J Radioanal Nucl Chem (2015) 306:237–242
DOI 10.1007/s10967-015-4009-5

Radioactivity in soils and some terrestrial foodstuffs from organic and conventional farming areas in Izmir, Turkey

Mehmet Bakım · Aysun Uğur Görgün

Received: 26 June 2014 / Published online: 28 February 2015

Abstract The activity concentrations of the naturally occurring radionuclides of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K were determined in wheat, grape leaf, garlic, onion and soil samples collected from organic and conventional farms in the İzmir region. In addition, soil-to-plant transfer factors were estimated. While the activity concentrations of ^{210}Po and ^{210}Pb were determined by alpha spectrometry, those of ^{226}Ra, ^{228}Ra and ^{40}K, were determined by gamma spectrometry. The samples collected from conventional farms showed higher activity concentrations of the above radionuclides when compared to those collected from organic farms. In general, the transfer factor values fall within the range given in the literature.

Keywords Conventional farming · Organic farming · Natural radioactivity · Transfer factor

Introduction

In recent years the importance of organic farming methods has increased due to growing consumer interest in certified organic products. Today the most widely used commercial farming systems are organic and conventional farming. Phosphate fertilisers are used in conventional systems, while in organic agriculture organic fertilisers are used, such as bovine manure. As a result of the consumption of products that are grown in the areas where phosphate fertilisers are used, human exposure to radiation due to the ingestion of food may increase on fertilised farmlands. Organic farming is a method of agricultural production where each phase from production to consumption is controlled in order to certify that the products are free of synthetic pesticides, hormones and chemical fertilisers. In organic farming, the soil is considered alive therefore the continuity of its health is considered in each phase. In this practice, certain substances (natural herbicides, insecticides, and rodenticides) are applied to plants in various forms in order to protect them against diseases and pests. Organic fertilisers used in organic farming linger in the soil for a longer period of time and provide a better environment for microorganisms. Since they have a better capacity to hold moisture, organic fertilisers inhibit the loss of soil minerals through washing thus preventing the salt ratio from increasing in soil and desertification in the long-term.

It is very well known that about 1300 different radionuclides exist that originate from both natural sources, and anthropogenical production [1]. Natural radionuclides can be generated by the activation of stable isotopes using cosmic radiation, or originate during the creation of the universe. The latter are known as primordial radionuclides and include ^{40}K ($t_{1/2} = 1.28 \times 10^9$ year) and isotopes of uranium and thorium which give rise to various daughter nuclides, including ^{226}Ra ($t_{1/2} = 1602$ year), ^{210}Pb ($t_{1/2} = 22.3$ year), ^{228}Ra ($t_{1/2} = 5.75$ year), and ^{210}Po ($t_{1/2} = 138$ days). These radionuclides are known to be present in foodstuffs as a result of their uptake by plants from soil and their concentrations vary from region to region. In Turkey, organic agriculture originated in İzmir in the form of dried fruit production in 1985. Since then, the region has become the biggest producer and exporter of organic products from Turkey. In the literature, there are some studies that investigate the differences in quality between products from conventional and organic farming or foodstuffs produced with the aid of different fertilisation systems, but there are

M. Bakım · A. U. Görgün (✉)
Institute of Nuclear Sciences, Ege University, Bornova, 35100 Izmir, Turkey
e-mail: aysun.ugur@ege.edu.tr

not many studies about the radioactivity levels on conventional and organic farmlands [2]. Very few studies have been conducted on the natural radioactivity levels in the organic and conventional farmlands of Turkey. Therefore, the objective of this study was to determine the activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K in wheat, grape leaf, garlic, onion and soil samples of conventional and organic farming management systems and to estimate the soil-to-plant transfer factor.

Experimental

Soil and plant samples were collected from commercial organic and conventional farms in the İzmir region. Plant samples were collected from six different conventional farms and seven organic farms in three different regions (Ahmetli-Manisa, Tahtalı dam basin, and Menemen Soil and Water Research Institute) as shown in Fig. 1. The sampling sites were selected as areas where both conventional and organic farming are intensely carried out. Plants and their corresponding soils were collected randomly from several cultivation plots. The soil was collected from the surface to a depth of 20 cm.

