doi: 10.17221/32/2016-SWR

Spatial Variability of Soil Potassium and its Relationship to Land Use and Parent Material

Fevzi AKBAS[1]*, Hikmet GUNAL*[2]* *and Nurullah ACIR*[3]

[1]*Konya Soil, Water and Deserting Control Research Center Meram, Konya, Turkey;* [2]*Soil Science and Plant Nutrition Department, Faculty of Agriculture, Gaziosmanpasa University, Tokat, Turkey;* [3]*Soil Science and Plant Nutrition Department, Faculty of Agriculture, Ahi Evran University, Kirsehir, Turkey*

**Corresponding author: hikmet.gunal@gop.edu.tr*

Abstract

Akbas F., Gunal H., Acir N. (2017): Spatial variability of soil potassium and its relationship to land use and parent material. Soil & Water Res., 12: 202–211.

Information on the spatial distribution of plant nutrients is a prerequisite to predict their behaviour and to monitor the fertility in a watershed. This study was conducted to evaluate variations of plant available potassium (PAK) and non-exchangeable potassium (NEK) of a watershed with different land use and parent materials. Eight hundred soil samples were taken from 0–30 and 30–60 cm depths across the Kazova watershed of 20 656 ha in size. Average PAK was 152.8 mg/K kg in surface layers and 167.2 mg/kg in subsurface layers. NEK was 925 mg K/kg in surface and 167.2 mg K/kg in subsurface layers. All forms of K were the lowest in soils formed over serpentinite. Soils in pastures had the highest PAK and NEK. Both K forms were positively related to clay content. Spatial variability patterns of PAK and NEK were similar and consistent at both soil depths. The variation in parent material and land use is considered as the main cause for large variations of potassium forms.

Keywords: alluvium; geostatistics; management; non-exchangeable potassium; plant available potassium

Potassium (K) in soils is typically found as soil solution K, exchangeable K, non-exchangeable K, and K in minerals. Different forms of K are in equilibrium with each other (Jalali 2007). The soils of arid and semiarid regions usually contain enough exchangeable potassium and K-bearing minerals which provide sufficient K to the crops. Exchangeable K concentration of soils in Central Anatolia of Turkey is considerably depleted due to the intensive crop production (Munsuz *et al.* 1996). Munsuz *et al.* (1996) stated that continued K removal in Anatolia without addition of K resulted in the destruction of K-bearing clay minerals and consequently depletion of K sources in soils. Øgaard and Krogstad (2005) showed the decline of interlayer K of micas and clay minerals with constant release of K from sources with no exchangeable K. Askegaard and Eriksen (2000) also reported that K is lost from loamy sand soils by plant uptake and leaching below the root zone. Losses of K from grasslands especially in coarse-textured soils were related to actual K input, surpluses and the level of exchangeable K (Kayser *et al.* (2012).

Improved understanding of soil K dynamics in the soil and spatial distribution pattern within a watershed are critical issues for better agronomic management (Sato *et al.* 2009). Numerous studies focused on the interaction of plant nutrients with different soil constituents to obtain an accurate description of the spatial autocorrelations of nutrients across a landscape, which is a prerequisite to predict their behaviour in the watershed. Specifically, to predict the yield of major crops grown, one must account for reserve and available nutrient concentrations and interactions of the various species in the soil environment.

doi: 10.17221/32/2016-SWR

Spatial variability of soil nutrients in arable soils is a consequence of interactions between parent materials, biology, climate, time and topography and as well as those partly created by human factors such as fertilization, tillage and cropping systems (Trangmar *et al.* 1985). The objective of this study was to examine the effect of parent materials (intrinsic) and land use (extrinsic) on plant available potassium (PAK) and non-exchangeable potassium (NEK) concentrations in Kazova watershed.

MATERIAL AND METHODS

The study area is located in the lower part of Kazova watershed encompassing ~20 600 ha of agricultural fields in the Tokat province of Turkey (Figure 1). The lowland of this watershed is an important agricultural region for wheat, sunflower, sugar beet, tomato and maize which are the major crops grown in rotation. The climate of the region is semiarid with the mean annual precipitation of 446 mm and mean temperature of 12.4°C.

Soil sampling. A total of four hundred surface (0–30 cm depth) and subsurface (30–60 cm) soil samples were collected from the lower part of Kazova watershed. The sampling pattern was prepared to reflect the variability caused by parent material and land use. The distance between soil samples was 1 km at maximum. Soil samples were also collected from the soil at 100, 200, 300 and 500 m intervals in order to determine the variability in a shorter distance than 1 km. The locations of sampling sites were recorded by a GPS (Figure 1). Average sampling distance was 460 m and sampling density was approximately one sample per 50 ha (20 656 ha/400 samples).

Table 1. Classification of soils based on plant available potassium concentrations (FAO 1990)

Index Group	Plant available potassium (mg K/kg)	Comments
1	< 50	insufficient
2	51–140	low
3	141–370	sufficient
4	371–1000	high
5	> 1000	very high

Soils in pastures of the study area are classified as Mollisols and those formed over limestone are Alfisols and Inceptisols. The most extensive soils formed over alluvial deposits in the lower part of the watershed are Inceptisols and mostly Entisols (Durak *et al.* 2006; Günal *et al.* 2008).

