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COMPARATIVE INTERACTION OF CS AND K IN THE SHOOTS OF *TRIFOLIUM PRATENSE* PLANTS

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Abstract: Under greenhouse conditions a pot experiment was carried out to investigate the comparative interaction of Cs and K in the shoots of plants, and to interpret the way that K^+ ions related to that of Cs^+ in soil-plant systems. Also the soil properties that affect Cs uptake by *Trifolium pratense* plants were determined. The plants grown on four different soil types, contaminated with 40 mg kg^{-1} of Cs, and sown at 60, 240 and 420 days after contamination (treatments). During each treatment two cuts of the shoots were performed. According to the results significantly variations on Cs uptake by *Trifolium pratense* plants observed among different cuts, soil types and treatments. Regardless to soil type or treatment, it was found that as the concentration of Cs decreased, the K content increased in shoots in both plant cuts. Such relationship, confirms the occurrence of a direct competition between Cs and K ions during the process of accumulation through the plant tissues, suggesting that the two elements could have a common accumulation mechanism and that Cs uptake by plants can be suppressed by the competition of Cs and K ions in the plant tissues. Due to the competitive interactions that occurred between Cs and K ions, the discrimination factor (DF), which is often used to evaluate plant's efficiency to absorb nutrients from soil, was additionally estimated. In all treatments DF values were below unity, suggesting a preferential uptake of K over Cs. Thus, K appears to be one of the main factors influencing the plant mobility of Cs and behaves not only as a competitor to Cs ions, but also as an effective inhibitor of Cs uptake by plants. Among the soil properties it was observed that the particle size fractions as well as the K content in soils play a predominant role on Cs availability to plants. Thus, Cs uptake by plants is a result of reactions both in the soil and in the plant, implying that Cs transport from soil to plant is controlled by a complex mechanism. Therefore the utilization of the K-status of plant tissues simultaneously with the soil properties is essential to monitor and estimate soil to plant Cs mobility.
Key Words: Cesium, Potassium, Soil, *Trifolium pratense* plants, Discrimination factor

1. INTRODUCTION

Radiocesium, an artificial radionuclide that is presented in soils due to natural processes, global fallout from nuclear weapon testing, discharge from nuclear installations, disposal of nuclear wastes and occasionally nuclear accidents, such as Chernobyl in 1986, poses a serious threat to biological systems. The knowledge of Cs behavior in the environment and of the factors that affect Cs uptake process by plants is not only important for monitoring the soils that are already contaminated, but also for facing the challenges of the expansion of nuclear power. Among the alkali metals, stable Cs (^{133}Cs), with identical chemical behavior to radioactive isotopes of Cs, has been proposed as suitable to investigate the transport route of ^{137,134}Cs in various environmental systems, such as soil-plant transfer (Cook et al., 2007). Thus as stable Cs provides a useful analogy for ^{137,134}Cs and as the fate of radionuclides in the environment follows the behavior of stable elements, ^{133}Cs can be used as an indicator of the long term behavior of the relative radioactive isotopes (Yoshida et al., 2004).

The mobility and fate of Cs in the soil to plant system is a function of processes occurring in the soil, since soil solution acts as an intermediate environment between the solid phase and plant roots, and in the plants, due to different physiological reactions for nutrient acquisition that are attributed to genotypic dissimilarities (White and Broadley, 2000). Among the soil properties there are certain soil parameters, such as clay content, CEC, clay mineralogy and potassium content that could diminish the mobility and availability of Cs to plants and thus its assimilation by biota (Shender and Eriksson, 1993). The retention of Cs in soils is controlled by ion exchange at highly sorption sites in the clay minerals that are especially located in the frayed edge sites of illite and in the hexagonal cavities of vermiculite (Cornell, 1993). Ions with physicochemical similarities with Cs, such as K, affect the selectivity of Cs sorption by the solid phase of clay minerals and consequently Cs availability to plants (Wendling et al., 2005).