The soil samples were homogenised and oven-dried at 75 °C, ground in an agate mortar, and sieved using a "30 mesh". Each dried sample was sealed in a 1000 ml Marinelli beaker prior to analysis. Plant samples were carefully cleaned with a plastic brush to eliminate extraneous soil particles and then weighted (wt). The plant samples were dried until a constant weight was achieved. Dried samples were ground in a small mill and the ground material was transferred to plastic sample containers (45 mm in diameter). They were stored for 1 month to attain radioactive equilibrium between ^{226}Ra and ^{222}Rn before being subjected to γ-spectrometric analysis.

^{210}Po and ^{210}Pb determinations in plant and soil samples

Measurements of ^{210}Po were realised through its 5.30 MeV alpha particle emission line, using ^{209}Po as the internal tracer, each sample was completely dissolved in HCl and HNO_3. For soil samples HF was also used in the dissolving process. Polonium was spontaneously plated onto silver discs in 0.5 M HCl in the presence of ascorbic acid to reduce Fe^{3+}–Fe^{2+}. In order to find the optimum conditions for plating, the standard technique given by Flynn was modified [3]. Alpha activities were measured by PIPS detectors, Ortec 450 mm^2 with 20 μm of depletion depth. The counting period was adjusted to obtain relative standard errors of 5 %. Following the initial plating of ^{210}Po, a silver disc was suspended in the plating solution which was stirred overnight to remove the remaining traces of ^{210}Po and ^{209}Po. The solution was then re-spiked with a known activity of ^{209}Po and left for at least 6 months to allow the ingrowth of ^{210}Po from ^{210}Pb. The sample was re-plated and the ^{210}Po activity was determined. Well-known Bateman equations were used to obtain the ^{210}Pb activity from the measured ^{210}Po

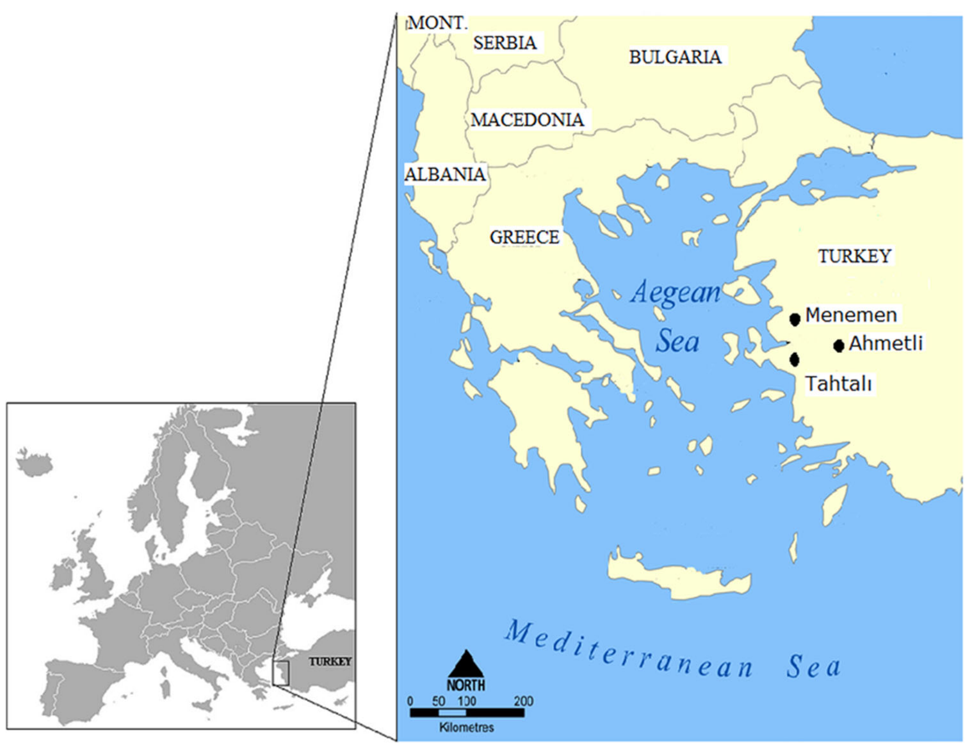

Fig. 1 The sampling areas

activity [4]. In this way, the second period of plating provided information on the ^{210}Pb content of the samples.

