RELATIONSHIP AMONG DIFFERENT FORMS OF SOIL POTASSIUM AND AVAILABILITY AS INFLUENCED BY THE CONTRASTING MANAGEMENT PRACTICES IN APPLE (MALUS DOMESTICA BORKH.) ORCHARDS OF KUMA....

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RELATIONSHIP AMONG DIFFERENT FORMS OF SOIL POTASSIUM AND AVAILABILITY AS INFLUENCED BY THE CONTRASTING MANAGEMENT PRACTICES IN APPLE (*MALUS DOMESTICA* BORKH.) ORCHARDS OF *KUMAON* REGION

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ABSTRACT

The distribution of K forms (water soluble, exchangeable, non-exchangeable, mineral and total K) in two apple (*cv.* Royal Delicious) orchards differing in fertilizer management practices located in the *Kumaon* region of Uttarakhand was investigated. The apple orchard at Mukteshwar is managed by the conventional fertilizer management practice, and the other at Dutkanedhar is managed organically. At Mukteshwar, the distribution of water soluble, exchangeable, non-exchangeable, mineral and total K was 0.23, 0.86, 5.46, 78.2, and 86.7 cmol kg^{-1}, respectively. Further, soil analysis revealed that both the soils contain very high levels of available K (>350 mg kg^{-1}). Leaf K content in orchard of Dutkanedhar was deficient (0.81%) with the appearance of K deficiency symptoms as necrotic leaf edges; whereas, the same at Mukteshwar was recorded as sufficient (1.93%). The positive and significant correlations were observed between available and water soluble (r= 0.78), available and exchangeable (r= 0.45), exchangeable and non-exchangeable (r= 0.33), non-exchangeable and mineral (r= 0.77) and mineral and total K (r= 0.95) in the orchard of Mukteshwar. It was concluded that K requirement in apple could not be satisfied entirely through addition of organic manures only, and thus, K fertilization is indispensable.

INTRODUCTION

Potassium (K) is the most abundant inorganic cation in plants and apart from its vital functions in metabolism; it also imparts tolerance to both biotic and abiotic stresses. It is a key element for plant growth and absorbed in quantities comparable to nitrogen. While K does not become a part of the chemical structure of plants, it promotes photosynthesis, controls stomatal opening, improves N utilization and facilitates assimilate transport to increase crop yields (Wang *et al.*, 2013). Therefore, adequate supply of K is essential for sustaining growth and yield of crops, especially in intensive cropping systems.

More than 98% of the total K reserve in soils and exist in different inorganic combinations that can be categorized as: water soluble, exchangeable, non-exchangeable or fixed and mineral K (Kundu *et al.*, 2014; Saini and Grewal, 2014). Water soluble and exchangeable forms of K constitute readily plant available K in soils whereas; fixed and non-exchangeable forms of K constitute slowly plant available K, and plants can use only very little of it during a single growing season (Sparks, 1987). The different forms of soil K are in dynamic equilibrium and any depletion in a given K form is likely to shift equilibrium in the direction to replenish it. Uptake of K from soil solution is buffered by readily exchangeable forms which, in turn is replinished by soil K reserves (Simard *et al.*, 1992). The ease with which K is released from non-exchangeable and mineral reserves is an index of the ability of soil to supply K to the plants not receiving any potassium fertilizer (Sharma *et al.*, 2010). Nonetheless, in many cases this release is not sufficient enough to meet the plants requirement and subsequently, plants can suffer from K insufficiency, in the absence of K fertilization (Bhaskarachary, 2011). With the intensification of agricultural production and low application of K fertilizers, the exchangeable K may become depleted and non-exchangeable K can be an important resource for providing K for plants (Ghiri *et al.*, 2010). Officer *et al.* (2006) observed a very significant relationship between plant available and non-exchangeable K. Sharpley (1989) stated that determining both exchangeable and non-exchangeable K could give a better indication of soil's potential K-supplying power. Thus, improving knowledge about different forms of soil K and their interrelationships is considered to be important aspect for a better understanding of the productivity and sustainability of agricultural ecosystems.

