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Effects of Long-Term Continuous Cropping of Sunflower on K Forms in Calcareous Soils of Western Azerbaijan Province Iran

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ABSTRACT

Potassium forms and clay mineral composition of soils under sunflower cropping were compared to those adjacent virgin soils. For this purpose forty surface soil samples belonging to 10 soil series in Western Azerbaijan province, Iran were selected to determine the changes in K forms and K adsorption behaviour of the cultivated soils after long-term cropping. The samples were analyzed for soil physical and chemical properties, mineralogy of clay fraction, different forms of K, and K adsorption characteristics. The soils studied were alkaline and calcareous. Illite, illite-smectite and chlorite- kaolinite were the dominant clay minerals in Typic Xerocrepts, Typic Xerofluventsand Fluventic Xerocrepts, respectively. No changes in K-bearing minerals (illite) were detected due to cropping and K depletion. Soil solution K (So-K) constituted 1.65% of exchangeable K (Ex-K) and 4.35 % of non-exchangeable (NEx-K) for the cultivated soils and 2.54 % of Ex-K and 4.35 % of NEx-K for the adjacent virgin land. Significant declines in Ex-K content from 464 to 241 mg kg^{-1} (48 %, on average), from 488 to 264 mg kg^{-1} (46%, on average), were observed for Fluventic Xerocrepts and Typic Xerofluvents($P \leq 0.01$) soil series, respectively. Significant changes in the NEx-K content were observed after long-term cropping of sunflowers in Fluventic Xerocrepts ($P \leq 0.05$) but no changes in Typic Xerofluventsand Typic Xerocrepts of the soils. A highly significant positive relationship ($r^2 = 0.70$, $P \leq 0.01$) was observed between NEx-K and illite contents, indicating that this form of K is mainly released from the frayed edges of illite. Paired t-test revealed that in Fluventic Xerocrepts and Typic xerofluvents, K adsorption significantly was increased ($P \leq 0.01$) and exchangeable K was decreased as a result of exhausting cropping of sunflower.

Keywords: Sunflower; K forms; K sorption; Clay mineralogy; Continuous cropping

İran'ın Batı Azerbaycan Bölgesi Kireçli Topraklarında Sürekli Ayçiçeği Yetiştirilmesinin Potasyum Formlarına Etkisi

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ÖZET

Ayçiçeği tarımı altındaki toprakların potasyum formları ve kil minerali bileşimleri bu topraklara bitişik bulunan kültüre alınmamış topraklarla karşılaştırılmıştır. Bu amaçla, uzun yıllardır ayçiçeği tarımı yapılan İran'ın Batı Azerbaycan bölgesinde 10 toprak serisinden alınan 40 yüzey toprak örneğinde K formları ve K adsorpsiyon özellikleri belirlenmiştir. Toprak örneklerinin fiziksel ve kimyasal özellikleri, kil fraksiyonunun minerolojisi, potasyumun farklı formları ve adsorpsiyon özellikleri analiz edilmiştir. Topraklar alkalin ve kireçli yapıdadır. Tipik Xerocrepts, Tipik Xerofluvents ve Fluventic Xerocrepts olan topraklarda sırasıyla dominant kil tipleri, illit, illit-smektit ve klorit-kaolinit olarak saptanmıştır. K-içeren minerallerde (illit) ürün yetiştirme ve K azalmasından dolayı bir değişim belirlenmemiştir. İşlenen toprakların toprak çözeltisinde bulunan K'un (So-K) % 1.65'i değişebilir K (Ex-K) ve %4.35'i değişmeyen K (NEx-K) K'dan oluşurken, işlenmeyen bitişik topraklarda ise %2.54'ü değişebilir K (Ex-K) ve 4.35'i değişmeyen K (NEx-K) K'dan oluşmaktadır. Fluventic Xerocrepts, Typic Xerofluvents($P \leq 0.01$) toprak serilerinde sırasıyla değişebilir K kapsamlarında 464' den 241 mg kg-1'a (ort.% 48), 488'den 264 mg kg-1'a (ort.%46), ye önemli azalmalar olduğu gözlenmiştir. Uzun yıllar ayçiçeği tarımı yapılan toprakların Fluventic Xerocrepts serisinde ki değişemeyen K kapsamında önemli değişim ($P \leq 0.05$) olmuştur, hâlbuki diğer serilerde herhangi bir değişim belirlenmemiştir. Değişemeyen K (NEx-K) ve illit kapsamları arasında, önemli pozitif bir ilişki ($r^2 = 0.70$, $P \leq 0.01$) belirlenmiştir ve bu K formunu çoğunlukla illitin yıpranmış kenarlarından salındığını gösterir. Eşleştirilmiş t-testi ile Fluventic Xerocrepts ve Typic xerofluvents'lerde sürekli ayçiçeği tarımının K adsorpsiyonunu önemli derecede arttırdığı değişebilir K miktarını ise azalttığı ortaya konmuştur ($P \leq 0.01$).

Anahtar sözcükler: Ayçiçeği; K formları; K sorpsiyonu; Kil mineralojisi; Sürekli işleme

1. Introduction

Successive cropping of potassium-demanding crops like sunflower (Helianthus annus) leads to depletion of soil potassium (K) and change the distribution of K forms. Changes in non-exchangeable K of soils under intensive cropping have been observed in many cases irrespective of the available K status and dominant minerals of soils. Some workers have shown that intensive cropping for a long period reduces the exchangeable K to a minimum level in which the release of non-exchangeable potassium starts (Sachdeva & Khera 1980). Application of K fertilizers increases and subsequent cultivation decreases the amount of exchangeable K. Little change in exchangeable K content of the surface layer (0-15 cm), of a sandy loam in Punjab, India, under a wheat /maize rotation for 10 years (64 kg K ha^{-1} yr^{-1} applied), was also observed by Sharma et al. (1984). In contrast, the application of 33.6 kg K ha^{-1} yr^{-1} for 47 years to a silt loam soil under winter wheat resulted in a 58% increase in exchangeable K content compared to the control (142 mg kg^{-1}) (Banks et al 1976).

