The influence of elevated concentrations of radium in the irrigation water on agricultural crops

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Introduction

Substantial land areas used for agriculture are located in arid zones including the Arava Valley where large amounts of irrigation water are required for crop production. The Arava valley exhibits limited water resources. The Judea Group and the Kurnub aquifers are the major available water sources for agricultural use in the region. In both aquifers high concentrations of radium isotopes were found; some of the wells exceeded the Israeli drinking water quality regulations (^{226}Ra = 0.6 Bq·l^{-1} and ^{228}Ra = 0.5 Bq·l^{-1}). At the Shizafon well (30^0 08' 29" N 35^0 01' 24" E) the ^{226}Ra concentration is 1.76 Bq·l^{-1}.

^{226}Ra availability for plant uptake depends upon soil texture, organic matter content, iron-manganese oxides content, cation exchange capacity and distribution of the radium between the solid phase and the soil solution. Madruga et al. (2001) measured Ra plant-to-soil transfer factors for different plants (*Cytisus spp, Pinus pinea, and Eucalyptus globolus*), suggesting that mechanisms for Ra transfer may actually be plant specific.

The study of Ra uptake by crops and its potential radiological implications is essential for further expansion of both water resources and agriculture in the Negev.

Methods

Three experiments were carried out using nine lysimeters filled with typical Southern Arava soil. Each lysimeter was equipped with a scale for continuous weighing which established a highly accurate water and Ra mass balance. The experiments involved four crops; the irrigation scheme for each experiment and each lysimeter is shown in Table 1.

2 kg of plant tissues were oven-dried at 105^{0}C for 24 h, and immediately pyrolized at 400^{0}C. The samples were kept in a sealed standard container for three weeks to achieve secular equilibrium of the Ra and its decay products. Water samples were filtered through MnO_2 coated fibers. The fibers were then transferred into a sealed standard container and counted by gamma spectrometry. Soil samples excavated 15, 30, 45 and 60 cm underneath the stem were analyzed for profile distribution of Ra.

Isotherms of Ra adsorption were constructed for the Arava soil. The soil was equilibrated with solutions containing 0, 1.7, 37.8, 1858, 4413, 5939 and 37763 Bq·l^{-1}. 10-g soil triplicate samples with 20 ml of solution were mixed in 50-ml polypropylene centrifuge tubes and shaken for 24 h at 25^{0}C. After equilibration, suspensions were centrifuged, filtered, and tested for pH and Ra.

Measurements of the radium activity concentrations in soil, water and plant tissues samples were performed by standard gamma spectrometry methods.

The kinetics of Ra distribution in soil and in drainage water was modeled by means of the HYDRUS 1-D software package (Simunek et al., 1998).

Table 1: Irrigation scheme for each lysimeter and experiment (^{226}Ra activity concentration in the irrigation water and total ^{226}Ra input).

	Exp. 1		Exp. 2		Exp. 3	
Lysimeter	Water quality (^{226}Ra conc- Bq·l^{-1})	Total ^{226}Ra input (Bq)	Water quality (^{226}Ra conc- Bq·l^{-1})	Total ^{226}Ra input (Bq)	Water quality (^{226}Ra conc- Bq·l^{-1})	Total ^{226}Ra input (Bq)
1	Ra-enriched water (110)	52800	Sprouting irrigation with "Arava line water"	2500	Shizafon (1.7)	816
2		52800		2500		816
3		52800	Enriched Ra water (80)	34500		816
4	Shizafon well (1.7)	864	Shizafon (1.7)	1242		816
5		864		1242		816
6		864		1242		816
7	"Arava line water" (<0.6)	20	"Arava line water" (<0.6)	28	"Arava line water" (<0.6)	15
8		20		28		15
9		20		28		15

Results

Ra activity concentrations for each experiment and lysimeter are presented in Table 2. Ra concentration in plant tissues appears to be related both to increased Ra concentration in irrigation water as well as to the irrigation history of the lysimeters. For all the crops in these experiments, concentrations in the leaves were measured to be higher than concentrations in the edible tissues. Moreover, the concentrations in the edible tissues of all crops were lower than the maximum allowed activity concentration of 10 Bq·l^{-1}, tentatively set by the Ministry of Health.

Table 2: ^{226}Ra activity concentrations (in Bq•kg^{-1}) measured in crops for each lysimeter and experiment.

	Exp 1		Exp 2		Exp 3		
Lysimeter	**Cucumber leaves**	**Cucumber fruits**	**Melon fruits**	**Melon leaves**	**Radish leaves**	**Radish roots**	**Lettuce leaves**
1	**177±9**	6.6±1			14.8±1.5	3.4±0.5	8.4±1.0
2					7.7±0.9	3.1±0.5	9.0±1.1
3			2.56±0.09	65.9±2.5	17.1±1.7	3.4±0.5	6.4±0.8
4	1.7±0.3	<0.6	<0.33	0.80±0.08	1.1±0.2	<0.16	1.8±0.4
5			<0.15	0.87±0.07	0.8±0.2	0.4±0.1	0.9±0.2
6			<0.13	0.91±0.08	0.7±0.2	<0.16	1.2±0.3
7	1.0±0.2	<0.6	<0.12	0.24±0.05	<0.21	<0.12	1.6±0.3
8			<0.3	0.39±0.16	<0.17	<0.36	0.9±0.2
9			<0.17	0.26±0.05	<0.09	<0.12	0.8±0.2

When Ra levels in the leaves of the crops grown in the 3 experiments were normalized by dividing the amount of evapotranspiration, they were found to be linearly correlated with the total Ra input from irrigation water (Fig. 1). This finding suggests that Ra uptake from soil solution is ruled by environmental conditions (water availability and climate) and is not plant specific.

