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Potassium pools equilibration during growth stages of two rapeseed cultivars under drought stress

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ABSTRACT- Different soil potassium (K) pools including soluble, exchangeable and non-exchangeable in surface and subsurface soils may be totally used by canola roots at different growth stages under drought conditions. A field experiment was conducted for one growing season (2013-2014) to study K pools changes during growth stages of two rapeseed cultivars under drought. The experiment was arranged in a randomized complete block design with four factors including different stages of rapeseed growth (before planting, seedling, stem elongation, flowering, grain filling and harvesting), drought (full irrigation, drought from flowering and silique formation), rapeseed cultivars (Sarigol and RGS) and soil depths (0-15 and 15-30 cm). Soil samples were collected and soluble, exchangeable and non-exchangeable K were determined. Results showed that the contents of soluble and non-exchangeable K (NEK) decreased during the growth stages (22 and 198 mg kg^{-1}, respectively) while the contents of exchangeable K increased until stem elongation (57 mg kg^{-1}) and then remained constant. Decrease in the contents of HNO_3-extractable K (sum of soluble, exchangeable and non-exchangeable K) in the topsoils was significantly more than that in the subsoils (198 vs. 142 mg kg^{-1}). Drought also had a significant effect on K pools distribution. Drought from flowering decreased the contents of NEK and HNO_3-extractable K; however, drought from silique formation had no significant effect on the contents of the different K forms. Type of rapeseed cultivar had no significant effect on K pools distribution. It is concluded that a severe decrease in HNO_3-extractable K occurs at the flowering stage (170 mg kg^{-1}) and it must be considered for K fertilizers management. Decrease in NEK during the rapeseed growth supports the hypothesis that this form of K may be released during a growth season and this large pool of K may be considered in K fertility management and fertilizer recommendations. Generally, K uptake by Sarigol cultivar was significantly higher than that by RGS cultivar (177.7 vs. 129.4 kg ha^{-1}). Potassium uptake by rapeseed decreased by drought and this decrease was more pronounced by drought from silique formation (more than 40% decrease in K uptake).

INTRODUCTION

Potassium (K) pools distribution among soluble, exchangeable and non-exchangeable may be affected by many factors such as soil physical and chemical properties, soil development, land physiographic position, soil moisture and temperature regimes, soil mineralogy and land use (Sharpley, 1989; Sharma et al., 2006; Najafi-Ghiri, et al., 2011c; Jalali and Khanlari 2014). There are equilibrium and kinetic reactions among different K forms that affect the level of soluble K in soil solution at any particular time, and subsequently, the amount of readily available K for plants. The forms of soil K regarding their availability to plants are soluble > exchangeable > non-exchangeable (Sparks, 2000).

Generally, plant roots can absorb K from soluble, exchangeable and non-exchangeable forms during the growth period. On the other hand, changes in different K forms during plant development stages may be related to the content of K absorbed by roots, irrigation management, K content in subsoil, etc. (Wang et al., 2013; Najafi-Ghiri, 2016). Potassium leaching by irrigation water to subsoils of coarse texture soils may be used by deep-rooted crops. Rao et al. (2001) indicated that the total amount of different forms of K in subsoil (15–30 cm) of 22 benchmark soil series of India was up to 96% of the topsoil.

Rapeseed (*Brassica napus* L.) cultivars are important for edible oil production under semiarid regions of Iran (Jabbari et al., 2013). Drought is a wide-spread problem seriously influencing rapeseed (Brassica napus L.) production and quality, but development of resistant cultivars is hampered by the lack of effective selection criteria (Rad and Abbasian, 2011). Rapeseed cultivars may be differed in K uptake and utilization which can lead to changes in K pools content in the topsoils and subsoils. Damon et al. (2007) indicated that the differences in the K efficiency among different genotypes of canola were due to genotypic differences in both the uptake and the utilization of K and K-efficient genotypes have a potential to improve canola yields on soils with low K availability.

Drought may affect K movement by mass flow and diffusion in soil to root surface and its uptake. On the other hand, under water stress, K uptake by canola cultivars was different and K alleviated some deleterious effects of drought (Eskandari et al., 2011). Sardans et al. (2008) observed a decrease in K uptake of plant under drought. Eskandari et al. (2011) concluded that water stress reduced the rates of K uptake by two cultivars of canola and also stated that the observed reduction was more pronounced in drought sensitive cultivar.

We hypothesized that different K pools including soluble, exchangeable and non-exchangeable in surface and subsurface soils may be exhausted by canola roots at different growth stages. On the other hand, drought may affect K uptake and utilization by canola. The main purposes of this investigation were to monitor changes in the contents of soluble, exchangeable and NEK in the topsoil and subsoil during different growth stages of two rapeseed cultivars and to investigate the effect of drought at different stages of rapeseed growth on K forms equilibration. The results of this research may be useful for K fertility management in calcareous soils of southern Iran where rapeseed is cultivated.