Soil analysis. Soil samples were air-dried, ground and passed through a 2mm sieve. PAK was extracted with 1N NH_4OAC and determined by flame atomic absorption spectrometry (Thomas 1982). The PAK concentrations of soils were grouped into five classes based on threshold values indicated by FAO (1990) (Table 1). NEK was extracted by the boiling HNO_3 method (Helmke & Sparks 1996). Organic matter was determined by the Walkley and Black method (Nelson & Sommers 1982). Cation exchange capacity (CEC) was measured by sodium acetate method (Chapman 1965). Exchangeable cations were extracted by ammonium acetate method (Thomas 1982). Particle size distribution was determined by the hydrometer method (Gee & Bauder 1986). The soil reaction (pH) and electrical conductivity (EC) were measured in saturated paste (Rhoades 1982). $CaCO_3$ was determined using the calcimeter method (Allison & Moodie 1965).

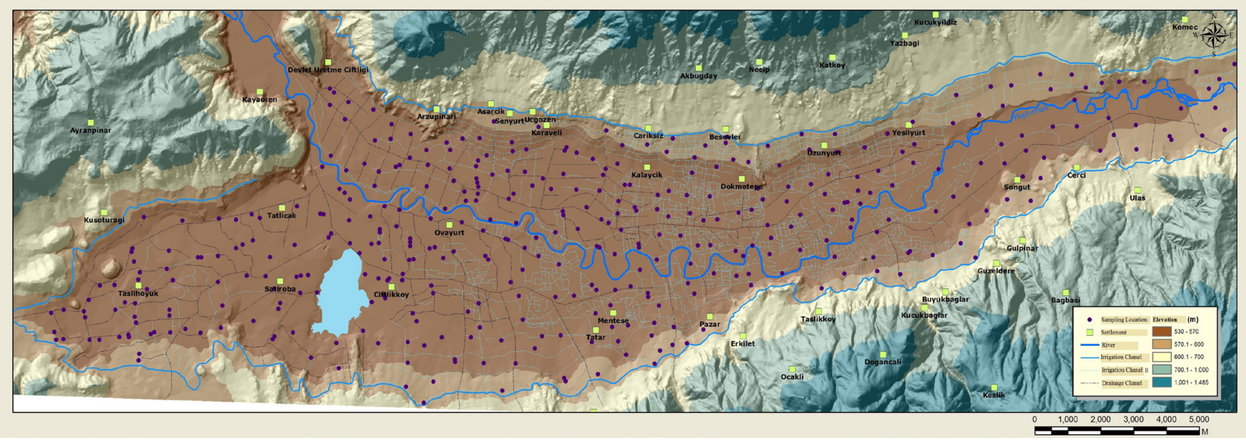

Figure 1. Sampling sites in the lowland of Kazova Watershed

doi: 10.17221/32/2016-SWR

Statistical analyses and spatial variability analysis of plant available potassium. One-way analysis of variance (ANOVA) was applied to compare the effects of parent material and land use on PAK and NEK concentrations of soils. Following the ANOVA, Duncan's homogeneity test was used to group the parent materials and land uses. Significance levels of 0.05 and 0.01 were applied in all the statistical analysis. Spearman's correlation coefficient was used to characterize the strength of the relationships. Descriptive statistics, correlations, ANOVA and Duncan's tests were conducted using SPSS software (Version 21.0, SSPS Inc., Chicago, USA).

Spatial heterogeneity of PAK and NEK concentrations was recorded using geostatistics. The analysis of spatial dependences was carried out through the calculation of variograms. The semi-variogram function was calculated as described by Goovaerts (1994).

The nugget-to-sill ratio is used to classify the spatial dependence of soil properties (Camberdella *et al.* 1994). The variable is considered to have a strong spatial dependence if the ratio is less than 25%, and it has a moderate spatial dependence if the ratio is between 25% and 75%; otherwise, the variable has a weak spatial dependence.

RESULTS AND DISCUSSIONS

The descriptive statistics of selected chemical and physical properties are given in Table 2. The soils have divergent texture, neutral to alkaline reactions, low EC and organic matter contents. The CEC ranges from 8.34 to 47.61 meq/100 g with a CV value of 34.26% indicating high variation within the study area which might be due to differences in type and content of clay, organic matter content, and calcium carbonate equivalent of soils. Organic matter contents in the surface and subsurface layers range from 0.2 to 6.78%.

Soils were formed over alluvium, serpentinite and limestone. The average PAK for the whole study area was 152.8 mg/kg (ranged from 17.1 to 1688.2 mg/kg) and 167.2 mg/kg (ranged from 23.7 to 2466.4 mg/kg) in surface and subsurface layers, respectively. Although the mean values of PAK do not show any deficiencies and even excess amount of PAK, the minimum values indicate the requirement for K fertilizer application for sustainable agricultural production. However, high PAK concentrations indicated that most crops might not respond to applied K. Although weathering of K-bearing minerals, release of K from minerals and

Table 2. Descriptive statistics of soil properties (Gunal *et al.* 2008)

