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Distribution of different potassium fractions in the soil profiles of Karaikal, Puducherry

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Abstract
While the methodology adopted to determine the potassium (K) releasing power of the soil in the laboratory quantifies the solution and exchangeable K, under field situations, the release from nonexchangeable K is trigged depending on the crop demands and K loses. In other words, a soil that may contain low levels of labile K may derive K from a non-exchangeable pool provided the level of non-exchangeable K pool is higher. Therefore, the response of the crop to K fertilization is more related to the shift in the equilibrium among the different forms of K rather than the amount of K available in the labile pool. An investigation was carried out in the farm soils of Pandit Jawaharlal Nehru College of Agriculture & Research Institute (PAJANCOA & RI), Karaikal to study different K-fractions. A total of 22 soil profiles were exposed and horizon wise soil samples were collected, processed and subjected to analysis. The results, thus obtained, were subjected to descriptive statistics, simple correlation and linear multiple regression analysis to establish the interrelationships of different fractions of soil K with other soil physicochemical properties.

Keywords: potassium, K-fraction, Karaikal, PAJANCOA & RI

Introduction
Among the major nutrients, potassium (K) is known to be a wonder element due to its role in crop growth and its behavior in the soil system. The essentiality of K to plant growth has been known since the work of Von Liebig has published in 1840 (Sparks, 2000) [14]. K has been recognized as a beneficial element to plant growth (Russell, 1961). K in soils can be divided into immediately available, readily available, slowly available, and relatively unavailable K, which are also termed as water-soluble, exchangeable, non-exchangeable, and mineral K, respectively (Martin and Sparks, 1985) [7]. The response of the crop to K fertilization is more related to the shift in the equilibrium among the different forms of K rather than the amount of K available in the labile pool. Accurate diagnosis of K status will be possible when measurements describing K dynamics in the soil system are included in routine soil K testing, upon which fertilizer K recommendations should be based.
Soil profile characteristics as conditioned by different factors and processes of soil formation have a great influence on soil fertility and crop productivity (Dash *et al.*, 2019) [1]. To achieve effective use of K fertilizers, the investigation of different K fractions is highly imperative. Taking this concept into cognizance, an experiment was formulated to study the potassium dynamics in the soils of the Karaikal area of Puducherry.

Materials and methods
The selected study site was the agricultural farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Tamil Nadu Agricultural University, Karaikal constituting a total area of 225 acres. The experimental site lies between 10˚49' and 11˚00' N Latitude and between 78˚43' and 79˚52' E longitude with an average elevation of 4 m above mean sea level. The mean maximum and mean minimum temperature of the region are 31.95˚C and 25.52˚C with a mean annual rainfall of 1506.87 mm. The farm area is subdivided into two units i.e. the eastern farm (having four blocks, namely A, B, C, D) occupying an area of 63.85 acres and the western farm (having six blocks, namely A, B, C, D, E, F) occupying an area of 24.40 acres. Soils of this farm have been reported to be *Fluventic Haplustept, Typic*

Haplustert and *Ustic Quartizipsamment* based on Keys to Soil Taxonomy.

Twenty-two soil profiles (thirteen in the eastern farm and nine in the western farm) were selected based on the heterogenetic nature of the soil concerning the morphological features, crop growth, and yield variability. Further, different soil horizons in each soil profile were differentiated based on the variability associated with soil color, texture, structure, root density, effervescence, consistency, etc. Horizon wise soil samples were collected and processed for further analysis.

The soil samples were analyzed for textural class by International pipette method (Piper, 1966) [11], organic carbon (Walkley and Black, 1934), Cation Exchange Capacity (Piper, 1966) [11], Exchangeable calcium and magnesium (Jackson, 1973) [6], exchangeable sodium and potassium (Stanford and English (1949), water-soluble potassium (Narayan Nambiar, 1972) [9], exchangeable potassium (Pratt, 1952), Non-exchangeable potassium (the difference between the normal nitric acid extractable K (Wood and De Turk, 1940) [17] and water-soluble plus exchangeable K), constant rate K (Metson, 1968) [8], step K (Haylock, 1956) [4] and plant available K (Hanway and Heidal, 1952) [3].