MATERIALS AND METHODS

Field Experiments

The experimental field was situated on a calcareous alluvial soil, Typic Haplustepts (Staff, 2014) in southeastern Fars province, Iran (28˚ 45.0΄N - 54˚ 26.8΄E). A Mediterranean climate prevails in the area with a mean annual temperature of 23˚C and 270 mm of precipitation. The physicochemical properties of the topsoil (0-15 cm) and subsoil (15-30 cm) were: pH of 7.54 and 7.64, EC of 2.6 and 1.6 dS m^{-1}, clay of 18 and 19 %, organic carbon of 0.05 and 0.05 %, total nitrogen of 0.16 and 0.16 %, available potassium of 160 and 140 mg kg^{-1} and available phosphorus of 35 and 28 mg kg^{-1}. A factorial experiment was done on a 3-ha field during 2013-2014 growing season. The experimental design was randomized complete block design with three replications. Treatments included different stages of rapeseed growth (one week before planting, seedling, stem elongation, flowering, grain filling and harvesting), irrigation regimes (full irrigation, drought from flowering and silique formation stages), rapeseed cultivars (Sarigol and RGS) and soil depths (0-15 and 15-30 cm). The amount of water applied was measured using a time–volume technique (Grimes et al., 1987). This technique is an irrigation technique in which irrigation water is applied by polyethylene pipes set in each plot and the irrigation time of each plot is calibrated by a timer and a standard container. Then, irrigation water amount of each plot (measured by gravimetric method) was converted to time (min) and applied.

The rationale for the selection of rapeseed cultivars in this study was to monitor changes in the content of soluble, exchangeable and NEK in topsoil and subsoil during different growth stages of Sarigol as an Iranian cultivar compared to RGS as a foreign cultivar. Both of the cultivars are early season plants with similar phenology. Also, there is no document about K use efficiency of these cultivars.

Mineralogical Analysis

For mineralogical analysis, cementing agents were removed from soil sample and then clay fraction was separated from sand and silt fractions (Kittrick and Hope, 1963; Jackson, 1975; Mehra and Jackson, 1960). Then X-ray diffraction (XRD) patterns were obtained with a Philips D500 diffractometer, using Ni-filtered Cuka radiation (40 kV, 30 mA) for clay samples treated with Mg, K, Mg+ethylene glycol and heat. The semi-quantitative percentages of the clay minerals were estimated according to Johns et al. (1954).

Soil Sampling and Analysis

About one kg composite soil samples from center and corners of plots from topsoil (0-15 cm) and subsoil (15-30 cm) were collected before planting and during different stages of the rapeseed growth (seedling, stem elongation, flowering, grain filling and harvesting) with a soil auger from each plot. The soil samples were air-dried and ground to pass a 2 mm sieve prior to analysis.

The contents of K present in different forms were determined by the methods outlined by Helmke et al. (1996). Soluble K was measured in the saturated extract. Exchangeable K was determined by extraction of 5 g soil sample with 20 mL 1M NH_4OAc (pH 7) for 5 min. Nitric acid-extractable K was measured by extraction of 2.5 g soil sample with 30 mL of boiling 1.0 M HNO_3 for 1 h. Non-exchangeable K (NEK) was calculated as the difference between HNO_3-extractable K and NH_4OAc-extracteable K. Potassium was measured on all filtrated extracts using a Corning 405 flame photometer (ELE, UK). Analyses were carried out in triplicate and the results for each form of K were presented as means.

Aerial parts of rapeseed were washed with distilled water, dried at 70˚C for 48 h in an oven and then were ground. The ground rapeseed samples were ashed at

500˚C, and digested with 2 N hydrochloric acid. Potassium content was determined by flame photometer (Corning 405, ELE, UK). Potassium uptake was determined as: biological yield × K concentration of foliage. At maturity, one square meter of central rows in each plot was harvested, dried in oven at 72ºC for 48 hr and weighted; then, the biological yield was determined as dry weight (kg) per unit area (m^{-2}).

Statistical Analysis

Statistical analysis was performed by the MSTAT-C software packages. Comparison of means was performed using the Duncan's Multiple Range Test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Mineralogical analysis for clay sample indicated that chlorite (30-40%), illite (20-30%), palygorskite (20-30%), smectite (5-10%) and quartz (5-10%) are dominant minerals within the soils (Figure 1). Results associated with clay mineralogy are in agreement with the findings of Khormali and Abtahi (2003) and Owliaie et al. (2006) for arid and semiarid soils of southern Iran.

Table 1 indicates the analysis of variance for the effect of growth stage, soil depth, irrigation regime, rapeseed cultivar and their interactions on the contents of soluble, exchangeable, non-exchangeable and HNO_3-extractable K.

Soluble K

Based on the analysis of variance (Table 1), the effects of growth stage and soil depth were found to be significant on soluble K content. As shown in Table 2, the content of soluble K was 36.4 mg kg^{-1} before planting and increased to 44.9 mg kg^{-1} at seedling stage, but it decreased after seedling stage and reached 14.9 mg kg^{-1} at harvesting stage. Generally, a severe decrease in soluble K was observed at flowering stage and remained constant until harvesting.