Soil solution K (So-K), exchangeable K (Ex-K), and non exchangeable K (NEx-K) forms are related to soil properties including surface area, mineralogy, surface charge density and degree of interlayering of clay minerals (Shaviv et al 1985). The So-K and Ex-K phases are regarded as readily available forms of K. The NEx-K form is generally considered to be slowly available form of K occurring in illitic clays and other 2:1 types of integrated minerals (Wood & DeTurk 1940).

Intensive sunflower cropping without proper replacement of nutrients absorbed from the soil especially K, led to a marked depletion of soil K resources, and in turn became a yield-limiting factor in some areas of Iran (Jalali 2005). According to Jalali and Zarabi (2006) the soils in most arid and semiarid regions contain large quantities of exchangeable and non-exchangeable K. The exchangeable K of these soils may be significantly depleted due to the intensive crop production systems. The continued K export without supply will tend to deplete soil potassium. This may take 3 to 10 years, depending on K storage (Kayser & Isselstein 2005). Since plant growth is not directly limited by the amounts of exchangeable K, therefore it should be necessary to elucidate this phenomenon on the basis of equilibrium studies in order to test the immediate power of soils to supply K to plants. This approach needs the use of equilibrium Quantity-Intensity (Q/I) concept as a good tool to provide sufficient data regarding K dynamics in calcareous soils of north-west of Iran under sunflower cropping. Various attempts have been made to characterize the relationship between intensity and capacity of soil K or soil K buffering characteristics. This relationship implies that the ability of a soil system to maintain a certain concentration of a cation in solution is determined by the total amount of the cation present in readily available forms (exchangeable and soluble) and the intensity by which it is released into the soil solution (Leroux & Sumner 1968). The linear portion of the curve has been ascribed to nonspecific sites for K (Beckett 1964), while the curved portion has been attributed to specific sites with high K affinity (LeRoux & Sumner 1968). The nonspecific sites have been attributed to planar surfaces (Lee 1973), whereas the specific sites have been ascribed to edges of clay crystals and to wedge sites of weathered mica (Rich & Black 1964). Crops with a high dry matter production such as beets have a high K-demand and affect distribution of K forms, K adsorption, and the availability of K to plants. Limited information is available, however, on the effect of continuous cropping on the relative distribution and amounts of K forms, K adsorption, and mineralogy of clay fractions for calcareous soils of Western Azerbaijan Province, Iran.

The aims of the present study were: (1) to determine the content, forms, and distribution of K in cultivated soils and adjoining virgin lands in relation to clay mineralogy composition and other properties; (2) to compared the adsorption of K onto cultivated soil as virgin soils: (3) to investigate the long-term effects of cultivation on the K status of sunflowers-growing calcareous soils.

2. Materials and Methods

2.1. Soils and climate

This study compares the K status of topsoils from sunflower farmlands and the adjacent uncultivated (virgin) areas in western Azarbaijan, Iran. Most of the cultivated areas have been cropped under sunflower-wheat rotations and received irregular application of K fertilizers for at least 50-80 years. The adjacent virgin areas are under vegetation including shrubs and various native grasses. The area studied predominantly presents a semi-arid climate with mean annual rainfall of 280 mm year^{-1} and mean minimum and maximum temperatures of -4°C in winter and 37°C in summer. Parent materials in study area originated mainly from calcareous rocks and concerned to the quaternary geology period.

Forty soil samples (20 cultivated and 20 virgin soils), (0-30 cm) belonging to 10 soil series were collected from the major sunflower growing soils and the adjacent virgin lands. Typic Fluventic Xerocrepts, Typic Xerocrepts and Typic Xerofluventsare the major soil sub group types found in this area. Typic Fluventic Xerocrepts and Typic Xerocrepts were classified under Inceptisols and Typic Xerofluventswas put under entisols order according to USDA Soil Taxonomy (Soil Survey 1999).

The soil samples were air dried and ground to pass through a 2 mm-sieve before use. pH was determined using 1:5 soil to 0.01 M $CaCl_2$ suspension by a glass electrode and EC was determined in saturated extracts of the soils (Blakemore et al 1981). Particle size distribution was determined by the sedimentation procedure using the pipette method (Gee & Bauder 1986). Total soil carbonates expressed as calcium carbonate equivalent (CCE) were determined by a rapid titration method (Rayment & Higginson 1992). Organic carbon was determined by wet digestion (Nelson & Sommer 1996). Cation exchange capacity (CEC) of the soils was determined by the 1 M NaOAc (pH 8.2) methods.

2.2. Soil mineralogy analysis

Soil mineralogy analysis by x-ray diffraction was performed on the < 2mm clay fraction. Prior to separation of soil particles, subsamples of the soils were treated with 1 M NaOAc (pH 5) to removal of carbonates and with 30% H_2O_2 to remove organic matter (Kunze 1965) and finally with Na-dithionite-citrate-bicarbonate to removal of Fe oxides (Mehra & Jackson 1960). Sand was separated from silt and clay by wet sieving and clay was separated from silt by centrifugation and decantation. After saturation of the specimens with Mg^{+2} (with and without glycerol salvation) and K^+ (with and without heating at 550°C) X-ray diffractograms were obtained by a computer-controlled Shimatzo XRD-6000 instrument employing a CuKα radiation source. Semi-quantitative percentages of clay minerals were calculated using diffractogram peak areas and standard weighting factors of Biscaye (1965) as follows: four times for the illite peak area, two times for the kaolinite + chlorite peak area, and one times for the smectite peak area and then normalized to 100%. Random powder diffraction patterns were obtained after packing the powdered samples into aluminum holders and scanning them from 3 to 60° 2θ. A step size of 0.02° 2θ and scan speed of 1° 2θ were used for all the samples.

