



Distribution of Various Geochemical Forms of Potassium under Horticulture Land Use System of District Ganderbal

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Authors' contributions

This work was carried out in collaboration among all authors. Author Khushboo designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors MAB, MAW and SAB managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Surface (0-20 cm) and sub-surface (20-40 cm) soil samples were collected from five locations under horticulture land use system of District Ganderbal. The distribution of potassium forms (water soluble, available, exchangeable, non-exchangeable, fixed, lattice and total) were investigated. Soil samples were analyzed for different physical and chemical properties and fractions of potassium. The soils were slightly acidic to neutral in reaction and soil texture varied from silty clay loam to silt loam. Irrespective of soil depth sequential order of potassium fractions were TK>LK>FK>NEK>AK>EK>WSK. The trend of decrease in water soluble and exchangeable K was noticed in these soils from surface to sub-surface layers. All forms were in dynamic equilibrium with one another and positively and significantly correlated with Organic carbon, CEC, Silt and clay and negatively to sand.

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1. INTRODUCTION

Potassium is one of the major element found in the soil and makes up on an average 2.6% of the earth crust, It is seventh most abundant element and fourth most abundant mineral nutrient in the lithosphere [1]. Potassium is a major essential nutrient which is denoted by letter K (Kalium, L.) and is involved in several physiological processes such as regulating the uptake of nitrates from soil, balancing phosphorus uptake, strengthening stalks of plants, hence helping in resisting fungal and bacterial attacks as well as lodging.

Potassium undergoes various transformations in the soil at different rates. A proper appreciation of different forms of soil potassium is thus possible only from understanding of its dynamics. More than 98% of the total potassium reserve in soils exists in inorganic combinations which can further be characterized as water soluble, exchangeable, non-exchangeable and mineral K. Knowledge of different forms of potassium in soil together with their distribution is of great relevance in assessing the long term availability of potassium to crops and in formulating a sound basis of fertilizer recommendation [2]. The estimation of K available to crops as well as most of the K fertilizer recommendations are based on water soluble K and exchangeable K and do not consider K release from non-exchangeable fractions [3]. There are physical, chemical, biological and climatic factors affecting K forms and equilibrium of K in soil, which could be related to clay mineralogy [4], texture [5], moisture [6], cation exchange capacity [7], pH [8], and concentrations of other ions [9]. Besides these soil properties, fertilization and cropping sequences are the most important management factors that influence potassium equilibrium in soils [10].

The distribution of K forms in the soil and the equilibrium between them determine the K status of the soil and the potential of K supply to plants [11]. The main aim of Potassium dynamics is to explain the movement of K in soil-solution-plant systems in relation to driving forces. The phenomenon of potassium fixation significantly affects potassium availability. Soil potassium distribution and availability could be altered due

to changes in soil management and land use practices [12]. For instance, it has been reported that increased addition of organic manures, yielded a corresponding increase in exchangeable potassium content of an Ultisol [13]. Mineralization of organic matter can be enhanced due to the low input of crop residues and deep plowing in long term [14]. Kayser and Isselstein, [15] indicated that continued K export with no K application will lead to depletion of the soil. This will eventually decrease soil quality and threaten food safety and security.

It is quite evident that soils having same content of total K may vary widely in potash supplying capacity depending upon the distribution of the different forms of K. Therefore, for estimating the potash supplying power of the soils, it is necessary to study the distribution and characterization of different forms of K in the soil [16]. Equilibrium and kinetic reactions exist between potassium forms in the soils and this affects their solution concentration and availability to plants [17]. Soil solution potassium concentration is depleted through leaching and plant uptake, but is immediately replenished by the other forms especially the exchangeable and non-exchangeable fractions [18]. Availability of potassium in soil solution could therefore be influenced by the solution-exchangeable potassium dynamics, rate of potassium exchange in soils, potassium fixation and release from soil minerals and leaching [19].

