



Mapping K dynamics in apple orchards' soils of Northern Punjab, Pakistan

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Abstract

Apple is highly sensitive to K deficiency and occurrence of K deficiency in the arid and semi-arid tracts was expected therefore a survey was carried out for examining and mapping of K dynamics in the soils of apple producing region of Murree. Eleven apple orchards were selected randomly and samples were collected from five different sites per orchard. One hundred and ten soil samples were collected from the surface (0-15 cm) and sub-surface (15-30 cm) soils. In the surface soils Ks (Soluble K) constituted 0.064 to 0.41 percent of the total K. Sub-surface soil contained Ks that was 0.03 to 0.24 percent of the total K indicating a gradual decrease in plant available K content with the increasing depth. Exchangeable potassium (Ke) constituted about 0.17 to 0.68 and 0.11 to 0.38 percent of total K in the surface and sub-surface soils. Non exchangeable K (Kne) ranged from 0.13 to 0.54 percent with the mean value of 0.29 ± 0.13 constituting about 13.35 to 47.27 percent of total K in the surface soils whereas 31 to 41 percent in the subsurface soils. Surface and subsurface soil contained 14.25 to 75.02 percent of total potassium (Kt) in the form of mineral potassium (Km).

Keywords: Potassium, fractions, mapping, apple orchards

Introduction

Potassium exists in four forms in the soils. Soluble (Ks) which is dissolved in the soil solution, Ke, exchangeable K retained electrostatically by negatively charged soil colloids (clays, organic matter, sesquioxides). Kne, non-exchangeable K trapped between interlayers of clay minerals (illites, vermiculites) and Mineral K (Km) found in primary minerals of micas and feldspars (Yawsan *et al.*, 2011). These distinctive quantifiable reserve forms of K can be fractionated using conventional diagnostic techniques according to their chemical extractability. However, these different forms of soil K are inter-convertible through a chain of reactions. Transformations among these four forms of potassium in soil are called potassium dynamics (Havlin *et al.*, 2004). The bioavailability order of these four forms is solution > exchangeable > non exchangeable > mineral K (Sparks, 2000).

Variety of rocks occurring in the surveyed area can be mainly classified in to five major parent rock groups and these included brick red and grayish green sandstone, calcareous purple shale marls, non calcareous grey shale and limestone. Soils developed from these parent materials are generally calcareous, moderately to strongly alkaline except the soils developed from the grey shale which are slightly acidic (GOP, 1979). Generally in mineral soil, K

contents range from 0.4 to 30 g kg⁻¹ (Sparks, 1987). Approximately 98% of total K is bound in the mineral form and only about 2% is in the soil solution and exchangeable phases (Sparks, 2000). The K content in a soil is a reflection of its parent material, degree of weathering, and amount of K fertilizer added minus losses due to crop removal, erosion and leaching. The average K content in igneous rocks (including metamorphic), shale, sand stone and limestone rocks in the lithosphere is in the order of 26, 27, 11 and 2.7 g kg⁻¹, respectively, (Bertsch and Thomas, 1985).

Potassium requirement of apple trees is similar to the total N requirement (Siddique *et al.*, 2009). It is the second most important macronutrient present in the leaf. Potassium deficiency reduces the yield, size and color of the fruit (Nielsen *et al.*, 2000). Potassium deficiency in fruit trees lead to lower rates of photosynthesis, reduced carbohydrate content, and increased drought susceptibility and fruit drop. Potassium deficiency in the foliage of apple trees is a common phenomenon in various parts of the Pakistan like Quetta and Swat (Khattak and Hussain, 2007).

Farmers mainly depend on apple orchards for their subsistence in the Murree region. Soils of this region are generally calcareous (Ahmed *et al.*, 2010) in nature and low in labile potassium. Strong focus on N and P has led to no or little use of K in Pakistan. Regular mining of plant

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available K and lack or scanty use of potassium fertilizers have led to plant available K deficiency in the soils of apple orchards. Keeping in view the occurrence of K deficiency in the soils and foliage of apple orchards in the Murree region, this research work was conducted to quantify various pools of K in the soils.

