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Extractable Potassium and its Relation to Clays of Mesaoria Plain Soils, Cyprus

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ABSTRACT

Potassium (K) is one of the major essential elements for plants nutrition. The objective of this study was to determine the origin of extractable K in soils of the Mesaoria plain. The study was conducted in 6 widely distributed soil series of the Mesaoria plain, which covers 1/3rd of the cultivated lands. Results showed that exchangeable K levels in soils are above 150 mg kg^{-1}, which was mainly, due to the presence of illite, even in low amounts, mineral in all studied series. Exchangeable and non-exchangeable K fractions were positively correlated. Results suggested that at present available K in the soils is not limiting for common crops in N. Mesaoria plain however, at soils close to insufficient levels, cropping K-demanding crops such as maize may cause K deficiencies. © 2010 Friends Science Publishers

Key Words: Extractable potassium; Clay minerals; Illite; Mesaoria plain; Cyprus

INTRODUCTION

The significance of K is related to how much extractable K exists in the soil and the level of crop production, which dictates K demand or removal from the soil. Relatively more researches were carried out on K in temperate, tropical and sub-tropical regions of the world (Bertsch & Grant, 1985). Not surprisingly, arid and semi-arid regions are generally characterized by adequate levels of available K, due to the slow weathering intensity of minerals, limited loss from the rooting zone by leaching and low crop consumption that are mainly constrained by drought (Etourneaud, 1993).

The Mediterranean region, although is characterized by limited use of K in contrast to N and P fertilizers in the last few decades (Etourneaud, 1993), increasing cropping intensity, especially irrigation, has raised concern about the sustainability of cropping without the K input. Central to the issue of soil K "mining", or significant depletion without any replenishment, is the complex quantity/intensity (Q/I) relationships that govern K forms in soils (Sparks, 1987). The extent to which any soil can replenish the available pool of K is dependent on the dynamics between the non-exchangeable and the exchangeable (plant-available) fractions, which are mainly related to clay mineralogy.

Despite the paucity of information on K in Mediterranean soils in the past, a database was gradually developed as evidenced by various studies (Etourneaud, 1993; Ryan, 2008). Authors gave an expanded list of country reports for the Mediterranean region, including Turkey, Egypt, Libya, Morocco, Tunisia, Jordan, Iraq and Syria.

The K-supplying power of the soils was documented by EUF-supply curves that reflected the capacity of the unavailable K fraction to be mobilized to replenish the supply of extractable K, where the K-release capacity was shown to be related to the cation exchange capacity (CEC), which in turn was dependent on the clay mineral suite, especially smectitic soils or soils rich in 2:1 clay minerals particularly illite (Karathanasis, 2006). There are two main K pools in soils called the exchangeable pool and non-exchangeable pool. Exchangeable K^+ ions are adsorbed on soil organic matter (OM). But non-exchangeable pool is much larger, which is about 90-99% of total K in many soils. Non-exchangeable K, on the other hand can contribute about 80-100% of the K supply available to plants. Soil clay mineral that contain anhydrous K^+ ions between its layers are known as illite (Barre *et al*., 2007).

Güzel *et al*. (2001) established a significant correlation between non-exchangeable and exchangeable K and suggested a dynamic relation between the two fractions. As exchangeable K is depleted by plant uptake, available pool is readily replenished from the non-exchangeable fraction in Harran soils (S.E. Turkey). Ryan (2008) suggested that the K supply of soils is finite and eventually K will be a crop growth-limiting factor. This may be due to shifting from traditional rainfed agriculture to traditional agriculture by the introduction and expansion of cash crops such as maize and potato that causes high K-uptake from the soil particularly in Mediterranean islands. Therefore, factors related to soil mineralogy contributing the K availability are determined in Mesaoria plain, which also will guide Mediterranean islands with similar ecology such as Sardinia, Crete and Sicily.

MATERIALS AND METHODS

Mesaoria plain (East Cyprus), located on the eastern part of the Mediterranean basin (Fig. 1) has a typical Mediterranean climate with hot, dry summers, mild winters with annual mean temperature of 18.8°C and average of 310 mm precipitation, which is classified as dry xeric moisture regime according to USDA-NRCS (2009). The main crops in the region are olives and cereals, which are mainly rainfed with small portions of vegetables and citrus orchards at irrigated zones.