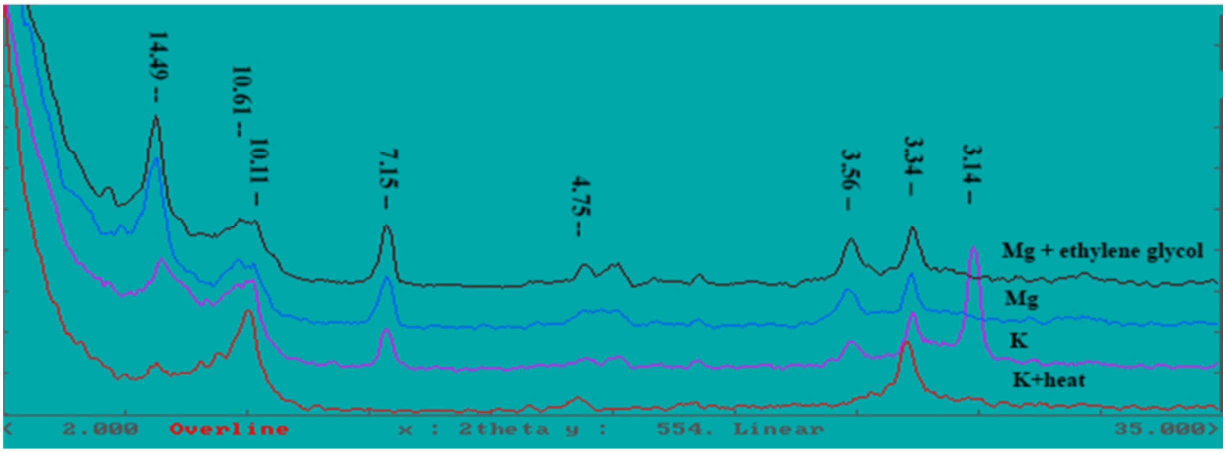


Fig. 1. X-ray diffraction patterns of clay fraction of the studied topsoil.

Table 1. Analysis of variance for the effects of growth stage (A), soil depth (B), irrigation regime (C), and rapeseed cultivar (D) and their interactions on different forms of K in the studied soils.

Source of variation	DF	Soluble K	Exchangeable K	NEK	HNO_3-extractable K
Replication	2	25.7	1891.5ns	7081.5**	19119.1**
Factor A	5	5558.5**	14874.3**	230746.4**	224834.2**
Factor B	1	1310.3**	115.6^{ns}	20261.4**	33301.5**
A×B	5	673.6**	996.1^{ns}	4295.2**	9218.9**
Factor C	2	89.1^{ns}	3537.6*	57123.1**	35889.3**
A×C	10	168.1**	1245.1^{ns}	7083.0**	2707.1^{ns}
B×C	2	56.7^{ns}	666.7^{ns}	1740.0^{ns}	3133.2^{ns}
A×B×C	10	204.0**	1136.7^{ns}	1620.4^{ns}	2114.1^{ns}
Factor D	1	88.2^{ns}	1611.6^{ns}	9868.5**	2588.2^{ns}
A×D	5	237.5**	1715.0^{ns}	3852.0**	3507.2**
B×D	1	35.9^{ns}	422.2^{ns}	3230.3**	1986.9^{ns}
A×B×D	5	129.7**	985.6^{ns}	2055.0^{ns}	739.4^{ns}
C×D	2	7.8^{ns}	3388.9*	2960.0^{ns}	4772.4**
A×C×D	10	95.1**	1364.5^{ns}	3306.6**	2324.5^{ns}
B×C×D	2	56.9^{ns}	1440.2^{ns}	6722.5**	11225.8**
A×B×C×D	10	71.2*	529.1^{ns}	2225.6*	2346.2^{ns}
Error	142	34.9	1090.8	1090.8	77.6
Total	215				
C.V		21.03	17.75	7.54	1.35

** and * represent 0.01 and 0.05 levels of significance, respectively. ns represents non-significant.

Table 2. Contents of soluble K (mg kg^{-1}) under different soil depths and growth stages of rapeseed.

Growth stage	Soluble K (mg kg^{-1})		Mean
	Topsoil	Subsoil	
Before planting	42.6b	30.3d	36.4B
Seedling	54.4a	35.4c	44.9A
Stem elongation	34.1cd	37.0c	35.6B
Flowering	19.1e	19.3e	19.2C
Grain filling	17.9ef	17.2ef	17.6CD
Harvesting	15.3ef	14.6f	14.9D
Mean	30.8A	25.7B	

Means followed by different letters are significantly different at *P<0.05* by Duncan's Multiple Range Test.

The content of soluble K was also affected by soil depth; its content in the topsoil was significantly higher than that in the subsoil. In fact, at earlier stages of rapeseed growth (before stem elongation), the contents of soluble K in the topsoils were larger than those in the subsoil; but this difference was diminished at later stages of rapeseed growth (from stem elongation to harvesting). Overall, from planting to harvesting, the decrease in the contents of soluble K in the topsoils was significantly higher than that in the subsoils (27.3 vs. 15.7 mg kg^{-1}).

Exchangeable K

Analysis of variance detected significant effects of growth stage and irrigation regime on the content of soil exchangeable K. The content of exchangeable K was 151 mg kg^{-1} before planting, increased to 208 mg kg^{-1} at stem elongation stage and remained constant during the three last stages (Figure 2). A severe increase was observed at stem elongation stage. Figure 3 indicates that irrigation regime has a significant effect on the contents of soil exchangeable K so that the drought from silique formation decreased exchangeable K more than the drought from the flowering stage. Interaction of irrigation regime and rapeseed cultivar also had a significant effect on the contents of exchangeable K (Table 1) and the highest and lowest contents of exchangeable K were found in soils cultivated with Sarigol cultivar under drought from flowering and soils cultivated with Sarigol cultivar under drought from silique formation, respectively.