Materials and Methods

Soil sampling and processing

A field survey was conducted to quantify various fractions of K in the soils of apple orchards of Murree region located at 33.90° latitude and 73.39° longitudes (Figure 1). Surveyed area is comprised of hilly tracts and has suitable climatic conditions for apple production. Eleven apple orchards were randomly selected from different location to represent the whole apple producing area of Murree. A high precision Global Positioning System (GPS) was used as a site identification tool and recorded coordinates were downloaded to Arc View GIS software to prepare the digital maps indicating various K fractions in the soils. Soil samples were taken from surface (0-15 cm) and subsurface (15-30 cm) from five different sites in each orchard to get a composite sample. These collected samples were air dried, ground and passed through 2 mm sieve for analysis purpose.

Soil analyses

The soils were analyzed for texture (Gee and Bauder, 1982), pH (Gupta, 2006), CaCO_3 contents (Leopert *et al.*, 1984), electrical conductivity (McLean, 1982), organic matter (Nelson and Sommers, 1982), cation exchange capacity (Rhoades and Polemio, 1977). Forms of K determined in the soils included Soluble K (Richards, 1954), exchangeable K (Richards, 1954), non exchangeable K (Kundsen *et al.*, 1982), mineral K (Rubio and Stores, 1997) and total K (Hernandez *et al.*, 1988).

Results and Discussion

Soil physico-chemical properties are summarized in Table 1. Sandy clay loam texture prevailed in the Union Councils Derya Gali, Phugwari and Ghel. Soils of Charhan, Murree and Ghora Gali, were clay loam, whereas the soils of orchard located in the Union Councils Alyot and Rawat were clayey in texture. The soils of apple orchards located at the sites of Sehr Bagla, Tret and Punjab Fruit Research Station (PFRS) were found to be loamy. Soil pH ranged from 7.3 to 8.3 with the mean value of 7.90 ± 0.35 . Soils of all apple orchards had ECEC less than 4 dS m^{-1} with the mean value of 0.41 ± 0.52 . In the surface soils CaCO_3 ranged from 0-24% with the mean value of 10.56 ± 7.53 and in the sub surface soil CaCO_3 ranged from 0-25% with the mean value of 11.03 ± 7.69 . Soil of the apple orchard located in

the Union Council Ghora Gali was found non calcareous. Soils of Union Councils Murree, Punjab Fruit Research Station (PFR), Sehr Bagla, Rawat and Phugwari were found moderately calcareous. Apple orchards located in the Union Councils Derya Gali, Charhan, Ghel, Alyot and Tret were found strongly calcareous in nature (Table 1) when compared with the critical values established by Amin and Ikram (2007).