Apple (*Malus domestica* Borkh.) is considered as one of the major temperate fruit crops grown in the *Kumaon* region of Uttarakhand. Apple production in this area has been generating a considerable remuneration to the orchardists. This crop is grown in soils developed in quaternary deposits that are in general micaceous in nature with considerable amounts of illite, vermiculite, smectite, chlorite, and mixed layer minerals (Patiram, 2001; Mukhopadhyay, 2009; Sharma *et al*., 2010). But to have merely presence of the reserves in soils does not imply that K from these reserves will easily be available to the plants. Consequently, temperate fruit crops of this region often suffer from K insufficiency leading to overall decline in fruit yield and quality parameters by impairing the synthesis of plant growth regulators and enzymes (Kaur *et al*., 2016). The major soil limitations of this region are highly porous, low water and nutrient retention capacity, deep percolation, moderate to severe erosion, and terrace cultivation on steep slopes (Anonymous, 2010). Thus, leaching of K and surface erosion could perhaps be the major reasons contributing to low K availability to this crop.

Further, the government of Uttarakhand has declared the state as an 'Organic State', an innovative approach to rejuvenate hill agriculture in the state, which urges the farming communities to grow crops organically. This declaration has made the orchardists less reluctant to use chemical fertilizers as a source of nutrients. Addition of organic manures often results in suboptimal replenishment of soil nutrients as compared to the crop demand, particularly at active growth stages. In recent years, studies on forms of K, their distribution and relationships among them have engaged the attention of many researchers in this country. However, most of these studies are confined to agricultural cropping systems, but very few studies have been made to generate information on these parameters in temperate fruit crops like apple. In this light, this study was aimed to decipher interdependency within and between K forms and release in soil, and to assess leaf nutrient status of major elements.

MATERIALS AND METHODS

Study site, climate and soil

Field observations were undertaken at ICAR-Central Institute of Temperate Horticulture (CITH), Regional Station-Mukteshwar, Uttarakhand (latitude: 29°28' N, longitude: 79°39' E; altitude: 2280 m above mean sea level) and a orchard located at Dutkanedhar, Uttarakhand (latitude: 29°26' N, longitude: 79°35' E; altitude: 2150 m above mean sea level). These sites are located on a ridge at the southern edge of the *Kumaon* hills of the north-western Himalayan range. This area is a temperate region, having hot and dry summer between April to June, and cold and chilly conditions from November to February, with an average annual rainfall ranges from 1300-1600 mm, three-fourth of which is received during July-September and the remaining one-fourth between October-June. Frequent snowfall occurs between December to February resulting in drop of minimum air temperature to subzero temperature. Annual maximum and minimum air temperature usually ranges between 25 to - 3°C, respectively. The soils of the study sites are classified as *Typic Hapludolls* (USDA Classification) which is sandy loam to loamy sand in texture, rich in mica, gravelly, deep and well drained with moderate permeability in the upper layer and rapid in the lower part. The soils are formed in a loamy mantle and sandy or gravelly sediments.

Orchard management practices

Temperate fruit crops in *Kumaon* region are generally grown under rainfed and terrace cultivation with land slope greater than 30%. The orchard at ICAR-CITH, Mukteshwar was planted with apple (*cv.* Royal Delicious) and the age of the trees varies between 14 to 16 years. The apple was planted as single row within the terrace (100 × 5 m) with spacing of 3.0 m (intra–plant). The fertilizer doses applied to apple are 700 g N tree^{-1}, 350 g P_2O_5 tree^{-1} and 700 g K_2O tree^{-1}. The apple trees are pruned after leaf–fall according to standard procedure, during second fortnight of December to maintain appropriate canopy size. Farmyard manure (FYM) at 45–50 kg tree^{-1} along with full dose of P_2O_5 and K_2O is added in the basin of the fruit crop, immediately after pruning. Nitrogen is applied in two equal split doses. Half dose of N is incorporated in the tree basin just 3 weeks before bud break (mid February) and, rest is applied 2–3 weeks after first dose. This package of practices *i.e.*, dose of fertilizers and manures, and their schedule of application is considered as 'recommended nutrient management practice' for apple in this region (Anonymous, 2012). Plant protection measures are adopted as per the scheduled practices, as and when required. Manual weeding is practiced throughout the year to keep the orchard weed-free.

