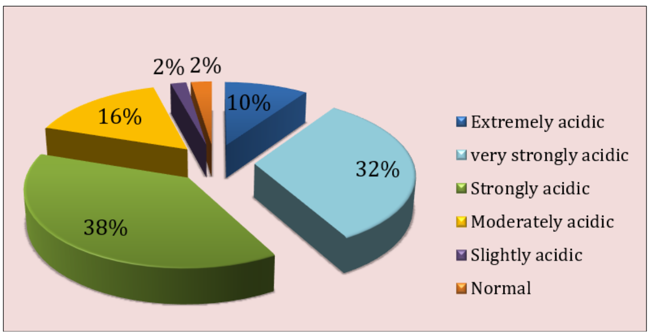

Fig 2: pH of soils under paddy cover of Udupi district, Karnataka

The EC of the soils was found to be low 0.01 to 0.28 dSm^{-1}) (Table 1) under range varying from 0.01-0.20, 0.02-0.25, 0.06-0.25, 0.02-0.27, 0.02-0.27, 0.01-0.28, 0.12-0.27, 0.02-0.27, 0.12-0.26 dSm^{-1} in soils of Byndoor, Vandse, Kundapur, Brahmavara, Udupi, Kota, Kapu, Karkala, Ajekaru hoblies respectively.

It was noticed from the results given in Table 1 and Fig.3. 33.94, 20.61 and 45.45 percent of the samples recorded low, medium and high organic carbon status, respectively Organic carbon content was low to high (0.60 to 25.30 g kg^{-1}) and varied from 0.60-18.90, 0.90-22.2, 0.60-13.80, 0.60-20.70, 2.70-16.20, 4.20-19.80, 0.60-19.20, 8.40-25.20, 6.90-25.30 g kg^{-1} in soils of Byndoor, Vandse, Kundapur, Brahmavara, Udupi, Kota, Kapu, Karkala, Ajekaru hoblies respectively.

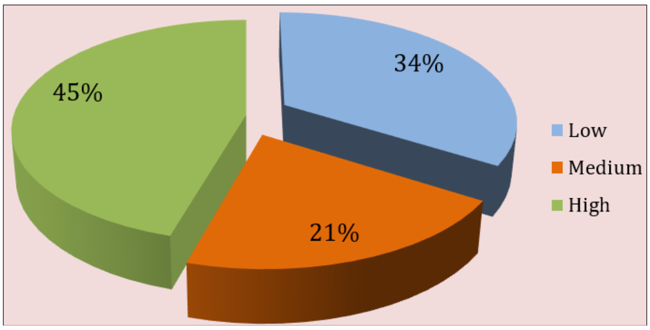

Fig 3: Organic carbon status in soils under paddy cover of Udupi distrcit, Karnataka

The CEC of the selected 18 samples varied from 11.20 to 23.12 cmol (p+) kg^{-1} (Table 1). The CEC in soils of Byndoor, Vandse, Kundapur, Brahmavara, Udupi, Kota, Kapu, Karkala, Ajekaru hoblies varied from 11.20-11.98, 22.00-12.00, 21.20-13.25, 13.00-13.21, 12.25-20.12, 22.62-12.28, 11.25-12.00, 22.52-22.52, 21.91-23.12 cmol (p+) kg^{-1}. The sandy clay loam soils recorded more CEC than sandy loam and loamy sand soils.

The results showed that more than 80 percent of the soils had pH in the range of extremely acidic to strongly acidic range. Continuous leaching of bases due to heavy rainfall might be the possible reason for low soluble salt concentration in soils.

The acidic nature of the soils may be attributed to the high intensity of weathering coupled with intensive leaching of bases due to heavy rainfall and accumulation of acidic constituents such as Fe and Al oxides in soils. Further, under strongly acidic conditions, hydrogen-saturated clay undergoes spontaneous decomposition, aluminium ions are liberated and adsorbed by the clay complex and H-Al clay will be formed which creates more acidity by stepwise hydrolysis and subsequent release of H^+ ions to the system (Shivanna, 2008) [10].