2.3. K forms and K exchangeable isotherms

Soil solution K (So-K) was determined by shaking 5 g air-dried soil in 25m*l* distilled water overnight, followed by centrifugation and filtration. Plant available K (exchangeable + water soluble) was measured by shaking 10 g soil in 100 m*l* 1M ammonium acetate (buffered at pH 7) for 30 minutes in an end-over-end shaker, followed by centrifugation, filtration and K determination using flame photometer (Knudsen et al 1982). The exchangeable K (Ex-K) was calculated by subtracting the amounts soil solution K from the NH_4AOc-extractable K values. The HNO_3 extractable K was determined by boiling 2.5 g soil with 25 m*l* 1M HNO_3 for 10 minutes and analyzing the extracted K using flame photometer (Knudsen et al. 1982). Non-exchangeable K (NEx-K) was calculated by subtracting the amounts of NH_4AOc-extractable K from the HNO_3-extractable K values. K-index was calculated with equation of K-index (%) $=(K_{av\ (cmol+/kg)}*100)/CEC_{\ (cmol+/kg)}$ (Mutscher 1995). Potassium sorption studies were performed by shaking soil samples (2.5 g) with solutions of 0.01mM $CaCl_2$ (25m*l*) containing different amounts of K (0 to 80 mg l^{-1}).The samples were equilibrated on an end-over-end shaker for 24 hours, followed by centrifugation, filtration and K determination using flame photometer.

3. Results and Discussion

3.1. Characteristics of soils

Selected properties of soils studied are presented in Table 1. The soils are calcareous and alkaline. The CCE content ranged from 4.4 to 19% with a mean of 14% for the cultivated soils and between 3.9 and 23% with a mean of 13% for the adjacent virgin soils. The pH values varied from 7.5 to 8.2 for the cultivated soils and between 7.7 and 8.3 for the virgin soils. The electrical conductivity (EC) ranged from 0.3 to 2.3 dS m^{-1} for the cultivated soils and between 0.52 and 9.01 dS m^{-1} for the virgin soils. Soil organic carbon (SOC) varied from 0.09 to 1.13% (0.6%, on average) for the cultivated soils and between 0.31 and 1.6 % (0.71%, on average) for the virgin lands. The soil texture varied form sandy loam to clay. The CEC ranged from 12 to 28 $cmol_c\ kg^{-1}$ (21 $cmol_c\ kg^{-1}$, on average) for the cultivated soils and between 9 and 28 (21 $cmol_c kg^{-1}$, on average) for the virgin soils. The Gotur soil series belonging to the Fluventic Xerocrept soil type had the highest clay content and CEC (Table 1). Regression analysis showed that for the soils investigated, CEC depends more on the soil clay content ($r = 0.75$, $P < 0.001$) than on OC content ($r = 0.51$, $P < 0.05$).

Continuous intensity cropping was related to changes in soil properties particularly SOC and CEC. A pronounced decline in SOC content (30%) was detected in the Typic Xerofluventsand to a less extent in Typic Xerocrepts, and Fluventic Xerocrepts soil types although it was not statistically significant (Table 2). Data from long-term cropping system experiments have repeatedly shown that continuous cultivation declines soil OC and degrades soil quality compared to conditions with native vegetation, regardless of cropping system (Scholes & Breemen 1997). When continuous cultivation is combined with removal of most crop residues after harvest, this decline may be high. The low clay content of soil may be an important factor in decomposing soil organic matter. The presence of a close relationship between soil OC and clay content ($P<0.01$) indicated that the clay particles protect soil organic matter from decomposition (Van veen & Paul 1979).

The semi-quantitative estimates of relative clay-mineral percentages revealed that the predominant minerals in the clay fraction are illite in Typic Xerofluvents(Moghanjog soil series) and Typic xerocrept (Khoy) and smectite in Typic Xerofluvents(Shorbolag) and chlorite - Kaolinite in Fluventic Xerocrepts (Gotur, Garataphe) (Table 3). Partial swelling found in glycerol-treated samples belonging to the Typic Xerocrepts, Typic Xerofluventsand Typic Xerocrepts soil types and collapse of the related peak to approximately 10 Å in K-saturated and heated (to 550°C) samples