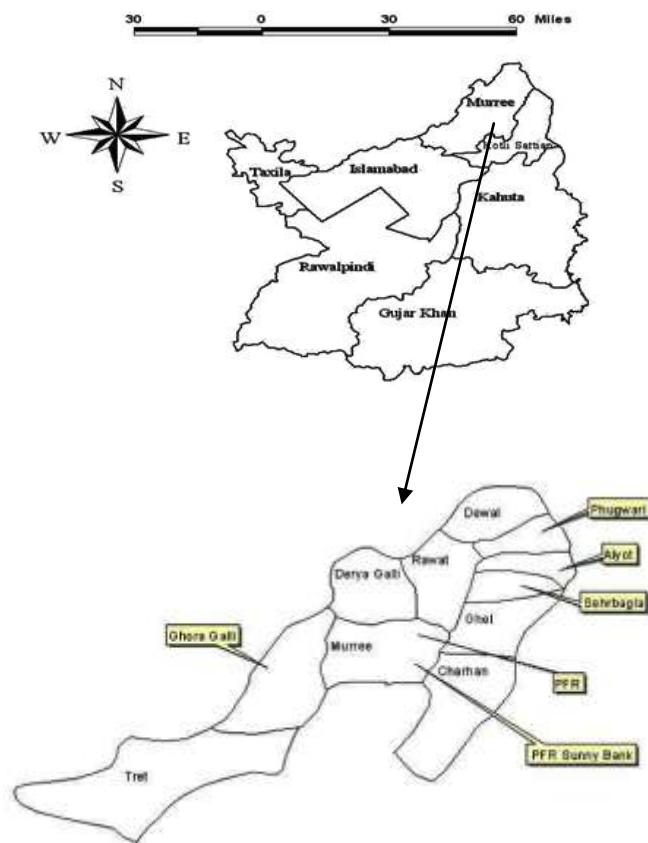


Figure 1: Geo-graphical location of the surveyed area

In surface soils, the cation exchange capacity ranged from 19 to $41 \text{ cmol}^+ \text{ kg}^{-1}$ with the mean value of 34 ± 5.92 and in the sub surface soil it ranged from 20 to $42 \text{ cmol}^+ \text{ kg}^{-1}$ with the mean value of 33 ± 6.16 . The apple orchard located in the Union Council Tret had low cation exchange capacity. While the soils of apple orchards grown in Union Council Sehr Bagla, Charhan, Phugwari, Derya Gali, Rawat and Alyot had high cation exchange capacity in the surface soil. The apple orchards located at the sites of Murree and Ghel had low cation exchange capacity in the surface soil as compared to the sub surface soil. Surface and subsurface soils had no difference in the cation exchange capacity in apple orchard of Ghora Gali. Soils of PFR had low cation



exchange capacity in the surface as compared to the subsurface soils.

prevailing in the region. Bretsch and Thomas (1985) suggested that K^+ adsorption is an exothermic process.

Table 1: Physico- chemical properties in the soils of the surveyed apple orchards

Site	Depth cm	pH	CEC $\text{cmol}^+ \text{kg}^{-1}$	Organic matter	Sand	Silt	Clay	CaCO ₃
				%				
Sehrbagla	0-15	7.80	35.6	2.2	42.9	24.8	32.3	1.4
	15-30	7.89	32.2	1.8	44.6	22.6	32.8	2.4
Charhan	0-15	7.60	37.0	1.2	28.8	35.0	36.2	25.0
	15-30	7.84	33.7	0.9	28.6	35.0	36.4	23.6
Phugwari	0-15	8.20	33.3	0.8	41.1	29.3	29.6	13.6
	15-30	8.29	31.4	0.8	40.8	29.6	29.6	14.6
Murree	0-15	7.30	34.0	3.7	24.1	44.0	31.9	13.5
	15-30	7.29	36.2	2.3	22.8	44.6	32.6	15.0
Derya Galli	0-15	7.60	40.4	1.4	51.4	25.0	23.6	18.0
	15-30	7.81	38.9	1.2	53.0	26.0	21.0	18.2
PFR*	0-15	7.80	26.9	4.0	52.5	27.9	19.6	6.0
	15-30	7.90	24.2	4.3	52.2	26.6	21.2	7.2
Rawat	0-15	8.20	38.3	1.8	28.6	29.2	42.2	7.4
	15-30	8.30	36.4	1.5	29.0	29.0	42.0	7.8
Ghel	0-15	7.7	37.7	3.8	31	35.2	33.8	16.7
	15-30	7.66	41.8	2.8	30.6	35.8	33.6	18.8
Ghora Galli	0-15	7.80	39.0	2.9	30.8	36.3	32.9	0.64
	15-30	8.02	39.4	2.2	30.4	36.2	33.4	0.94
Alyot	0-15	8.10	41.2	1.4	26.5	15.8	57.7	18.8
	15-30	8.09	37.1	1.0	27.6	16.4	56	21.4
Tret	0-15	8.30	19.7	1.8	28.5	39.8	31.7	16.4
	15-30	8.37	20.6	0.9	30.8	40.8	28.4	14.8

PFR*=Punjab Fruit Research Station

Soluble potassium

In the soils of surveyed apple orchards, soluble potassium ranged from 4.24 to 31.07 $\mu\text{g g}^{-1}$ with the mean value of 10.10 ± 7.01 in the surface soil while in the sub surface soils it ranged from 10.95 to 53.04 $\mu\text{g g}^{-1}$ with the mean value of 28.15 ± 12.67 . In the surface soils, Ks constituted 0.064 to 0.41 percent of the total K. Sub-surface soil contained 0.03 to 0.24 percent Ks of the total K indicating a gradual decrease in plant available K content with the increasing depth. In the upper arable layer maximum 8.98 $\mu\text{g g}^{-1}$ K content were observed in the soils of apple orchard located in the Punjab Fruit Research Station Lower Topa. Minimum soluble K content (4.8 $\mu\text{g g}^{-1}$) was observed in the soils of apple orchard located at the site of Sehrbagla. Soils of apple orchard located at the sites of Charhan, Phugwari, Murree, Derya Gali, Rawat, Ghel, Ghora Galli, Alyot, Tret contained 6.75, 7.97, 5.96, 7.15, 11.4, 30.9, 11.8, 9.32 and 5.87 $\mu\text{g g}^{-1}$ of Ks, respectively, (Figure 2).

