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Assessing of Potassium Reserve and their Relationship with Soil Properties in Western Plain of Arid India

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A B S T R A C T

In order to investigate changes of potassium (K) status in western plain of Rajasthan, two hundred nine surface (0-15cm depth) soil samples were collected from seventeen tehsils of three districts (Bikaner, Churu and Jaisalmer). Soils were in general light in texture and neutral to slightly alkaline in reaction. The OC content of the soils varied from 0.1 to 2.5 g kg^{-1}. H_2O-K and NH_4OAc-K ranged from 2.9 to 47.1 (mean value 18.3) mg kg^{-1} and 13.8 to 202.7 (mean value 91.2) mg kg^{-1}, respectively. The HNO_3-K and HCl-K varied from 154.4 to 635.5 (mean value 318.7) mg kg^{-1} and 8.1 to 99.3 (mean value 40.8) mg kg^{-1}, respectively. Highly significant positive relationships amongst various fractions of soil K indicated existence of a dynamic equilibrium between different forms of K. The studied soils had major portion of their K fraction content in lattice-K it contributed about 87.0 to 90.3 % of total-K because of rich K bearing minerals of soils followed by 6.7 to 9.9 % of Non-exch-K and 2.3 to 3.3 % of Exch-K towards total-K. On the basis of nutrient index mostly soils were found medium (68.4 %) in available K.

Introduction

Potassium (K) is a major constituent of the earth crust contained more in igneous rocks than the sedimentary rocks. K comprise on an average of 1.9 % of the earth crust, making it the seventh most abundant element and fourth most abundant mineral nutrient in the lithosphere but only a very small proportion of it become available to plants (Tisdale *et al.*, *1985*). Because of large differences in soil parent materials and the effect of weathering of these materials, the amount of K supplied by soils varies. However, actual soil concentrations of this nutrient vary widely ranging from 0.04 to 3.0 % (Sparks and Huang, 1985). Plants can take up K only from the soil solution and its availability is dependent upon the K dynamics as well as on total K content. K is present in soil in four main forms (Jalali, 2007). These are: (i) water soluble K (solution K) which is dissolved in the soil solution; (ii) exchangeable K is the form that is electrostatically retained by negatively charged soil colloids (clays, organic matter, sesquioxides); (iii) Non-exch-K is temporarily trapped between the interlayers of clay minerals (illites, vermiculites); and (iv) mineral K which are present as primary minerals (micas and feldspars) (Krauss 2003). There are dynamic, equilibrium reactions between different forms of K. Amount in a soil depends on the parent material, degree of weathering, gains through manures and fertilizer, losses due to crop removal, erosion and leaching (Ajiboye *et al.*, 2015). The bulk of the K (92-98%) in soil is known to be present in the mineral forms as feldspars and micas (Sood *et al.*, 2008). The feldspars occur almost entirely in sand and silt fractions of soils, whereas biotite and muscovite mica are mainly present in the silt and coarse clay particles. Non-exch-K can be an important reservoir of K in soils. Several studies demonstrate that Non-exch-K from reserves makes an important contribution to plant K supply (Otobong *et al.*, 2012). For optimal nutrition of crop, the replenishment of a K depleted soil solution is affected predominately by the release of Non-exch-K from clay minerals and organic matter (Subba Rao *et al.*, 2010). Therefore, for maximum crop growth, soil solution and exchangeable K need to be replenished continually with K through the release of Non-exch-K through the weathering of K reserves (Brady and Well, 2002) or the addition of K fertilizers. Water-soluble K is taken up directly by plants but is usually found in low quantities in soils. NH_4^+-exchangeable K is held by negative charges of organic matter and clay particles and is readily available to plants (Ghiri *et al.*, 2011).

Arid soils in western plain of Rajasthan are dominated by clay minerals of smectite, mica and vermiculite with small amounts of kaolinite (Choudhari and Dhir 1982). The soils of arid and semiarid regions soils contain sufficient exchange K (exchange with NH_4^+ acetate) and K bearing minerals able to release enough K to meet crop requirements. Although arid soils may contain large quantities of exchangeable and non-exchangeable K, the exchangeable K^+ may become depleted in these regions due to the intensive crop production (Jalali and Zarabi 2006). Continued K export without K supply will lead to depletion of soil and depending on K storage, may take 3 to 10 years (Kayser and Isselstein, 2005). The delicate arid soils of Rajasthan have in many areas been subjected to intense agricultural production due to increasing demand for food. Several studies revealed that any activity associated with change in land use and agricultural management practices can affect soil properties and K dynamics (Sharpley, 1989; Natarajan and Renukadevi, 2003; Ghiri *et al.*, 2011), but limited studies are available in arid desertic ecosystem. The objectives of this study were: (*i*) to determine the content and distribution of K pools in western plain of a hot arid Rajasthan; and (*ii*) to examine the relationship between different pools of K and soil properties.

Materials and Methods

Study area

This study was conducted in seventeen tehsils of three districts (Bikaner, Churu and Jaisalmer) which are comes under hot arid region, located in the western plain of Rajasthan which contains the dominantly sandy Thar Desert. Its geographical location is between 26^0 55’ to 28^0 19’ North latitude and 70^0 52’ to 75^0 52’ East longitude (Fig. 1). The total cultivable area of study region is 37.72 Mha. The climate of the region is hot arid, erratic rainfall (100-450 mm/year ~90% during July-September), extreme temperatures (often >45°C in the peak of summer and sub-zero in winter) and high summer winds (>30 km h^{-1} during sandstorms in summer). Drought is a major determinant of agriculture in the region. Major crops grown in western plain of hot arid Rajasthan are pearl-millet (*Pennisetum glaucum*), guar (*Cyamopsis tetragonoloba*), moth bean

(*Vigna aconitifolia*), green gram (*Vigna radiata*), chickpea (*Cicer arietinum*), mustard (*Brassica juncea*), wheat (*Triticum aestivum*) and groundnut (*Arachis hypogaea*).