Gamma spectrometric analysis of ^{226}Ra, ^{228}Ra and ^{40}K in plant and soil samples

The ^{226}Ra, ^{228}Ra and ^{40}K activity concentrations of plant samples were determined using a Canberra 76 × 76 mm, high sensitivity NaI(Tl) detector connected to a Nucleus PCA-8000 multichannel analyser. The detector was well-shielded with 75 mm thick lead bricks to reduce the background counting rate. The ^{226}Ra, ^{228}Ra and ^{40}K contents were detected using 1.76 MeV ^{214}Bi, 2.62 MeV ^{208}Tl and 1.46 MeV ^{40}K lines, respectively. The detection limits of the spectrometer system for ^{238}U, ^{228}Ra, and ^{40}K are 5.92, 1.84, and 1.27 Bq kg^{-1}, respectively.

The soil samples were analysed for ^{226}Ra, ^{228}Ra and ^{40}K by direct gamma assay, using a 184 cc *p*-type coaxial HPGe detector with a relative efficiency of 25 % and a resolution of 1.85 keV at 1.332 MeV (with associated electronics provided by EG&G Ortec). The detector was sealed by 100 mm thick lead bricks internally lined with 1.5 mm thick copper foil. The spectrum was acquired and analysed using a PC-based 8 K multichannel analyser and its associated software. ^{40}K was detected via its gamma emission lines at 1.46 MeV, ^{232}Th was detected by the 2.62 MeV gamma rays from ^{208}Tl and ^{226}Ra using the 295 and 352 keV γ-rays emitted by its daughter isotope ^{214}Pb. Counting times varied from 10 to 24 h, depending on the activity in the samples, providing a precision of better than ±10 % and a 90 % level of confidence [5]. Corrections were made for the effect of self-absorption of low energy γ-rays within the sample [6].

Background counts were measured at regular intervals to ensure that low background characteristics were maintained. In order to confirm the results, three sub-samples were taken from each plant and the same chemical and radiometric procedure was repeated on them.

The soil-to-plant radionuclide transfer factor (TF) is defined using the following equation [7]:

$$\text{Transfer factor (Fv)} = \frac{\text{Activity of radionuclide in plant material (Bq kg}^{-1}\text{, dry weight)}}{\text{Activity of radionuclide in soil (Bq kg}^{-1}\text{, dry weight)}}$$

Results and discussion

The mean activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K radionuclides in plant and soil samples from three different areas (Ahmetli-Manisa, Tahtalı dam basin, and Menemen Soil and Water Research Institute) are presented in Figs. 2, 3, 4, 5 and 6. In plants collected from organic fields, the relative concentration ranges of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K were between 0.21 ± 0.04 and 1.40 ± 0.36 Bq kg^{-1}, 0.67 ± 0.10 and 4.81 ± 0.67 Bq kg^{-1}, ND and ND, ND and ND, and ND and 7.34 ± 1.50 Bq kg^{-1}, respectively. In the soils of organic agricultural areas the activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K were between 19 ± 1 and 48 ± 1 Bq kg^{-1}, 24 ± 2 and 47 ± 3 Bq kg^{-1}, 20 ± 1 and 52 ± 3 Bq kg^{-1}, 23 ± 1 and 40 ± 2 Bq kg^{-1}, and

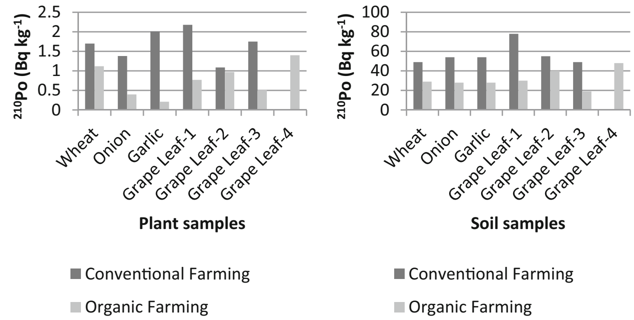

Fig. 2 Comparison of ^{210}Po activity concentrations (Bq kg^{-1}) in plant and soil samples collected from organic and conventional farming areas

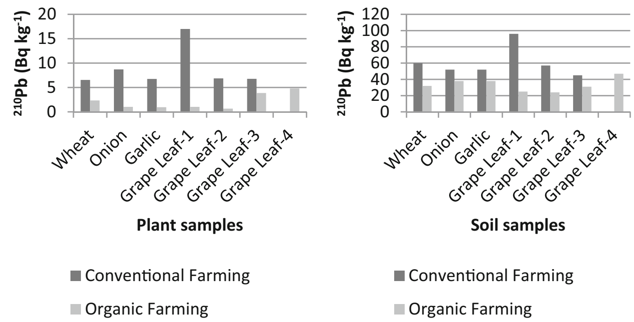

Fig. 3 Comparison of ^{210}Pb activity concentrations (Bq kg^{-1}) in plant and soil samples collected from organic and conventional farming areas