2. MATERIALS AND METHODS

2.1 Collection of Soil Samples

Surface soil samples (0-20 cm) and sub- surface soil samples (20-40 cm) were randomly selected covering five different locations of district Ganderbal viz. Chattergul Bala, Babanagri, Zazana, Ahan and Wakura to study the distribution of different forms of potassium and various physico-chemical properties of soils. The collected soil samples were air dried in shade, grounded with wooden mallet and passed through a 2 mm sieve. For organic carbon determination, the soil was passed through 0.2 mm sieve. The co-ordinates of the sites were recorded using GPS receiver (Garmin Oregon 650).

Table 1. Location of soil samples collected from district Ganderbal under horticultural land use system

S.no	Site/ Location	Latitude	Longitude
1	Chattergul Bala	34 ⁰ 19' 8.18"N	74 ⁰ 53' 51.6"E
2	Babanagri	34 ⁰ 18' 52.44"N	74 ⁰ 55' 59.04"E
3	Zazana	34 ⁰ 13' 45.3"N	74 ⁰ 40' 47.22"E
4	Ahan	34 ⁰ 13' 47.43"N	74 ⁰ 40' 7.51"E
5	Wakura	34 ⁰ 12' 23.068"N	74 ⁰ 41' 20.664"E

2.2 Water Soluble Potassium (WSK)

Two grams of soil and 20 ml distilled water were added to a 50 ml centrifuge tube and shaken on a reciprocating shaker at 25°C for 30 minutes. The supernatant was separated by centrifugation and potassium was determined photometrically as described by Jackson [20].

2.3 Available Potassium (AK)

Available potassium was extracted with normal neutral ammonium acetate in the ratio of 1:5 after shaking for five minutes and determination was carried out with the help of flame photometer [21].

2.4 Exchangeable Potassium (EK)

Two and a half grams of soils and 25 ml of 1 mol L⁻¹ NH₄OAc at pH 7.0 were added to a 100 ml plastic bottle and shaken at 25°C for 60 minutes and was filtered before analysis. EK was obtained from the difference between WSK and the NH₄OAc – extracted K.

2.5 Non Exchangeable Potassium (NEK)

Five grams of soil and 50 ml 1 mol L⁻¹ HNO₃ were boiled in a 250 ml glass beaker (covered with a watch glass) for 10 minutes, filtered, washed with hot water and made up to 100 ml before analysis. NEK was calculated by subtracting the extracted K with NH₄OAc from the K extracted with HNO₃.

2.6 Fixed K (FK)

The applied K that cannot be recovered by boiling 1 mol L⁻¹ HNO₃ was considered as fixed K.

2.7 Lattice Potassium (LK)

Lattice potassium was taken as the difference between the total potassium and fixed potassium.

2.8 Total Potassium (TK)

0.5 gm of soil was digested in 12 ml of aqua Regia on hot plate for 3 hours at 110°C. After evaporation to near dryness, the sample was diluted with 20 ml of 2% HNO₃ and transferred to 100 ml volumetric flask after filtering through whatman no. 42 paper and dilution to 100 ml with deionised water.

3. RESULTS AND DISCUSSION

3.1 Water Soluble Potassium

Water soluble potassium in surface soils varied from 7.73 to 8.43 mg kg⁻¹ with a mean value of 8.08 mg kg⁻¹ and in sub-surface soils it varied from 4.03 to 6.53 mg kg⁻¹ with a mean value 5.57 mg kg⁻¹ (Table 3). The content of this fraction was too low to meet the plant requirement. Sparks [22] also reported that water soluble potassium can be found in low concentrations and is mobile. Depth wise analysis of these soils for water soluble potassium showed a decreasing trend owing to decreased organic matter content in lower soil surfaces. The more water soluble K in the surface may be due to higher organic matter content in the surface soil or due to application of potassic fertilizers as observed by Das et al. [23]. The potassium concentration in soil solution influences the rate of potassium diffusion and mass flow towards the roots and therefore the uptake of potassium by plants [24]. Water soluble potassium in surface soils was significantly and positively correlated with organic carbon (r=0.562*), which may be attributed to rapid release of potassium ions from the decayed part of organic manures and its subsequent transport to exchange sites [25], CEC (r=0.530*), silt (r=0.749**) and clay (r=0.740**) (Table 4). While in sub-surface soils it was significantly and positively correlated with pH (r=0.597*), organic carbon (r=0.535**), CEC (r=0.682**), silt (r=0.696*) and clay (r=0.673**) (Table 5). These results are in accordance with the findings of Sahoo and Gupta [26,27].