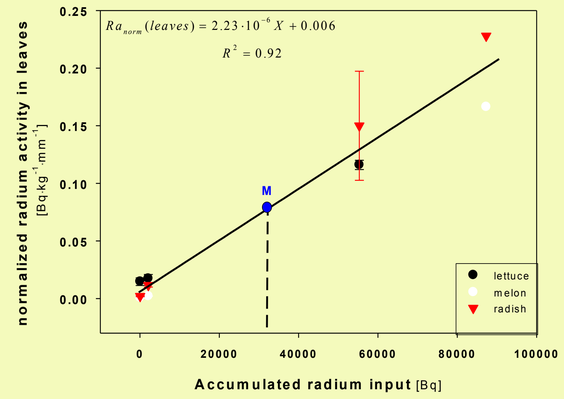

Figure 1: Evapotranspiration normalized ^{226}Ra activity in crop leaves as a function of the accumulated Ra input per each lysimeter. Point M indicates 15 years of irrigation with Shizafon water under the Southern Arava climatic conditions and irrigation practice.

The Ra activity concentration in the soil profile of Lysimeter 1 from the end of each experiment is presented in Fig. 2. The Ra content in the entire profile increased significantly from experiment 1 to 2. Conversely, the reduced Ra activity concentration of the irrigation water in experiment 3 caused a decrease in the concentration of the surface layer and an increase in the concentration of the soil beneath 20 cm. Ra transport downward is limited and is highly controlled by the soil surface layer interactions.

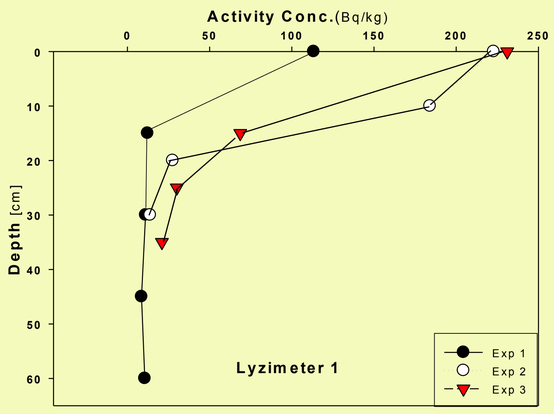

Figure 2: ^{226}Ra activity concentration in the soil profile of Lysimeter 1 at the end of each experiment.

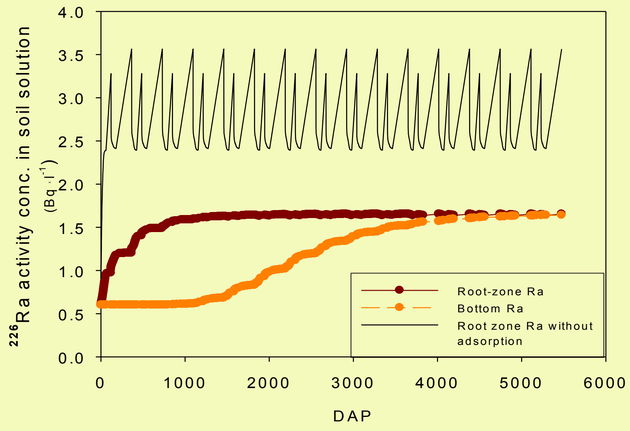

Figure 3: HYDRUS 1-D simulation of ^{226}Ra activity concentration in the soil solution with time in the root zone (bold black curve) and in the drainage water (white curve). The thin black curve represents the hypothetical activity concentration, when assuming no adsorption to soil.

15 years of crop irrigation with Shizafon water under the Southern Arava climatic conditions are simulated in Fig. 3. Soil surface interactions simultaneously decrease the Ra concentration in the soil solution and significantly narrow its fluctuations during the growing seasons. The Ra activity concentration reaches a steady-state level of 1.65 Bq·l^{-1} after 3 and 12 growing seasons in the soil solution and in the drainage water (below 100 cm), respectively.

Conclusions

- Ra uptake by plants is mainly controlled by environmental conditions: water availability and potential evapotranspiration
- Ra activity concentrations in the edible tissues of all the crops grown under all treatments were lower than the maximum allowed activity concentration. When irrigating with Shizafon water, Ra concentrations in leaves were also lower than the maximum allowed activity concentration
- Soil surface interactions of Ra decrease its concentration in the soil solution and therefore limit its accumulation in plant tissues

Reference

Madruga, M.J., Brogueira, A., Alberto, G. and Cardoso, F. 2001. 226Ra bioavailability to plants at the Urgeirica uranium mill tailings site. J. Environ. Radio. 54:175-188.