Low soluble K contents were observed in the soils of surveyed area which might be due to cold temperature

Release of K from non-exchangeable forms to exchange phase is dependent on the temperature i.e., the higher the temperature the faster the rate of release.

Exchangeable potassium

Surface soils of surveyed apple orchards contained exchangeable K ranging from 10.95 to 53.04 $\mu\text{g g}^{-1}$ with the mean value of 28.15 ± 12.67 . In the sub-surface soils it ranged from 8.53 to 39.81 $\mu\text{g g}^{-1}$ with the mean value of 18.62 ± 9.16 . Maximum exchangeable K contents were observed in the soils of apple orchard situated in the Union Council Ghel (50.70 $\mu\text{g g}^{-1}$) whereas the minimum exchangeable K content (13.33 $\mu\text{g g}^{-1}$) were observed in the soils of apple orchard located at the site of Murree. Apple cultivated soils at the sites of Sherbagla, Charhan, Phugwari, Derya Galli, Rawat, Ghora Galli, Alyot and Tret contained 39.73, 18.49, 40.64, 36.25, 20.64, 23.56, 15.92, 13.6 $\mu\text{g g}^{-1}$ exchangeable K in upper arable layer, respectively.

Exchangeable K content in the surface soils of apple orchards located at Sehrbagla, Charhan, Phugwari, Murree, Derya Galli, Rawat, Ghel, Ghora Galli, Alyot, Tret and PFR



were 13, 12.16, 27.54, 9.89, 23.85, 15.49, 35.84, 14.20, 11.93, 9.97 and 30.89 $\mu\text{g g}^{-1}$, respectively. Total K was found to be composed of 0.17 to 0.68 percent of the Ke in the surface soils and 0.11 to 0.38 percent of Ke in the sub-surface soils (Figure 3). Annual temperature of the surveyed region ranges from 0 to 15 °C. Temperature is usually below 0 °C during the months of January and February. It approaches to 4 °C during the month of March and with the slight increase it reaches to 15 °C in the month of June and July and again starts falling in the next months. Low annual temperature in the region hinders the release of K from non-exchangeable forms to the exchange phase as adsorption of K is an exothermic process causing low soluble and exchangeable K content in the soils of Murree. Bretsch and Thomas (1985) also suggested a decreased exchangeable K content in the soils due to low temperature. Apple orchards of the surveyed area require a continuous application of K fertilizer for getting optimum yield and quality.

percent non exchangeable K content, respectively. Non exchangeable K content had an increasing trend with increasing depth. Sub-surface soils contained 0.26, 0.34, 0.63, 0.51, 0.32, 0.25 and 0.37 percent non exchangeable K content. The high level of non exchangeable potassium in the sub surface soils might be due to the leaching of potassium from the surface soil and higher accumulation of that depleted potassium in the sub soil (Figure 4).

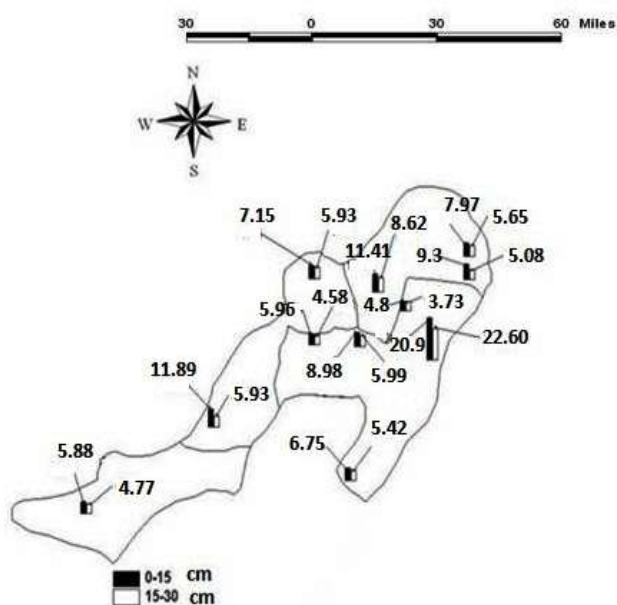


Figure 2: Site Specific Ks ($\mu\text{g g}^{-1}$) content in the soils
Non exchangeable potassium