The farmer's orchard at Dutkanedhar was also planted with same variety of apple, with an average age of the trees ranging from 13 to 15 years. The intra-plant spacing was 5.0 m and the orchard was planted as single row within the terrace (100 × 4 m). This orchard is managed organically and farmyard manure (10–15 kg tree^{-1}) is incorporated in the basin of the fruit tree during the last week of December. Therefore, excluding chemical fertilization, it is evident that the quantities of organic manure added to the apple trees are far below compared to the recommended dose of organic manure. Other management practices such as pruning and plant protection measures are followed as described in the preceding section.

Soil and leaf analysis

Soil and leaf sampling from these orchards was carried out in second fortnight of June 2014 and 2015. Soil samples were collected randomly from different terraces (n = 4) just below the plant canopy as described by Debnath *et al*. (2015a) up to a depth of 30 cm. The greater depth was sampled in the view of deep rooted nature of apple trees. At sampling, apple was at fruit development stage (70% of final size), which is considered as an active phase of growth and nutrient requirement by the crop remains high. During sampling, a trench of 30 × 40 × 30 cm (width × length × depth) was dug, from which soil samples were collected with a spatula from four sides of the trench. Sub-samples were bulked to make a composite sample (approximately 500 g). Soil samples were air dried and sieved through 2 mm and stored for further analytical purposes. The soil was analyzed for pH (1:2 w/v; Jackson, 1973), electrical conductivity (1:2 w/v; Jackson, 1973), organic carbon (Walkley and Black, 1934), cation exchange capacity through NaOAc method (Jackson, 1973), available N (Subbiah and Asija, 1956), and available P (Olsen *et al*., 1954). The available K was extracted with NH_4OAc, pH 7.0 (Schollenberger and Simon, 1945) and water soluble K was determined in the soil extracted with water (1:5 w/v) shaken for 5 min. Exchangeable K was calculated by subtracting water soluble K from available K. Non-exchangeable K was measured by extraction of soil sample with boiling 1.0 M HNO_3 with a soil: HNO_3 ratio of 1:10 (Knudsen *et al*., 1982). Total K was determined following digestion of soil with 48% HF and 6 M HCl (Knudsen *et al*., 1982). Mineral K was calculated as the difference between total and HNO_3-extractable K. All forms of K in the extract were determined by using a flame photometer (Flame Photometer 128, Systronics India Ltd., Ahmadabad).

At the time of soil sampling, leaf samples from the middle of terminal shoot (bearing braches) were collected. The leaves were washed thoroughly with phosphate-free liquid detergent (HiSpark, Himedia Laboratories Pvt. Ltd., Mumbai) to remove waxes followed by rinsing with 0.1 N HCl to remove possible contaminants, and rinsed with double distilled water to remove acid, and dried at 70°C to constant weight. The nitrogen content in leaves was determined by a micro-Kjeldahl method (Bhargava and Raghupathi, 2009). Further, they were analyzed for phosphorus and potassium contents by digestion with HNO_3:$HClO_4$ (4:1 v/v) mixture, and subsequent determination by vanadomolybdophosphoric acid and flame photometric method, respectively (Bhargava and Raghupathi, 2009).

Statistical analysis

Duncan's multiple range test (DMRT) and LSD at $p \leq 0.05$ for comparison of significant differences between means have been performed using SPSS 16.0 (SPSS Inc., Chicago, USA) windows version package. The relationships between different forms of K were analyzed by linear regression analysis. Multivariate correlation matrix (Pearson) was also worked out between soil chemical properties and forms of K to show their degree of associations.