Results and discussions

Distribution of different K fractions in the soil profiles

Solution–K

The results of the solution–K analysis in the profile soil samples (Table 1) for the entire farm revealed that it ranged from 4 to 45 mg kg^{-1} with a coefficient of variation of 54.35 percent. However, in the eastern farm soils, it ranged from 4 to 44 mg kg^{-1} and in the western farm it ranged from 5 to 45 mg kg^{-1}. Simple correlation analysis further indicated that the solution K is positively correlated to exchangeable-K (r=0.839**), step-K (r=0.839**) and organic carbon (r=0.413**) but negatively correlated to the coarse sand content (r=-0.288**). The multiple regression analysis further suggested that the solution–K could be significantly predicted by the different soil separates (R^2=0.114*) at a 5 percent level. Organic carbon content contributed significantly towards solution-K of the soil (R^2=0.170**); whereas CEC didn't contribute significantly.

Exchangeable – K

The exchangeable K content of the soil samples (Table 1) revealed that on the overall farm level, it ranged from 32 to 623 mg kg^{-1}. In the soils of the eastern farm, the corresponding values were 32 to 449 mg kg^{-1} and in the soils of the western farm, it ranged from 39 to 623 mg kg^{-1}. The simple correlation studies had indicated a significant and positive relationship of this property with step–K (r=0.892**), constant–K (r=0.214*), organic carbon (r=0.379**) and clay content of the soils (r=0.249*). Moreover, the simple regression analysis suggested that exchangeable–K was more closely predicted by the organic carbon (R^2=0.143**) content than the CEC (R^2=0.004^{NS}) of the soils.

Non–exchangeable K

In the entire farm, the non-exchangeable–K content of profile soil samples ranged from 122 to 2346 mg kg^{-1}. It ranged from 122 to1890 mg kg^{-1} and 123 to 2346 mg kg^{-1} in the eastern and western farm soils respectively. Concerning the simple correlation analysis, the non- exchangeable–K content was observed to be having significant positive correlations with constant–K, CEC, exchangeable Mg and clay content but negative correlations with the fine sand content of soil profiles. The linear multiple regression analysis to quantify the contribution of different soil separates to that of non-exchangeable K had indicated a trend, wherein 85.2 percent of variations in non-exchangeable K could be attributed to the different sized soil particles, with a significant contribution from the clay content. It is quite expected that the exchangeable and non-exchangeable K content could be closely linked with the clay content as K being a cation is held on the exchange complex and as well as gets locked up in the exchangeable sites of clay which are specific to potassium (Parfitt, 1992) [10].

Step – K

The step – K content of the profile soil samples ranged from 38 to 747 mg kg^{-1} in the entire farm soils. In the case of the eastern farm, it ranged from 38 to 538 mg kg^{-1} and that in the case of the western farm, it ranged from 47 mg kg^{-1} to 747 mg kg^{-1}. The simple correlation analysis confirmed a significant positive relationship of step-K with the solution–K (r=0.839**), exchangeable–K (r=0.892**), constant–K (r = 0.214*), organic carbon (r =0.379**) and clay content (r=0.249*).

Constant–K

The constant–K content, which represents the steady rate of K release after the labile pool is extracted, ranged from 1 to 15 mg kg^{-1} in the farm soils. It ranged from 1 to 15 mg kg^{-1} and 2 to 15 mg kg^{-1} in the eastern and western farms respectively. Further analysis by simple correlation studies revealed that the constant–K was having significant positive correlations with exchangeable–K (r=0.214*), non-exchangeable K (r=0.847**), step–K (r=0.214*), CEC (r=0.290**), exchangeable–Mg (r=0.214*) and clay content (r=0.902**), but negatively correlated to fine sand content (r =-0.436**). The above result was further supported by the multiple regression analysis, wherein 83 percent of the variations in the constant–K release could be explained by the different soil separates with significant contribution from the clay content. It is quite evident that these two fractions are closely related to the K fractions since the release either by repetitive extraction is due to the release of K from the exchangeable complex when the solution K level declines. A significant and positive correlation of step and constant–K with different fractions had confirmed the above statement.