Soil

The soils are mainly derived through aeolian activity prevailing in the area. The dominant soils are deep to very deep, calcareous to non-calcareous and sandy in nature. The windblown sand of recent to sub recent period is mainly consists of quartz, with minor biotite and magnetite. Gypsite rich beds are found in shallow depression surrounded by sand dunes. The clay mineralogical suites were predominantly of illite with small amounts of chlorite, vermiculite, mixed layer minerals and kaolinite. Thickness of soil ranged between 115 to 140 cm. Colour was 10 YR hue, 4 to 6 value and 3 to 4 chroma. Texture varied from sandy to loam with weak to moderate prismatic structure. The soil was moderately saline and sodic; organic C and $CaCO_3$ contents were 0.27 and 2.6%, respectively. The soil moisture control section remains dry throughout the year. These soils are classified as Typic Torripsamments. The other less extensive soils occupying relatively lower topographic position in the interdunal plains are classified under Typic Calciorthids, Typic paleorthid and Typic salorthid (Shyampura *et al.*, 1995).

Soil sampling and analysis

The surface soil samples (n= 209) were collected from irrigated and non-irrigated fields covering three districts (Bikaner, Churu and Jaisalmer) in western plain of hot arid Rajasthan. The samples were air-dried in shade, grind to pass through a 2 mm sieve and used for the estimation of soil properties and potassium fractions. Particle size distribution was determined by the suspension procedure using the hydrometer method after dispersing the soil with sodium hexa metaphosphate (Bouyoucos, 1927). The pH was determined using 1:2.5 soil and water suspension by a glass electrode (Jackson, 1973) and EC was determined using standard precision conductivity bridge (Jackson, 1973). The $CaCO_3$ in soil was determined by a rapid titration method (Puri, 1930). Organic matter was determined by Walkley and Black's wet digestion method (Walkley and Black, 1934). Cation exchange capacities of the soils were determined by the procedure described by (Jackson, 1973). The water soluble potassium (WSK) was determined by shaking air-dried soil (5 g) with distilled water (25 mL) overnight, followed by centrifugation and filtration. Plant available potassium (NH_4AOc-extractable K) was measured by shaking soil with ammonium acetate for 5 min in an end-over-end shaker; it was then centgrifuged and filtered, and potassium was analysed using flame photometer (Hanway and Heidel, 1952). The HNO_3-extractable K (HNO_3-K) was determined by boiling soil (<2 mm, 2.5 g) with HNO_3 (1 mol/L, 25 mL) for 10 min and analysing the extracted potassium using flame photometer (Knudsen *et al.*, 1982). The HCl soluble potassium (HCl-K) was determined by using Garman (1957) method with some modifications made by Pal and Mukhopadhyaya (1992). Five gm soil was transferred in centrifuged tube, 50 ml of 0.01 *N* HCl was added, shaken for 15 minutes centrifuged at 2000 rpm and potassium was determined by flame photometrically in the supernatant liquid. To same soil, another 50 ml 0.01*N* HCl was added and the same procedure was repeated 15 times or till the amount of potassium released, attained a constant value or zero. The cumulative potassium releasing power of soil was calculated by adding all the values of potassium extracted by the successive extractions. Total potassium (Total K) was determined using the method of (Knudsen *et al.*, 1982). One gram of soil was completely digested in hydrofluoric (HF) and perchloric ($HClO_4$) acid mixtures under a fume hood. The filtrate was brought to volume in a 100 mL volumetric flask, and total potassium was content determined with a flame photometer. The exchangeable potassium (Exch K), non-exchangeable potassium (Non-exch K) and lattice potassium (Lattice K) were obtained according to the mathematical procedures used by (Samadi *et al.,* 2008), which are described below:

Exch K= NH_4AOc extractable K - WSK -- (i)

Non-exch K= HNO_3 extractable K - Exch K --------- (ii)

Lattice K= Total K - HNO_3 extractable K ------------ (iii)

Statistical analysis

Statistical analysis was carried out for data calculation using Microsoft Excel (Microsoft Corporation, USA) and Pearson's correlation matrix for different pools of potassium and soil properties was computed by the SPSS 16 (Statistical Package for the Social Science, SPSS, Inc., Chicago, USA, window version 16.0).

Results and Discussion

Variation in soil properties

Selected important physical and chemical properties of the soil studied are given in (Table 1). The particle size analysis gives the percentage of sand, silt and clay fractions in soils and there by textural class. The texture class of western plain of hot arid Rajasthan varied from loam to loamy sand in nature indicating dominance of sand fraction in the studied area (Fig. 2). The recorded particle size analysis of soils indicated that these soils might have been formed from alluvial material and are thus have characteristic coarse texture due to poor profile development which subscribed to same as (Jalali, 2005). The pH value of studied soil varied from 7.04 to 9.98 with an average value of 8.79 which shows that the mojority of soil is alkaline in nature (Table 1). The highest (9.23) mean value of pH were found in Kolayat tehsils of Bikaner district hot arid region because of there is no effective vegetation grown and the lowest (7.50) mean value of pH were observed in pugal tehsils of Bikaner district (Table 1). The relatively high pH of these soils might be due to medium to high degree of sodium saturation which on hydrolysis imparted OH^- ions and high carbonate and bicarbonate (Singh *et al.,* 2010). The electrical conductivity (EC) of these soils varied from 0.01 to 0.85 dsm^{-1} with an average value of 0.13 dsm^{-1} (Table 1) and the highest (0.21 dsm^{-1}) mean value of EC were noticed in Bikaner tehsil of Bikaner district possibly because of basic parent materials from which soil have been formed and may be due to high temperature, low rainfall and low application of organic manures (Abu-Zahra *et al.,* 2008; and Sarwar *et al.,* 2010). The lowest (0.07 dsm^{-1}) mean value of EC was observed at Taranagar tehsil of Churu district it may be due to applying organic manures higher than those from the mineral fertilizer (Singh *et al.,* 2010). Low mean value of electrical conductivity in soil samples showed that the presence of salts in these soils was negligible. The organic carbon (OC) is ranged from 0.01 to 0.25 % with mean value of 0.07 % (Table 1). Among the seventeen tehsils of western plain of hot arid Rajasthan the highest (0.18 %) mean value of OC were found at Pugal tehsil of Bikaner district it may be due to the native residue of crops and addition of farm yard manure (Singh *et al.,* 2007). The lowest (0.03 %) mean value was noticed at Churu tehsil of Churu district because there is lack of natural vegetation, poor decomposition due to low rainfall, high oxidation due to high summer temperature and wind erosion. No farm yard manure (FYM) has been applied to most of the soils for last many years which might be another reason for low OC status of these soils (Meena and Biswas, 2014). The calcium carbonate ($CaCO_3$) content in western plain of Rajasthan varied from 0.05 to 26.80 % with an average value of 7.65 % (Table 1) indicating that most of the soil is calcareous in nature. The highest (25.58 %) mean value of $CaCO_3$ was observed in Churu tehsil of Churu district of western plain of Rajasthan it may be due to the basic parent material; low rainfall and high temperature are found (Singh *et al.,* 2006). The lowest (1.57 %) mean value of $CaCO_3$ was noticed at Ratangarh tehsil of Churu district of western Rajasthan. Such a type of variations in $CaCO_3$ content in the studied area might be due to variation in the parent material and pedogenic processes by which soils have developed. The cation exchange capacity (CEC) from western plain of hot arid region soils varied from 3.26 to 14.05 cmol (p^+) kg^{-1} with an average value of 5.17 cmol (p^+) kg^{-1} (Table 1). The highest (8.52 cmol (p^+) kg^{-1}) mean value of CEC was observed at Khajuwala tehsils of Bikaner district which could be ascribed to using input as organic manure and inorganic fertilizers that lead to amount of OC content and clay content in the soils of arid region (Srinivasarao *et al.,* 2014). Whereas the lowest mean value of CEC was observed at Churu tehsil of Churu district in western plain of arid Rajasthan which might be due to low OC content, coarse texture, low rainfall, and no addition of manures and fertilizers (Dan *et al.,* 2004).