Maximum non exchangeable K contents were observed in the soils of the apple orchards located at the site of Derya Galli that contained 0.52 and 0.65 percent in the surface and sub-surface soils, respectively. Minimum Kne content were observed in the surface (0.16%) and sub-surface (0.20%) soils of apple orchard located at the site of Tret. Surface soils of apple orchards located at the sites of Phugwari, Alyot, Sehrbagla, Charhan, Murree, Ghora Galli and Rawat contained 0.18, 0.27, 0.49, 0.42, 0.19, 0.15, 0.21 and 0.27

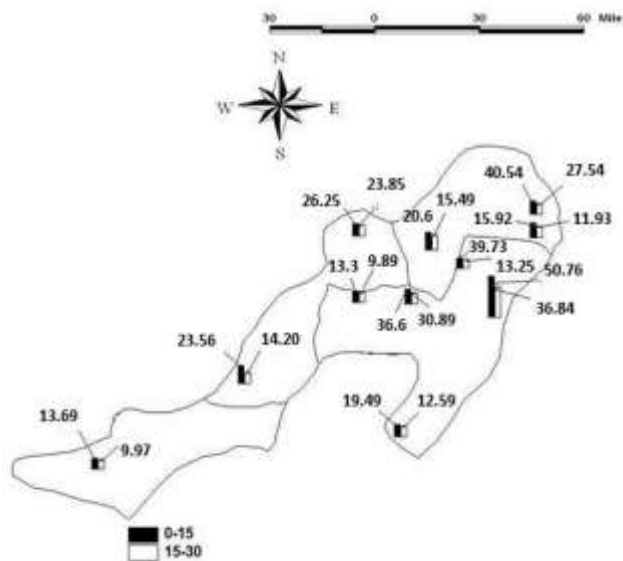


Figure 3: Site Specific distribution of Ke ($\mu\text{g g}^{-1}$) in the soils

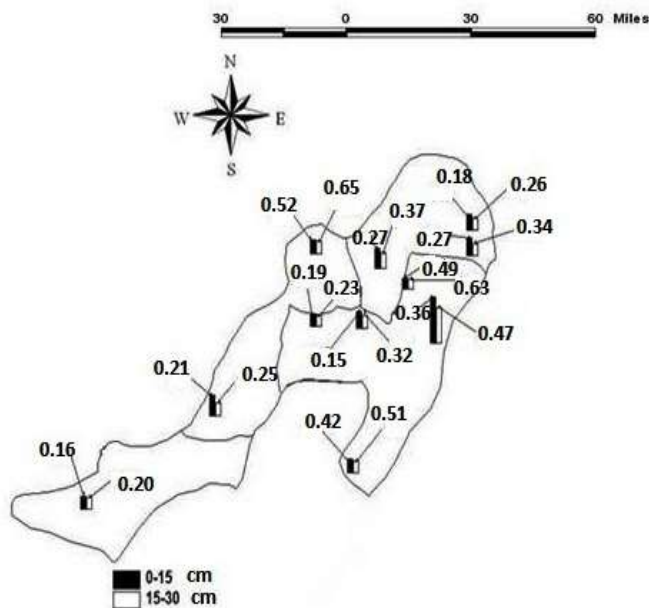


Figure 4: Site specific distribution of Kne (%) in the soils



Mineral potassium

Mineral potassium ranged from 0.15 to 0.87 percent with the mean value of 0.45 ± 0.19 in the surface soil where as in the subsurface soil it ranged from 0.22 to 0.71 percent with the mean value of 0.62 ± 0.18 . In the surface soils, highest mineral potassium contents (0.83%) were observed in the soils of apple orchards located at Derya Gali where as lowest mineral potassium content (0.16%) was found in the soils of apple orchard located at the site of Alyot. Mineral K content in the soils of apple orchards located at Sehrbagla, Charhan, and Phugwari were 0.61, 0.72, and 0.35 percent, respectively. Soils of apple orchards located at the sites of Murree, Rawat, Ghel, Ghora Gali, Tret and PFR contained mineral potassium contents 0.37, 0.31, 0.51, 0.36, 0.36 and 0.38 percent, respectively.