RESULTS AND DISCUSSION

Physico-chemical properties of the soils

Selected physico-chemical properties determined in the orchard soils are summarized in Table 1. The soil analysis indicates that the soils of the studied orchards are slightly acidic. Organic C content of the orchards ranged from 14.5 g kg^{-1} at Mukteshwar to 11.7 g kg^{-1} at Dutkanedhar. Apart from regular addition of organic manures, the litter-fall and its incorporation are common due to deciduous nature of apple that adds residues and substrates leading to enhancement in organic matter content (Debnath *et al*., 2015a) in these soils over years of cultivation. High rainfall and prevailing low temperatures throughout the year could also be responsible for accumulation of organic matter to such extent in these soils. Cation exchange capacity (CEC) of the soils was 20.4 and 16.9 cmol kg^{-1} at Mukteshwar and Dutkanedhar, respectively. The higher value of CEC at Mukteshwar over Dutkanedhar could be attributed to relatively high clay content in the former. Therefore, nutrient retention capacity of soil at Mukteshwar is presumed to be higher than at Dutkanedhar. The available N, P, and K level in soil was also higher at Mukteshwar over Dutkanedhar. The reasons are being attributed to the proper nutrient management in the apple orchard at Mukteshwar. It was interesting to observe that available K content in both of the sites comes under same fertility category, *i.e.*, very high level. This high level of available K can cause mineral imbalance of other cations like Ca and Mg in soil (Debnath *et al*., 2015b), and can render their

Table 1: Soil physico-chemical properties of the two studied apple orchards

S.No.	Soil property	Mukteshwar	Dutkanedhar	Method employed	Reference
1	Mechanical-analysis			Hydrometer	Bouyoucos (1962)
	Sand (%)	70	80		
	Silt (%)	16	11		
	Clay (%)	14	9		
	Textural class	Sandy loam	Loamy sand		
2	pH	6.01	6.15	1:2 (w/v) soil to water	Jackson (1973)
3	Electrical conductivity (dS m^{-1})	0.12	0.24	Conductivity bridge	Jackson (1973)
4	Organic C (g kg^{-1})	14.5	11.7	Chromic acid oxidation	Walkley and Black (1934)
5	Organic matter* (g kg^{-1})	25	20.2	-	-
6	Cation exchange capacity (cmol kg^{-1})	20.4	16.9	1 N CH_3COONa, pH 8.2	Jackson (1973)
7	Available N (mg kg^{-1})	112.1	74.5	Alkaline permanganate	Subbiah and Asija (1956)
8	Available K (mg kg^{-1})	414.6	384.6	1 N CH_3COONH_4, pH 7.0	Schollenberger and Simon (1945)
9	Available P (mg kg^{-1})	7.3	4.9	0.5 M $NaHCO_3$, pH 8.5	Olsen *et al*. (1954)

*Organic C (OC) data were converted to organic matter (OM) using the conventional conversion OM = OC × 1.724

Table 2: Different fractions of soil potassium (cmol kg^{-1}) observed at the two apple orchards

	Available K				
Location	Water soluble K	Exchangeable K	Non-exchangeable K	Mineral K	Total K
Mukteshwar	0.23^{a}	0.86^{a}	5.46^{a}	78.2^{a}	86.7^{a}
Dutkanedhar	0.05^{b}	0.76^{a}	3.14^{b}	71.2^{b}	80.3^{a}

Values followed by different alphabets as superscript differ significantly at $p \leq 0.05$ based on Duncan's multiple range test

Table 3: Pearson's correlation coefficient (r values) of variables related to different soil properties at apple orchard of Mukteshwar

	A	B	C	D	E	F	G	H	I	J	K
A	1.00										
B	0.98*	1.00									
C	0.56	0.85**	1.00								
D	0.83**	0.97**	0.50*	1.00							
E	0.63	0.29	–0.29	0.93*	1.00						
F	0.37	0.45*	0.92**	0.50*	0.42*	1.00					
G	–0.43	0.37*	0.27	0.46	0.78*	0.41*	1.00				
H	0.65	0.78**	0.27	–0.12	0.45**	0.44**	0.76*	1.00			
I	–0.78	0.68	0.01	–0.20	0.93*	0.36**	0.87**	0.33**	1.00		
J	0.91	0.25	–0.27	–0.51	0.78	0.02	0.38*	0.85*	0.77*	1.00	
K	–0.84	0.07	–0.36	0.27	0.60*	0.01	0.08**	0.96	0.65*	0.95**	1.00

A- pH; *B*- organic carbon; *C*- available N; *D*- available P; *E*- available K; *F*- cation exchange capacity; *G*- water soluble K; *H*- exchangeable K; *I*- non-exchangeable K; *J*- mineral K; *K*- total K *Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$