Variation in extractable K

NH_4OAc-extractible K (NH_4OAc-K)

NH_4OAc-K plays a very important role in the growth of plants because exchangeable and solution K are only sources of K which are readily available to plants. The content of NH_4OAc- K ranged from 13.8 to 202.7 mg kg^{-1} with mean value of 91.2 mg kg^{-1} in soils of arid region (Table 2). The highest amount (131.9 mg kg^{-1}) of NH_4OAc-K was recorded at Khajuwala tehsil of Bikaner district where being relatively finer in texture have clay fraction consisting of mica (illite), smectite and vermiculite soils. Further, mica being the most dominant clay mineral in the coarse clay fraction might have contributed in available K Besides, due to better cropping history of the area to the fact that with increase in organic matter in soils, the clay-humus increases organic matter and clay-humus complex's possibly have provided more exchange sites and access to K (Joshi *et al.,* 1978; Sharma *et. al.,* 2009). The lowest (64.7 mg kg^{-1}) mean value of NH_4OAc-K was recorded in at Pokran tehsil of Jaisalmer district which could be ascribed to low amount of OC, coarse texture of soils and no application of manures and K fertilizers (Dovalti *et al.,* 2010). NH_4OAc-K showed highly significant and positive relationship with clay fraction (r=0.94**), and CEC (r=0.92**) (Table 4) which is very much expected because of the fact that higher content of OC in the soil leads to higher CEC resulting in higher adsorption of the cations including K (Shankhayan *et al.,* 1996; Sharma *et. al.,* 2009).

Water soluble K (WS-K)

WS-K is the major source of plant nutrients, nutrient cycling in ecosystems, and pollutant transformation and transport in soil (Agbenin, 2003). WS-K is taken up directly by plants, although amounts found in the soils are generally small. The K concentration in soil solution influences the rates of K diffusion and mass flow towards the root and therefore the uptake of K by plants (Mengel and Kirkby 1982). The water soluble K is the pool of soil K that can be readily absorbed by growing plants. However this is very small pool of total K and even in the fertile soil this pool cannot supply the major requirements of the crops (Arnon, 1975). The data on WS-K of soils in the studied area have been presented in (Table 2) and the content of WS-K ranged from 2.9 to 47.1 mg kg^{-1} with mean value of 18.3 mg kg^{-1} in tehsils of western arid region soils.

Among the different tehsils, the highest amount (28.4 mg kg^{-1}) of WS-K was recorded at Fatehgarh tehsil of Jaisalmer district could be ascribed to better release of K due to some addition of FYM and low order removal of K by the crop because of less intensive cropping (Singh and Bansal, 2009). Whereas on the other hand the lowest (14.3 mg kg^{-1}) amount of WS-K were found at Pokran tehsil of Jaisalmer district because of higher removal of K as compare to addition comparatively or may be leach down to lower layers because of faulty irrigation through canal water (Yaduvanshi; and Swarup, 2006).

The data presented in (Table 4) reveal that water soluble K has significant and positive correlation with OC ($r=0.54^{*}$) which may be attributed to rapid release of K ions from the decayed part of organic manures and its subsequent transport to exchange sites (Ammal; and Muthiah, 1996). WS-K also had highly significant and positive correlation with CEC ($r = 0.81^{**}$) (Sonar and Patil, 1996). The positive and highly significant correlations of WS-K with the clay ($r = 0.83^{**}$) fraction indicated that clay fraction had higher amount of WS-K (Sahoo and Gupta, 1995). However water soluble K has negative and significant correlation with soil pH ($r = -0.57^{*}$) (Prasad 2010). WS-K has highly significant and positively correlated with exch-K ($r=0.80^{**}$), Non-exch-K ($r=0.77^{**}$), HNO_3 -K ($r=0.80^{**}$), lattice-K ($r=0.84^{**}$) and total-K ($r = 0.84^{**}$) (Table 4) indicating that rapid establishment of equilibrium between these forms (Prasad, 2010).

Nitric acid extractible K (HNO_3-K)

HNO_3-K is most frequently used as a measure of Non-exch-K which constitutes major part of the total-K. It has ranged from 154.4 to 635.5 mg kg^{-1} with mean value of 318.7 mg kg^{-1} in different tehsils of hot arid western plain soils (Table 2). The highest (478.8 mg kg^{-1}) amount HNO_3-K were recorded in pugal tehsil of Bikaner district which could be due to having slightly better amount of silt and clay content (Tomar *et al.,* 1997) and enriched through fertilization and biocycling (Thakur *et al.*, 1994). The lowest amount of (257.7 mg kg^{-1}) HNO_3-K was found at Pokran tehsil of Jaisalmer due to more removal of K then input, and soils having lower amount of silt plus clay contents (Choudhary; and Pareek, 1976). It has been seen that most soils formed on basement complex materials and alluvial sediments contain some amount of weathered mica and thus high values of fixed K reserve (Al-Zubaidi *et al.*, 2008).