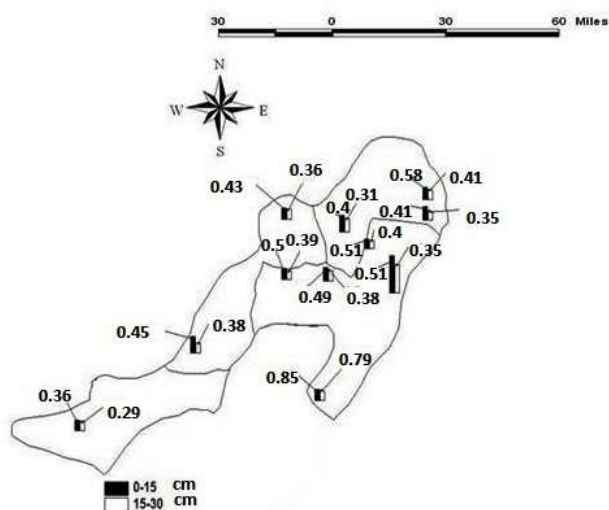


Figure 5: Site specific distribution of Km (%) in soils

Mineral K in the sub-surface soils ranged from 0.23 to 0.99 percent with the mean value of 0.56 ± 0.23 . Highest mineral potassium contents were found in the soils of apple orchards located in Sehrbagla with the mean value of 0.94 percent and low content of mineral potassium contents were observed in the soil of apple orchard located at the site of Tret (0.24%). Apple cultivated soils in the Union Councils of Charhan, Phagwari, Murree, Derya Gali, PFR, Rawat, Ghel, Ghora Gali, and Alyot contained 0.85, 0.41, 0.47, 0.86, 0.49, 0.41, 0.66, 0.40, and 0.43 percent of mineral K content, respectively (Figure 5).

Total potassium

Total potassium contents in the surface soils of surveyed apple orchards ranged from 0.14 to 0.29 percent with the mean value of 0.75 ± 0.31 . Maximum total potassium contents were observed in the soil of apple

orchards located in Derya Gali (0.14%). Lowest total potassium content (0.14%) was observed in the soils of apple orchard located at the site of Tret. Total K content in the soils of apple orchards located at the sites of Sehrbagla, Charhan, Phugwari, Murree and Derya Gali were observed as 0.11, 0.12 and 0.54, 0.56 and 0.14 percent, respectively. Soils of apple orchards located at the sites of PFR, Rawat, Ghora Gali, and Alyot contained total K contents of 0.53, 0.89, 0.56, 0.62 percent, respectively.

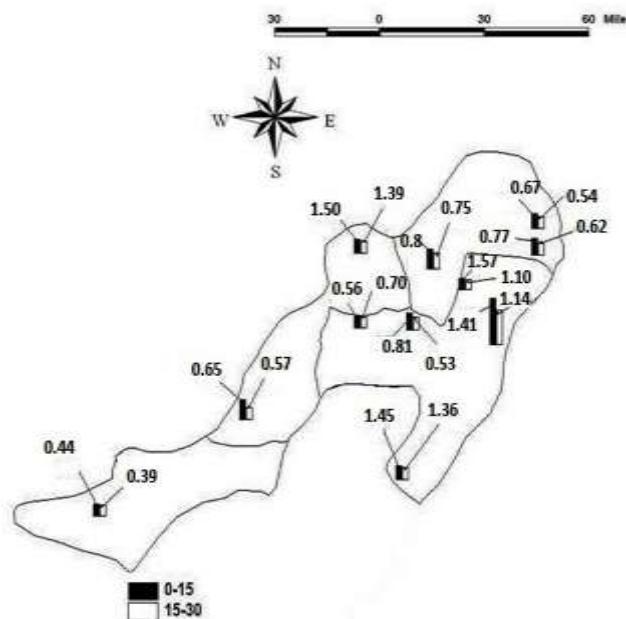


Figure 6: Site specific distribution of Kt (%) content in the surveyed area

Total K content in the sub-surface soils of surveyed area ranged from 0.43 to 0.16 percent with the mean value of 0.95 ± 0.37 . Highest total K contents were observed in the apple orchard located in the Union Council Sehrbagla (0.44%) where as the minimum K contents were observed in the apple orchard located in the Union council Tret (0.31%).

Soils of apple orchards located at the site of Charhan, Phugwari, Murree, Derya Gali, PFR, Rawat, Ghel, Ghora Gali, and Alyot contained 0.14, 0.67, 0.70, 0.15, 0.81, 0.78, 0.11, 0.65 and 0.78% total K content, respectively (Figure 6).