Table 1-Physical and chemical properties of the selected soils

Çizelge 1-Seçilen toprakların fiziksel ve kimyasal özellikleri

Soil series		pH 0.01M $CaCl_2$		SOC		CCE		SP %		Clay		Sand		CEC $cmol_c kg^{-1}$	
No.		C	V	C	V	C	V	C	V	C	V	C	V	C	V
						Fluventic Xerocrepts									
1	Gotor	8.2	7.8	0.34	0.43	17	17	50	43	40	37	25	28	20	21
2	Gotor	8.0	8.1	0.89	0.69	14	13	52	50	52	55	15	10	26	25
3	Gotor	7.9	7.7	0.77	1.37	15	11	52	49	42	37	10	18	27	27
4	Gotor	7.6	7.9	0.70	0.75	15	14	49	46	50	35	15	20	26	25
5	Garetappe	7.9	8.3	0.57	0.38	19	23	39	31	21	18	35	39	23	23
6	Garetappe	8.0	7.9	0.51	0.61	19	18	36	34	17	20	50	45	20	20
7	Garetappe	7.8	8.0	0.09	0.46	7.5	9.0	34	31	5	12	80	70	18	18
8	Dizaj.diz	8.0	8.1	0.46	0.69	10	13	32	32	15	20	20	60	18	19
						Typic Xerocrepts									
9	Emamkandi	8.0	8.0	1.13	0.99	15	12	50	43	45	40	18	30	25	26
10	Pirfrozan	7.5	7.7	0.69	0.84	13	12	42	41	15	10	53	53	20	20
11	Khoy	7.9	7.8	0.81	0.99	19	18	53	47	45	42	7.9	20	28	25
12	Khoy	7.7	7.7	0.41	0.31	4.4	3.9	29	29	15	12	55	60	13	9.3
13	Khoy	7.9	7.9	0.61	0.57	13	10	39	39	32	32	33	35	23	28
14	Khoy	7.7	7.9	0.67	0.39	10	5	27	27	7.1	8.3	68	67	18	18
						Typic Xerofluvents									
15	Sarab	8.0	8.1	0.97	0.52	15	15	43	33	17	22	53	40	23	20
16	Abdollah kandi	8.2	7.8	0.21	0.63	18	18	33	32	27	20	45	53	14	12
17	Abdollah kandi	8.0	7.9	0.55	0.69	18	18	41	37	20	20	38	43	18	20
18	Shorbolagh	7.8	7.7	0.31	0.94	14	14	27	37	10	32	65	38	15	19
19	Moghanjog	8.1	8.0	0.60	1.55	10	10	37	45	35	27	33	45	17	23
20	Moghanjog	8.0	7.9	0.69	0.39	15	15	34	26	22	7	40	70	20	13

CCE: calcium carbonate equivalent, SOC: soil organic carbon, sp: saturation percentage, CEC: cation exchange capacity

Table 2-Mean ± standard deviation (SD) values of selected soil properties and K forms

Çizelge 2-Toprak özellikleri ve K formları analiz sonuçları ortalamaları ve standart sapmaları

Variable	*Fluventic Xerocrepts*				*Typic Xerocrepts*				*Typic Xerofluvents*			
	V	C	Change %	Paired t-test	V	C	Change %	Paired t-test	V	C	Change %	Paired t-test
pH (0.01M $CaCl_2$)	7.97±0.2	7.9±0.18	0.90	0.691	7.8±0.14	7.77±0.2	0.4	0.326	7.89±0.14	8.0±0.15	-1.4	0.269
SOC (%)	0.67±0.32	0.54±0.25	19	0.241	0.68±0.3	0.72±0.24	-5.9	0.607	0.79±0.42	0.55±0.27	30	0.088
CCE (%)	14.4±4.3	14.5±4.1	-0.7	0.693	9.98±4.98	12.3±5.0	-23	0.017	13.1±2.6	15.1±2.5	-15	0.092
SP (%)	39.5±8.4	42.8±8.6	-8.4	0.016	37.7±8.1	40.1±10.4	-6.4	0.099	35.1±6.5	35.9±5.8	-2.3	0.321
Clay (%)	28.2±15.6	30.1±17.8	-6.7	0.429	24±15.7	26.2±16.4	-10	0.079	21.3±8.5	21.7±8.6	-2.2	0.867
Sand (%)	36.5±21.3	37.3±27.8	-2.2	0.717	44.4±18.3	39.2±23.4	12	0.089	48.4±12	46±11.8	5.2	0.314
CEC($cmol_c$ kg^{-1})	22.4±3.3	20.9±5.5	6.7	0.157	21.1±6.9	21.3±5.2	-0.9	0. 867	17.9±4.4	17.6±3.3	1.8	0.663
EC (dS m^{-1})	4.5±3.2	1.38±0.75	69	0.016	0.77±0.27	0.72±0.10	6.5	0.687	4.8±2.6	1.3±0.49	74	0.012
So-K (mg l^{-1})	29.2±20.3	11.1±3.6	62	0.033	12±9.7	10.6±6	12	0.784	49.7±25.2	10.5±6.6	79	0.005
KHNO3 (mg kg^{-1})	668±108	532±79.4	20	0.0095	610±224	622±220	-2	0.929	821±404	613±259	25	0.038
NEx-K (mg kg^{-1})	193±113	286±78.4	-48	0.032	270±206	334±142	-24	0.193	315±235	345±77	-9.4	0.756
Av-K (mg kg^{-1})	475 ±142	246±119	48	0.0071	341±262	288±246	15.5	0.689	506±233	268±222	47	0.003
Ex-K (mg kg^{-1})	464±144	241±119	48	0.0071	336±262	284±246	15.5	0.689	488±235	264±223	46	0.002
K-index (%)	5.4±1.86	2.93±1.2	46	0.0099	3.9±2.2	3.49±3.33	11	0.804	6.8±1.8	3.5±2.3	48	0.002
PBC^K(cmol kg^{-1})/ (mol l^{-1})$^{0.5}$	32±8.2	34.3±31.9	-7.2	0.842	37.5±9.9	50.7±40.1	-35	0.541	21.1±6.37	31.4±10.2	-49	0.021

[a] Differences with $P \geq 0.05$ are not significantly different according to paired t-test results. V: virgin, C: Cultivate soil, PBC^K: Potential Buffering Capacity, K-index (%)= $K_{av\ (cmol+/kg)}$*100/CEC $_{cmol+/kg}$, CCE: calcium carbonate equivalent, SOC: soil organic carbon, sp: saturation percentage, CEC: cation exchange capacity, So-K: soil solution K, Ex-K: soil exchangeable K, NEx-K: non exchangeable K, Av-K: available K

indicated that the smectite was randomly interstratified with vermiculite, which is quite common in soil smetites (Figure 1). Similar observations were also made by other workers (Bedrossian & Singh 2004). The random powder diffraction patterns of whole samples showed the presence of quartz in all of the samples. Calcite and alkaline feldspars were the other minerals that frequently occurred in most samples. Peaks for chlorite, illite, and kaolinite were also observed in the random powder XRD pattern (not shown here). The quartz content decreased considerably in the clay fraction.