In contrast to this, the soils of the sedimentary sandstones origin were found to be greater than those of the basement complex origin. The correlation matrix showed significant positive relationship between HNO_3-K with OC (r= 0.29), CEC ($r= 0.77^{**}$), and clay ($r=0.80^{**}$) (Sharma *et al.*, 2009) (Table 4). HNO_3-K was highly significant and positive correlation with lattice-K ($r=0.97^{**}$) and total-K (0.98^{**}) indicating that there exists an equilibrium between these forms of potassium and with the depletion of one is replenished (Das *et al.*, 1997).

Hydrochloric acid extractible K (HCl-K)

The HCl-K in studied soils varied from 8.1 to 99.3 mg kg^{-1} with a mean value of 40.84 mg kg^{-1} in western plain of Rajasthan (Table 2).

Table.1 Variation in soil properties of western plain of hot arid Rajasthan

Tehsils	pH (1:2.5)		EC (1:2.5, dSm^{-1})		OC (%)		$CaCO_3$ (%)		CEC [cmol (p^+) kg^{-1}]	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
District: Bikaner (n=77)										
Bikaner	8.37-9.13	8.81	0.07-0.62	0.21	0.04-0.08	0.06	0.40-8.52	3.60	3.64-8.00	5.23
Khajuwala	7.65-8.67	8.81	0.09-0.31	0.19	0.06-0.23	0.14	2.31-19.53	10.09	4.39-14.05	8.52
Pugal	7.04-9.16	7.50	0.13-0.17	0.15	0.16-0.21	0.18	5.02-11.62	8.89	6.61-8.87	7.68
Chhatargarh	8.87-9.13	8.84	0.06-0.28	0.13	0.04-0.21	0.10	3.60-20.30	9.84	4.36-8.76	6.34
Nokha	8.6-9.18	8.81	0.08-0.14	0.11	0.02-0.09	0.05	0.53-11.20	3.46	3.69-7.02	5.22
Dungargarh	8.67-9.12	8.86	0.06-0.19	0.09	0.02-0.11	0.07	0.21-11.53	5.44	4.14-7.13	5.47
Kolayat	9.14-9.37	9.23	0.08-0.2	0.13	0.01-0.14	0.07	4.70-16.72	8.44	3.84-9.20	5.81
Lunkaransar	8.62-9.57	8.92	0.10-0.31	0.18	0.06-0.16	0.12	0.05-9.42	5.14	4.30-7.59	5.64
District: Churu (n=83)										
Churu	8.54-9.13	8.94	0.05-0.13	0.08	0.01-0.05	0.03	24.91-26.82	25.58	3.28-6.95	4.21
Ratangarh	8.68-9.98	9.01	0.06-0.12	0.09	0.02-0.10	0.07	0.50-2.52	1.57	4.18-8.12	5.45
Shardarshahar	8.86-9.07	8.96	0.05-0.16	0.09	0.03-0.15	0.09	0.81-9.33	5.33	4.09-6.76	5.04
Rajgarh	8.32-9.16	8.78	0.03-036	0.10	0.01-0.11	0.06	0.31-9.60	3.93	3.42-7.82	4.78
Sujangarh	8.69-9.15	8.93	0.04-0.23	0.10	0.02-0.13	0.06	0.52-10.90	4.62	3.62-6.63	4.70
Taranagar	8.75-9.18	8.97	0.04-0.11	0.07	0.02-0.09	0.05	5.03-11.32	7.64	4.19-7.26	5.56
District: Jaisalmer (n=49)										
Jaisalmer	7.19-9.38	8.78	0.03-0.77	0.17	0.01-0.07	0.05	5.80-19.95	13.03	3.72-5.24	4.27
Fatehgarh	7.56-8.54	8.19	0.09-0.41	0.18	0.02-0.11	0.07	0.10-8.32	4.55	3.93-6.75	5.47
Pokran	8.25-9.02	8.70	0.01-0.85	0.19	0.02-0.25	0.09	0.50-25.05	12.01	3.26-6.43	4.29
WP of Rajasthan	7.04-9.98	8.79	0.01-0.85	0.13	0.01-0.25	0.07	0.05-26.80	7.65	3.26-14.05	5.17

WP = Western Plain, n = No. of sample

Table.2 Distribution of different extractible potassium in western plain of hot arid Rajasthan

Tehsils	**NH_4OAc-K (mg kg^{-1})**		**H_2O-K (mg kg^{-1})**		**HNO_3-K (mg kg^{-1})**		**HCl-K (mg kg^{-1})**	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
				District: Bikaner (n=77)				
Bikaner	23.8-135.0	87.3	2.9-35.3	18.0	173.0-392.8	279.8	28.1-62.8	46.2
Khajuwala	72.6-202.7	131.9	7.4-40.3	25.3	218.5-586.1	430.1	43.2-58.2	50.6
Pugal	102.8-132.7	117.1	24.7-34.8	27.9	403.1-586.5	478.8	47.9-61.3	55.3
Chhatargarh	87.2-132.6	109.9	11.8-32.5	22.8	242.2-498.3	387.2	8.1-55.4	33.3
Nokha	47.9-132.6	92.0	4.9-29.5	16.4	154.4-451.7	276.2	28.5-62.4	43.7
Dungargarh	66.1-130.3	97.3	10.6-33.4	21.1	194.3-561.6	358.4	34.2-52.4	42.7
Kolayat	81.6-148.1	107.7	9.4-43.3	23.4	284.4-635.5	410.5	8.1-53.3	31.5
Lunkaransar	70.4-140.9	102.1	6.8-47.1	21.4	215.8-573.3	355.2	30.2-53.4	38.4
				District: Churu (n=83)				
Churu	69.3-136.9	85.9	9.1-26.7	15.3	242.1-496.2	337.1	24.0-36.0	29.7
Ratangarh	60.9-129.6	90.5	6.9-31.1	18.3	189.1-375.1	266.9	29.6-64.4	46.1
Shardarshahar	62.0-124.8	91.3	7.5-23.8	17.1	193.7-386.4	292.9	23.8-61.1	45.2
Rajgarh	31.5-130.5	82.6	4.9-26.9	14.6	174.1-367.4	258.3	23.5-62.8	39.9
Sujangarh	32.7-131.4	83.5	3.9-32.4	14.7	169.2-427.5	277.7	27.3-61.2	46.3
Taranagar	89.3-124.6	105.7	18.5-29.1	24.2	254.3-519.4	393.4	24.1-60.3	38.5
				District: Jaisalmer (n=49)				
Jaisalmer	62.9-101.3	83.9	4.8-22.5	14.6	218.2-462.0	344.9	30.1-99.3	46.7
Fatehgarh	80.3-128.3	106.5	17.5-44.9	28.4	279.5-396.4	336.8	20.2-58.3	36.5
Pokran	13.9-103.6	64.7	3.5-24.4	14.3	174.9-471.9	257.7	19.1-62.1	37.6
WP of Rajasthan	13.8-202.7	91.2	2.9-47.1	18.3	154.4-635.5	318.7	8.1-99.3	40.8