The variation in organic carbon status may be attributed to management practices with or without the addition of organic manures and also the acidic nature of these soils. The applying of FYM along with inorganic fertilizers helps stimulate the growth and activity of microorganisms; higher biomass production may be a possible reason for the higher status of organic carbon in soils (Bhabulkar *et al*., 2000) [1].

It was noticed that the CEC of the selected samples varied from 11.20 to 23.12 cmol (p+) kg^{-1} and appeared to be low. The CEC varies with the organic matter and clay content of these soils, as evidenced by a positive correlation observed between CEC, organic matter, and clay content of these soils (Table 3). Further, the low CEC of the soils may be attributed to the lower amounts of clay dominated by kaolinite and Fe and Al oxides (Tripathi *et al*., 2006) [12].

Particles size distribution

In relation to the particle size distribution, out of 18 selected soil samples analyzed, five samples were recorded as sandy clay loam in texture with sand, silt, clay contents varied from 68.25 to 70.50, 7.00 to 9.72 and 21.50 to 24.00 percent, respectively. Two samples were found to be loamy sand with sand, silt, and clay contents were in the range of 83.60 to 84.50, 6.91 to 7.90 and 8.50 to 8.59 percent, respectively and the remaining samples (11 samples) w belonged to sandy loam texture with sand, silt, and clay contents varying from 74.10 to 80.20, 7.00 to 11.28 and 11.52 to 17.20 percent, respectively (Table1).

Available potassium status in soils under paddy cover of Udupi District

The available potassium status (Table 2) varied from 26.34 to 659.90 kg K_2O ha^{-1} in the soils of the Udupi district. The available potassium status in Byndoor, Vandse, Kundapur, Brahmavara, Udupi, Kota, Kapu, Karkala, Ajekaru hoblies varied from 51.07-172.03, 52.82-175.12, 30.64-311.67, 26.75-214.37, 26.34-170.82, 45.83-177.95, 53.63-261.54, 30.24-553.73,70.29-659.90 kg K_2O ha^{-1}. It was observed from the results in Table 2 that out of 165 soil samples analyzed, 64.85 percent of the samples analyzed (107 samples) recorded low potassium status, and 29.00 percent of the samples (49 samples) showed medium status. Only 5.45 percent (9 samples) recorded a high level of potassium available. From the results presented in Table 2, it was observed that more than 60 percent of the samples coming under the paddy land use cover of the Udupi district were found to be low in available potassium status, and the remaining samples had medium status.

However, 65 percent of the soils recorded low status (< 141 kg K_2O ha^{-1}) and, about 30 percent recorded medium status, as depicted in Fig.3. The low status of available K in soils may be due to high intensity of weathering coupled with intensive leaching of bases due to heavy rainfall, Low clay content, low CEC and strongly acidic nature of these soils might be a cause for leaching loss of potassium from soils due to heavy rainfall (victor *et al*., 2004 and Sparks and Huang, 1985) [13, 11] and it was evidenced by a positive and significant correlation observed between available K and CEC and clay content in soils (Table 3).

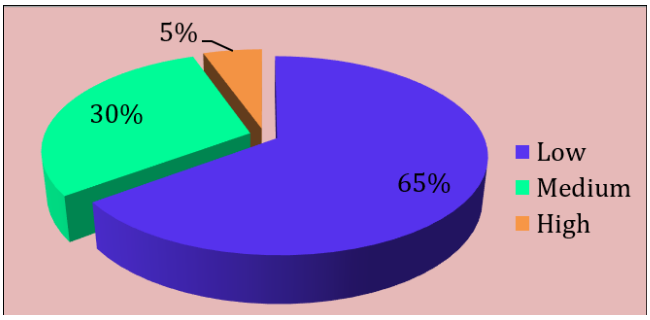

Fig 4: Available K status in soils under paddy cover of Udupi district

Quantity- Intensity (Q/I) parameters of potassium in soils

The PBC^K of the soils (Table 1) was found to be 14.39, 07.00, 09.00 cmol (p+) kg^{-1} and, ARe^K was $6.33x10^{-3}$, $3.67x10^{-3}$, $2.67x10^{-3}$ moles L^{-1} in sample I, II, III respectively.