Depth (cm)		Minimum	Maximum	Mean	SD	CV (%)	Skewness
0–30	sand (%)	6.3	65.0	26.6	11.80	44.5	0.52
	clay (%)	12.5	77.5	40.9	12.46	30.4	0.50
	silt (%)	12.5	51.3	32.5	7.75	23.8	0.05
	CEC (meq/100g)	8.34	47.61	22.56	7.73	34.3	0.82
	Ca (meq/100g)	16.60	76.90	42.00	10.80	25.7	0.34
	Mg (meq/100g)	1.57	19.62	6.61	3.28	49.6	1.10
	org matter (%)	0.59	6.78	2.02	0.90	44.4	2.08
	$CaCO_3$ (%)	1.79	28.05	8.43	4.13	49.0	1.56
	pH	7.07	9.47	8.16	0.26	3.1	0.67
	EC (dS/m)	0.126	1.72	0.333	0.193	57.9	3.85
30–60	sand (%)	5.5	87.5	28.5	14.91	52.3	0.94
	clay (%)	6.3	76.3	38.2	13.81	36.2	0.26
	silt (%)	5.0	62.0	33.3	9.43	28.3	0.18
	CEC (meq/100g)	4.32	47.10	20.35	7.94	39.0	0.94
	Ca (meq/100g)	20.02	68.98	46.33	7.41	16.0	–0.25
	Mg (meq/100g)	1.66	23.71	7.75	4.22	54.5	0.95
	org matter (%)	0.20	3.60	1.22	0.54	44.3	0.86
	$CaCO_3$ (%)	2.27	29.39	9.27	4.09	44.0	1.28
	pH	7.07	10.07	8.40	0.39	4.6	1.60
	EC (dS/m)	0.13	3.49	0.34	0.28	81.7	5.67

SD – standar deviation; CV – coefficient of variation; CEC – cation exchange capacity; EC – electrical conductivity non-exchangeable K sites in the surface soils have been reported as higher (Ghiri & Abtahi 2011), PAK concentrations of subsurface layers were higher for all parent materials than those of surface soils (Table 3). This may be due to the intensive crop production and the sandy texture of soils in the study area.

Parent material had a significant effect ($P \leq 0.05$) on PAK and NEK contents of soils. The lowest PAK was found in soils formed over serpentinite with average PAK of 86.4 and 88.0 mg/kg for surface and subsurface layers (Table 3), indicating that the soils were low in PAK. Bertsch and Thomas (1985) also reported that the amount of K in a soil is a function of the parent material and degree of weathering along with K fertilizer applied, crop removal, erosion, and leaching. PAK concentrations of soils over alluvium and limestone were quite similar to each other and not significantly different from each other (Table 3). Khan and Fenton (1996) found higher PAK and NEK in soils of the Missouri River floodplain than in upland soils in Iowa. This difference was attributed to the amounts of K associated with variation in the degree of weathering experienced by minerals in soils formed over alluvial deposits.

Values of PAK (CV of 92.33 and 112.83%) and NEK (CV of 52.48 and 62.94%) varied greatly among the studied soils. The concentration of K in agricultural soils may be partly associated to the variations of intensive management such as crops in rotation, irrigation, reclamation and fertilizer application. The average farm size in the study area is 2.17 ha (Sayili & Esengun 1996). The differences in agricultural practices adopted by farmers in small farms considerably affected the concentrations of PAK and K release from NEK, yielding a high variation shown in high CV values (Table 3).

Land use in the study area was divided into five categories based on crops planted: field crops, vegetables, orchards, pastures and fallow fields. The PAK and NEK concentrations under different land use types were not statistically different. The only difference was recorded in PAK concentrations of pastures for surface soils (Table 4). The highest PAK concentration was recorded in pastures which have never been cultivated and used only for grazing (Table 4). Average PAK values in surface soils were lower as compared to those of subsurface layers for all land use types. The lower value of PAK in subsurface layers indicates the greater plant uptake of K because of higher root density in the subsurface layers and low mobility of K fertilizers applied (Goli-Kalanpa *et al.* 2008). Continued removal of K without any supply as mineral fertilizer or manure led to depletion of PAK. Kayser & Isselstein (2005) stated that K deficiency in grasslands can occur within 3 to 10 years, if K is not supplied under continued

Table 3. Descriptive statistics of potassium concentrations (mg K/kg) based on parent materials

	Parent material	Depth (cm)	Minimum	Maximum	Mean*	SD	CV (%)	Skewness
PAK	study area	0–30	17.1	1688.2	152.8	141.09	92.3	4.66
	N = 400	30–60	23.7	2466.4	167.2	188.69	112.8	6.19
	alluvium	0–30	17.1	1688.2	161.9^{b}	155.26	95.9	4.56
	N = 294	30–60	23.7	2466.4	177.1^{b}	212.11	119.8	5.80
	serpentinite	0–30	23.6	243.8	86.4^{a}	47.22	54.7	1.04
	N = 43	30–60	30.2	193.0	88.0^{a}	44.15	50.2	1.00
	limestone	0–30	33.6	414.5	155.7^{b}	96.05	61.7	0.97
	N = 63	30–60	41.1	482.3	175.4^{b}	101.50	57.9	0.74
NEK	study area	0–30	228.5	3135.4	925.8	485.84	52.5	1.22
	N = 400	30–60	154.8	2639.6	734.6	462.40	62.9	1.52
	alluvium	0–30	228.5	3135.4	903.6^{b}	489.68	54.2	1.28
	N = 294	30–60	154.8	2639.6	706.5^{b}	466.51	66.0	1.65
	serpentinite	0–30	255.7	2017.7	703.8^{a}	355.25	50.5	1.83
	N = 43	30–60	313.8	826.1	539.5^{a}	144.09	26.7	0.50
	limestone	0–30	425.1	2918.5	1181.3^{c}	444.38	37.6	1.26
	N = 63	30–60	280.9	2368.0	998.8^{c}	482.05	48.3	0.65