WP = Western Plain, n = No. of sample

Table.3 Distribution of different potassium pools in western plain of hot arid Rajasthan

Tehsils	Total K (mg kg^{-1})		Exch K (mg kg^{-1})		Non-exch K (mg kg^{-1})		Lattice K (mg kg^{-1})	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
District: Bikaner (n=77)								
Bikaner	2194.4-3517.0	2935.1	20.9-102.1	69.6	130.0-293.1	208.6	2040.6-3086.4	2638.9
Khajuwala	2701.1-4705.4	3729.8	65.3-162.4	129.1	153.2-463.6	329.2	2475.1-4038.9	3245.6
Pugal	3647.7-4356.1	3897.7	78.1-100.7	89.4	314.5-488.5	388.5	3230.3-3731.9	3391.6
Chhatargarh	2798.4-4237.3	3495.8	75.5-103.4	87.5	166.7-402.1	300.3	2544.3-3699.2	3085.1
Nokha	2354.8-3710.2	2920.3	43.1-103.0	75.6	111.3-354.3	200.9	2195.3-3223.2	2627.1
Dungargarh	2475.8-4424.7	3296.6	52.9-100.9	76.3	138.8-460.4	282.3	2273.3-3829.8	2916.8
Kolayat	2834.3-4599.9	3555.6	71.1-115.2	84.8	212.9-530.6	326.2	2540.7-3910.7	3121.1
Lunkaransar	2719.0-4200.1	3309.5	63.6-96.9	80.9	144.3-476.7	273.7	2504.2-3579.3	2933.3
District: Churu (n=83)								
Churu	2733.9-3663.6	3093.0	59.2-110.1	70.4	182.6-386.0	266.6	2482.0-3140.6	2740.5
Ratangarh	2570.4-3322.8	2915.3	49.8-106.2	72.4	127.1-268.9	193.4	2298.0-3097.4	2631.0
Shardarshahar	2570.0-3322.8	2917.9	49.9-107.3	73.5	139.2-307.9	220.6	2373.3-2883.7	2606.6
Rajgarh	2048.4-3521.3	2807.2	25.5-103.6	67.9	126.8-263.8	189.4	1891.0-3126.9	2535.1
Sujangarh	2314.4-3399.6	2900.1	26.2-101.7	68.8	121.2-344.6	208.7	2163.0-2920.7	2607.8
Taranagar	2808.6-4121.4	3354.2	70.8-95.6	81.6	183.2-423.8	311.7	2536.0-3572.7	2936.6
District: Jaisalmer (n=49)								
Jaisalmer	2497.3-4231.6	3266.0	58.0-78.8	69.3	154.3-383.1	275.3	2280.1-3747.0	2906.7
Fatehgarh	2592.8-4492.9	3342.0	62.8-108.1	80.2	216.7-313.2	258.6	2295.7-4026.5	2974.6
Pokran	2260.1-4343.0	2877.8	5.5-79.1	50.2	128.7-392.7	205.6	2022.2-3846.6	2607.6
WP of Rajasthan	2111.5-4665.3	3112.4	5.5-162.4	72.9	111.3-530.6	245.6	1891.0-4038.9	2775.0

WP = Western Plain, n = No. of sample

Table.4 Pearson's correlation matrix between soil properties and potassium fractions in western plain of hot arid Rajasthan

	Sand	Silt	Clay	PH	EC	OC	$CaCO_3$	CEC	NH_4OAc-K	WSK	HNO_3-K	HCl-K	Exch K	Nonexch K	Lattice K
Silt	-0.29														
Clay	-0.27	0.64**													
PH	0.28	-0.45	-0.58*												
EC	-0.15	0.36	0.34	-0.64**											
OC	0.32	0.29	0.57*	-0.57*	0.40										
$CaCO_3$	-0.89**	-0.13	-0.16	0.01	-0.05	-0.57*									
CEC	-0.25	0.64**	0.99**	-0.64**	0.42	0.64**	-0.18								
NH_4OAc-K	-0.27	0.60*	0.94**	-0.47	0.27	0.44	-0.12	0.92**							
WSK	-0.20	0.48	0.83**	-0.57*	0.41	0.54*	-0.14	0.81**	0.90**						
HNO_3-K	-0.54*	0.33	0.80**	-0.49*	0.21	0.29	0.27	0.77**	0.85**	0.80**					
HCl-K	0.16	0.39	0.40	-0.55*	0.28	0.48	-0.39	0.46*	0.23	0.11	0.12				
Exch-K	-0.28	0.61**	0.94**	-0.40	0.19	0.37	-0.11	0.90**	0.98**	0.80**	0.82**	0.26			
Non-exch K	-0.57*	0.26	0.74**	-0.49*	0.21	0.26	0.33	0.72**	0.79**	0.77**	0.99**	0.09	0.75**		
Lattice K	-0.47	0.33	0.83**	-0.58*	0.33	0.34	0.19	0.81**	0.86**	0.84**	0.97**	0.16	0.82**	0.96**	
Total K	-0.49*	0.33	0.83**	-0.56*	0.31	0.34	0.20	0.81**	0.86**	0.84**	0.98**	0.15	0.82**	0.97**	0.99**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Fig.1 Location map of study area