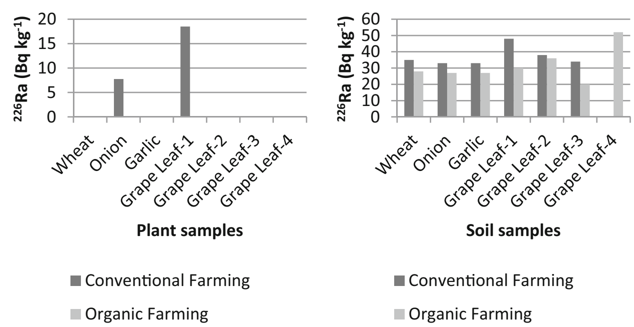

Fig. 4 Comparison of ^{226}Ra activity concentrations (Bq kg^{-1}) in plant and soil samples collected from organic and conventional farming areas

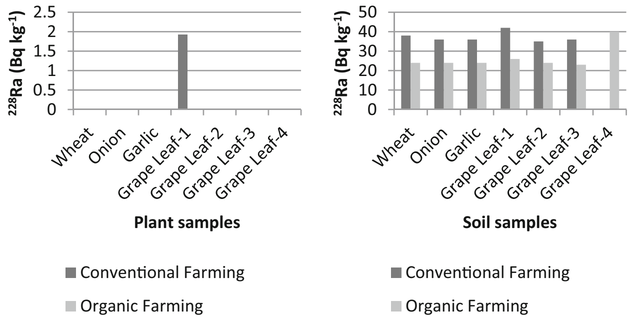

Fig. 5 Comparison of ^{228}Ra activity concentrations (Bq kg^{-1}) in plant and soil samples collected from organic and conventional farming areas

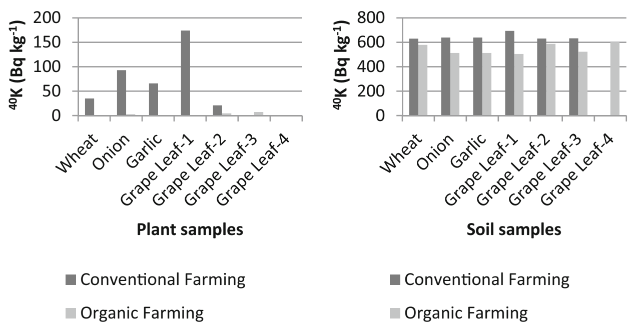

Fig. 6 Comparison of ^{40}K activity concentrations (Bq kg^{-1}) in plant and soil samples collected from organic and conventional farming areas

505 ± 26 and 602 ± 31 Bq kg^{-1}, respectively. On conventional farms, the activity concentrations of soils were found to vary between 49 ± 1 and 78 ± 2 Bq kg^{-1} for ^{210}Po, 45 ± 3 and 96 ± 6 Bq kg^{-1} for ^{210}Pb, 33 ± 2 and 48 ± 2 Bq kg^{-1} for ^{226}Ra, 35 ± 2 and 42 ± 3 Bq kg^{-1} for ^{228}Ra and 630 ± 32 and 694 ± 36 Bq kg^{-1} for ^{40}K. In plants collected from conventional fields, the relative concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K were found to be between 1.09 ± 0.30 and 2.18 ± 0.40 Bq kg^{-1}, 6.56 ± 0.80 and 17.00 ± 1.25 Bq kg^{-1}, ND and 18.5 ± 2.0 Bq kg^{-1}, ND and 1.92 ± 0.30 Bq kg^{-1}, and ND and 174 ± 9 Bq kg^{-1}, respectively.