PAK – plant available potassium; NEK – non-exchangeable potassium; SD – standar deviation; CV – coefficient of variation; *mean values in a column followed by the same letter are not significantly different (Duncan test, $P \leq 0.05$); N – No. of samples

doi: 10.17221/32/2016-SWR

Table 4. Plant available potassium contents (mg K/kg) for several crops

	Crops	Depth (cm)	Minimum	Maximum	Mean*	SD	CV (%)	Skewness
PAK	fallow	0–30	71.2	319.3	158.6^a	69.18	43.6	0.88
	N = 16	30–60	89.8	301.3	171.1^a	61.72	36.1	1.06
	field crops	0–30	23.6	1688.2	138.8^a	132.61	95.5	6.78
	N = 255	30–60	23.7	2466.4	157.3^a	190.09	120.9	7.92
	vegetable	0–30	28.4	540.2	134.2^a	108.95	81.2	1.99
	N = 73	30–60	24.0	568.9	133.6^a	105.61	79.0	2.08
	orchard	0–30	26.4	254.1	120.0^a	83.55	69.6	0.47
	N = 15	30–60	36.0	333.5	148.1^a	103.80	70.1	0.69
	pasture	0–30	17.1	1069.1	289.2^b	207.02	139.7	1.57
	N = 39	30–60	40.4	1226.5	300.2^a	289.65	103.6	1.86
NEK	fallow	0–30	439.1	1536.8	1010.0^a	337.00	33.4	–0.42
	N = 16	30–60	302.7	1189.3	751.6^a	234.64	31.2	–0.39
	field crops	0–30	255.7	2488.9	862.1^a	444.66	51.6	1.25
	N = 255	30–60	154.8	2394.6	704.4^a	444.46	63.1	1.58
	vegetable	0–30	351.2	2232.2	956.1^a	459.74	48.1	0.87
	N = 73	30–60	189.8	2639.6	828.9^a	538.29	64.9	1.27
	orchard	0–30	425.1	2918.5	1032.9^a	652.00	63.1	1.86
	N = 15	30–60	280.9	1682.2	651.7^a	326.47	50.1	2.38
	pasture	0–30	228.5	3135.4	1194.7^a	659.04	55.2	0.72
	N = 39	30–60	203.3	2545.7	785.5^a	533.07	67.9	1.31

PAK – plant available potassium; NEK – non-exchangeable potassium; SD – standar deviation; CV – coefficient of variation; *mean values in a column followed by the same letter are not significantly different (Duncan test, $P \leq 0.05$); *N* – No. of samples

mowing and nutrient conditions. Soils in Kazova watershed have been used for more than 50 years in irrigated agriculture with extensive crop rotation and low addition of K fertilizers.

According to the criterion of FAO (1990) on the availability of K, the critical value of K fertilizer recommendation for most crops is 140 mg/kg (soluble and exchangeable K) (Table 1, Figures 2 and 3). The maps of NH_4OAc-extractable K clearly show that the PAK level in the major part of the study area is well below this limit. However, the release of NEK can be considered as a K pool and can act as a source for providing K for plants in K-depleted soils. Although soils in Turkey contain large quantities of PAK and NEK, the reserves have considerably decreased (Munsuz *et al.* 1996), because of intensive crop production and little or no application of K fertilizers. Thus, the use of K fertilizers is required for sustainable agricultural production.

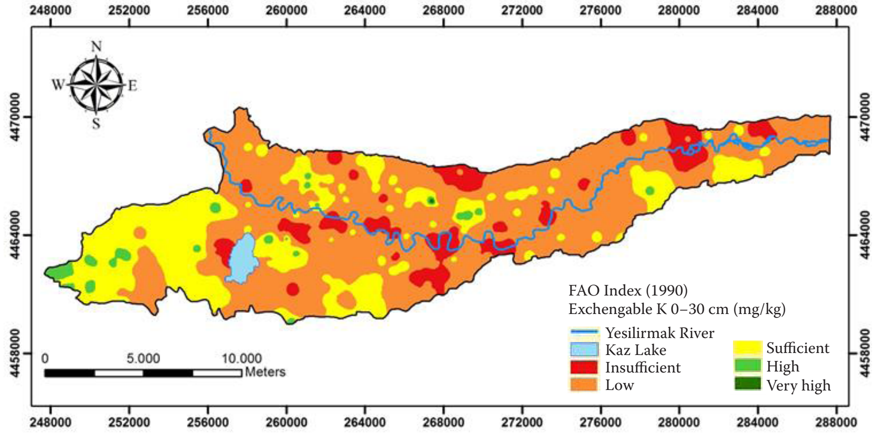

Figure 2. Plant available potassium classes of surface soils based on FAO (1990)