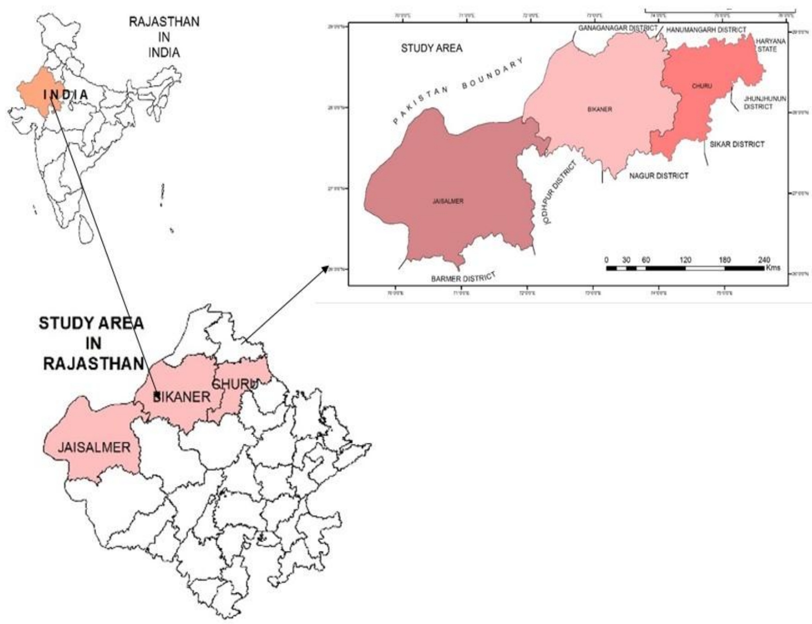


Fig.2 Distribution of particle size in western plain of hot arid Rajasthan

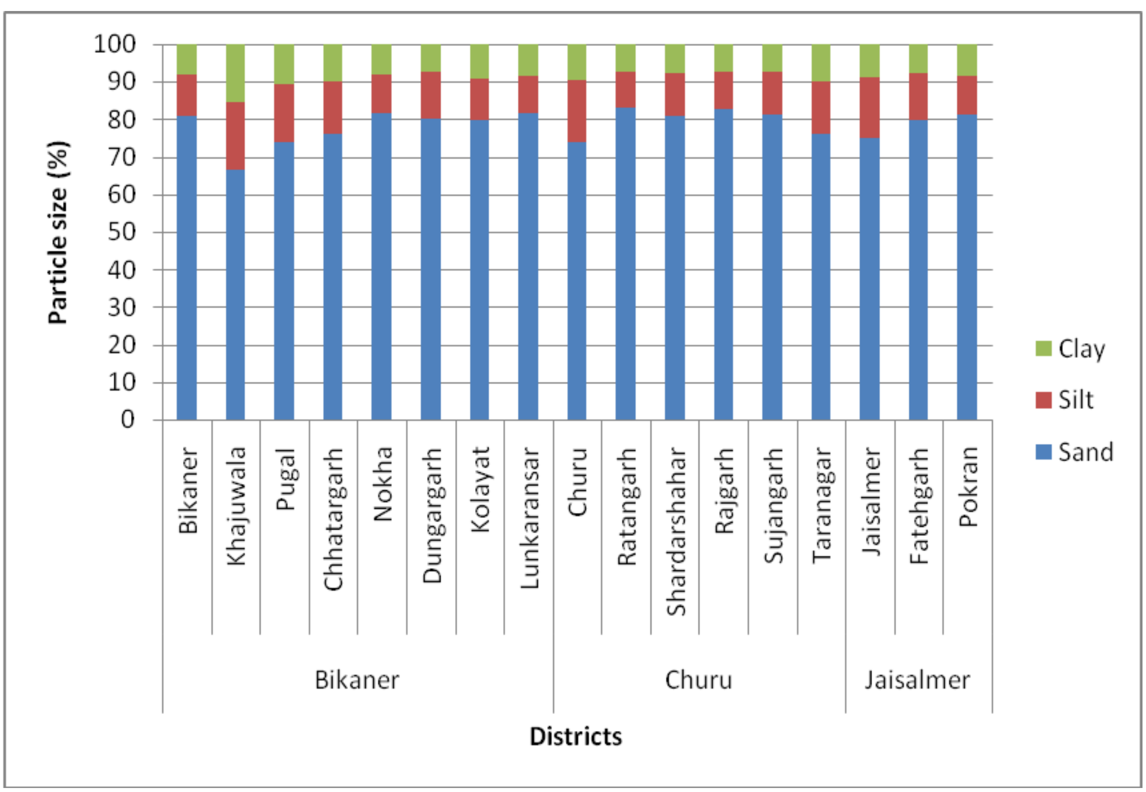
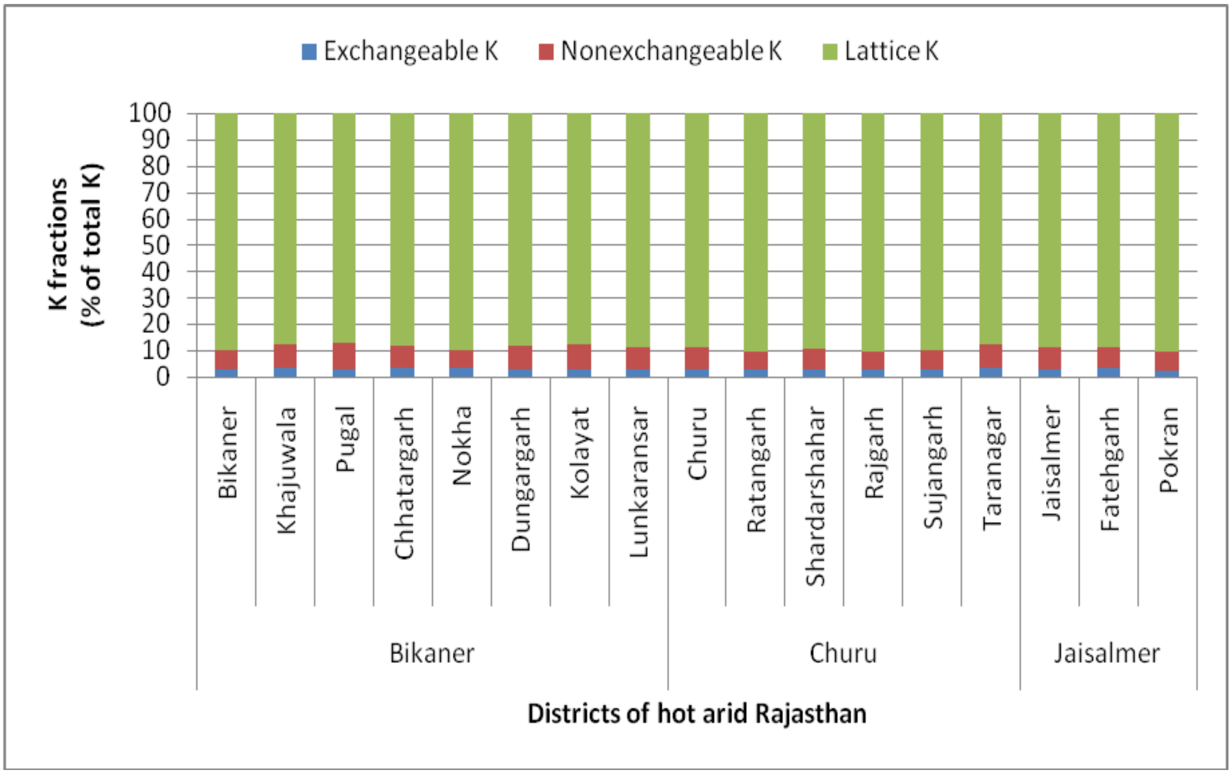