Non-exchangeable K

Analysis of variance (Table 1) indicated that the content of non-exchangeable K (NEK) was affected by all parameters including growth stage, soil depth, irrigation regime, rapeseed cultivar and their interactions. Figure 4 indicated that the content of NEK was 539 mg kg^{-1} before planting, decreased during the next stages and reached 341 mg kg^{-1} at harvesting (36% decrease in NEK). Unlike soluble and exchangeable K, the content of NEK decreased from grain filling stage and then remained constant. There was a significant difference in NEK content among different irrigation regimes (Table 3). The lowest contents of NEK were found in soils that were under drought after flowering. On the other hand, this result was not observed for soils that were under drought after silique formation. The content of NEK was also affected by the interaction of soil depth and rapeseed cultivar so that the highest content of NEK was found in the topsoils of RGS cultivar.

HNO_3-extractable K

Based on the analysis of variance (Table 1), growth stage, soil depth and irrigation regime were found to be significant on HNO_3-extractable K values. The mean contents of the HNO_3-extractable K (sum of soluble, exchangeable and NEK) in topsoils and subsoils decreased during the growth stages of rapeseed from 727 mg kg^{-1} before planting to 556 mg kg^{-1} at harvesting. In fact, it remained constant until stem elongation.

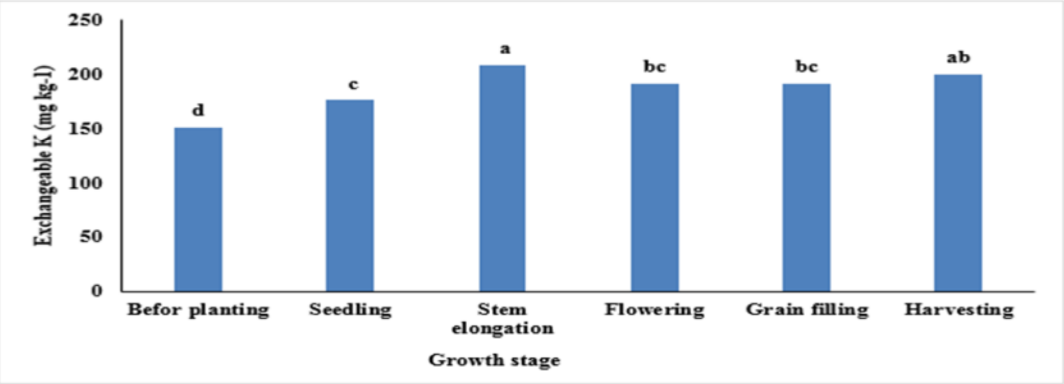


Fig. 2. Changes in contents of exchangeable K during different stages of rapeseed growth. Means followed by different letters are significantly different at *P<0.05* by Duncan's Multiple Range Test.

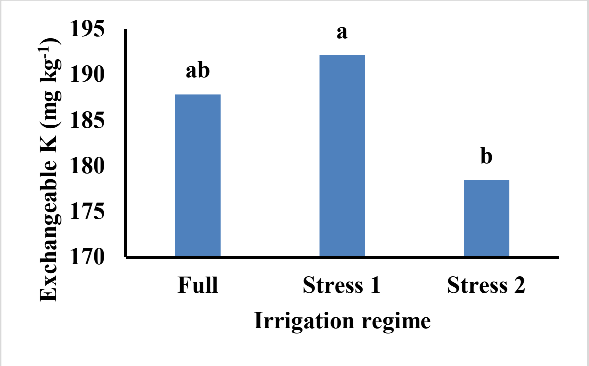


Fig. 3. Contents of exchangeable K under different irrigation regimes (Full: Full irrigation; Stress 1: Drought from flowering stage; Stress 2: Drought from silique formation stage). Means followed by different letters are significantly different at *P<0.05* by Duncan's Multiple Range Test.

Then, a severe decrease was observed at stem elongation. It is essential to note that the reduction in the contents of HNO_3-extractable K in the topsoil was significantly more than that in the subsoils (198 vs. 142 mg kg^{-1}) (Figure 5).

Generally, the contents of HNO_3-extractable K in the topsoils were significantly more than those in the subsoil. As is evident from the data in Table 4, drought from flowering decreased the contents of HNO_3-extractable K while the contents of HNO_3-extractable K were not affected by drought from silique formation. Also, plant variety had no significant effect on the contents of HNO_3-extractable K.

Table 3. Content of NEK under different soil depths, irrigation regimes and rapeseed cultivars.

Soil depth	Rapeseec cultivar	Irrigation regime Full	Stress 1	Stress 2	Mean
Topsoil	Sarigol	453.1ab	395.4f	455.2ab	434.6AB
	RGS	444.6abc	435.1bcd	449.9a	443.2A
Subsoil	Sarigol	419.7de	403.6ef	461.7a	428.3B
	RGS	426.3cde	410.9ef	449.0abc	428.7B
Mean		435.9A	411.3B	454.0A	

Full: Full irrigation; Stress 1: Drought from flowering stage; Stress 2: Drought from silique formation stage. Means followed by different letters are significantly different at *P<0.05* by Duncan's Multiple Range Test.

Potassium Pools Distribution

Fig. 6 shows K pools distribution among soluble, exchangeable and non-exchangeable forms during different stages of rapeseed growth. Potassium pools distribution is calculated as a ratio of each form of K divided by the sum of soluble, exchangeable and NEK (HNO_3-extractable K) contents and expressed as percentage. Generally, during the growth stages of rapeseed, the percentage of non-exchangeable and soluble K decreased while the percentage of exchangeable K increased. The percentage of NEK severely decreased at stem elongation and then remained constant. Results also indicated that soil depth, irrigation regime, rapeseed cultivar and their interactions had no significant effects on K pools distribution (Table 1).