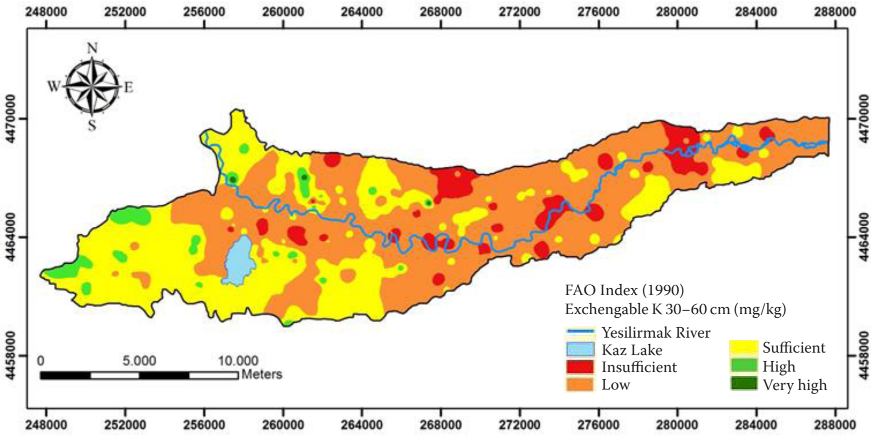

Figure 3. Plant available potassium classes of subsurface layers based on FAO (1990)

The values of NEK, which represent the soil supplying capacity of potassium in the long term, (Ghiri & Abtahi 2012) showed a wide variation and ranged from 228.5 mg/kg to 3135.4 mg/kg for surface and 154.8 mg/kg to 734.6 mg/kg for subsurface layers (Table 4). The introduction of high-yielding varieties, particularly vegetables and intensive cropping systems, into the watershed caused depletion of PAK in some parts of the study area.

The results of bivariate correlation analysis for K forms and soil properties are presented in Table 5. Soil properties have significant impacts on PAK through non-exchangeable K release from soils (Jalali & Khanlari 2014). The PAK and NEK concentrations had a significant positive correlation with clay content whereas significant negative correlations with silt and sand contents of soils. Nilawonk *et al.* (2008) reported that ninety-six percent of the total release of non-exchangeable K was from the clay-size fraction and approximately 4% was from the sand and silt fractions of soils. Madaras *et al.* (2014) also reported higher available K content in soils with higher clay content, which confirms the high dependence of K fractions on soil texture. The difference in K release from the non-exchangeable K sources in Kazova watershed mostly results from the variation of soil texture and organic matter content of soils.

The correlation analyses revealed that PAK contents were closely related to pH; in contrast, NEK showed no significant relationships with soil pH. Exchangeable Ca and Mg concentrations have significant correlations both with PAK and NEK (Table 5) for surface soils. Rowell (1985) also indicated that the levels of K in solution as well as the release of K are dependent on the concentrations of Ca and Mg in soil solution. Although Mg concentrations have a positive correlation with PAK, it has significant negative correlations ($P < 0.01$) with NEK concentrations (Table 5). The negative correlation between Mg and NEK probably results from the higher power of Mg than Ca to replace K in micas due to its greater hydrated size compared to Ca (Mengel & Kirkby 1987). Jalali (2008) also reported the occurrence of greater K release when Mg reaches the internal sites.

Significant positive relationships ($r = 0.54$ and $r = 0.51$, $P < 0.01$ surface and subsurface, respectively) were found between NEK and PAK (Table 5). Jalali (2007) and Ghiri and Abtahi (2011) reported that this can be due to the amounts of K adsorbed to sur-

Table 5. The relationship between plant available (PAK) and non-exchangeable potassium (NEK) and selected soil characteristics

	OM	EC	pH	$CaCO_3$	P	CEC	Ca	Mg	Sand	Clay	Silt	NEK
0–30 cm												
PAK	0.32**	0.19**	0.15**	0.15**	0.00	0.21**	0.26**	0.16**	–0.21**	0.27**	–0.12*	0.54**
NEK	0.15**	0.06	–0.01	0.00	0.02	–0.01	0.18**	–0.13**	–0.15**	0.22**	–0.13*	1.00
30–60 cm												
PAK	0.11*	0.28**	0.23**	0.15**	0.12*	0.21**	0.07	0.12*	–0.10*	0.19**	–0.11*	0.51**
NEK	0.25**	0.07	–0.07	–0.13*	0.09	0.11*	0.02	–0.23**	–0.09	0.25**	–0.22**	1.00

OM – organic matter; CEC – cation exchange capacity; EC – electrical conductivity**Significant at the 0.01 level, 2-tailed test; *significant at the 0.05 level

Table 6. Geostatistical parameters of plant available potassium (PAK) and non-exchangeable potassium (NEK)

	Model	Model r^2	Model RSS	Nugget variance (Co)	Sill (Co + C)	Range (m)	Spatial dependency (%)
PAK							
Surface	Exp	0.794	0.0175	0.027	0.432	2400	6.25
Subsurface	Exp	0.757	0.0234	0.194	0.437	3450	44.40
NEK							
Surface	Exp	0.931	0.00248	0.075	0.254	2220	29.54
Subsurface	Exp	0.968	0.00314	0.048	0.333	3870	14.41

Exp – exponential model; RSS – residual sum of squares

face exchangeable sites that is in equilibrium with K reserves and thus, its concentration in the soil solution will reflect the ability of soils to buffer the K supply.