Fig.3 Distribution of potassium fractions (as % of total K) in western plain of hot arid Rajasthan



The highest (55.3 mg kg^{-1}) amount of HCl-K were noticed at Pugal tehsil of Bikaner district which might be ascribed to better release of some K absorbed on the edges of inner side of lattice K, and which could not be replaced by exchangeable NH_4^+ but could be extracted with HCl which is slowly exchangeable (Ghosh; and Bhattacharyya 1982). The lowest (29.7 mg kg^{-1}) amount of HCl-K were found at Churu tehsil of Churu district possibly due to low amount of silt plus clay content in these arid regions soils (Joshi *et al.*, 1982).

The positive relationship between HCl-K and HNO_3-K (Table 4) with that of CEC showed that perhaps some K absorbed on the edges (Ghosh; and Bhattacharyya 1982; Sharma *et al.*, 2009) of inner side of the lattice, which could not be replaced by exchangeable $NH4^+$ but could be extracted with HNO_3/HCl, was a part of the exchange complex which is slowly exchangeable. HCl-K was showed significant positive relationship with CEC (r= 0.46^*), and significant negative relationship with soil pH (r= -0.55^*) (Table 4) (Singh *et al.*, 2010).

Variation in K pools

Total K (Total-K)

Total-K depends on the presence of K bearing primary and secondary minerals in the soil. Clay mineralogy is a key factor affecting dynamics of K in the soils (Ghiri; and Abtahi, 2011). Soils differing in clay mineralogy may respond differently to K application (Akhtar; and Dixon, 2013). Total-K content in different tehsils of western plain of hot arid Rajasthan ranged from 2111.5 to 4665.3 mg kg^{-1} with an average value of 3112.4 mg kg^{-1} (Table 3). The maximum (3897.7 mg kg^{-1}) amount of total-K was observed at Pugal tehsils of Bikaner district where soils being relatively finer in texture, possibly dominated with mixed clay mineralogy and the presence of substantial quantities of K bearing minerals in the soils. Many other workers were also obtained similar results (Joshi *et al.,* 1982; Raskar; and Pharande 1997; Kaskar *et al.,* 2001, Sharma *et al.,* 2009). The lowest (2807.2 mg kg^{-1}) amount of total-K was noticed at Rajgarh tehsils of Churu district which may be ascribed to sandstone type parent material and their degree of weathering (Ahmed; and Walia, 1999). Recently, it has been reported that the presence of specific clay minerals affect the K-fixing capacity and slow and fast release of K in different soils (Wakeel *et al.,* 2013). Smectite along with the mica is the reason for a soil having appreciable amount of total-K. Only 1 - 2% of the total soil K is in a readily available form. Of this small percentage, 90% is weakly adsorbed to colloidal surfaces on the outside of 2:1 clays, 1:1 clays and humus. Continuous crop production without K application may result in mica weathering particularly that of biotite into vermiculite and smectite and decomposition of feldspar structure over a longer period of time (Shaikh *et al.,* 2007). Total-K has highly significant and positive correlation with clay ($r = 0.83^{**}$) fraction showing that most of the total-K is derived from interlayer of clay structure and increase total-K with finesse of soils (Das *et al.,* 1997). Highly significant positive relationship of total-K with CEC ($r = 0.81^{**}$) suggest the organic matter also contributes to total-K content of the soils (Dhaliwal *et al.,* 2004), while it showed negative significant relationship with soil pH ($r= -0.56^{*}$) (Gangopadhyay *et al.,* 2005; and Sharma *et al.,* 2009).