3.2. Contents of K forms

Mean ± standard deviation (SD) values of various K forms for the soil series of three major soil types are presented in Table 2. In general, the Typic Xerofluventsand Fluventic Xerocrept soil types had larger amounts of soluble K, exchangeable K, and non-exchangeable K compared with the Typic Xerocrepts (Table 2). This could be attributed to the presence of high amount of mica-K mineral which on weathering releases and contributes to various forms of soil potassium as evident from the semi-quantitative clay mineralogical studies (Table 3) (Hebsur & Satyanarayana 2002).

3.3 Soil solution K (So-K)

Soil solution K is available immediately to the plant and the concentration is affected by soil weathering, cropping history, past fertilizer use, but the amount present is insufficient to meet crop requirement. Concentration of K in solution of the investigated soils ranged from 2.4 to 21 mg l^{-1} with a mean value of 11 mg l^{-1} for the cultivated soils and between 4.8 and 97 mg l^{-1} with a mean value of 30 mg l^{-1} for the adjacent virgin land. According to the results Typic Xerofluventscontain the highest amount of So-K (Table 4).The soil solution data for the soils studied are comparable with those from south Australia (Pal et al. 1999) where the range was 5.1- 17.2 mg l^{-1} for the cultivated soils. Gawander et al (2002) found that the range of So-K for soils of sugar cane growing area in Fiji was 2.34-62 mg l^{-1} (with a mean value of 12.1 mg l^{-1}), which is also comparable with those for the studied cultivated soils. On average, So-K constituted 1.6 % of Ex-K and 1.35 % of NEx-K for the cultivated soils and 2.5 % of Ex-K and 4.4 % of NEx-K for the adjacent virgin land.

Long-term cultivation resulted in changes in So-K contents. In general, there was a decline in So-K with cultivation in all soil types except Typic Xerocrepts (Table 2). A significant decline ($P<0.05$) in So-K content from 29.2 to 11.1 mg l^{-1} (62%) was detected in the soil type of fluventic xerocreprts and significant decline ($P<0.01$) in So-K content from 49.7 to 10.5 mg l^{-1} (79%) was detected in the soil type of typic xerofluvents. As expected, So-K showed similar trends to those of Ex-K, i.e., cultivated soils had lower levels of So-K than virgin land for the Veritic calcixerepts soil type.

3.4. Available K (Av-K)

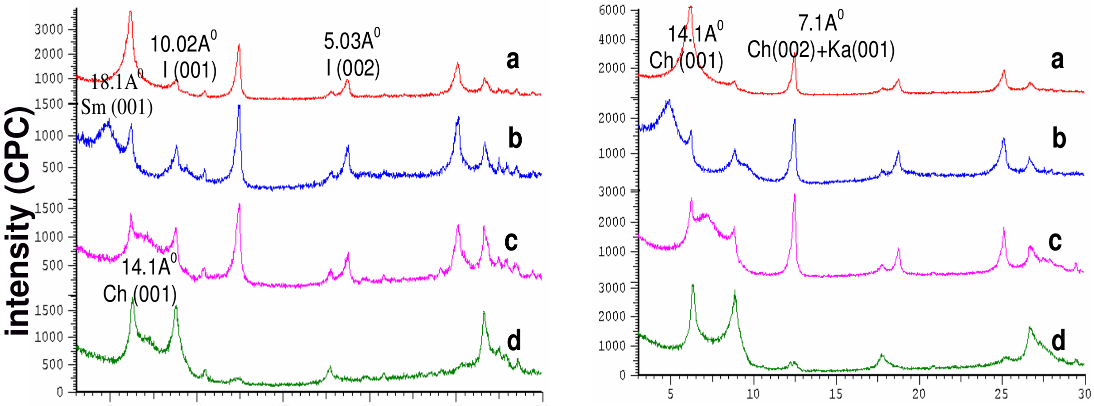
Available K plays a very important role in the growth of plants because exchangeable and solution K are only sources of potassium which are readily available to plants. Values of Av-K ranged from 55 to 699 mg kg^{-1} with mean value of 265 mg kg^{-1} for the cultivated soils and between 106 and 865 mg kg^{-1} with mean value of 444 mg kg^{-1} for the adjacent virgin land. According to the new soil test interpretation classes for K, all of the cultivated soils are grouped in very high category (>201 mg kg^{-1} K). The optimum category of this interpretation is 131 to 170 mg kg^{-1} K measured with ammonium acetate for 0 to 15 cm of the soil (Mallarino et al 2003).

Exchangeable potassium is often used as indicator of soil K status and the likelihood of a response to K fertilizer because of the close relationship between crop response and the amount of Ex-K in soil. Concentration of Ex-K varied greatly between the cultivated soils and the virgin lands (Table 4). Ex-K contents ranged from 54 to 694 mg kg^{-1} with a mean value of 261 mg kg^{-1} for the cultivated soils and between 103 and 902 mg kg^{-1} with a mean value of 434 mg Kg^{-1} for the adjacent virgin lands. These values are comparable with those found for sunflower growing soils in eastern Anatolia, Turkey (Cimarin et al 2004). The Fluventic Xerocrepts, Typic Xerocrepts and Typic xeroflovents soil types had the high amount of exchangeable K.