Rapeseed Yield and K Uptake

Biological yield of rapeseed was affected by irrigation regime (Table 5). The highest biological yield was obtained under full irrigation while the drought, especially from flowering, reduced biological yield significantly (Table 6). On the other hand, the mean biological yield of Sarigol cultivar was significantly higher than that of RGS cultivar (0.91 kg m^{-2} vs. 0.66 kg m^{-2}). Also, under drought from flowering, the highest biological yield (0.54 kg m^{-2}) was obtained in Sarigol cultivar.

Total K uptake by rapeseed was also affected by irrigation regime and rapeseed cultivar (Table 7). Generally, K uptake by Sarigol cultivar was significantly higher than that by RGS cultivar (177.7 vs. 12.4 kg ha^{-1}). Potassium uptake by rapeseed decreased by drought and this decrease was more pronounced by drought from silique formation (more than 40% decrease in K uptake).

Consequently, it can be deduced from the results that two trends can be discussed and compared in more detail during different stages of rapeseed growth: changes in the content of K forms and K pools distribution. During rapeseed growth, the content of soluble and NEK decreased while the content of exchangeable K increased (Table 2 and Figures 2 and 4). Therefore, the content of HNO_3-extractable K (sum of soluble, exchangeable and non-exchangeable forms) decreased (Fig. 5). Generally, numerous factors may affect the content of different K forms during plant growth. It seems that the most important factors were K uptake by plant and K leaching to a lower depth (>30 cm). At seedling stage, no significant change was observed in the content of HNO_3-extractable K; but K distribution among soluble, exchangeable and NEK changed (Figs. 5 and 6). During seedling stage, the importance of plant uptake in K equilibration is not significant, but soil tillage and irrigation activities may affect K pools distribution.

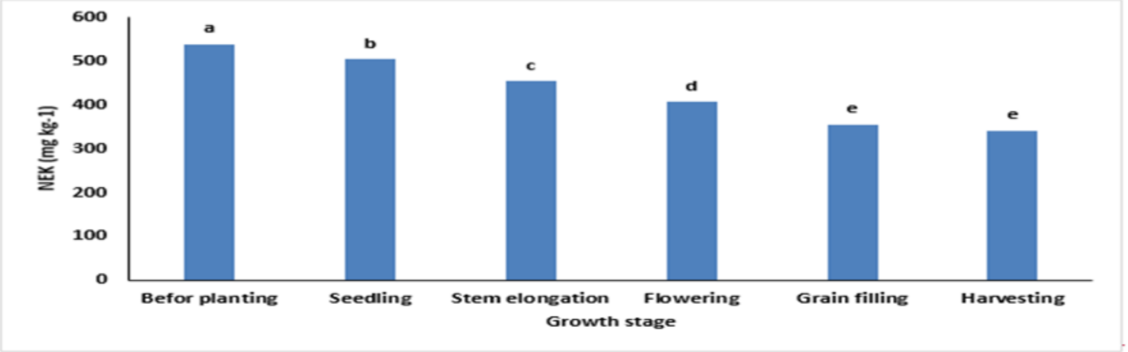


Fig. 4. Changes in contents of NEK during different stages of rapeseed growth. Means followed by different letters are significantly different at $P<0.05$ by Duncan's Multiple Range Test.