Exchangeable K (Exch-K)

Exch-K is the portion of the soil K that is electrostatically bound as an outer-sphere complex to the surfaces of clay minerals and humic substances. It is readily exchanged with other cations and also is readily available to plants. The amount of Exch-K ranged from 5.5 to 162.4 mg kg^{-1} with mean value of 72.9 mg kg^{-1} and it contributed about 2.3 to 3.3 % towards total-K (Fig. 3) in western plain of hot arid region soil (Table 3). The highest (129. 1 mg kg^{-1}) amount of Exch-K was observed at Khajuwala tehsils of Bikaner district which could be due to the presence of comparable amounts of K-rich micaceous and other 2:1 minerals (Samadi *et al.,* 2008). It is worth noting that decline Exch-K content at Pokran tehsils of Jaisalmer district is being removed at a greater rate than can be replenished from Non-exch-K forms (Gawander *et al.,* 2002) and fertilizer rates for these soils may need to be raised. Past research has shown that K can increase yield significantly in arid and semi-arid regions because of diffusion of K inhibited by cool soil temperature and low water content, and the presence of highly charged clays in these regions (Skogley; and Haby, 1981). Exch-K showed positive relationship with OC ($r = 0.36$), CEC ($r = 0.90^{**}$) which is very much expected because of the fact that higher content of OC in the soil leads to higher CEC resulting in higher adsorption of the cations including K (Shankhayan *et al.,* 1996). Exch-K has also shown highly significant and positive relationship with silt ($r = 0.61^{**}$) and clay ($r = 0.94^{**}$) fraction which may be attributed to higher proportion of potash rich minerals (illite) in the coarse clay particles (Tomar *et al.,* 1997). Positive and highly significant relationships were also observed between Exch-K, Non-exch-K ($r=0.74^{**}$), HNO_3-K ($r= 0.81^{**}$), lattice-K ($r=0.81^{**}$) and total K ($r = 0.82^{**}$) (Table 4) (Sharma *et al.,* 2009).

Non-exchangeable K (Non-exch-K)

Non-exch-K or fixed K differs from mineral K in that it is not bonded with in the crystal structures of soil mineral particles. It is held between adjacent tetrahedral layers of di-octahedral and tri-octahedral micas, vermiculites, and intergrade clay minerals such as chloritized vermiculite (Rich, 1972; Sparks and Huang, 1985; Sparks, 1987). The amount of Non-exch-K ranged from 111.3 to 530.6 mg kg^{-1} with mean value of 245.6 mg kg^{-1} (Table 3) and it contributed about 6.7 to 9.9 % towards total-K (Fig. 3). Concerning the magnitude of the Non-exch-K the highest (388.5 mg kg^{-1}) amount were found at Pugal tehsil of Bikaner district probably because their found high contents of illite clay mineral, low order removal of K through cropping system, and the presence of higher clay and OC content (Bhaskar *et al.*, 2001). Whereas on the other hand the lowest (189.4 mg kg^{-1}) amount of Non-exch-K was found at Rajgarh tehsil of Churu district due to crop removal and soil pH, and may be attributed to preponderance of 2:2 type clay mineral rather than micas, might be due to the release of fixed K to compensate the removal of WS-K and Exch-K by planting and leaching losses, moreover, it obvious that the clay soil contain higher levels of this form than the calcareous sandy soil. The difference between Exch-K and Non-exch-K was very narrow, indicating the low weathering status of K minerals, particularly micaceous which are relatively less prone to acid attack (Datta; and Sastry, 1993; Bedrossian; and Singh, 2004). Non-exch-K was shown positively correlated with OC (r = 0.26) and CEC ($r = 0.71^{**}$) this may be ascribed to increase Exch-K with increases in OC content which by means of dynamic equilibrium between exch-K and Non-exch-K forms of K slowly shifts towards the later form resulting in its higher amount with increase in the OC content. Similarly with the increase in CEC due to dynamic equilibrium between Exch-K and Non-exch-K (Shankhayan *et al.*, 1996). Non-exch-K showed significant positive relationship with $CaCO_3$ (r = 0.33) which could be attributed to change in rate of release of K due to presence of high free $CaCO_3$ (Tomar *et al.*, 1997). Positive and significant relationship between Non-exch-K with silt (r = 0.26) and clay ($r= 0.74^{**}$) fractions (Raskar; and Pharande, 1997). The non-exch-K of soils showed positive and highly significant correlation with HNO_3-K ($r = 0.99^{**}$), lattice-K ($r=0.97^{**}$) and total-K ($r = 0.98^{**}$) (Table 4) indicating that Non-exch-K serves as a good index for the K supplying capacity to the soils (Gangopadhyay *et al.*, 2005).

Lattice K (Lattice-K)

The lattice-K fraction of the soils is considered as difficultly available to the plants and it represents the largest portion of soil K. This pool of K varied from 1891.0 to 4038.9 mg kg^{-1} (Table 3) and it contributed about 87.1 to 90.3 % towards total-K in western plain of hot arid Rajasthan (Fig. 3). It has been observed that highest (3391.6 mg kg^{-1}) content of lattice or mineral K at Pugal tehsil of Bikaner district indicates that these soils have been developed from mica-rich parent material and much of K is present in the mica lattice (Gangopadhyay *et al.*, 2005). The lowest (2535.1 mg kg^{-1}) content of lattice-K were noticed at Rajgarh tehsil of Churu district due to course texture in nature and low application of manures and fertilizers with high intensive cropping (Singh; and Bansal, 2009). Lattice-K has highly significant and positive correlation with CEC ($r =0.81^{**}$) and clay ($r =0.83^{**}$) fraction but negative correlation with soil pH ($r = -0.58^{*}$) and sand (r = -47) fraction indicating that sizable fraction of lattice-K is present in the coarse clay and silt fraction containing minerals such as mica and illite. Rich relationship between lattice-K and soil properties could be attributed to the more reactive nature of lattice-K (Table 4) (Sharma *et al.*, 2009). Lattice-K has also shown highly significant and positive correlation with total-K ($r=0.99^{**}$). These results have indicated the existence of dynamic equilibrium between forms of K in soils of western plain of

Rajasthan (Table 4) (Dixit *et al.*, 1993; Chand and Swami, 2000; Prasad, 2010).

Hot arid region soils needed more information on the nature and K status in alkali and calcareous soils. Most of studied soils contain low to medium Non-exch-K and other forms of K due to low weathering status of K minerals, particularly micaceous minerals, crop removal and high soil pH, and may be attributed to preponderance of 2:2 type clay mineral rather than micas, might be due to the release of fixed K to compensate the removal of water soluble and Exch-K by planting and leaching losses. K uptake during plant growth is a dynamic process with periods of K depletion in the root zone and release of Non-exch- K to exchange and solution phases by K bearing soil minerals. It should be also considered that depletion of interlayer K reduces K release rates, and over a long period of time, these rates may become insufficient for optimum K nutrition of crops. Therefore, permanent cropping without K fertilizer application may lead to a degradation of 2:1 phylosilicates.

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