Table 1: Content of K fractions, step K and constant K of the soil profiles

Descriptive statistics					
	Solution - K	**Exchangeable – K**	**Non Exchangeable-K**	**Step-K**	**constant - K**
Overall farm soils					
Mean	17	190	641	228	6
S.D	9.50	111.83	485.08	134.20	3.44
Minimum	4	32	122	38	1
Maximum	45	623	2346	747	15
C.V (%)	54.35	58.66	75.64	58.66	55.77
Eastern farm soils					
Mean	18	188	620	225	5
S.D	8.588	78.69	387.20	94.43	2.837
Minimum	4	32	122	38	1
Maximum	44	449	1890	538.2	15
C.V (%)	45.41	41.99	62.39	41.99	48.89
Western farm soils					
Mean	15	196	673	235	6
S.D	10.50	150.80	611.93	180.9	4.197
Minimum	5	39	123	47	2
Maximum	45	623	2346	747	15
C.V (%)	68.88	77.07	90.88	77.07	62.18

Available–K content

The available–K content of the soil samples as extracted by neutral normal ammonium acetate ranged from 21 to 415 mg kg^{-1} (Table 2). The available-K content ranged from 21-299 mg kg^{-1} in the eastern farm and that in the western farm ranged from 26-415 mg kg^{-1}. In the eastern farm the available–K was ranging from 21 to 299 mg kg^{-1} and in the western farm, the corresponding values were 26 to 415 mg kg^{-1}. From the multiple regression analysis, it was computed that 57.5 percent of the variation in the available–K content could be due to the K-fractions and that of 56.2 percent by the exchangeable cations.

Organic carbon content

The organic carbon content of the soil samples of the PAJANCOA & RI farm is presented in table 2. The organic carbon content ranged from 0.896 to 7.642 mg g^{-1} with a co-efficient variation of 46.52 percent. The range of organic carbon content was from 1.237 mg g^{-1} to 6.975 mg g^{-1} and 0.896 to 7.642 mg g^{-1} in the eastern and western farm respectively. It was further observed from the simple correlation analysis that the organic carbon content of the profile soils was having significant positive correlations with the solution–K (r=0.413**), exchangeable–K (r=0.379**), step–K (r=0.379**) and exchangeable–Mg (r=0.233*). From simple regression analysis, it was inferred that the organic carbon content could significantly predict the available–K (R^2=0.060*), solution–K, (R^2=0.170**) exchangeable–K (R^2=0.143**), non-exchangeable–K and step–K (R^2=0.143**).

Cation exchange capacity

The cation exchange capacity of the soil samples collected from the different horizons of the profiles of PAJANCOA & RI is furnished in table 2. The CEC of the study area ranged from 8.65 to 42.65 cmol (p+) kg^{-1} with a coefficient of variation of 34.38 percent. It ranged from 12.44 to 38.48 cmol (p+) kg^{-1} and from 8.65 to 42.65 cmol (p+) kg^{-1} in the eastern and western farms respectively. From the simple correlation analysis, it was inferred that the CEC was positively and significantly correlated with non-exchangeable–K (r=0.305**), constant-K (r=0.290**), exchangeable–Ca (r=0.620**), Mg (r=0.645**) and Na (r=0.462**) and the per cent clay content (r=0.394**). However, it was found to be negatively correlated to the percent fine sand content of the soil (r=-0.206*). The simple regression analysis also suggested that the CEC could significantly contribute to non–exchangeable–K (R^2=0.305**).

Table 2: The organic carbon, available K, and CEC of the soil profile samples

Descriptive statistics			
	OC ($mg\ g^{-1}$)	**NH_4OAcK ($kg\ ha^{-1}$)**	**CEC (cmol (p^+) kg^{-1})**
Overall farm soil			
Mean	3.122	127	21.53
SD	1.444	75	7.40
Minimum	0.896	21	8.65
Maximum	7.642	415	42.65
C.V (%)	46.25	58.67	34.38
Eastern farm soil			
Mean	3.244	125	22.34
SD	1.504	52	5.21
Minimum	1.237	21	12.44
Maximum	6.957	299	38.48
C.V (%)	46.38	41.99	23.33
Western farm soil			
Mean	2.933	130	20.27
SD	1.344	101	9.85
Minimum	0.896	26	8.65
Maximum	7.642	415	42.65

Exchangeable cations

Exchangeable Calcium

The exchangeable calcium content of the soil samples of the profiles ranged from 4.25 to 29.25 cmol (p+) kg^{-1} at the farm level (Table 3). For the eastern farm soils, the minimum exchangeable-Ca content was 4.50 cmol (p+) kg^{-1} and the maximum was 29.25 cmol (p+) kg^{-1}. The corresponding values for the western farm soils were 4.25 and 25.25 cmol (p+) kg^{-1} respectively. The simple correlation studies had shown significant positive relationships of exchangeable–Ca with CEC (r=0.620**) and exchangeable–Na (r=0.307**).