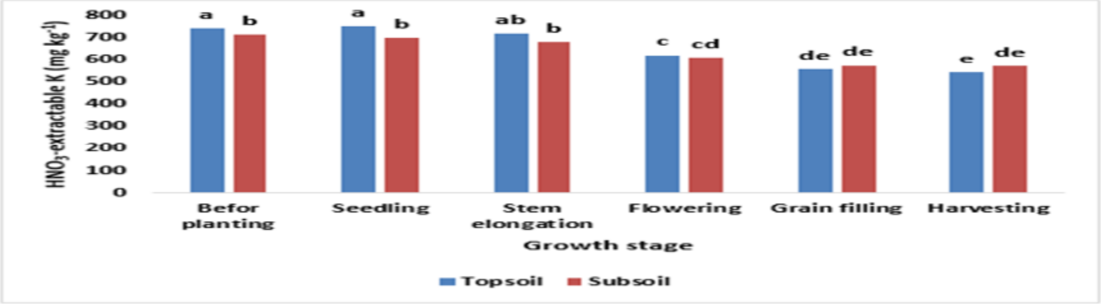
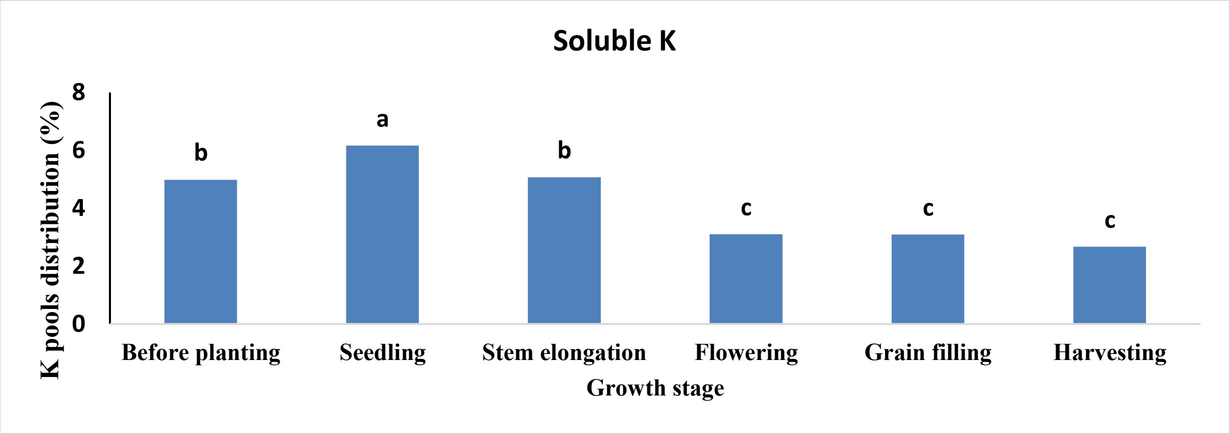
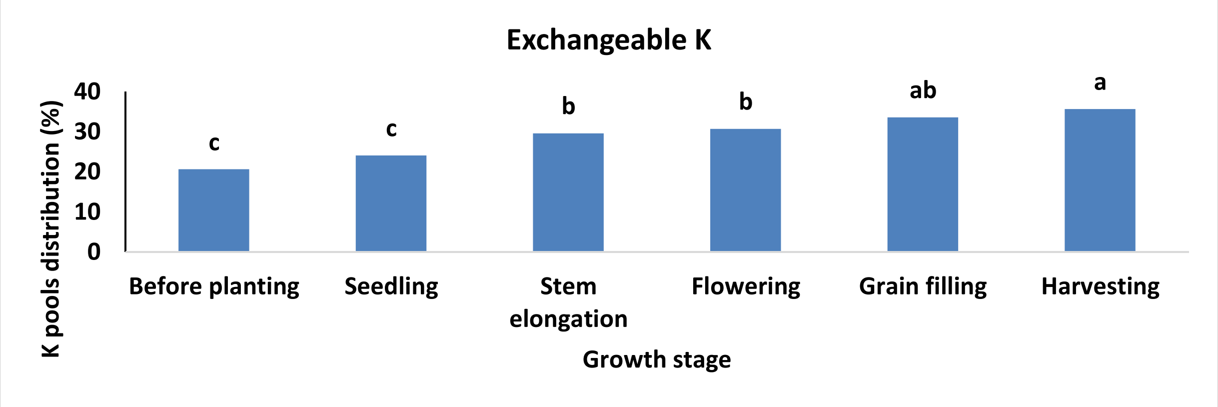


Fig. 5. Changes in contents of HNO_3-extractable K during different stages of rapeseed growth. Means followed by different letters are significantly different at $P<0.05$ by Duncan's Multiple Range Test.





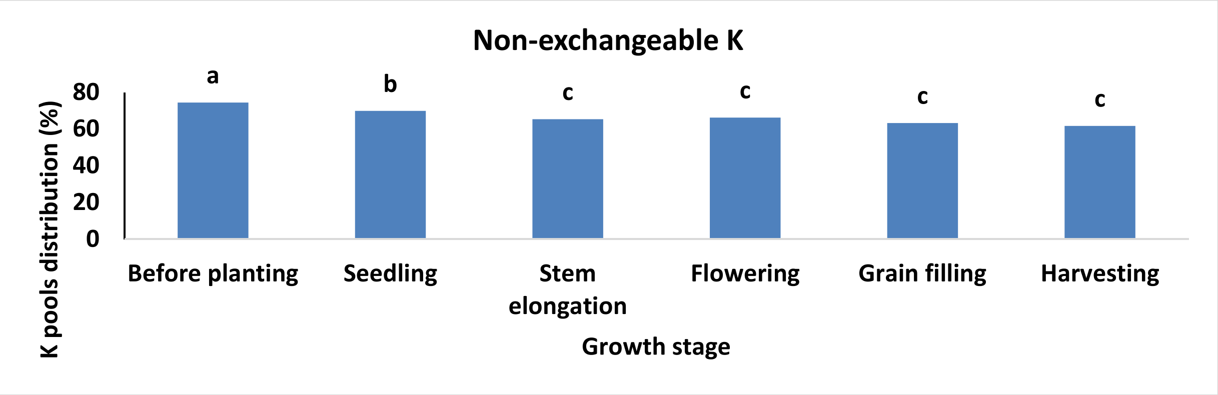


Fig. 6. Changes in distribution of soluble, exchangeable and non-exchangeable K during different stages of rapeseed growth. Means followed by different letters are significantly different at *$P<0.05$* by Duncan's Multiple Range Test.

The increase in the contents of soluble and exchangeable K may be due to the release of K ions from the non-exchangeable form (Najafi-Ghiri et al., 2011a). In dry soil (before planting), soluble K becomes more concentrated in a smaller volume of soil solution, which increases the concentration gradient and thereby diffusion of K to non-exchangeable form; but when soil is irrigated (before seedling), the release of NEK occurs (Najafi-Ghiri and Abtahi, 2012, Najafi-Ghiri et al., 2011b; Olk et al., 1995). Since most calcareous soils of southern Iran are dominated by mica and illite (as important K-bearing minerals), release of NEK may be considerable (Najafi-Ghiri et al., 2011a). At stem elongation, the content of HNO_3-extractable K decreased due to K uptake by plant and presumably K leaching. At later stages of plant growth, irrigation cutoff (decrease in K leaching) and decrease in plant growth rate (low K uptake) and thereby negligible K removal allow soil to come close to the K equilibration.