The uptake of Cs has been studied both in soil and hydroponic experiments with special references to potassium competition, as K is generally considered an effective inhibitor for Cs uptake by plant roots (Belli et al., 1995; Zhu, 2001). However most of these studies focused in the quantitative relationship between external K concentration and Cs uptake by plants without taking into consideration the interaction between Cs^+ and K^+ ion in the root uptake process and their accumulation within the tissues (Smolders et al., 1996). Thus single correlations between Cs concentration and soil properties are generally very weak and the applicability of these studies in natural complex systems are not always reliable and capable to predict Cs transfer from soil to plant. The purpose of this study was, therefore, to examine the soil properties that affect Cs uptake by *Trifolium pratense* plants and the comparative interaction of Cs and K in the shoots of plants, so as to interpret the way that K^+ is related to Cs^+ in soil-plant systems.

2. MATERIAL AND METHODS

2.1. Pot Experiment

To accomplish the aims of the present study, a completely randomized greenhouse pot experiment, in four replicates, was conducted. The plants grown on four mineral soils with contrasting physicochemical properties. Soil in each pot contaminated with 40 mg kg^{-1} of Cs in the form of CsCl by spraying the solution in layers (Skarlou et al., 1996; Massas et al., 2002). *Trifolium pratense* seeds, chosen as the test plant, appropriately sown in the pots after 60 days (1^{st} treatment), 240 days (2^{nd} treatment) and 420 days (3^{rd} treatment) of soil contamination. For all treatments the cultivation period was 110 days. The shoots of *Trifolium pratense* plants were collected at two different intervals - 75 days (1^{st} cut) and 110 days (2^{nd} cut) and prepared for further analyses. To monitor possible changes in soil properties, two control pots for each treatment were used (pots with no Cs contamination).

In order to examine the relationship between Cs and K ions in the shoots the discrimination factor was used, according to the following equation (Ciuffo et al., 2003).

$$DF = \frac{\text{Cs in plants (mg kg}^{-1}\text{) / K in plants (mg kg}^{-1}\text{)}}{\text{Cs in soil (mg kg}^{-1}\text{) /K in soil (mg kg}^{-1}\text{)}}$$

2.2. Analytical Methods

Plant material was dried at 70°C for 48 hours, weighted and ground. 0.5g of the plant sample was dry-ashed in an oven at 500°C for 4h and the ash was subjected to wet digestion in concentrated nitric acid (Westerman, 1990). Cs and K concentrations were determined by using a Varian SpectrAA-300 atomic absorption spectrophotometer (Veresoglou et al.,1996).

2.3. Soil Analysis

Four surface soil samples from Northern Greece were chosen in order to give a range of physicochemical properties that are important in controlling the availability of Cs in plants. The soils were air-dried, passed through a 2 mm sieve and stored before analysis.

Particle size analysis was made using the hydrometer method with a 2 – h reading for clay content (Gee and Bauder, 1986). Soil pH was measured in a 1:1 soil: distilled water (w-v) suspension (McLean, 1982). Cation exchange capacity and exchangeable K^+ and Cs^+ were determined according to the ammonium acetate (pH=7.0) method (Thomas, 1982). The soil samples were treated in duplicates and the means reported.

3. RESULTS AND DISCUSSION

Selected physicochemical properties of the studied soils after each treatment are presented in Table 1. The soils were either slightly acidic or alkaline (pH > 5.5). Exchangeable K, as an index of soil available K for plant uptake in all cases was low, and in all treatments soils 2 and 3 showed the highest values. Sand content ranged between 34 and 62% and clay content between 12 and 45%. According to the results, significant differences in Cs plant concentration emerged among the different cuts, the soil types or the treatments (Figure 1). Regardless to the soil type or treatment the concentration of Cs in plants ranged from 53.9 to 427.7 mg kg^{-1} and from 45.1 to 389.1 mg kg^{-1} in first and second cut respectively. Cs concentration was lower in all cases in the second cut, probably due to the shorter plant growth period.

Table 1. Selected properties of the studied soils at the end of each cultivation

	Soil 1	*Soil 2*	*Soil 3*	*Soil 4*
Particle size analysis (%)				
Clay	14	35	45	12
Silt	24	31	20	40
Sand	62	34	35	48
Texture	SL	CL	C	L
CEC (meq $100g^{-1}$)				
1^{st} treatment	8	20	28	11
2^{nd} treatment	8	19	27	11
3^{rd} treatment	8	20	28	11
Exchangeable K^+ (meq $100g^{-1}$)				
1^{st} treatment	0.27	0.45	0.48	0.27
2^{nd} treatment	0.17	0.38	0.38	0.27
3^{rd} treatment	0.14	0.32	0.39	0.21
Exchangeable Cs^+(meq $100g^{-1}$)				
1^{st} treatment	0.09	0.09	0.10	0.10
2^{nd} treatment	0.06	0.06	0.07	0.05
3^{rd} treatment	0.05	0.06	0.07	0.06