Spatial distribution of potassium. Geostatistical information and parameters of variograms for PAK and NEK (0–30 and 30–60 cm depths) are given in Table 6. The distributions of PAK are shown in Figures 4 and 5.

The experimental semivariogram for the intercept of the parabolic equation shows a higher nugget variance (0.194) in subsurface compared with the nugget variance of PAK in surface (0.027) (Table 6). Measurement error and variation that occurs over a distance less than the sampling interval are the components of nugget variance. PAK with the low nugget value relative to sill variance in surface soil may be an indicator of spatial variability affected by intrinsic factors (i.e. soil formation, such as soil parent material). Soil properties are isotropic if they vary in a similar manner in all directions, in which case, the variogram depends on the distance between samples. There is no evidence of anisotropy in the variograms. This means that the level of NEK and the

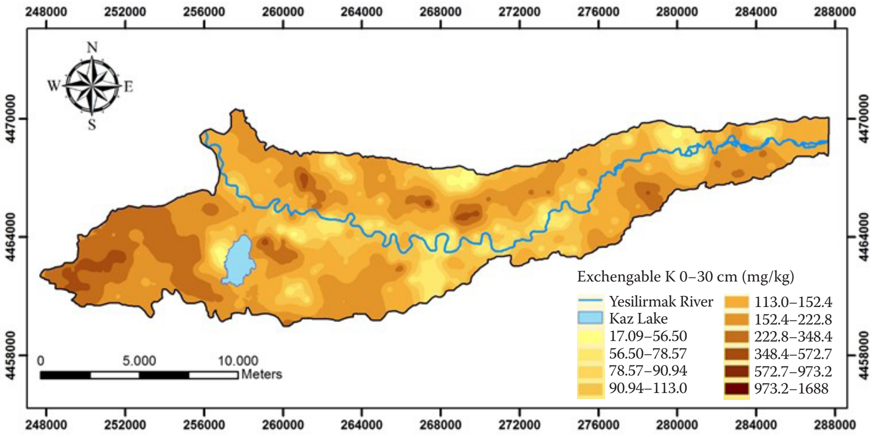

Figure 4. Spatial distribution of plant available potassium for 0–30 cm depth

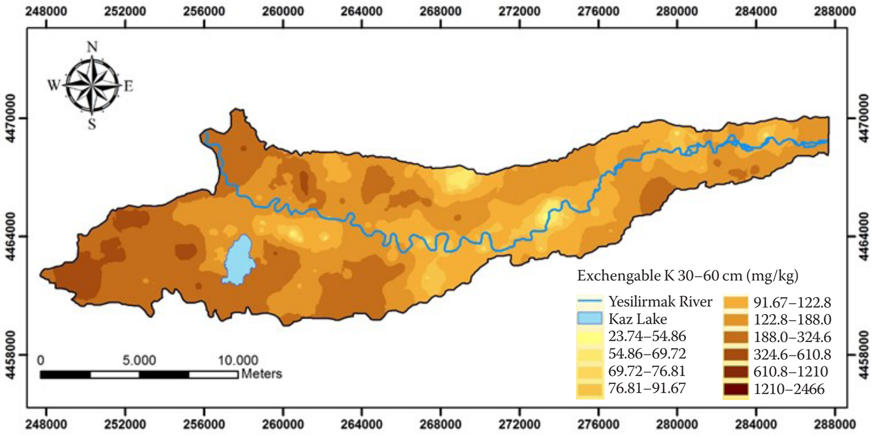

Figure 5. Spatial distribution of plant available potassium for 30–60 cm depth

doi: 10.17221/32/2016-SWR

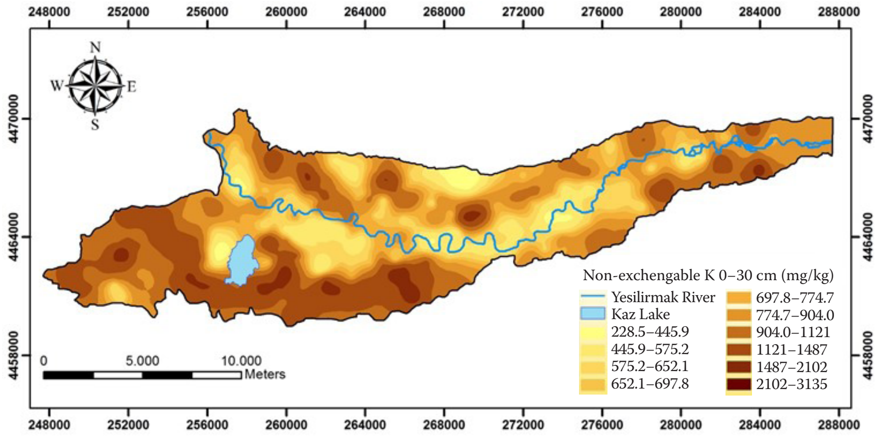

Figure 6. Spatial distribution of non-exchangeable potassium for 0–30 cm depth

intercept of the parabolic equation vary in a similar manner in all directions on the site and the semivariance depends only on the distance between samples (Andronikov *et al.* 2000). Therefore, isotropic models for the variograms were fitted using non-linear least squares regression analysis. Best-fit models are determined when the RSS is not further minimized by a significant change in model parameters.