Relationship of various K fractions and physico-chemical properties

Correlation coefficient values among K fractions and selected physico-chemical properties are given in the Table 2. Non significant negative relationship was established between the water soluble K and pH ($r = -0.107$). Negative



relationship between the pH and soluble K indicated low solubility of K with the increased pH because K fixation increases with the increase in pH and fixation becomes highest under alkaline conditions (Martin *et al.*, 1946; Thomas and Hipp, 1968). Low soluble K content in the surveyed area might be due to alkaline to strongly alkaline nature of soils. Negative correlation between the sand and soluble potassium content ($r = 0.156$) might be due to low cation exchange capacity resulting in less retention of nutrients. Significant positive relationship observed among the soluble K, cation exchange capacity ($r = 0.33$; $p < 0.05$),

exchangeable K was positive ($r = 0.354$). Mineral potassium content were negatively correlated with organic matter ($r = -0.12$), silt ($r = -0.26$) whereas positively with cation exchange capacity ($r = 0.39$; $p \leq 0.05$), sand ($r = 0.40$; $p \leq 0.05$) and CaCO_3 content ($r = 0.13$).

It might be due to the prevalence of fixed K in the primary minerals of sand and silt fractions. Total K content were negatively correlated with pH ($r = -0.34$ $P \leq 0.05$), Silt ($r = -0.323$; $p \leq 0.05$) and clay ($r = -0.131$). Positive correlation between the total K and organic matter ($r = -$

Table 2: Correlation coefficient values of K fractions with various Physico-chemical properties of surveyed apple orchard soils

Physico-chemical property	r value				
	Ks	Ke	Kne	Km	Kt
O.M	0.39*	0.34*	-0.20	-0.12	0.16
CEC	0.33*	0.14	0.40	0.39*	0.41*
Sand	-0.15	-0.51*	0.35	0.40*	0.38*
Silt	0.12	-0.18	0.39	-0.26	0.32*
Clay	0.057	0.37*	0.03	0.18	0.13
CaCO_3	-0.12	-0.12	0.13	0.13	0.66*
pH	-0.10	-0.15	0.22	-0.42	-0.34*

OM: Organic matter; CEC: Cation exchange capacity; n=110 *Significant ($p \leq 0.05$)

organic matter ($r = 0.39$; $p < 0.05$) and non significant but positive relationship between silt ($r = 0.12$) and clay ($r = 0.057$) indicated high nutrient holding capacity of soils having high CEC due to clay and organic matter content (Khattak and Hussain, 2007). Non significant positive relationship between the soluble K content and CaCO_3 ($r = 0.122$) indicated the replacement of K on the exchange complex with Ca and enhancing the K availability to plants. Similar results were reported by Nolan and Pritchett (1960).

Exchangeable K also correlated negatively with sand (-0.51 $p \leq 0.05$), pH ($r = -0.158$), CaCO_3 ($r = -0.123$) where as positively correlated with organic matter ($r = 0.343$; $p \leq 0.05$), silt ($r = 0.186$), clay ($r = 0.37$; $p \leq 0.05$) and cation exchange capacity ($r = 0.146$). Results were in line with the finding of (Venkatesh *et al.*, 2004; Thomas and Hipp, 1968).

Organic matter contents were negatively correlated with non exchangeable K ($r = -0.202$). Non exchangeable K is not present on the exchange complex. Organic matter enhances the CEC and hence positively related to soluble and exchangeable K but negatively related to non exchangeable K. Non exchangeable K was positively correlated with pH ($r = 0.224 \leq 0.05$), silt ($r = 0.39 \leq 0.05$) and clay ($r = -0.0397$). A positive relationship between non exchangeable K and CEC ($r = 0.405 \leq 0.05$) was established. Relationship between sand and non

0.152) and CaCO_3 content ($r = 0.165$) was observed.