Samples were collected from widely distributed soil series of Balıkesir (Vertic Xerofluvent), Zümrütköy (Typic Haploxerept), Geçitkale (Chromic Haploxerert), Doğanci (Vertic Haploxeroll), Mormenekşe (Lithic Calcixerept) and Aslanköy (Typic Calcixerept), which represents approximately 1/3rd of the cultivated lands of the Mesaoria plain. Some physical and chemical properties, pH, EC_e, CEC, OM and texture of the samples were determined using the methods employed routinely (Sparks, 1996). Clay minerals are determined semi-quantitatively by preparation of oriented slides. X-ray diffraction (XRD) patterns were taken at 3-13 (2θ) at 1°min^{-1} using CuKα radiation (Jackson, 1979). Semi-quantitative estimates of the clay minerals were obtained from individual measurements of the area under the (001) reflections (Weingarten *et al.*, 1990).

Exchangeable K was extracted using the standard 1*N* neutral ammonium acetate method (Knudsen *et al.*, 1982) and measured with a spectrophotometer. Non-exchangeable K was extracted and determined using a method as described by Karamanos (1980). Soil (5 g) was mixed with 50 mL 0.5 *N* HCl and shaken in a horizontal shaker for 30 min, centrifuged for 10 min and clear supernatant liquid decanted into a 50 mL flask and K concentration of the extract was determined spectrophotometrically. Seven successive extractions were made in this way, but since the first extract, which might had K impurities from chemical fertilizers was discarded, while the successive extractions were evaluated in the study. The amount of exchangeable K was used to classify the soils namely the K index groups (Cooke, 1982), for the evaluation of the available K contents of soils according to their crop pattern.

Correlation coefficients were calculated using MSTAT-C statistical computer program (MSTAT-C, 1988).

RESULTS

Soil properties: Soils of the Mesaoria plain (Table I) mainly developed from calcareous sediments transported from Beşparmak Mountains and Quaternary shallow marine sediments, which are low in K-bearing minerals such as mica and orthoclase, which produces illite following weathering. Thus the illite content of the soils is generally low (Table II). Physical and chemical soil properties of the six soil series are given in Table I. Soil pH values are over 7.5, most probably due to high amounts of free $CaCO_3$. The Balıkesir, Aslanköy and Geçitkale series were relatively rich

Table I: Some physical and chemical properties of the soils studied

Horizon	Depth cm	Sand %	Silt %	Clay %	pH %	EC dS m^{-1}	OM %	$CaCO_3$ %	CEC cmol kg^{-1}
Balıkesir (Vertic Xerofluvent)									
Ap	0-14	26	40	34	8.0	2.0	2.5	23	30
A2	14-31	26	44	30	7.7	5.0	1.1	23	38
C	31-66	15	47	38	7.8	8.0	1.1	23	40
Zümrütkoy (Typic Haploxerept)									
Ap	0-16	45	28	27	7.8	4.0	3.0	6.0	37
A2	16-35	40	33	27	8.0	2.0	1.2	8.0	37
BA	35-57	50	20	30	8.0	2.0	0.6	2.0	30
Bw	57-73	52	21	27	8.0	1.8	0.6	2.5	35
Geçitkale (Chromic Haploxerert)									
Ap	0-10	26	46	28	7.5	2.0	1.8	25	25
A2	10-25	20	50	30	7.6	2.5	1.0	27	30
C1	25-56	24	48	28	7.8	4.0	0.8	26	20
Doğancı (Vertic Haploxeroll)									
Ap	0-15	48	22	30	7.8	1.0	1.2	10	40
A2	15-33	45	20	35	8.2	1.0	0.8	10	45
BA	33-48	42	8	50	8.0	1.5	0.5	10	50
Bt	48-76	32	14	54	8.2	4.0	0.5	20	52
Mormenekşe (Lithic Calcixerept)									
Ap	0-16	35	25	40	7.5	3.0	2.0	2.0	38
Ad	16-27	23	32	45	7.5	3.0	2.0	2.0	40
Bw	27-39	35	25	40	7.5	5.0	1.0	2.0	40
Aslanköy (Typic Calcixerept)									
Ap	0-21	25	45	30	7.8	1.8	2.0	25	25
Ad	21-38	40	30	30	8.2	1.0	1.0	25	20
Bw	38-54	40	30	30	7,6	4.0	1.0	25	22

CEC: Cation exchange capacity; EC: Electrical conductivity; $CaCO_3$: Calcium carbonate