The K retained by nonspecific sites ($-\Delta K^o$) in all three samples were found to be very low with values 0.100, 0.025, 0.030 cmol (p+) kg^{-1}, with lower values of labile K (K_L) 0.21, 0.05, 0.05 cmol(p+) kg^{-1}. The K held by specific sites

(K_X) were also low, with the values 0.110, 0.05, 09.00 cmol (p+) kg^{-1} in samples I, II, and III, respectively.

Specifically bound potassium (K_X), a part of labile K (Table 4 and Fig. 5, 6, and 7), and the K retained by nonspecific sites ($-\Delta K^o$) were found to be very low. Hence, these soils' labile potassium (K_L) appeared low. This may be attributed to these soil's fewer specific sites and coarse textured nature. Shivanna (2008) [10] also reported similar findings for hilly zone soils of Karnataka. The low values of PBC^K (14.39, 07.00, 09.00 cmol (p+) kg^{-1}) indicated that the soils had very low buffering capacity (PBC^K).

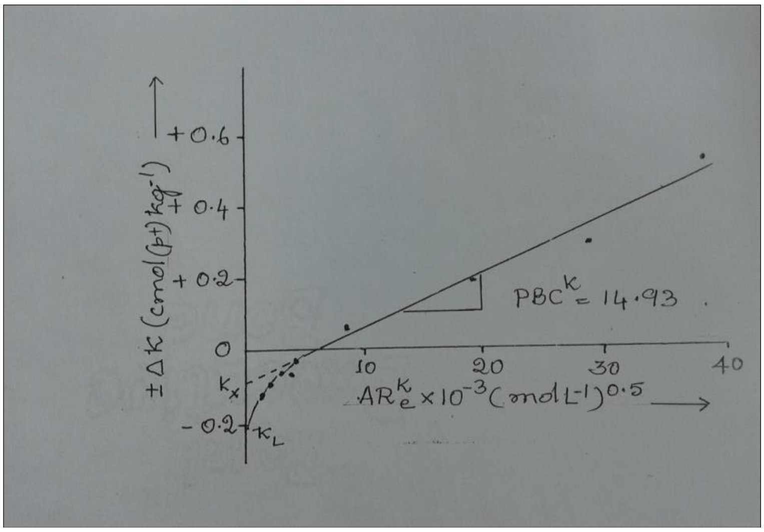

Fig 5: Quantity-Intensity relationship of potassium in soil (I)

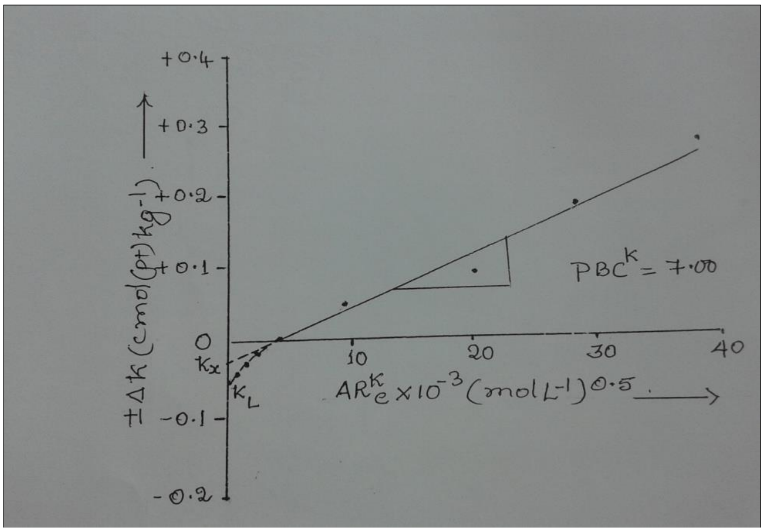

Fig 6: Quantity-Intensity relationship of potassium in soil (II)