Table 4. Contents of HNO_3-extractable K under different soil depths, irrigation regimes, and rapeseed cultivars

Soil depth	Rapeseed cultivar	Irrigation regime Full	 Stress 1	 Stress 2	Mean
Topsoil	Sarigol	670.9a	631.0d	659.7b	653.9A
	RGS	657.8b	640.7c	670.7a	656.4A
Subsoil	Sarigol	630.2d	622.4e	660.2b	637.6B
	RGS	641.5c	628.8d	654.6b	641.6AB
Mean		650.1A	630.7B	661.3.3A	

Full: Full irrigation; Stress 1: Drought from flowering stage; Stress 2: Drought from silique formation stage. Means followed by different letters are significantly different at *$P<0.05$* by Duncan's Multiple Range Test.

Comparison of different K forms before planting and at harvesting stage indicated that the major part of K removal by plant uptake and leaching is originated from the NEK pools that is defined as a slowly available form of K (Havlin et al., 1999). On the other hand, the content of readily available K (soluble and exchangeable forms) showed no significant change. At fallow period (before planting) that is synchronized with dry summer, most K ions from solution and exchange sites are diffused to the wedge zone and interlayers of K-fixing minerals (Najafi-Ghiri and Abtahi, 2012).

Table 5. Analysis of variance for irrigation regime (A) and rapeseed cultivar (B) and their interaction.

Source of variation	df	Yield	K uptake
Replication	2	22.8	720.2
Factor A	2	224.6*	9474.4*
Factor B	1	391.1*	16464.2*
A×B	2	262.5*	7272.7*
Error	10	55.7	1453.2
Total	17		
C.V (%)		24.64	24.83

* represents 0.05 level of significance. ns represents non-significant.

Table 6. Biological yield of two rapeseed cultivars (kg m^{-2}) affected by irrigation regime.

Rapeseed cultivar	Irrigation regime Full	 Stress 1	 Stress 2	Mean
Sarigol	1.22a	0.98cd	0.54g	0.91d
RGS	1.09bc	0.61fg	0.28i	0.66f
Mean	1.15ab	0.79e	0.41h	

Full: Full irrigation; Stress 1: Drought from flowering stage; Stress 2: Drought from silique formation stage. Means followed by different letters are significantly different at *$P<0.05$* by Duncan's Multiple Range Test.

At growing season when soil was irrigated, K ions were released from wedge zone and interlayering sites to soluble and exchangeable forms and were subsequently absorbed by plant. Thus, the content of NEK decreased while the content of soluble and exchangeable K was not affected significantly. However, Tening et al. (1995) concluded that fallow lands had available K more than continuously fertilized lands.

Potassium pools distribution as a function of soil depth indicated the importance of subsoil in supplying K for plant. Generally, K removal from the subsoil was up to 70% of the topsoil. Decrease in the content of NEK in the topsoil was more than that in the subsoil and this may be due to the higher weathering nature of the topsoil and release of mineral and NEK to more available form (Najafi-Ghiri et al., 2011c). Generally, the content of K in the subsoil was up to 98 % of that in the topsoil. This result is consistent with the finding of Rao et al. (2001) for 22 benchmark soil series of India and Najafi-Ghiri et al. (2011c) for 56 calcareous soils of southern Iran.

Drought may affect K pools distribution due to the effect on vegetative growth rate, exploration of subsoil by roots for water and subsequently K, decrease in K leaching, capillary movement of K ions to the topsoil, etc. In the current research, drought from flowering decreased the content of NEK and HNO_3-extractable K while drought from silique formation had no significant effect on the contents of different forms of K. This may be due to the increase in root growth for better exploration of soil for water and thereby K under drought. Sardans et al. (2008) observed a decrease in K uptake by plant under drought and concluded that it is due to the reduction of soil water content and photosynthetic capacity that decreased plant uptake capacity.

Although, biological yield of rapeseed may be affected by drought, RGS cultivar showed no significant decrease. However, Sarigol cultivar was sensitive to drought and its yield decreased from 44.2 to 20.9 ton ha^{-1} (53% decrease).

Potassium uptake by RGS cultivar was not affected by drought, while drought from silique formation reduced K uptake by Sarigol cultivar from 229.7 to 94.0 kg ha^{-1}. Potassium uptake by rapeseed had a significant relationship with biological yield of rapeseed (Fig. 7). However, no significant relationships were found between K uptake and biological yield with different forms of K (soluble, exchangeable, non-exchangeable and HNO_3-extractable K).