Table II: Relative abundance (semi-quantitative, Drever, 1973) of clay minerals in the surface horizons soils studied

		Clay mineralogy			
Horizon	Depth cm	Smectite	Kaolinite	Palygorskite	Illite
Balikesir					
Ap	0-14	+	+	+	+
A2	14-31	++++	+	+	+
Zümrütkoy					
Ap	0-16	++++	+	+	+
A2	16-35	++++	+	+	+
Gecitkale					
Ap	0-10	++++	+	+	+
A2	10-25	++++	+	+	+
Doğanci					
Ap	0-15	+++	+	+	+
A2	15-33	+++	+	+	+
Mormenekşe					
Ap	0-16	+	+	+	+
Ad	16-27	+	+	+	+
Aslanköy					
Ap	0-21	+++	+	+	+
Ad	21-38	++++	+	+	+

a ++++: high; +++: abundant; ++: moderate; +: low (Drever, 1973)

Table III: Exchangeable and non-exchangeable K of the soils

Horizon	Depth cm	Successive K Extractions						
		1	2	3	4	5	6	Sum
		mg 100 g^{-1}						
Balikesir								
Ap	0-14	24	13	8	7	1	5	58
A2	14-31	14	10	7	5	5	4	44
C	31-66	9	9	7	9	4	4	42
Zümrütkoy								
Ap	0-16	16	12	19	3	1	1	52
A2	16-35	2	2	1	9	2	2	18
BA	35-57	4	4	3	2	1	2	17
Bw	57-73	3	2	1	5	1	1	13
Geçitkale								
Ap	0-10	17	7	9	5	5	5	48
A2	10-25	14	8	7	5	1	3	38
C1	25-56	16	13	8	5	5	4	50
Doğancı								
Ap	0-15	9	8	9	5	7	5	42
A2	15-33	10	9	7	1	1	1	29
BA	33-48	25	13	9	5	4	3	58
Bt	48-76	25	18	14	6	9	9	81
Mormenekşe								
Ap	0-16	10	6	4	5	3	3	31
Ad	16-27	10	7	5	4	3	2	31
Bw	27-39	12	8	6	3	5	4	38
Aslanköy								
Ap	0-21	5	12	8	3	5	3	36
Ad	21-38	5	8	6	1	2	4	26
Bw	38-54	1	2	2	5	2	5	18

Fig. 1: Location of the study site

in $CaCO_3$ (23-27%) based on analyses of surface horizons, whereas other series showed low $CaCO_3$ (1-5%). The soil OM content in the surface horizons varied from 1.2% in the Doğancı series to 3.0% in the Zümrütköy soils. The distribution of OM showed a typical decrease with increasing depth (Table I). The cation exchange capacity (CEC) of soils is determined up to 52 cmol kg^{-1} but varies were between 25 and 40 cmol kg^{-1} due to clayey texture, which ranged between 27% (Zümrütköy) and 40% (Mormenekşe).

The dominant clay mineral is smectite (Table II) in the soils studied, except Mormenekşe soil, where only minor amounts were determined. This is attributed to relatively advance stage of weathering of Mormenekşe soils. Smectite is followed by kaolinite, palygorskite and K-bearing illite.

Exchangeable K values of the surface soils were

Fig. 2: Exchangeable potassium (mg 100 g^{-1}) and index values of the soils studied

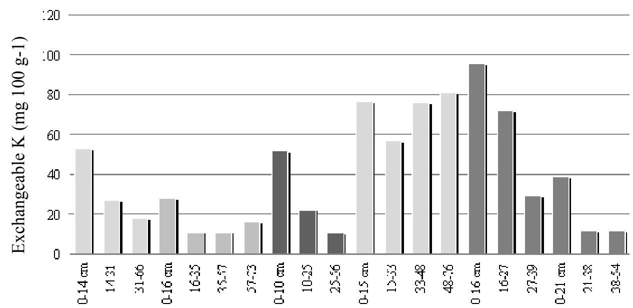
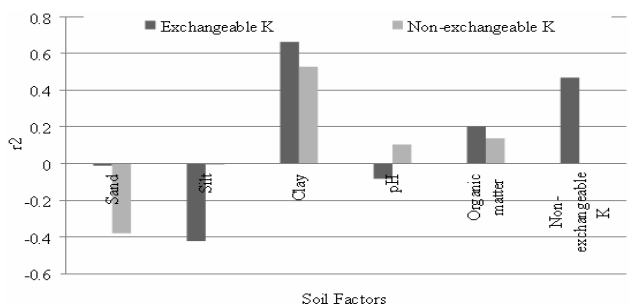