The autocorrelation results from 400 sampling locations were used to determine the maximum separation distance where soil samples could have been taken and still allow for adequate interpolation between sample locations. The nugget-to-sill ratio showed a strong spatial dependence for soil pH and soil available K. The results showed that surface PAK and subsurface NEK were strongly spatially dependent with means of 152.82 and 734.61 mg/ kg. Subsurface PAK and surface NEK had a moderate spatial dependence with means of 167.23 and 925.82 mg/kg. Usually, strong spatial dependence of soil properties can be attributed to intrinsic factors, and weak spatial dependence can be attributed to extrinsic factors (Cambardella *et al.* 1994). The experimental variogram of K concentrations has been fitted with an exponential model. Maps of PAK and NEK contents were generated through the interpolation of measured values by kriging.

The highest PAK concentrations were found in the western part of the study area where the soils have high clay contents. Whereas the lowest concentrations of PAK were found in soils located at the Yesilirmak River bank where the soils are mostly high in sand content (Figures 4 and 5). Subsurface layers of the study area exhibited a similar pattern of distribution for high and low concentration of PAK.

The maps indicated an area in the west of the watershed with elevated NEK. In the middle part of the study area, there is relatively low NEK due to the high sand content of soils (Figures 6 and 7).

CONCLUSION

Watershed-scale determination of plant nutrients is needed to monitor and evaluate regional soil fertility. Many soils in lower Kazova watershed have high contents of NEK but relatively small amounts of PAK.

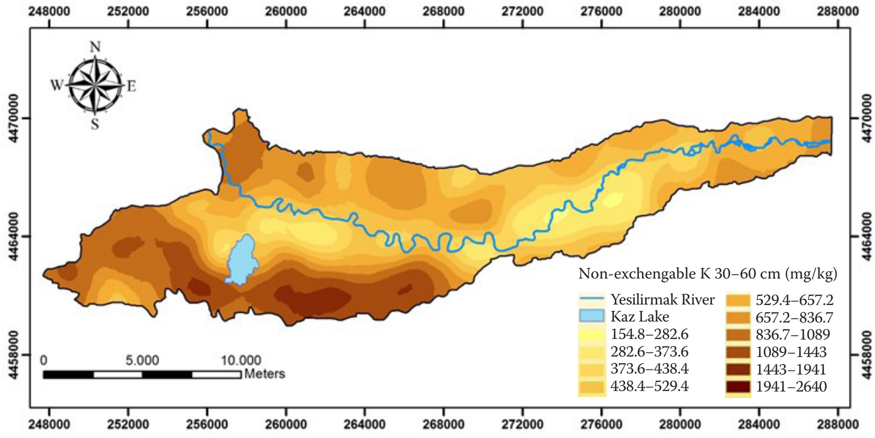

Figure 7. Spatial distribution of non-exchangeable potassium for 30–60 cm depth

Based on CV values, PAK was more variable than NEK in Kazova watershed soils. Soil parent material (alluvium, serpentine, limestone) caused differences in PAK and NEK of soils. Soils formed over serpentinite had the lowest PAK and NEK contents. While limestone originated soil had the highest NEK, and alluvium originated soil had the highest PAK.

Spatial variability patterns of PAK and NEK were similar and consistent at both soil depths. However, the spatial pattern of NEK was more differentiated in which high and low NEK areas were clearly represented. Our results also indicated that the spatial structure of PAK and NEK alters with soil parent material and with soil texture. The quantification of PAK and NEK provides useful information to improve soil fertility as well as soil quality of the lower Kazova Watershed.

***Acknowledgements**.* This study was funded by the Scientific and Technological Research Council of Turkey under a Grant Agreement No. TOVAG 107 O 879.

References

Allison L.E., Moodie C.D. (1965): Carbonate. In: Black C.A. *et al.* (eds): Methods of Soil Analysis. Part 2. Agronomy Series No. 9, Madison, American Society of Agronomy: 1379–1400.

Andronikov V.L., Afanas'yeva T.V., Simakova T. (2000): Mapping the soils of the major natural zones of the USSR from remote sensing imagery. Mapping Sciences and Remote Sensing, 28: 109–118.

Askegaard M., Eriksen J. (2000): Potassium retention and leaching in an organic crop rotation on loamy sand as affected by contrasting potassium budgets. Soil Use and Management, 16: 200–205.

Bertsch P.M., Thomas G.W. (1985): Potassium status of temperate region soils. In: Munson R.D. (ed.): Potassium in Agriculture. Madison, American Society of Agronomy Madison: 131–162.

Camberdella C.A. Moorman T.B., Novak J.M., Parkin T.B., Karlen D.L., Turco R.F., Konopka A.E. (1994): Field scale variability soil properties in central Iowa soils. Soil Science Society of America Journal, 58: 1501–1511.

Chapman H.D. (1965): Cation-exchange capacity. In: Black C.A. *et al.* (eds): Methods of Soil Analysis. Part 2. Agronomy Series No. 9, Madison, American Society of Agronomy: 891–901.