CONCLUSIONS

In this research, we concluded that soil K equilibration may change during different stages of rapeseed growth. Generally, a severe decrease in soluble and NEK occurred while exchangeable K increased until stem elongation and then remained constant. Therefore, it is necessary to consider the content of soil NEK in K fertilizers recommendation for rapeseed cultivars. It means that methods that extract soil soluble and exchangeable K may not be suitable in soils containing K-bearing minerals. Potassium pools distribution analysis also indicated that K ions tend to concentrate in the exchangeable form at the end of rapeseed growth. The contents of soluble K and NEK in topsoils were significantly higher than those in the subsoils, which indicated the importance of surface soil in supplying K for plant roots. However, exchangeable K was not affected. Irrigation regime had a significant effect on exchangeable K and NEK so that the highest content of exchangeable K and the lowest content of NEK were observed in soils affected by drought from flowering stage of rapeseed growth. Thus, in arid and semiarid regions where plants may be exposed to drought season, this should be considered for K fertility management. There was no significant difference in soil K equilibration between two rapeseed cultivars. Decrease in NEK during the growth stages of rapeseed supports the hypothesis that this form of K may be released during a growth season and this large pool of K may be considered in K fertility management and fertilizer recommendations. It seems that RGS cultivar is more resistant to drought and its yield and K uptake may be less affected by water tension during growth season. Therefore, this cultivar is recommended for arid and semiarid regions of southern Iran.

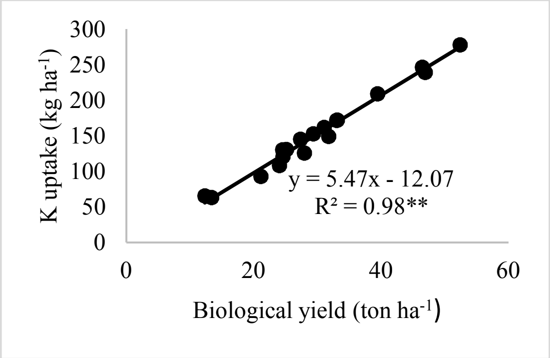


Fig. 7. Relationship between biological yield of rapeseed and K uptake.

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تعادل شکل‌های پتاسیم در طول دوره رشد دو رقم کلزا در شرایط خشکی

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چکیده- شکل‌های مختلف پتاسیم شامل پتاسیم محلول، تبادلی و غیرتبادلی در خاک‌های سطحی و زیرسطحی می‌تواند به‌وسیله ریشه کلزا در مراحل مختلف رشد و در شرایط تنش خشکی جذب شوند. به منظور بررسی تغییرات منبع پتاسیم آزمایشی مزرعه‌ای در مراحل مختلف رشد دو رقم کلزا در شرایط تنش خشکی در طول فصل رشد ۱۳۹۲-۱۳۹۳ اجرا شد. آزمایش به‌صورت کرت‌های خرد شده در قالب طرح بلوک‌های کامل تصادفی انجام شد که شامل سه تیمار مراحل مختلف رشد کلزا (قبل از کاشت، رشد گیاهچه، رشد طولی ساقه، گلدهی، دوره پر شدن دانه و برداشت کلزا)، تنش خشکی (آبیاری کامل و تنش خشکی از گلدهی و تشکیل خورجین)، رقم کلزا (ساری‌گل و آر جی اس) و عمق نمونه برداری (۰-۱۵ و ۱۵-۳۰ سانتیمتر) بود. نمونه‌های خاک جمع آوری و میزان پتاسیم محلول، تبادلی و غیرتبادلی خاک اندازه‌گیری شدند. نتایج نشان داد در طی مراحل رشد کلزا میزان پتاسیم محلول و غیرتبادلی کاهش یافت (به ترتیب ۲۲ و ۱۹۸ میلی‌گرم بر کیلوگرم)؛ در حالی که مقدار پتاسیم تبادلی تا مرحله ساقه رفتن افزایش (۵۷ میلی‌گرم بر کیلوگرم) و سپس ثابت باقی ماند. کاهش در میزان پتاسیم قابل استخراج با اسید نیتریک (مجموع پتاسیم محلول، تبادلی و غیرتبادلی) در خاک سطحی به طور معنی‌داری بیشتر از مقدار آن در خاک زیرسطحی بود (۱۹۸ در مقایسه با ۱۴۲ میلی‌گرم بر کیلوگرم). تنش خشکی همچنین تأثیر معنی‌داری بر توزیع شکل‌های پتاسیم خاک داشت. تنش خشکی از گلدهی باعث کاهش پتاسیم غیرتبادلی و قابل استخراج با اسید نیتریک شد؛ هر چند که تنش خشکی از مرحله تشکیل خورجین تأثیر معنی‌داری روی مقادیر شکل‌های مختلف پتاسیم نداشت. نوع رقم کلزا تأثیر معنی‌داری بر توزیع شکل‌های پتاسیم نداشت. می‌توان نتیجه گرفت که یک کاهش پتاسیم شدیدی در خاک در مرحله گلدهی کلزا اتفاق می‌افتد (۱۷۰ میلی‌گرم بر کیلوگرم) که برای مدیریت کود پتاسیم باید در نظر گرفته شود. کاهش در میزان پتاسیم غیرتبادلی در طول دوره رشد کلزا این فرضیه را تقویت می‌کند که این شکل از پتاسیم ممکن است در طول فصل رشد آزاد شود و این منبع بزرگ پتاسیم می‌بایست در مدیریت حاصلخیزی و توصیه کودی پتاسیم در نظر گرفته شود. به طور کلی، جذب پتاسیم به‌وسیله رقم ساری‌گل به‌طور معنی‌داری بیشتر از رقم آر جی اس بود (۱۷۷/۷ در مقابل ۱۲۹/۴ کیلوگرم در هکتار). جذب پتاسیم به‌وسیله کلزا با تیمار خشکی کاهش یافت و این کاهش در تیمار خشکی از مرحله تشکیل خورجین مشخص‌تر بود (بیش از ۴۰ درصد کاهش در جذب پتاسیم).