Exchangeable Magnesium

The content of exchangeable–Mg in the profile soil samples ranged from 0.98 to 11.40 cmol (p+) kg^{-1} (Table 3). The minimum and maximum values in the eastern farm soils were 1.25 to 11.40 cmol (p+) kg^{-1} and that of western farm soils were 0.98 and 11.26 cmol (p+) kg^{-1}. The simple correlation studies revealed the significant relationship of this parameter with the non–exchangeable–K (r=0.293**), constant–K (r=0.214*), CEC (r=0.645**), exchangeable–Na (r=0.213*), organic carbon (r=0.233*), and clay content (r=0.321**).

Exchangeable Sodium

The exchangeable sodium content of the soil samples was found to range from 0.59 to 12.88 cmol (p+) kg^{-1} in the entire farm (Table 3). In the eastern farm soils, it was found to range from 0.77 to 10.23 cmol (p+) kg^{-1} and in the western farm, the corresponding values were 0.59 to 12.88 cmol (p+) kg^{-1}. The simple correlation studies had further revealed that the exchangeable sodium content of the soil was positively correlated with CEC (r=0.462**), exchangeable-Ca (r=0.307**) and exchangeable-Mg (r=0.213*) content and percent clay (r=0.216*) content.

Table 3: The exchangeable cations of the soil profile samples

Particulars	Exchangeable cations [cmol (p+) kg^{-1}]			
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Overall farm soil				
Mean	11.34	4.99	3.18	0.258
SD	5.01	2.84	2.34	0.227
Minimum	4.25	0.98	0.59	0.038
Maximum	29.25	11.40	12.88	1.692
C.V (%)	44.13	57.02	73.66	87.71
Eastern farm soil				
Mean	12.31	5.39	3.28	0.230
SD	5.05	2.49	2.15	0.113
Minimum	4.50	1.25	0.77	0.038
Maximum	29.25	11.40	10.23	0.660
C.V (%)	40.98	46.20	65.51	49.08
Western farm soil				
Mean	9.84	4.37	3.02	0.303
SD	4.62	3.27	2.63	0.332
Minimum	4.25	0.98	0.59	0.038
Maximum	25.25	11.26	12.88	1.692
C.V (%)	46.92	74.70	87.31	109.49

Exchangeable potassium

The exchangeable–K content of the soil samples in the profiles ranged from 0.038 to 1.692 cmol (p+) kg^{-1} (Table 3). It ranged from 0.038 to 0.660 cmol (p+) kg^{-1} in the eastern farm and from 0.038 to 1.692 cmol (p+) kg^{-1} in the western farm. From the correlation studies it was inferred that the exchangeable K content was found to be positively and significantly related to the solution–K (r=0.627**) and exchangeable–K fractions (r=0.710**), step–K (r=0.710**) and organic carbon content (r=0.282**) of the soils. From the multiple regression analysis, it was concluded that 89.7 percent of the variation in the available K content of soil could be attributed to the exchangeable cations with significant contributions from the exchangeable–K.

Relative proportion of soil separates

The mechanical analysis of the soil samples revealed the relative proportion of the different soil separates which is presented in table 4. The distribution of the different sized particles is described in the following sections.

Coarse sand content

The coarse sand content in the soil samples of the entire study site ranged from 4.11 to 75.12 percent. In the eastern farm, a minimum of 4.11 percent and a maximum of 65.32 percent of course sand content was recorded. The corresponding values for the western farm soils were 5.02 and 75.12 percent respectively. The simple correlation studies had revealed that the coarse sand content was negatively correlated to the solution–K (r=-0.288**).