3.2 Available Potassium

The content of the available potassium in surface soils varied from 72.10 to 82.18 mg kg⁻¹ with a mean value of 76.74 mg kg⁻¹ and in sub-surface soils it varied from 61.68 to 76.24 mg kg⁻¹ with a mean value of 67.91 mg kg⁻¹ (Table 3). The higher content of available potassium might be accredited to higher organic matter content of these soils. Kashmir soils being illitic in nature might have contributed to higher content of available potassium. The results are corroborating with the findings of Shafi [28]. Available potassium in surface soils was significantly and positively correlated with organic carbon ($r=0.852^{**}$), CEC ($r=0.575^*$), silt ($r=0.640^*$) and clay ($r=0.653^{**}$) (Table 4), which is much expected because of the fact that higher content of OC in the soils leads to higher CEC resulting in higher adsorption of the cations including K [29]. It was negatively and significantly correlated with calcium carbonate ($r=-0.634^*$) and fine sand ($r=-0.632^*$). The negative correlation with fine sand suggested that the finer texture and higher biomass contribution promoted the available potassium in these soils. These results are in accordance with the findings of Singh et al. [30]. While in sub-surface soils Available potassium was significantly and positively correlated with pH ($r=0.467^*$), organic carbon ($r=0.818^{**}$), CEC ($r=0.445^*$), silt ($r=0.599^*$) and clay ($r=0.497^*$) (Table 5).

3.3 Exchangeable Potassium (EK)

The exchangeable potassium content in surface soils varied from 63.87 to 73.81 mg kg⁻¹ with a mean value of 68.65 mg kg⁻¹ and in sub-surface soils it varied from 55.48 to 70.65 mg kg⁻¹ with a mean value of 62.33 mg kg⁻¹ (Table 3). The higher content of exchangeable potassium in surface soils of forests may be due to more amounts of litter addition from the tree component that might have contributed to more exchangeable K which occupied in equilibrium with non exchangeable K. In addition exchangeable K could give a better indication of the potential K supplying power of a soil and used for making fertilizer recommendation to the crops [31]. Exchangeable potassium at surface zone was mainly due to the fact that the soils had good amount of organic matter content which might have retained more K ions at exchange sites and also potassium retained through external source [32]. The decrease in content of

exchangeable K at sub-surface zone was mainly due to capillary action of K ions from sub-surface to surface sites and decreased exchange sites and increased compactness at lower depth [33]. Exchangeable potassium in surface soils was significantly and positively correlated with organic carbon ($r=0.856^{**}$), CEC ($r=0.521^*$), silt ($r=0.603^*$) and Clay ($r=0.618^*$). It was significantly and negatively correlated with calcium carbonate ($R=-0.563^*$) and fine sand ($r=-0.594^*$) (Table 4). While in sub-surface soils it was significantly correlated pH ($r=0.483^*$), organic carbon ($r=0.797^{**}$), CEC ($r=0.538^*$), silt ($r=0.543^*$) and clay ($r=0.438^*$), which may be attributed to higher proportion of potash rich minerals (illite) in the coarse clay particles [34]. It was negatively and significantly correlated with calcium carbonate ($r=0.443^*$) (Table 5). Similar findings were also reported by Das et al. [23].