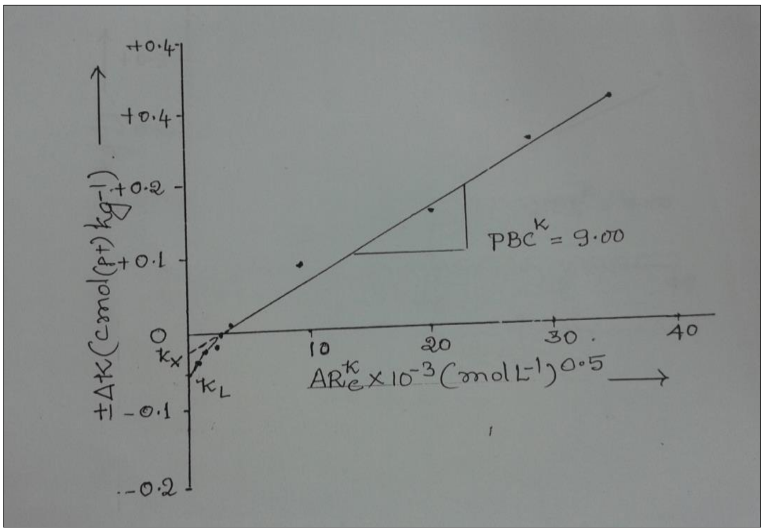

Fig 7: Quantity-Intensity relationship of potassium in soil (III)

In other words, the activity ratio for potassium will drop rapidly following potassium absorption by plants which indicate that the soil becomes low with respect to available potassium status and susceptible to rapid changes in the AR_e^K, signifying frequent K fertilization with a small amount but multiple times so that AR_e^K may be maintained at a higher and more stable value. (Lalitha and Dhakshinamoorthy, 2015, Yong Hong Lin, 2010, Wang *et al*., 2004) [7, 15, 14].

Among the three soils, one soil recorded slightly higher buffering capacity (14.39 cmol (p+) kg^{-1}) and other aspects of the Q/I relationship compared to the other two soils, probably due to its higher clay content (Ranjha *et al*., 2001) [9].

Table 1: Physical and chemical properties of the soils under paddy cover of Byndoor hobli, Kundapur taluk, Udupi district

Taluk	Hobli	No. of samples	pH	EC (dSm^{-1} at 25 °C)	Sand	Silt	Clay	Texture	OC (g kg^{-1})	CEC (cmol (p+) kg^{-1})
Kundapur	Byndoor	20	4.38-6.86	0.01-0.20	80.20-84.50	8.28-6.91	8.59-11.52	Loamy sand-Sandy loam	0.60-18.90	11.20-11.98
	Vandse	25	4.08-6.26	0.02-0.25	79.12-79.13	7.28-8.37	12.50-13.60	Sandy loam	0.90-22.2	22.00-12.00
	Kundapur	25	4.71-6.17	0.06-0.25	70.50-79.12	7.28-7.38	13.60-22.12	Sandy clay loam-Sandy loam	0.60-13.80	21.20-13.25
Udupi	Brahmavara	24	4.00-6.98	0.02-0.27	75.12-78.88	7.50-11.28	13.60-13.62	Sandy loam	0.60-20.70	13.00-13.21
	Udupi	09	4.01-6.85	0.02-0.27	75.80-79.11	7.00-8.30	12.59-17.20	Sandy loam	2.70-16.20	12.25-20.12
	Kota	15	4.06-5.97	0.01-0.28	68.40-79.12	8.68-9.72	13.20-21.88	Sandy clay loam-Sandy loam	4.20-19.80	22.62-12.28
	Kapu	13	4.08-5.86	0.12-0.27	79.50-83.60	8.00-7.90	8.50-12.50	Loamy sand-sandy loam	0.60-19.20	11.25-12.00
Karkala	Karkala	22	4.72-5.98	0.02-0.27	68.25-69.10	8.83-9.40	21.50-22.92	Sandy clay loam	8.40-25.2	22.52-22.52
	Ajekaru	12	4.65-6.64	0.12-0.26	69.00-74.10	7.00-8.90	17.00-24.00	Sandy loam-Sandy clay loam	6.90-25.30	21.91-23.12
	Total	165	4.00-6.98	0.01-0.28	68.40-84.50	6.91-11.28	8.50-22.92		0.60-25.30	11.20-23.12