References

- Ahmad, H., M.T. Siddique, I.A. Hafiz and Ehsan-ul-Haq. 2010. Zn status of apple orchards and its relationship with selected physico-chemical properties in Murree Tehsil. *Soil and Environment* 29: 142-147.
- Amin, R. and M. Ikram. 2007. Keys to soils of Punjab and Sindh. Ministry of Food Agriculture and Livestock, Government of Pakistan. p. 20-25.
- Bertsch, P.M. and G.W. Thomas. 1985. Potassium status of temperate region soils. p. 131-162. *In: Potassium in Agriculture*. R.D. Munson (ed.), American Society of Agronomy, Madison, WI, USA.
- Gee, G.W and J.W. Bauder. 1982. Hydrometer method. p. 383-411. *In: Methods of Soil Analysis, Part I*. A. Klute and A.L. Page (eds). American Society of Agronomy. Madison, WI, USA.
- Government of Pakistan (GOP). 1979. Reconnaissance Soil Survey Murree - Kahuta Area. Directorate of Soil Survey, Reconnaissance, Lahore. Govt. of Pakistan, Lahore.
- Gupta, P.K. 2006. Soil, Plant, Water and Fertilizer Analysis. Agrobios, India. 84p.
- Hernández, J., O.N. Casanova and J.P. Zamalvide. 1988. Capacidad de suministro de potasio en suelos del Uruguay. *Boletín de Investigación* No. 19. Facultad de Agronomía. Montevideo, Uruguay. 20p.



- Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson. 2004. Soil Fertility and Fertilizers. 6th Ed. Pearson Education, Patparganj, Delhi, India.
- Khattak, R.A. and Z. Hussain. 2007. Evaluation of soil fertility status and nutrition of orchards. *Soil and Environment* 26(1): 22-32.
- Kundsen, D., G.A. Peterson and P.F. Pratt. 1982. Lithium, Sodium, Potassium. p. 225-246. *In: Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties*. A.L. Page, R.H. Miller and D.R. Keeney (eds.). American Society of Agronomy, Madison, WI, USA.
- Leoppert, R.H., C.T. Hallmark and M.M. Koshy. 1984. Routine procedure for rapid determination of soil carbonates. *Soil Science Society of America Journal* 48: 1030-1033.
- McLean, E.O. 1982. Soil pH and lime requirement. p. 198-209. *In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*. A.L. Page, R.H. Miller and D.R. Keeney (eds.). American Society of Agronomy, Madison, WI, USA.
- Neilsen, G.H., P. Parchomchuk, D. Neilsen and B.J. Zebarth. 2000. Drip fertigation of apple trees affects root distribution and the development of K deficiency. *Canadian Journal of Soil Science* 80: 353-361.
- Neilsen, G.H., P. Parchomchuk, M. Meheriuk and D. Neilsen. 1998. Development and correction of K-deficiency in drip irrigated apple. *Horticultural Science* 33: 258-261.
- Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. p. 539-579. *In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties*. A.L. Page, R.H. Miller and D.R. Keeney (eds.). American Society of Agronomy Madison, WI, USA.
- Nolan, C.N. and W.L. Pritchett. 1960. Certain factors affecting the leaching of potassium from sandy soils. *Proceedings of Soil and Crop Science Society of Florida* 20: 139-145.
- Rhoades, J.D. and M. Polemio. 1977. Determining cation exchange: A new procedure for calcareous and gypsiferous soils. *Soil Science Society of America Journal* 41: 524-300.
- Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Agric., Handbook 60. Washington, D.C. USA. 160p.
- Rubio, B. and F.G. Sotres. 1997. Distribution of four major forms of potassium in soils of Galicia (N.W. Spain). *Communication in Soil Science and Plant Analysis* 28: 1805-1816.
- Siddique, M., M.T. Siddique., S. Ali and A.S. Javed. 2009. Macronutrient assessment in apple growing region of Punjab. *Soil and Environment* 28: 184-192.
- Sparks, D.L. 1987. Potassium dynamics in soils. *Advances in Soil Science* 6: 1-63.
- Sparks, D.L. 2000. Bioavailability of soil potassium. p. 38-52. *In: Handbook of Soil Science*. M.E. Sumner (ed.). CRC. Press, Boca Raton, Florida, USA.
- Thomas, G.W. and B.W. Hipp. 1968. Soil factors affecting potassium availability. p. 269-291. *In: The Role of Potassium in Agriculture*. V.J. Kilmer, S.E. Younts and N.C. Brady (eds.). American Society of Agronomy, Madison, WI, USA.
- Venkatesh, M.S., T. Satyanarayana, N.S. Hebsur and Basavaraj. 2004. Potassium fixation capacity in vertisols of North Karnataka. *Journal of Agricultural Sciences* 17: 577-579.
- Yawson, D.O., P.K. Kwakye, F.A. Armah and K.A. Frimpong. 2011. The dynamics of potassium (K) in representative soil series of Ghana. *ARP Journal of Agricultural and Biological Science* 1: 48-55.