Table 3-Percent distribution of minerals in clay fraction of the selected cultivated soils

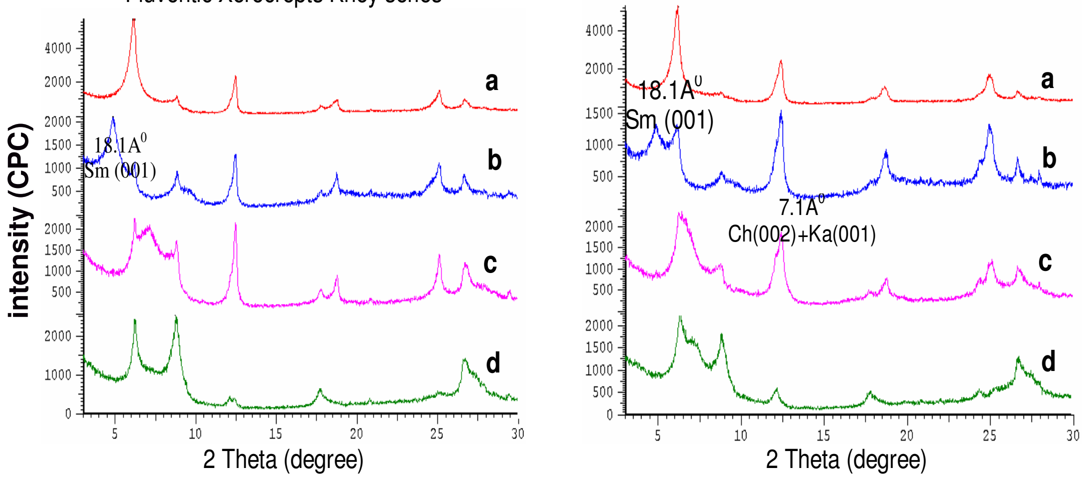
Çizelge 3-Ekim yapılan toprakların kil mineralleri yüzde dağılımları

	No.	Soil series	% Illite	% Chlorite+Kaolinite	% Smectite
Fluventic Xerocrepts	2	Gotur	22	71	7
	3	Gotur	17	73	10
	4	Gotur	18	67	15
	7	Garataphe	25	44	31
Typic Xerocrepts	12	Khoy	36	47	17
	10	Pirfruzan	18	68	14
Typic Xerofluvents	18	Shorbolag	24	28	47
	19	Moghanjog	45	47	8



Fluventic Xerocrepts Khoy series

Fluventic Xerocrepts Garatape series



Typic Xerofluvents Shorbolag series

Typic XerocreptsPirfruzan series

Figure 1-The X-ray diffractograms correspond to the following treatments: a) Mg saturation at 25°C; b) Mg saturation and glyscerol salvation; c) K saturation at 25°C; d) K saturation at 550°C for the studied major soil types under sunflower cultivation. Ch, chlorite; Ka, kaolinite; I, illite; Sm, smectite

Şekil 1-Ekim yapılan bazı toprakların, kil minerallerin XRD grafikler

Table 4-Potassium saturated index and K contents of the various K forms for soil series of three major types

Çizelge 4-Üç faklı toprak alt grubunda K formlarının K içerikleri ve potasyum doymuşluk indeksi

	Soil series	So-K mg L^{-1}		Ex-K		HNO_3-K mg kg^{-1}		NEx-K		Av-K		K index %	
No.		C	V	C	V	C	V	C	V	C	V	C	V
						Fluventic Xerocrepts							
1	Gotor	10.8	53.8	216	478	504	793	283	292	220	500	2.7	4.2
2	Gotor	14.2	21.5	351	489	516	566	160	70	356	496	3.9	3.2
3	Gotor	10.2	39.5	73	560	428	667	352	95	77	572	3.2	6.6
4	Gotor	12.7	52.6	276	543	579	717	299	158	280	560	0.9	3.2
5	Garetappe	10.8	4.8	393	320	617	579	218	257	398	322	3.1	5.5
6	Garetappe	10.8	4.8	329	701	579	793	244	89	335	703	4.5	6.2
7	Garetappe	3.6	14.4	92	303	416	504	322	194	93	309	1.6	8.1
8	Dizaj.diz	15.6	41.9	200	320	617	723	409	388	208	335	4.0	7.5
						Typic Xerocrepts							
9	Emamkandi	11.7	31.1	452	839	793	956	335	104	458	852	4.6	8.4
10	Pirfrozan	12.4	4.8	160	329	390	579	224	248	166	331	2.1	4.2
11	Khoy	3.6	9.6	104	266	390	453	285	182	106	271	1.0	2.8
12	Khoy	4.8	12.0	54	103	667	767	612	661	55	106	1.1	2.9
13	Khoy	10.7	7.2	238	277	554	579	312	299	242	280	2.7	2.6
14	Khoy	20.2	7.2	694	202	937	328	238	124	699	204	9.8	2.9
						Typic Xerofluvents							
15	Sarab	21.2	97.0	682	820	1069	1593	378	728	691	865	7.8	9.6
16	Abdollah kandi	4.8	50.2	66	281	390	717	323	421	68	297	1.3	6.4
17	Abdollah kandi	13.2	46.7	202	367	535	592	327	206	208	385	3.0	5.0
18	Shorbolagh	10.4	46.7	125	268	353	428	225	148	127	280	2.2	5.5
19	Moghanjog	2.4	25.1	207	516	667	830	459	305	208	525	3.2	7.0
20	Moghanjog	11.2	32.3	301	675	661	767	355	81	305	686	4.0	8.6

V: virgin, C: cultivated soil, So-K: soil solution K, Ex-K: soil exchangeable K, NEx-K: non exchangeable K, Av-K: available K

Conversion of nature lands to cultivated soils and continuous cultivation resulted in changes in Ex-K contents. In general, there was a decline in Ex-K content with cultivation in all soil types (Table 2). A pronounced significant decline ($P < 0.01$) in Ex-K content from 464 to 241 mg kg^{-1} (48 %) in Fluventic Xerocrepts and from 488 to 264 mg kg^{-1} (46%) in Typic Xerofluventswas detected. However, there was a non-significant ($P = 0.69$) decline in Ex-K content (336 to 284 mg kg^{-1}) of Typic Xerocrepts caused by cultivation.