Durak A., Gunal H., Akbas F., Kılıc S. (2006): Long term cultivation effects on soil properties in pastures. Asian Journal of Chemistry, 18: 1953–1962.

FAO (1990): Micronutrients. Assessment at the Country Level. Soil Bulletin No. 63. Roma, FAO.

Gee G.W., Bauder J.W. (1986): Particle-size Analysis. In: Page A.L. (ed.): Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. 2nd Ed. Agronomy Monograph No. 9, Madison, American Society of Agronomy: 383–411.

Ghiri M.N., Abtahi A. (2011): Potassium dynamics in calcareous Vertisols of southern Iran. Arid Land Research and Management, 25: 257–274.

Ghiri M.N., Abtahi A. (2012): Factors affecting potassium fixation in calcareous soils of southern Iran. Archives of Agronomy and Soil Science, 58: 335–352.

Goli-Kalanpa E., Roozitalab M.H., Malakouti M.J. (2008): Potassium availability as related to clay mineralogy and rates of potassium application. Communications in Soil Science and Plant Analysis, 39: 2721–2733.

Goovaerts P. (1994): Study of spatial relationships between two set of variables using multivariate geostatistics. Geoderma, 62: 93–107.

Günal H., Akbaş F., Özgöz E., Ünlükara A., Yıldız H., Kurunç A., Çetin A., Ersahin S. (2008): Creating a Soil Database Required for Sustainable Agricultural Production in Kazova. TUBITAK Project TOVAG. 105 O 617, Ankara, TUBITAK. (in Turkish)

Helmke P.A., Sparks D.L. (1996): Lithium, sodium, potassium, rubidium, and cesium. In: Sparks D.L. (ed.): Methods of Soil Analysis. Part 3. Book Series No. 5, Madison, Soil Science Society of America: 551–573.

Jalali M. (2007): Spatial variability in potassium release among calcareous soils of western Iran. Geoderma, 140: 42–51.

Jalali M. (2008): Effect of sodium and magnesium on kinetics of potassium release in some calcareous soils of western Iran. Geoderma, 145: 207–215.

Jalali M., Khanlari Z.V. (2014): Kinetics of potassium release from calcareous soils under different land use. Arid Land Research and Management, 28: 1–13.

Kayser M., Isselstein J. (2005): Potassium cycling and losses in grassland systems: a review. Grass and Forage Science, 60: 213–224.

Kayser M., Benke M., Isselstein J. (2012): Potassium leaching following silage maize on a productive sandy soil. Plant, Soil and Environment, 58: 545–550.

Khan F.A., Fenton T.E. (1996): Secondary iron and manganese distributions and aquic conditions in a Mollisol catena of Central Iowa. Soil Science Society of America Journal, 60: 546–551.

Madaras M., Koubova M., Smatanova M. (2014): Long-term effect of low potassium fertilization on its soil fractions. Plant, Soil and Environment, 60: 358–363.

doi: 10.17221/32/2016-SWR

Mengel K., Kirkby E.A. (1987): Principal of Plant Nutrition. Bern, International Potash Institute.

Munsuz N., Çaycı G., Süeri A., Turhan M., Kibar M., Akıncı N., Mühürdaroğlu Y., Erel K. (1996): The relationship between clay mineralogy of soils in sugar beet grown fields and K release capacities in Central Anatolia. Publication No. 219, Ankara, The General Directorate of Turkish Sugar Industry: 59–60. (in Turkish with English abstract)

Nelson D.W., Sommers L.E. (1982): Total carbon, organic carbon, and organic matter. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd Ed. Madison, American Society of Agronomy: 539–579.

Nilawonk W., Attanandana T., Phonphoem A., Yost R., Shuai X. (2008): Potassium release in representative maize-producing soils of Thailand. Soil Science Society of America Journal, 72: 791–797.

Øgaard A.F., Krogstad T. (2005): Release of interlayer potassium in Norwegian grassland soils. Journal of Plant Nutrition and Soil Science, 168: 80–88.

Rhoades J.D. (1982): Cation exchange capacity. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis. Part 2. Agronomy Monograph No. 9, Madison, American Society of Agronomy: 149–157.

Rowell D.L. (1985): The reduction in sodicity during the displacement of mixed $CaCl_2$-NaCl salts from soils by water. Irrigation Science, 6: 11–18.

Sato S., Morgan K.T., Ozores-Hampton M., Simonne E.H. (2009): Spatial and temporal distributions in sandy soils with seepage irrigation: II. Phosphorus and potassium. Soil Science Society of America Journal, 73: 1053–1060.

Sayili M., Esengun K. (1996): A research on the determination of capitalization rate in the field land of Kazova Region of Tokat province. Gaziosmanpaşa University. Journal of Agricultural Faculty, 13: 211–233. (in Turkish)

Thomas G.W. (1982): Exchangeable cations. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis. Part 2. Agronomy Monograph No. 9, Madison, American Society of Agronomy: 159–165.

Trangmar B.B., Yost R.S., Uehara G. (1985): Application of geostatistics to spatial studies of soil properties. Advances in Agronomy, 38: 45–94.

Received for publication February 18, 2016
Accepted after corrections December 22, 2016