Table 4: Pearson's correlation coefficient (r values) of variables related to different soil properties at apple orchard of Dutkanedhar

	A	B	C	D	E	F	G	H	I	J	K
A	1.00										
B	0.58*	1.00									
C	0.75	0.90**	1.00								
D	0.67**	0.62*	0.68**	1.00							
E	–0.34	0.73	0.49	0.77	1.00						
F	0.28	0.58	0.97**	–0.57	0.44**	1.00					
G	0.48	0.67	0.55*	–0.39	0.42**	0.62	1.00				
H	0.21	–0.44	–0.34	–0.08	0.36**	0.29*	0.46	1.00			
I	–0.54	0.17	–0.21	–0.14	0.77*	0.25*	0.66**	0.24**	1.00		
J	–0.37	–0.56	–0.07	0.35	0.76	0.11	0.34	0.90	0.68	1.00	
K	–0.33	–0.14	0.03	0.18	0.43	0.08	0.15	0.61	0.60	0.98*	1.00

A- pH; *B*- organic carbon; *C*- available N; *D*- available P; *E*- available K; *F*- cation exchange capacity; *G*- water soluble K; *H*- exchangeable K; *I*- non-exchangeable K; *J*- mineral K; *K*- total K; *Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$

deficiency in apple or any other crops grown in these soils.

Forms of K in soils

Data showing the contents of various forms of K determined in the soils are presented in Table 2. Water soluble, exchangeable and non-exchangeable K varied between 0.05 to 0.23, 0.76 to 0.86, and 3.14 to 5.46 cmol kg^{-1} at Dutkanedhar and Mukteshwar, respectively. Water soluble, non-exchangeable and mineral K contents were significantly ($p \leq 0.05$) different between the studied sites. At Mukteshwar, the contribution of water soluble, exchangeable, and non-exchangeable K towards total K was 0.27, 1.00, and 6.30 %, respectively; however, the contribution was 0.06, 0.95, and 3.91 %, respectively at Dutkanedhar (Fig. 1).

The quantities of different forms of K recorded in this study are comparable with those earlier reported by Mukhopadhyay (2009) in some Himalayan soils of Uttarakhand. Water soluble K is the immediately available form of K in soil. The amount of water soluble K seemed to be quite inadequate to meet the requirement for K, particularly during the active growth phase of apple at Dutkanedhar. However, the same at Mukteshwar was sufficient to meet the crop requirement as described by Mukhopadhyay (2009), Kundu *et al*. (2014), and Saini and Grewal (2014). Removal of K from soil solution is buffered by readily exchangeable forms, which in turn, is replenished by soil K reserves that further depends on clay mineralogical composition of soils (Simard *et al*., 1992). Therefore, it could be said that a weak dynamics between the forms of K existed in orchard soil of Dutkanedhar, and has resulted in low quantity of water soluble K. Inadequate replenishment of K from organic manures upon its removal could be another reason for low available K. Leaching of K beyond root zone due to the sandy nature of the soil perhaps was also responsible for small amount of water soluble K. Exchangeable K forms the major pool of immediate plant-available K and depends on type of clay minerals and their K contents, CEC and organic matter content of the soil. Higher CEC arising from high clay and organic matter content could have accounted for higher value of exchangeable K at Mukteshwar.

Soils of the north-west Himalayas are assumed to have sufficient non-exchangeable K reserves for agriculture (Sharma *et al*., 2010). But to have merely sufficient reserves does not mean that the K from these reserves will be available to plants. The availability of this form of K depends upon its quantitative release from the reserves which further depends on clay mineralogical composition, soil quality and potassium-fixing capacity of these soils (Mukhopadhyay, 2009; Sharma *et al*., 2010). The releasing power of non-exchangeable K determines its availability in soil system which is influenced by finer fractions of soil. In other words, higher the clay content of soil better will be the release of non-exchangeable K into exchangeable and water soluble K, and its subsequent availability to plants. Higher values of water soluble and exchangeable K at Mukteshwar than at Dutkanedhar could be supported by this. Although, identification of clay minerals has not been made in this study, the quantities of total and