Fine sand content

The content of fine sand ranged from 2.92 percent to 70.11 percent in the entire farm, while it was 5.11 to 70.11 percent in the eastern farm and 2.92 to 60.82 percent in the western farm. The fine sand content was found to be significantly and negatively related to non- exchangeable–K (r -0.399**), constant–K (r=-0.436**), CEC (r=-0.206*) and clay content (r=0.369**).

Silt content

The silt content ranged from 0.75 to 24.00 percent in the soil samples of PAJANCOA & RI. In the eastern farm, the minimum silt content was 0.75 percent and the maximum was 21.30 percent. The corresponding values in the western farm soils were 1.11 and 24.00 percent respectively.

Clay content

The clay content of soil samples varied from 6.20 percent to 60.12 percent with a minimum value of 7.90 percent and a maximum of 51.65 percent in the eastern farm. Both the minimum and maximum values at the entire farm level were recorded in the western farm itself. It was further seen that the clay content of profile soil samples had a significant and positive relationship with exchangeable K (r=0.249*), non-exchangeable–K (r=0.918**), step–K (r=0.249*), constant–K (r=0.902**), CEC (r=0.394**), exchangeable–Mg (r=0.321**) and exchangeable-Na (r=0.216*). However, it was negatively correlated with fine sand content (r=-0.369**). It was further observed by multiple regression analysis that the clay content could significantly contribute to the solution–K, non-exchangeable–K, and constant–K along with other soil fractions, though their contribution was not marked.

Table 4: The relative proportion of soil separates of the profile samples

Particulars	Mechanical composition (%)			
	Fine sand	Coarse sand	Clay	Silt
Descriptive statistics				
Overall farm soil				
Mean	32.73	26.86	27.44	6.31
SD	20.64	19.43	12.80	5.15
Minimum	2.92	4.11	6.20	0.75
Maximum	70.11	75.12	60.12	24.00
C.V (%)	63.06	72.35	46.63	81.59
Eastern farm soil				
Mean	37.40	22.67	27.64	5.04
SD	19.20	18.16	9.94	4.83
Minimum	5.11	4.11	7.90	0.75
Maximum	70.11	65.32	51.65	21.30
C.V (%)	51.33	80.10	35.96	95.90
Western farm soil				
Mean	25.47	33.37	27.13	8.30
SD	20.96	19.80	16.44	5.07
Minimum	2.92	5.02	6.20	1.11
Maximum	60.82	75.12	60.12	24.00
C.V (%)	82.31	59.32	60.61	61.03

Conclusion

The analysis of K fractions in the soil profile samples had shown that the content of solution K, exchangeable K, and nonexchangeable K ranged from 4 to 45, 32 to 623 and 122 to

2346 mg kg^{-1}, respectively. The step K content, which is a measure of easily as well as slowly available K ranged between 38 to 747 mg kg^{-1}. The constant K releasing power of the study site ranged between 1 and 15 mg kg^{-1}. The simple correlation studies indicated that solution K was positively correlated to the exchangeable K, step K and organic carbon content of the soils. It was also noticed that the exchangeable K content was positively related to step K, constant K, organic carbon content and the percent clay. Among the soil properties, the constant K, CEC, exchangeable Mg, and percent clay content were positively correlated to the non-exchangeable K content of the soils. The step-K was significantly correlated with solution K, exchangeable K, constant K, organic carbon content and percent clay. Similarly, the constant K content of the soil was positively correlated to exchangeable K, non-exchangeable K, step K, CEC and percent clay content of the soils. The textural analysis of the profile samples indicated that the coarse sand, fine sand silt, and clay content ranged from 4.11 to 75.12, 2.92 to 70.11, 0.75 to 24.00 and 6.20 to 60.12 percent, respectively. The available K content of the profile soil samples ranged from 21 to 415 kg ha^{-1}. The organic carbon content of the profile soil samples ranged between 0.896 and 7.642 mg g^{-1}. The cation exchange capacity was found to vary between 8.65 and 42.65 cmol (p^+) kg^{-1} in the profile soils of the farm. Among the exchangeable cations Ca^{2+} was the dominant one (4.25 to 29.25 cmol (p^+) kg^{-1}) followed Mg^{2+} (0.98 to 11.40 cmol (p^+) kg-1), Na+ (0.59 to 12.88 cmol (p^+) kg^{-1}) and K+ (0.038 to 1.692 cmol (p^+) kg^{-1}).

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