Table 2: Organic carbon and available potassium status in soils under paddy cover in different hoblies of Udupi district

Taluk	Hobli	Number of samples	Organic carbon status			Available K_2O (kg ha^{-1})	Available potassium status		
			Low	Medium	High		Low	Medium	High
Kundapur	Byndoor	20	11 (55.00)	3 (15.00)	06 (30.00)	51.07-172.03	14 (70.00)	6 (30.00)	-
	Vandse	25	10 (40.00)	5 (20.00)	10 (40.00)	52.82-175.12	18 (72.00)	7 (28.00)	-
	Kundapur	25	14 (56.00)	8 (32.00)	03 (12.00)	30.64-311.67	18 (72.00)	7 (28.00)	-
Udupi	Brahmavara	24	12 (50.00)	7 (29.17)	05 (20.83)	26.75-214.37	16 (66.67)	8 (33.33)	-
	Udupi	09	05 (55.56)	1 (11.11)	03 (33.33)	26.34-170.82	08 (88.89)	1 (11.11)	-
	Kota	15	01 (06.67)	4 (26.67)	10 (66.67)	45.83-177.95	11 (73.33)	4 (26.67)	-
	Kapu	13	02 (15.38)	5 (38.46)	06 (46.15)	53.63-261.54	10 (76.92)	3 (23.08)	-
Karkala	Karkala	22	-	-	22 (100.0)	30.24-553.73	11 (50.00)	5 (22.73)	6 (27.27)
	Ajekaru	12	01 (8.33)	1 (8.33)	10 (83.33)	70.29-659.90	01 (08.33)	8 (66.67)	3 (25.00)
		Total=165	56 (33.94)	34 (20.61)	75 (45.45)	26.34-659.90	107 (64.85)	49 (29.70)	9 (05.45)

Figures in the paranthesis indicate the percent organic carbon and available potassium status.

Table 3: Quantity- Intensity (Q/I) parameters of potassium in soils of Udupi district, Karnataka

Sample. No	ARe^K x 10^{-3} (moles L^{-1})	$-\Delta K^0$	K_X	K_L	PBC^K	Clay (%) in soil
		← cmol (p+) kg^{-1} →				
I	6.33	0.100	0.110	0.21	14.39	22.35
II	3.67	0.025	0.025	0.05	07.00	13.24
III	2.67	0.030	0.020	0.05	09.00	11.86

Where,

AR_e^K = Equilibrium activity ratio of K in solution

$-\Delta K^0$ = A portion of labile K –released from planar surfaces

K_X = K held by specific sites of clay minerals

K_L = Labile K

PBC^K = Potential buffering capacity of K

Sl. No.	Ratings	Organic carbon (g kg^{-1})	Available K_2O (kg ha^{-1})
1	Low	< 5	<141
2	Medium	5 to 7.5	141 to 336
3	High	>7.5	>336

Table 4: Quantity- Intensity (Q/I) parameters of potassium in soils of Udupi district, Karnataka

Sample. No	ARe^K x 10^{-3} (moles L^{-1})	$-\Delta K^0$	K_X	K_L	PBC^K	Clay (%) in soil
		← cmol (p+) kg^{-1} →				
I	6.33	0.100	0.110	0.21	14.39	22.35
II	3.67	0.025	0.025	0.05	07.00	13.24
III	2.67	0.030	0.020	0.05	09.00	11.86

Conclusion
Finally, owing to coarse textured nature of strongly acidic soils with low CEC, low to medium status with respect available K. Soils coming under paddy cover of Udupi district recorded very low K supplying power indicating that frequent K fertilization with a small amount but multiple times so that K concentration in soil solution may be maintained at a higher and more stable value for sustainable production of crops.

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