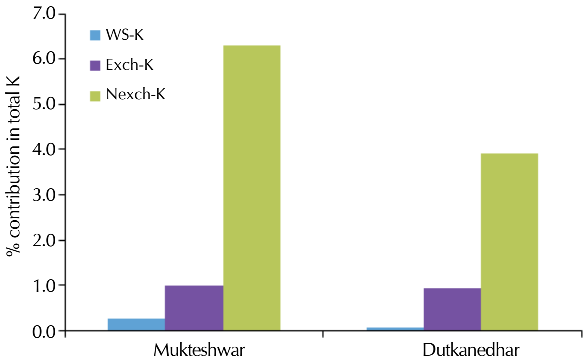

Figure 1: Contributions of different form of K towards total K content in soils of the studied sites

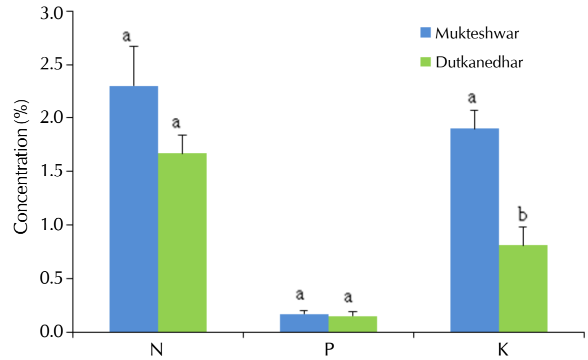

Figure 2: Leaf nutrient status of the major elements at the two apple orchards. Bars indicate standard error (n = 3). Columns sharing different alphabets differ significantly at $p \leq 0.05$ based on Duncan's multiple range test

Figure 3(A): Apple leaves suffering from K deficiency at Dutkanedhar having low K supply and (B) Healthy leaves of apple at Mukteshwar having adequate K supply

mineral K indicated that micaceous soils of these orchards are dominated by illite and vermiculite (Mukhopadhyay, 2009; Sharma *et al*., 2010).

Leaf nutrient contents

Analysis of major leaf nutrient contents revealed that N, P, and K contents were 2.3, 0.17 and 1.9 % at Mukteshwar (Fig. 2). In contrast, the major nutrient contents in the leaves were much lower at Dutkanedhar. There was also significant difference ($p \leq 0.05$) in leaf K contents between the orchards. Leaf K content recorded at Mukteshwar was more than double to that at Dutkanedhar. In general, the sufficient range of K in apple leaves ranges from 1.0 to 1.5%, and if K concentration falls below 1.0%, it is considered to be deficient (Bhargava and Raghupathi, 2009; Attar and Joolka, 2015). Therefore, the K content in apple leaves was deficient at Dutkanedhar. This insufficiency was apparent from the appearance of K deficiency symptom on apple leaves as scorched zone along the edges of leaves which rolled inwards (Fig. 3A). As K is mobile in plants, the appearance of symptom on younger leaves indicated the severity of K deficiency. In general, fleshy apple fruits are well supplied with K, and serve as strong sinks for this nutrient (Neilsen and Neilsen, 2003). Therefore, with fruits approaching maturity, leaf K concentration may be decreased, and consequently, deficiency symptom is more likely to appear.

Addition of fertilizers and organic manures (i.e., recommended management practice) have maintained a better K availability to apple at Mukteshwar; whereas, organic practice seemed to have caused in suboptimal replenishment of K, to meet the crop demand at Dutkanedhar. Apple, being a fruit crop, the demand for K remains high throughout the year, especially at the fruit development stage. Increased rate of K uptake by apple at this stage exhausts the labile pool of K, made up of water soluble and exchangeable K. The labile pool of K can be depleted to a great extent after prolonged periods of fruit production and removal of produce, if not returned back to soil. Once this pool gets exhausted, plants can rely partly on the release of non-exchangeable or mineral K to recharge the exchangeable and soluble pools, the size of the fixed potassium pool in many soils, or the rate at which it is released, is insufficient to meet plant demand. Bhaskarachary (2011) also noted that the release of non-exchangeable or fixed K is not fast enough to meet the requirement of rapidly growing crops. Inadequate K supply delays vegetative development of