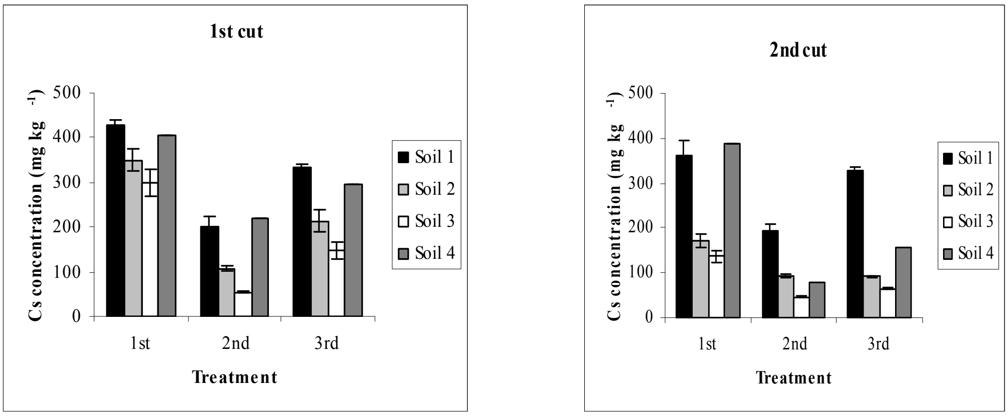

Figure 1. Cs concentration in the shoots of *Trifolium pratense* plants grown on the four soils, for the 1st and 2nd cut

Considering the effect of soil properties on Cs uptake by plants, a significant negative correlation between the concentration of Cs in the shoots of *Trifolium pratense* plants in both cuts and the ratio of cation exchange capacity to exchangeable soil K at the end of the each cultivation ($r = -0.89$, $p<0,001$, $n=12$ / $r = -0.63$, $p<0.05$, $n=12$, respectively for each cut) was observed, indicating that as this ratio increased, Cs concentration in plants decreased (Figure 2). Thus, not only the particle size distribution, as CEC was highly correlated to clay content, ($r = 0.95$, $p<0.05$), plays a predominant role on Cs availability in plants but also the content of exchangeable K influence the Cs concentration in plants. The uptake of Cs by plants is a function of soil properties and it is amplified with decreasing clay and exchangeable potassium content (Smolders et al., 1997; Morina et al., 2005).

Competitive and inhibitory interactions play an important role in the uptake and the translocation of alkaline and alkaline-earth metals by plant roots (Singh et al., 2008). As Cs is analogue of K and belongs in the same homologous series, the relationship of Cs and K in shoots was also examined, regardless to the variations in Cs concentration in plants due to the soil type. In both cuts a significant negative correlation between Cs concentration and K content in the shoots of *Trifolium pratense* plants was observed (Figure 3). As the concentration of Cs decreased, the K content increased in the shoots of *Trifolium pratense* plants. Such a relationship confirms the occurrence of a direct competition between Cs and K ions during the process of accumulation through the plant tissues and suggests that the two elements could have a common accumulation mechanism in plants. It also points to that Cs uptake by plants can be suppressed by the competition of Cs and K ions in the plant tissues. Similar results are reported by Carvalho et al. (2006), who showed a similar relationship between K-Cs in the plant tissues of some tropical and subtropical plants and observed that with the decrease of Cs levels in plants, K tends to return and to be redistributed in the different plant organs.

Due to the competitive interactions that occurred between Cs and K ions, the discrimination factor (DF), which is often used to evaluate a plant's efficiency to absorb nutrients from soil, was additionally estimated (Table 2). The obtained Cs/K DF values ranged from 0.005 to 0.056 and varied among the treatments and the soil types. These results are in agreement with Smolders et al. (1996), who reported that the DF values ranged from 0.04 and 0.26 in spring wheat plants grown at different soil K concentrations. The discrimination factor was in all cases below unity, indicating that Cs is less efficiently absorbed from soil than its nutrient analogue, K.