3.4 Non- Exchangeable Potassium

Non- exchangeable potassium content in surface soils varied from 518 to 696.22 mg kg⁻¹ with a mean value of 611.61 mg kg⁻¹ and in sub-surface soils it varied from 600.97 to 775.56 mg kg⁻¹ with a mean value of 685.28 mg kg⁻¹ (Table 3). The lower amounts of non exchangeable K in the surface layers of soils under each land use might be due to the release of fixed K to compensate the removal of water-soluble K and exchangeable K by plants and leaching losses. Dhillon et al. [35] revealed that the pattern of non-exchangeable K at different depths and it was higher in sub-surface soils compared to the surface soils. In surface soils, non-exchangeable potassium showed non-significant and negative correlation with all properties except organic carbon ($r=0.742^{**}$), CEC ($r=0.579^*$), silt ($r=0.782^{**}$) and clay ($r=0.811^{**}$) (Table 4), this may be ascribed to increase Exchangeable-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 [36]. While in sub-surface soils it showed positive and significant correlation with pH ($r=0.435^*$), organic carbon ($r=0.712^{**}$), CEC ($r=0.517^*$), silt ($r=0.698^{**}$) and clay ($r=0.72^*$). It was negatively and significantly correlated with calcium carbonate ($r=-0.452^*$) (Table 5), which could be attributed to change in rate of release of K due to presence of free CaCO₃ [34].

Table 2. Some selected physico-chemical properties of surface (0-20 cm) and sub-surface (20-40 cm) soils of horticulture land use of district Ganderbal

Sample No.	Depth	pH	EC (dSm ⁻¹)	OC (%)	CaCO ₃ (%)	CEC	course sand (%)	sand	Silt	clay
S ₁	0-20	7	0.15	1.14	0.56	14.47	1.38	19.56	50.21	28.85
	20-40	7.14	0.18	1.08	0.67	15.26	1.19	18.14	50.89	29.78
S ₂	0-20	7.13	0.25	1.16	0.68	15.2	1.43	17.61	51.81	29.15
	20-40	7.24	0.27	1	0.7	15.83	1.18	16.12	52.94	29.76
S ₃	0-20	6.6	0.21	1.27	0.57	15.38	1.49	21.94	52.73	23.84
	20-40	6.63	0.23	1.18	0.62	16.88	1.18	21.8	52.48	24.54
S ₄	0-20	7.2	0.25	1.07	0.66	15.36	1.38	22.15	40.02	36.45
	20-40	7.28	0.28	0.98	0.74	15.82	1.18	20.32	39.66	38.84
S ₅	0-20	7.36	0.22	0.88	0.62	15.18	1.42	22.68	45.7	30.2
	20-40	7.45	0.24	0.59	0.68	16.96	1.19	21.23	43.7	33.88

Table 3. Different forms of potassium in surface (0-20 cm) and sub-surface (20-40 cm) soils of horticulture land use of district Ganderbal (mg Kg⁻¹)

Sample	Depth	WSK	AK	EK	NEK	FK	LK	Total K
S ₁	0-20	7.73	72.41	64.68	600.97	673.38	14186.51	14859.89
	20-40	4.03	64.38	60.35	518.95	583.33	14755.99	15339.32
S ₂	0-20	8.06	81.87	73.81	745.3	827.17	14642.29	15469.46
	20-40	6.53	73.63	67.1	696.22	769.85	15478.33	16248.18
S ₃	0-20	7.98	75.16	67.18	642.35	717.51	13373.72	14091.23
	20-40	5.53	63.63	58.1	593.25	656.88	14333.06	14989.94
S ₄	0-20	8.43	82.18	73.75	775.56	857.74	14990.89	15848.63
	20-40	5.59	76.24	70.65	639.4	715.64	15605.9	16321.54
S ₅	0-20	8.23	72.1	63.87	662.24	734.34	13164.83	13899.17
	20-40	6.2	61.68	55.48	610.23	671.91	13960.85	14632.76