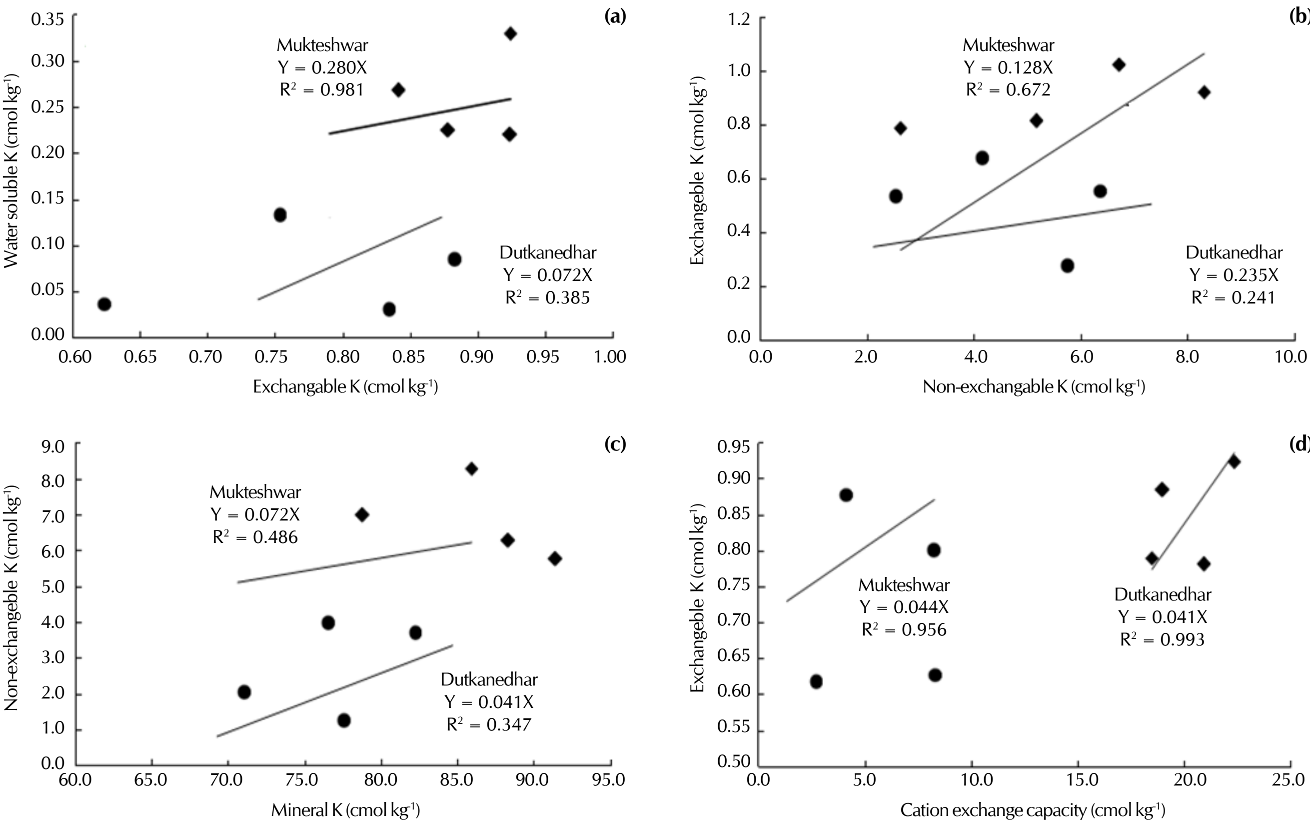

Figure 4: Relationship between (a) water soluble and exchangeable K content, (b) exchangeable and non-exchangeable K content, (c) non-exchangeable and mineral K content and, (d) exchangeable K and cation exchange capacity in soils of two apple orchards.

plants and the supply of photosynthates to the storage parts like fruits (Wang *et al.*, 2013). Thus, the adequate K fertilization is essential for sustainable production systems, particularly for high K requiring crops (Prasad, 2009).