Correlation coefficients (r) for the linear relationships between soil properties and K forms are given in Table 5. There were positive significant relationships between Ex-K and soil OC content in the cultivated and adjacent soils ($P < 0.01$), but there were no significant relationships between Ex-K and clay content in the cultivated and adjacent soils. These results are comparable with those found for sugar beet growing soils in eastern Anatolia, Turkey (Mesut et al 2004) indicating that as the amount of exchange complex increases, Ex-K content increases. This is a well-known fact in the literature (Pal et al 1999). The trend could be corroborated with mineralogy, which is rich in K-bearing minerals like mica and feldspars in course fractions and illite in clay fractions. Significant relationship between Ex-K and other K forms suggests that K forms are present in dynamic equilibrium (Sharma et al 2006).

3.5. Non-exchangeable K (NEx-K)

Native fixed K and recently fixed K could be grouped together to make up the pool of non-exchangeable inorganic K in the soil (Liu et al 1997). K fixation and release are determined by the amount of lattice clay (illite, vermiculite, and other K-rich minerals) in the soil as well as such factors

Table 5-Correlation coefficients (r) for linear relationship between K forms and soil properties

Çizelge 5-Toprak özellikleri ve K formları arasındaki linear korelasyon katsayıları

	K_{ex}		K_{so}		K_{nex}		Clay		CEC	
Variable	C	V	C	V	C	V	C	V	C	V
So-K	0.52^{*}	0.03^{ns}								
NEx-K	-0.51^{ns}	-0.73^{**}	-0.32^{ns}	-0.02^{ns}						
K-index	0.96^{***}	0.89^{****}	0.81^{***}	0.62^{**}	0.23^{ns}	0.08^{ns}				
Clay	-0.06^{ns}	0.21^{ns}	-0.41^{ns}	-0.21^{ns}	-0.02^{ns}	0.006^{ns}	0.26^{ns}	0.13^{ns}		
CEC	0.34^{ns}	0.43^{ns}	0.052^{ns}	-0.22^{ns}	-0.37^{ns}	-0.31^{ns}	0.75^{***}	0.70^{***}	0.13^{ns}	0.008^{ns}
SOC	0.61^{**}	0.59^{**}	0.2^{ns}	0.18^{ns}	-0.17^{ns}	0.14^{ns}	0.52^{*}	0.45^{*}	0.81^{***}	0.51^{*}

*, **, ***, significant at $P < 0.05$ $P < 0.01$ and $P<0.001$ respectively, ns: non-significant, Kex: soil exchangeable K, Kso: soil solution K, Knex: non exchangeable K, Kav: available K

as past additions of fertilizer and manure K, depletion of soil K due to crop removal and soil pH. The effect of weathering processes on potassium feldspars results in the release of a small amount of lattice K into the soil solution. NEx-K is in equilibrium with Ex-K and So-K as an important reservoir of potassium. Because of this equilibrium, some potassium applied as fertilizer can be temporarily converted to the non-exchangeable form. Non-exchangeable K ranged from 160 to 612 mg kg^{-1} with a mean value of 318 mg kg^{-1} for the cultivated soils and between 70 and 728 mg kg^{-1} with a mean value of 253 mg kg^{-1} for the virgin adjacent lands. The NEx-K values in our study are higher than the values reported by Pal et al (1999) for Western Australia soils and Gawander et al (2002) for sugarcane growing soils from Figi, but are lower than the values reported by Bedrossian & Singh (2004) for cotton growing soils (819 mg kg^{-1}) from northern New South Wales, Australia. The soil types of Khoy and Moghanjogh series, contained much NEx-K, (612 and 459 mg kg^{-1}, respectively) probably because they have high contents of illite, (36 and 45%, respectively) the reverse was true for the soil types of Typic Xerocrepts (with a mean value of 166 mg kg^{-1} for NEx-K) containing low illite (18%) (Table 3). A highly significant positive relationship was observed between the values of NEx-K and illite contents ($r^2 = 0.70$, $P < 0.01$) (Figure 2), indicating that this form of K is mainly released from the frayed edges of illite. These results are consistent with earlier published works (Bedrossian & Singh 2004).

Long-term continuous sunflower cultivation did not result in changes in NEx-K contents in the soils were studied except Fluventic Xerocrepts sub groups (48%) ($P < 0.05$) (Table 2). The lack of significant changes in the NEx-K form indicates that sunflower has met its K requirement mainly from available form (Ex-K + So-K forms) during long-term cropping. Fergus & Martin (1972) show that, providing of depletion Ex-K more than 80% to release NEx-k in soil solution.

3.6. K sorption isotherms

Potassium sorption isotherms for the studied soil types under continuous sunflower cropping and the adjacent virgin lands are presented in Figure 3. The soils differed in their K-sorption behavior. In general, sorption K increased in the all soil series. Equilibrium K concentration (EKC) in soil solution of the soils (i.e., no net sorption or desorption) ranged from 0.02 to 54.7 mg l^{-1} for the cultivated soils and between 24 and 203 mg l^{-1} for the adjacent virgin lands.

The K power buffer capacity (PBC^K), is defined as the capacity of soils to resist change in the K concentration in soil solution. The content of PBC^K for the cultivated and virgin soils has shown in Table 2. In general, the higher PBC^K are for the soils containing large amounts of clay and smectite and indicative of the continuing availability of adequate K over a long period of cropping, whereas a low power buffering indicates the need for frequent fertilisation (Pal et al 1999).