3.5 Fixed Potassium

The fixed potassium in surface soils varied from 673.38 to 857.74 mg kg⁻¹ with a mean value of 762.02 mg kg⁻¹ and in sub-surface soils varied from 583.33 to 769.85 mg kg⁻¹ with a mean value 679.52 mg kg⁻¹ (Table 3). The higher amount of this potassium fraction might be ascribed to presence of higher amounts of potassium bearing minerals. A decrease in the fixed potassium was observed with increasing depth which was also reported by Waheeda and Radhwan [37]. Fixed potassium in surface soils was significantly and positively correlated with pH ($r=0.676^*$), organic carbon ($r=0.749^{**}$), CEC($r=0.519^*$), Silt ($r=0.716^{**}$) and clay ($r=0.683^{**}$) (Table 4). Positive correlation between fixed K and silt fraction is an indication that interlayer positions of minerals retained fixed K. While in sub-surface soils, fixed potassium showed positive and significant correlation with organic carbon ($r=0.771^{**}$), CEC ($r=0.509^*$), silt ($r=0.791^{**}$) and clay ($r=0.820^{**}$) (Table 5). Similar findings were also reported by Pal et al. [5].

3.6 Lattice Potassium

The content of the lattice potassium in surface soils varied from 13164.83 to 14990.89 mg kg⁻¹ with a mean value of 14071.65 mg kg⁻¹ and in sub-surface soils it varied from 13960.85 to 15478.33 mg kg⁻¹ with a mean value of 14826.83 mg kg⁻¹ (Table 3). The large presence of lattice K could be because the soils are rich in K-bearing minerals. Its higher reserve in the sub-surface than surface soil indicates that these soils have been developed from illite-rich parent material and the lower values of percentage of mineral-K in surface layers indicate a relatively high degree of weathering of K-bearing minerals and vice versa. The lattice K is made available to plants by weathering and the amount released depends upon in the soil texture and environmental conditions [38]. These findings are in accordance with the findings of Karwade et al. [39]. The release and fixation of the lattice K is mainly governed by the type of clay minerals, soil reaction, type of cation etc. In surface soils, lattice potassium showed positive relationship with organic carbon ($r=0.781^{**}$), CEC ($r=0.595^*$), silt ($r=0.702^{**}$) and clay ($r=0.696^{**}$) (Table 4), 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 [29]. while it showed negative and significant correlation with calcium carbonate ($r=0.579^*$). In sub-surface soils, it was significantly and positively correlated with EC ($r=0.454^*$), organic carbon ($r=0.832^{**}$), CEC($r=0.483^*$), silt ($r=0.683^{**}$) and clay ($r=0.590^*$). It was negatively and significantly correlated with calcium carbonate ($r=-0.573^*$) and fine sand ($r=-0.486^*$) (Table 5).

3.7 Total Potassium

The content of the total potassium in surface soils varied from 13899.17 and 15848.63 mg kg⁻¹ with a mean value of 14833.68 mg kg⁻¹ and in sub-surface soils it varied from 14632.76 to 16248.18 mg kg⁻¹ with a mean value of 15506.35 mg kg⁻¹ (Table 3). An increase in the total potassium content was observed with increase in the depth of these soils. The content of total potassium depends on the type of parent material, type of primary and secondary minerals and type of soil fraction. Illite, mica and feldspars being the primary potassium bearing minerals may be accredited for higher content of total potassium in the examined soils which are capable of releasing large amount of potassium. The predominance of these minerals in soils of Kashmir has also been reported by Wani *et al.* [40]. The higher values of total K obtained were mainly because of high lattice K concentration. The results are on par with results obtained by Abdul et al. [41]. The total potassium in surface soils was positively and significantly correlated with Organic carbon ($r=0.794^{**}$), CEC ($r=0.593^*$), Silt ($r=0.723^{**}$) and clay ($r=0.719^{**}$) (Table 4), showing that most of the total-K is derived from interlayer of clay structure and increase total-K with finesse of soils [23] and the organic matter also contributes to total-K content of the soils. In sub-surface soils, total potassium was significantly and positively correlated with organic carbon ($r=0.847^{**}$), CEC ($r=0.422^*$), Silt ($r=0.705^{**}$), clay ($r=0.615^*$) and EC ($r=0.428^*$) and significantly and negatively correlated with calcium carbonate ($r=-0.474^*$) and fine sand ($r=-0.486^*$) (Table 5). This is because of the presence of sand fraction which does not retain K. These relationships further suggest that silt fraction would supply K when soil solution and exchangeable K are depleted, and that clays are very much depleted of potassium.