Existence of weak dynamics, as indicated in preceding section and soil conditions (low CEC and sandy nature) favoring K leaching were perhaps the main reasons for poor availability of K that led to K deficiency at Dutkanedhar. Further, this study has indicated that estimating K availability through NH_4OAc-extraction method may not be appropriate to assess the actual K availability in these orchard soils, as both sites fall in same fertility category in terms of available K. Nonetheless, apple trees suffered from K deficiency at Dutkanedhar. Therefore, it is evident that neutral-normal NH_4OAc overestimated plant available K, and moreover, this method failed to reflect the quantity of soil K that is actually accessible to the plant roots for uptake. Upon exhaustion of exchangeable K due to uptake or leaching, non-exchangeable K is being released, and therefore, real plant availability does not necessarily correspond to soil test K values based on soil exchangeable K extraction (Madaras and Koubová, 2015). Use of NH_4OAc to extract plant available K (water soluble + exchangeable K) is the most used soil K availability index, but its suitability as a measure of plant available K remains controversial, particularly in soils rich in K-bearing minerals (Sekhon, 1999). In a recent study by Madaras and Koubová (2015) found that best prediction of plant-available K in soil was obtained with sodium tetraphenylboron (Carey *et al.*, 2011) and Step-K (Richards and Bates, 1988) methods as compared to neutral-normal NH_4OAc. Hence, assessment of available K by these methods could also be explored to decipher the actual available K status in these soils.

Regression and correlations studies

The interrelationships between water soluble, exchangeable, non-exchangeable, and mineral K were determined by linear regression analysis (Fig. 4a, 4b and 4c). Around 98% of variance (r^2 value) of water soluble K could be explained by exchangeable K in soil of Mukteshwar; however, the same in soil of Dutkanedhar was 38%. It indicates that when water soluble K gets depleted due to crop removal or leaching, its replenishment from exchangeable K would be more in soil of Mukteshwar. The regression analysis between exchangeable K and CEC also revealed a strong relation between them in soils of Mukteshwar (Fig. 4d), which could be attributed to high clay and organic matter content.

Results of simple correlation analysis between different forms of K and the various soil chemical properties are given in Table 3 and 4. Water soluble and exchangeable K forms were correlated positively and significantly with organic C, with r values 0.37 and 0.78, respectively at Mukteshwar (Table 3). As the pH of the soil increases, the H^+ ions on the functional groups of organic matter (carboxylic and phenolic) dissociate, resulting in the creation of negative charges on the organic matter. The negative charges created, therefore, have affinity for K^+ ions; hence, the positive correlation (r= 0.45) between organic carbon and the K forms could have occurred. The CEC of soil at Mukteshwar was correlated positively and significantly with available (r= 0.42), water soluble (r= 0.41), exchangeable (r= 0.44), and non-exchangeable K (r= 0.36). Although, CEC of soil at Dutkanedhar was significantly correlated with available (r= 0.44), exchangeable (r= 0.29), and non-exchangeable K (r= 0.25); however, the relationships were quite weak compared to Mukteshwar. Such kind of correlations between CEC and forms of K is reported by Sahu *et al*. (2009) and Ghiri *et al*. (2011). The differences in clay and organic matter contents between the sites could have accounted for such variations. It is indicative of weak K-buffering capacity of the coarse textured soil of Dutkanedhar. Available K content in soil of Mukteshwar correlated positively and significantly with water soluble (r= 0.78), exchangeable (r= 0.45), and non-exchangeable (r= 0.93) and total K (r= 0.60). Similar correlations recorded in the orchard soil of Dutkanedhar, although they were weak. This observation was not unexpected because exchangeable K which, in turn is replinished by soil K reserves, is released into the soil solution from the exchange sites when plants deplete the solution K, indicative that the size of the exchangeable K pool will determine the effectiveness of K re-supply, as well as the concentration of K in the soil solution. These findings corroborate with the findings of Ghiri *et al*. (2011) and Kundu *et al*. (2014).

This study has indicated that inadequate nutrient management for replenishment could lead to K deficiency in fruit crops like apple, a high K-requiring crop, even in mica-rich soils of the *Kumaon* region. In addition, K requirement in apple could not be satisfied entirely through addition of organic manures only, and it can, therefore, be concluded that K fertilization would be required for sustainable apple production in this region. This study also indicated that other suitable methods for determining plant-available K should also be deployed, while assessing its availability in orchard soils.

Conflict of interest

The authors declare no conflict of interest with the funds acquired, data or any other components presented in this manuscript.

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