In the organic farming areas, grape leaf-4 samples have the maximum ^{210}Po and ^{210}Pb concentrations as 1.40 ± 0.36 and 4.81 ± 0.67 Bq kg^{-1}, respectively. ^{40}K showed the lowest activity concentrations in these farming areas. ^{210}Po:^{210}Pb ratios in plant samples were also investigated in the present study to examine the unsupported ^{210}Po enhancement. Except for grape leaf-2 (1.45), the ^{210}Po:^{210}Pb activity ratios were derived as between 0.03 and 0.75. The organic farming area, in which grape leaf-4 samples were collected, was a conventional farm up till 2 years ago and the excessive use of fertilisers during conventional farming may be a reason for the higher activity concentration of ^{210}Po in these samples. In addition, it is considered that the existence of conventional nearby farming areas nudged up the activity concentrations in plants and soil samples in that region. The two ^{238}U daughters, ^{210}Po and ^{226}Ra, showed a very strong relationship with an almost perfect correlation. The overall ^{210}Po:^{226}Ra activity ratio is almost 1 indicating a secular equilibrium in the soil collected from organic farming areas (Table 1). The ^{210}Po:^{210}Pb activity ratio was found to be slightly higher in soil where grape leaves were collected. The maximum ^{210}Pb:^{226}Ra activity ratio was observed in soil where grape leaf-3 was collected.

Table 1 The activity ratios in soil samples collected from organic farming areas

Organic farming	^{210}Po:^{210}Pb	^{210}Po:^{226}Ra	^{210}Pb:^{226}Ra
Wheat	0.91	0.66	1.14
Onion	0.74	1.04	1.41
Garlic	0.74	1.04	1.41
Grape leaf-1	1.20	1.00	0.83
Grape leaf-2	1.67	1.11	0.66
Grape leaf-3	0.61	0.95	1.55
Grape leaf-4	1.02	0.92	0.90

In the conventional farming areas, grape leaf-1 samples have the maximum ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K concentrations as 2.18 ± 0.40, 17.00 ± 1.25, 18.50 ± 2.00, 1.92 ± 0.30 and 174 ± 9 Bq kg^{-1}, respectively. The ^{210}Po:^{210}Pb activity ratios in plant samples from conventional farms were estimated and the minimum and maximum values of the ratio were 0.13 and 0.30. ^{210}Po:^{226}Ra and ^{210}Pb:^{226}Ra activity ratios were found to vary between 1.40 and 1.64 and 1.32 and 2.00 respectively, indicating that the main source of ^{210}Po and ^{210}Pb in soils is not merely the radioactive decay of ^{226}Ra but also the intensive use of fertilisers (Table 2). The ^{210}Po:^{210}Pb activity ratio was almost 1. The ^{210}Po concentrations in garlic and grape leaf-1 from the conventional farming areas, were higher than the others and the highest ^{210}Po concentrations were measured in soil samples where grape leaf-1 samples were grown. A conversation was held with the owner of the farmland in order to understand the reason why high levels were observed in the farmland where grape leaf-1 samples originated from. It turned out that in that farmland artificial fertilisers were used intensively.

The relationship between the organic and conventional farming areas was investigated by a *t* test statistical analysis. Some significant differences ($0.003 < 0.05$) were observed between the two types of farming in terms of ^{210}Po, ^{210}Pb, ^{226}Ra and ^{228}Ra radionuclides. The results of the analysis indicated that the activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K of the plant and soil samples that were collected from the conventional farming

Table 2 The activity ratios in soil samples collected from conventional farming areas

Conventional farming	^{210}Po:^{210}Pb	^{210}Po:^{226}Ra	^{210}Pb:^{226}Ra
Wheat	0.82	1.40	1.71
Onion	1.04	1.64	1.58
Garlic	1.04	1.64	1.58
Grape leaf-1	0.81	1.63	2.00
Grape leaf-2	0.96	1.45	1.50
Grape leaf-3	1.09	1.44	1.32

Table 3 The radionuclide transfer factors for organic farming

	^{210}Po	^{210}Pb	^{226}Ra	^{228}Ra	^{40}K
Wheat	0.039	0.073	–	–	–
Onion	0.014	0.027	–	–	0.0055
Garlic	0.0075	0.025	–	–	–
Grape leaf-1	0.026	0.041	–	–	0.00147
Grape leaf-2	0.024	0.028	–	–	0.0078
Grape leaf-3	0.027	0.125	–	–	0.014
Grape leaf-4	0.029	0.102	–	–	–

areas were higher than the ones collected from the organic farming areas.