Table 4. Correlation coefficient among different forms of potassium and physico-chemical characteristics of surface soils (0-20 cm)

Physico-chemical properties	pH	EC (dSm ⁻¹)	OC (%)	CaCo ₃ (%)	CEC	Coarse Sand	Fine sand	Silt	Clay
Forms of potassium									
Water soluble K	0.361	0.257	0.562*	-0.270	0.530*	-0.378	-0.550*	0.749**	0.740**
Available K	0.307	0.304	0.852**	-0.634*	0.575*	-0.246	-0.632*	0.640*	0.653**
Exchangeable K	0.313	0.315	0.856**	-0.563*	0.521*	-0.335	-0.594*	0.603*	0.618*
Non-exchangeable K	0.380	0.452	0.742**	-0.462	0.579*	-0.207	-0.347	0.782**	0.811**
Fixed K	0.320	0.473	0.771**	-0.498	0.509*	-0.232	-0.458*	0.791**	0.820**
Lattice K	0.486	0.436	0.781**	-0.579*	0.595*	-0.392	-0.310	0.702**	0.696**
Total K	0.471	0.429	0.794**	-0.582*	0.593*	-0.210	-0.427	0.723**	0.719**

*Significant at 0.05 level; **Significant at 0.01 level

Table 5. Correlation coefficient among different forms of potassium and physico-chemical characteristics of sub-surface soils (20-40)

Physico-Chemical Properties	pH	EC (dSm ⁻¹)	OC (%)	CaCo ₃ (%)	CEC	Coarse Sand	Fine sand	Silt	Clay
Forms of potassium									
Water soluble K	0.597*	0.241	0.535*	-0.477*	0.682**	-0.442*	-0.397	0.696**	0.673**
Available K	0.467*	0.291	0.818**	-0.322	0.445*	-0.336	-0.398	0.599*	0.497*
Exchangeable K	0.483*	0.308	0.797**	-0.443*	0.538*	-0.222	-0.248	0.543*	0.438*
Non-exchangeable K	0.435*	0.313	0.712**	-0.452*	0.517*	-0.392	-0.309	0.698**	0.672**
Fixed K	0.676*	0.327	0.749**	-0.494*	0.519*	-0.232	-0.336	0.716**	0.683**
Lattice K	0.419	0.454*	0.832**	-0.573*	0.483*	-0.205	-0.468*	0.683**	0.590*
Total K	0.397	0.428*	0.847**	-0.474*	0.422*	-0.219	-0.486*	0.705**	0.615*

*Significant at 0.05 level; **Significant at 0.01 level

4. CONCLUSION

The contribution of different K fractions at surface and sub-surface soil depth was in order of lattice K > non-exchangeable K > available K > exchangeable K > water-soluble K. However, the non-exchangeable K pool in the soil can serve as K reserves, which can slowly release available K to satisfy crops requirements when the soluble and exchangeable K pools becomes depleted. The positive correlation with clay showed that some of K⁺ adsorbed are on the edge of inner side of lattice, which could be replaced by exchangeable sites. Silt principally holds fixed K, which is a primary supplier of K to plants in these soils. Clay is a non-significant partner of retaining fixed K. Further significant positive correlation was observed among the different forms of K indicating the existence of equilibrium among the comparatively easily available forms. A future study on parent material and its make-up of the soils may help calibrating the reserve pool of K and the extent of its mining in soils. This may help the planners to formulate an effective potassium fertilizer program in general for a soil, particularly based on soil type.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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