Paired t-test revealed that continuous sunflower cultivation increased significantly ($P < 0.01$) K depletion in Fluventic Xerocrepts (Gotur series No. 3) and Typic Xerofluvents (Abdollahkandi series No. 17) (Table 2, Figure 3), where exchangeable K was decreased as a result of intensive cultivation

(Gawander et al 2002). Similar results has been reported that the original exchangeable K content (54 mg kg^{-1}) of six surface soils (0-15 cm) in Alabama under a 2-yr cotton (Gossypium hirsutum L.)/vetch (Vicia villosa L.)/corn (Zea mays L.) rotation, receiving no fertilizer K, decreased 26% over a 50-yr period, whereas application of 112 kg K ha^{-1} yr^{-1} over a 21-yr period, increased exchangeable K an average of 240% (Cope 1981). So in these soils with increase initial concentration of K, increase quantity sorption. For Typic Xerocrepts (Khoy series No 14), E$_X$-K was increased due to a partial build up of exchangeable K probably as a consequence of application of fertilizer and or manure.

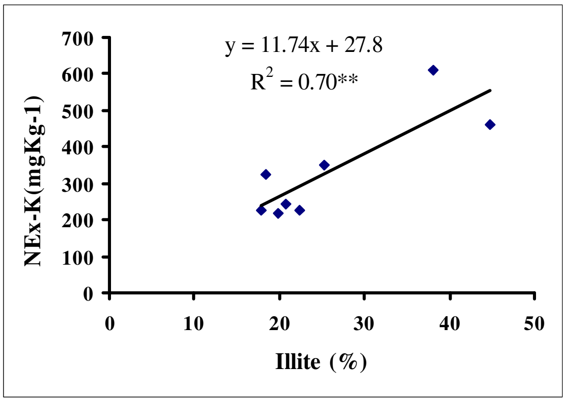


Figure 2-Relationship between the values of NEx-K and illite contents. (, significant at *P* < 0.01)**

*Şekil 2-İllit içerikleri ve NEx-K değerleri arasındaki ilişkiler (**, P < 0.01 önemli)*

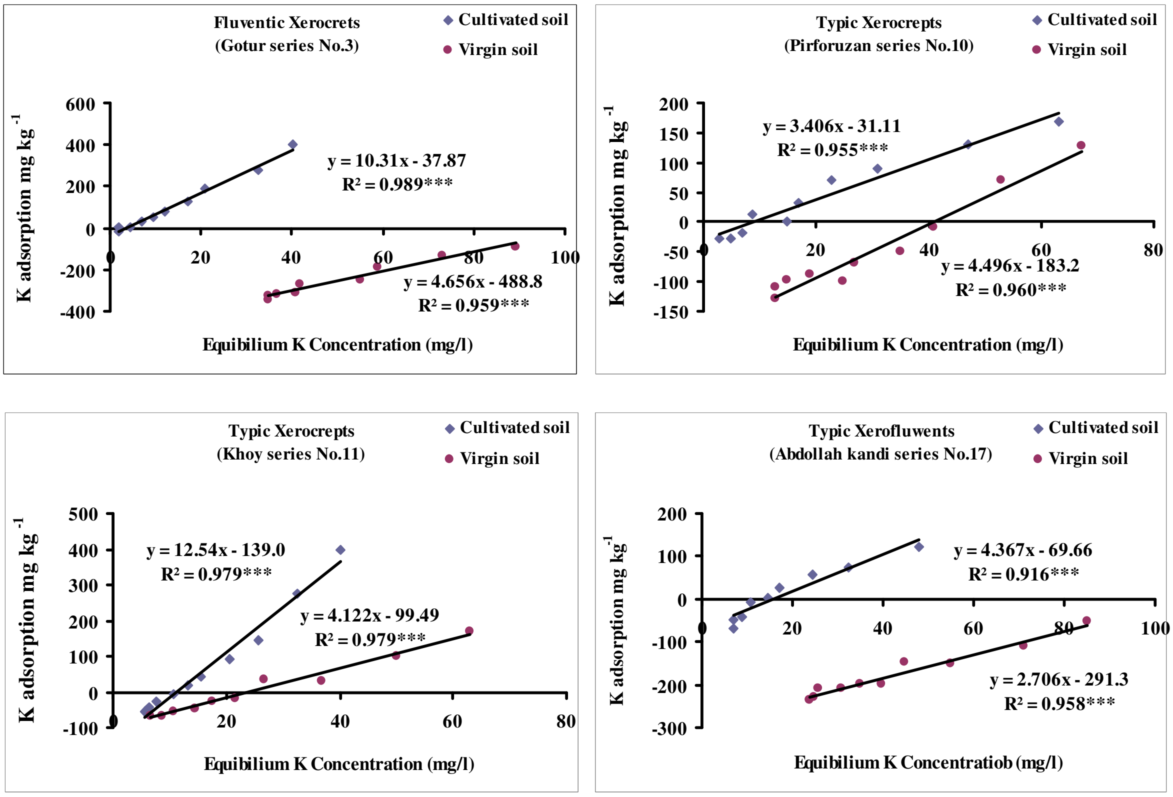


Figure 3-K sorption isotherms for the cultivated and virgin major soil types

Şekil 3-Ekim yapılan ve yapılmayan bazı toprak tiplerinin K adsorpsiyon izotermleri

4. Conclusion

Most of the soils studied contain medium to high plant-available K and other forms of K due to their high contents of K-bearing minerals. Despite continuous cultivation and K removal by sunflower as a high K-demanding crop, no transformations of micaeous minerals could be detected by XRD in the investigated soils. A highly significant positive relationship was observed between the value of non-exchangeable K and illite content indicating that this form of K is mainly released from the frayed edges of illite. Although conversion of virgins to cultivated soils and subsequent continuous cropping resulted in pronounce a significant decline (46%) in the exchangeable K contents, the potassium potential of the soils, regarding both non-exchangeable and exchangeable K, is sufficient for the current agricultural practices. Paired t-test revealed that continuous cropping increased significantly K adsorption in most of the soils studied.

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