Lindahl et al. indicated that no significant difference ($p > 0.05$) in activity concentrations of the four radionuclides determined in wheat grains (i.e. ^{40}K, ^{226}Ra, ^{228}Ra and ^{228}Th) was observed between organic and conventional agricultural systems in Belgium [8]. For organic and conventional areas the concentration ratios (CR) were almost 1 for stems and grains. However for roots, ^{40}K and ^{228}Th exhibited tendencies of higher uptake in the conventional fields even though there is a trend suggesting a lower uptake of ^{226}Ra in the same fields. Similarly, no difference was observed for Ra and U in vegetables grown in organic and conventional farming systems in Brazil (Lauria et al. [9]).

Soil-to-plant transfer factors (TF) for the natural radionuclides ^{210}Po, ^{210}Pb, ^{226}Ra, ^{232}Th and ^{40}K were calculated and are shown in Tables 3 and 4. The values were generally lower for ^{210}Po than for ^{226}Ra and ^{210}Pb. In organic farming systems, the lowest TFs were obtained for ^{40}K and ^{210}Po. Statistically (Paired *t*-test) significant differences $p > 0.05$ were found between the data sets of TF values for Po, Pb and K isotopes from conventional and organic agriculture managements. In general, the TF values fall within the range given in the literature. Vandenhove et al. indicated that TF-Pb was highest for pastures/grasses (1.4×10^{-1}), followed by leafy vegetables (8.0×10^{-2}) and fodder (2.5×10^{-2}) and was lowest for tubers (1.5×10^{-3})[6]. Highest TFs-Po (1.2×10^{-2}) were found

Table 4 The natural radionuclide transfer factors for conventional farming

	^{210}Po	^{210}Pb	^{226}Ra	^{228}Ra	^{40}K
Wheat	0.035	0.110	–	–	0.055
Onion	0.026	0.168	0.235	–	0.145
Garlic	0.037	0.130	–	–	0.103
Grape leaf-1	0.028	0.177	0.385	0.046	0.250
Grape leaf-2	0.020	0.121	–	–	0.033
Grape leaf-3	0.036	0.150	–	–	–

for pastures and grasses and the observed difference is significant [10].

Karunakara et al. have investigated soil-to-rice transfer factors for ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{40}K and ^{137}Cs in Kaiga where a nuclear power station has been in operation since 1999 [7]. The mean soil-to-rice plant transfer factors for ^{40}K and ^{210}Pb were 1.5 and 1.4×10^{-1}, respectively.

Strok and Smodis calculated soil-to-plant transfer factors for natural radionuclides in grass in the vicinity of a former uranium mine in Slovenia [11]. The researchers found that the transfer factors varied between 3.46×10^{-2} and 4.65×10^{-1} for ^{226}Ra, and 9.83×10^{-2} and 1.52 for ^{210}Pb.

Fernandes et al. have calculated soil-to-plant transfer factors in a semi-arid region in Brazil [12]. The researchers stated that a range from 10^{-3} to 10^{-1} may conveniently encompass most of the transfer factor values for soil/plant systems, i.e. involving different cultures, different soils and natural radionuclides.

Asaduzzaman et al. have investigated soil-to-plant transfer factors for tapioca and sweet potato in west Malaysia [13]. The researchers found that the uptake of radionuclides during the middle or late growth stages produced higher TFs than those during the early growth stage.

Al-Kharouf et al. have calculated soil-to-plant transfer factors in Jordan [14]. The researchers found that the average value of the total TFs of ^{238}U for courgette and watermelon plants were $1.05 \pm 0.08 \times 10^{-2}$ and $0.45 \pm 0.19 \times 10^{-2}$, respectively.

James et al. have investigated soil-to-leaf transfer factors for the radionuclides ^{226}Ra and ^{40}K in the region of Kaiga in India [15]. ^{226}Ra and ^{40}K activities in leaves of herbaceous plants are higher than those of tree leaves. The soil-to-leaf transfer factors for ^{226}Ra and ^{40}K were found to be in the range of 0.03–0.65 and 0.32–8.04, respectively.

Pulhani et al. have calculated soil-to-wheat grain transfer factors in Maharashtra, India [16]. The soil-to-wheat grain transfer factors were calculated and observed to be in the range of 4.0×10^{-4} to 2.1×10^{-3} for ^{238}U,

6.0×10^{-3} to 2.4×10^{-2} for ^{232}Th, 9.0×10^{-3} to 1.6×10^{-2} for ^{226}Ra and 0.14 to 3.1 for ^{40}K.