Fig. 3: Some correlation coefficients (r2 = 1 perfect correlation) between the selected soil properties and K values



variable. However, they decreased with depth except Doğancı series, which have the highest K value in the subsoil (Table III). As crop availability of K largely exists in the surface horizon, where most plant roots are concentrated, the availability index is provided for this horizon. The soil's K-status, in terms of increasing availability, ranged from Zümrütköy (Index 3), the lowest with 280 mg kg^{-1}, to highest, Doğancı and Mormenekşe (Index 6). As the critical exchangeable K values for dryland crops is 100-200 mg kg^{-1}, all soil K values are considerably above the critical level, which indicate sufficiency in plant-available K and which is likely related to the presence of illite in all soil series even found in low amounts (Table II). An additional dimension of exchangeable K from a single one-time extraction reflects the soil's K supplying capacity, presumably from non-exchangeable forms (Table III). Thus the six sequential K-extractions using 0.5 *N* HCl confirmed the different release pattern of the soils studied. With few exceptions, both topsoil and subsoils decreased with increasing extraction number (Table III). After the 4th and 5th extraction, apparent equilibrium was reached, with some soils being as low as 1 mg kg^{-1} (Zümrütköy) and other as high as 5 mg kg^{-1} (Geçitkale). The particular interest was the ranking of K values of the first three extractions or the sum of all six extractions, which were poorly related to the ranking for exchangeable K (Fig. 2). For example, the soil with the highest exchangeable K index (Mormenekşe) had the lowest total K extracted by HCl. The discrepancies between exchangeable and "non-exchangeable" K revealed for soils such as Mormenekşe and Doğancı the exchangeable K fraction was over 50% of the total K extracted by both methods (Fig. 2; Table III).

The variable relationship between exchangeable K and that extracted by 0.5 *M* HCl (or "non-exchangeable" K) is described by a correlation coefficient of 0.47. However, neither K forms were significantly related to organic matter, pH or sand and silt contents. Both K forms were positively correlated with each other, reflecting the fact that K is in the exchangeable form (Fig. 3).

DISCUSSION

Soils of the Mesaoria plain, in general, with high K values in the surface layers are mainly a reflection of relatively advanced weathering intensity in the development of the soil as well as the influence of upward transport of the growing crop residues (Table III) (Karathanasis, 2006). Although illite in the Mesaoria plain soils are not dominant (Akça *et al*., 2001) (Table II), relatively low amounts revealed sufficient K-supply, which is also in line with the findings of Güzel *et al*. (2001) and Çimrin *et al*. (2004).

As in many other studies from the Mediterranean region (Ryan, 2008; Goli-Kalampa *et al.*, 2008), the exchangeable and non-exchangeable K fractions were positively related to the clay fraction and 2:1 layered silicate clay minerals contents i.e., smectite and illite, in the soil clay fraction (Table III). As noted in this study, Güzel *et al.* (2001) also showed that the exchangeable K was closely related to non-exchangeable K. In contrast with Çimrin *et al*. (2004), no clear relationship was found between exchangeable K and OM, although OM content of the soils was relatively higher. This apparent discrepancy does not necessarily discount the generally observed parallel relationship between the available and slowly available K fractions (Table III; Fig. 2 & 3). It is well known that equilibrium would be expected between the two fractions (Syers, 1998). However, due to the depletion of the extractable K fraction by crop uptake the normal equilibrium between the two phases would be distorted.

CONCLUSION

Soils of Mediterranean basin, in general, had sufficient amounts of plant-available K in the form of exchangeable K due to the presence of illite. Extractable K in most soils of the Mediterranean region is sufficient for several crops. There was little or no evidence to suggest that fertilization practices in the Mesaoria plain were in a state of imbalanced leading to "nutrient mining" for main agricultural crops. However, current demand in Mediterranean islands for cultivation of cash crops, such as maize, requiring irrigation removes relatively high amounts of K may lead to K-deficiencies in soils unless K-fertilizers are applied. While this study has provided information with practical implications about K deficiency for growing crops in the Mesaoria plain, it also may serve as a guide to K status of Mediterranean islands soils, where extensive agricultural practices are increasing since 1990s.

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