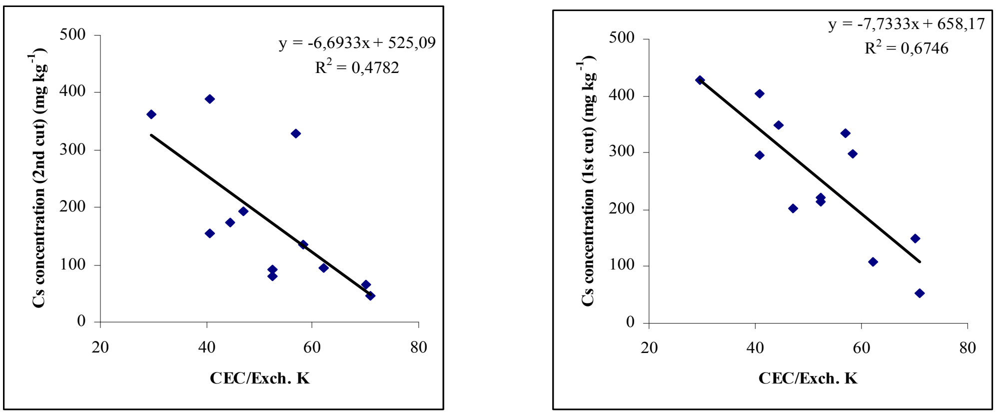

Figure 2. Relationships of Cs concentration in the shoots of *Trifolium pratense* plants in the 1st and 2nd cut with the ratio of cation exchange capacity (CEC) / exchangeable soil K

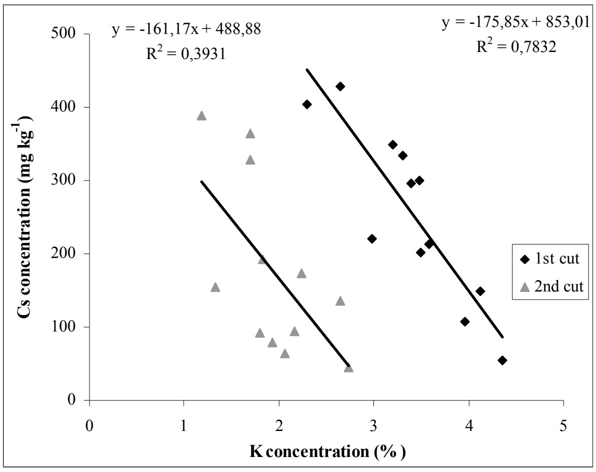

Figure 3. Cs concentrations relationships with K content in the shoots of *Trifolium pratense* plants in the 1st and 2nd cut

Table 2. Discrimination factor (DF) values in the shoots of *Trifolium pratense* plants grown on the four soils, for the 1st and 2nd cut

	1st Treatment		2nd Treatment		3rd Treatment	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
soil 1	0.043	0.056	0.010	0.018	0.014	0.027
soil 2	0.048	0.034	0.010	0.016	0.019	0.016
soil 3	0.040	0.024	0.005	0.006	0.014	0.012
soil 4	0.047	0.056	0.020	0.011	0.010	0.013

The more efficient absorption of K than of Cs by plant roots may be due to the different physiological role of the two elements within the plant. Potassium is an essential macronutrient for plant growth, plays an important role in adjusting the osmotic pressure of cells and maintains the enzyme activity of photosynthesis (Chino and Obata, 1991). On the contrary, Cs is not an essential element for plant growth and its concentration in plant tissues is less than 1 mg kg^{-1} (Shaw and Bell, 1989). Thus, it is possible that plants reject Cs^+ ions and absorb K^+ ions, which are necessary for their growth. Moreover, the obtained DF values indicate that Cs^+ ions are tightly bound by the soil colloids, hence are not easily available to the plants. So, K appears to be one of the main factors influencing plant mobility of Cs and behaves not only as a competitor to Cs ions, but also as an effective inhibitor of Cs uptake by plants.

4. CONCLUSION

According to the results of the present work, Cs uptake by plants is a consequence of sequence reactions both in the soil and in the plant, implying that Cs transport from soil to plant is controlled by a complex mechanism. Therefore the concurrent utilization of soil properties and the K-status in plant tissues is essential to monitor and to estimate soil to plant Cs mobility.

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