Conclusions

In this study, 12 plant and 11 soil samples were investigated. The samples were taken from the farmlands where conventional and organic farming are performed. The results of the analysis indicated that the activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K of the plant and soil samples that were collected from the conventional farming areas were higher than the ones collected from the organic farming areas. The determined soil-to-plant transfer factors are comparable with the results given in the literature and by IAEA [17]. Further studies are needed to provide comparative data on natural radioactivity levels in different types of plant samples in the Aegean region in order to confirm the preliminary observations reported in this study. In addition, as Al-Masri stated it is important to investigate the differences between the open and sheltered systems [18].

Acknowledgments This research work is supported by a grant from Ege University Scientific Research Project, Contract No: 09 NBE 008.

References

1. Strebl F, Ehlken S, Gerzabek MH, Kirchner G (2007) In: Shaw G (ed) Radioactivity in the environment, radioactivity in the terrestrial environment, vol 10. Elsevier, Amsterdam
2. Woese K, Lange D, Boess C, Bogl KW (1997) A comparison of organically and conventionally grown foods: results of a review of the relevant literature. J Sci Food Agric 74:281–293
3. Flynn WW (1968) The determination of low levels of ^{210}Po in environmental materials. Anal Chim Acta 43:221–227
4. Magill J, Galy J (2005) Radioactivity radionuclides radiation. Springer, Heidelberg
5. Uğur A, Özden B, Saç MM, Yener G, Altınbaş Ü, Kurucu Y, Bolca M (2004) Lichens and mosses for correlation between trace elements and ^{210}Po in the areas near coal-fired power plant in Yatağan, Turkey. J Radioanal Nucl Chem 259(1):87–92
6. Appleby PG, Richardson N, Nolan PG (1992) Self-absorption corrections for well-type germanium detectors. Nucl Instrum Methods B 71:228–233
7. Karunakara N, Rao C, Ujwal P, Yashodhara I, Kumara S, Ravi PM (2013) Soil-to-rice transfer factors for ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{40}K and ^{137}Cs: a study on rice grown in India. J Environ Radioact 118:80–92
8. Lindahl P, Maquet A, Hult M, Gasparro J, Marissens G, Gonzalez de Orduna R (2011) Natural radioactivity in winter wheat from organic and conventional agricultural systems. J Environ Radioact 102:163–169
9. Lauria DC, Ribeiro FCA, Conti CC, Loureiro FA (2009) Radium and uranium levels in vegetables grown using different farming management systems. J Environ Radioact 100:176–183
10. Vandenhove H, Olylaegers G, Sanzharova N, Shubina O, Reed E, Shang Z, Velasco H (2009) Proposal for new best estimates of the soil-to-plant transfer factors of U, Th, Ra, Pb and Po. J Environ Radioact 100:721–732
11. Strok M, Smodis B (2013) Soil-to-plant transfer factors for natural radionuclides in grass in the vicinity of a former uranium mine. Nucl Eng Des 261:279–284
12. Fernandes HM, Filho FFL, Perez V, Franklin MR, Gomiero LA (2006) Radioecological characterization of a uranium site located in a semi-arid region in Brazil. J Environ Radioact 88:140–157
13. Asaduzzaman K, Khandaker MU, Amin YM, Bradley DA, Mahat RH, Nor RM (2014) Soil-to-root vegetable transfer factors for ^{226}Ra, ^{232}Th, ^{40}K, and ^{88}Y in Malaysia. J Environ Radioact 135:120–127
14. Al-Kharouf SJ, Al-Hamarneh IF, Dababneh M (2008) Natural radioactivity, dose assessment and uranium uptake of agricultural crops at Khan Al-Zabeeb, Jordan. J Environ Radioact 99:1192–1199
15. James JP, Dileep BN, Ravi PM, Joshi RM, Ajith TL, Hegde AG, Sarkar PK (2011) Soil-to-leaf transfer factors for the radionuclides ^{226}Ra, ^{40}K, ^{137}Cs and ^{90}Sr in the Kaiga region of India. J Environ Radioact 102:1070–1077
16. Pulhani VA, Dafauti S, Hegde AG, Sharma RM, Mishra UC (2005) Uptake and distribution of natural radioactivity in wheat plants from soil. J Environ Radioact 79:331–346
17. IAEA (2010) Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments, IAEA Technical Report Series No. 472, IAEA, Vienna
18. Al-Masri MS, Al-Hamwi A, Eadan Z, Amin Y (2010) Transfer factors of Polonium from soil-to-parsley and mint. J Environ Radioactiv 101:1038–1042