Ecosystem Health and Sustainable Agriculture

Sustainable Agriculture

Editor: Christine Jakobsson
All organisms on earth are permanently exposed to ionising radiation coming from natural and artificial sources. Natural radionuclides (NRN) come to the planet without anthropogenic activities. They are generated in the atmosphere under the influence of cosmic radiation ($^{14}\text{C}$, $^3\text{H}$, $^{22}\text{Na}$ etc.) and are found in rocks (radioactive long-life isotopes $^{40}\text{K}$, $^{87}\text{Rb}$ and members of two radioactive series originating from $^{238}\text{U}$ and $^{232}\text{Th}$). It is mainly $^{238}\text{U}$ and $^{232}\text{Th}$ that form background radiation in ecosystems. The level of radiation is not the same in different places on the globe and depends on the concentration of radionuclides in the Earth’s crust. Concentrations of natural radionuclides in soil usually correlate to the radionuclide concentration in bedrock. Concentrations of radionuclides (ultra microelement) in plants are linearly related to the radionuclide concentration of the soil.

The natural background levels of an agroecosystem can be increased if phosphorus fertilisers are applied. Concentrations of natural radionuclides (NRN) in phosphorus fertilisers can be similar to mean concentrations in soil (25 Bq kg$^{-1}$), or ten-fold higher (Tables 36.1 and 36.2) (Drichko et al., 2008).

Production, transportation, storage and application of such fertilisers cause an additional exposure dose for humans. Therefore it is necessary to set limit values for NRN concentrations in fertilisers.

The strictest normative value in Russia has been set for exposure to fertiliser dust and this still remains today. However, during the past 20 years numerous regulations were revised and finally the normative rate of NRN in phosphorus fertilisers was set to:

$$C(\text{U}) + 1.5C(\text{Th}) \leq 4.0 \text{ kBq kg}^{-1}$$

where $C(\text{U})$ and $C(\text{Th})$ are the concentrations of $^{238}\text{U}$ ($^{226}\text{Ra}$) and $^{232}\text{Th}$ ($^{228}\text{Th}$) in radioactive equilibrium with the other isotopes of the U and Th series. This limit value has been included into the valid normative documents on radiological safety in Russia (Anon., 1999).

The content of artificial radionuclides in soil depends on the number of nuclear weapons tests and on the quality of work at atomic industries. With nuclear weapon testing the majority of radioactive substances go to the stratosphere (10-50 km from the Earth’s surface). They stay there for a very long time, slowly descending and dispersing everywhere on the Earth’s surface. Radioactive fallout contains hundreds of different radionuclides. The most significant in soil contamination are $^{14}\text{C}$, $^{137}\text{Cs}$, $^{95}\text{Zr}$, $^{90}\text{Sr}$.

The nuclear fuel cycle, part of which are nuclear power stations, is also accompanied by emissions of radioactive substances to the environment. The highest amounts of radionuclides reach the environment after accidents at nuclear power stations. In this case, most important from the agroecological point of view are $^{137}\text{Cs}$ and $^{90}\text{Sr}$. These radionuclides are chemical analogies of the macro-elements K and Ca respectively and they actively migrate in...
the food chain. If soil is contaminated with $^{137}\text{Cs}$ and $^{90}\text{Sr}$, the quality of agricultural products may be degraded for a long time, because the half-life of these radionuclides is 30 years. $^{137}\text{Cs}$ and $^{90}\text{Sr}$ transfer from soil to plants is dependent on the physical-chemical properties of the radionuclides and the soil, climate factors and genetic peculiarities of the plants.

Cs belongs to a group of alkaline elements and has the oxidation state I, which means that it does not form insoluble compounds naturally. Sr belongs to a group of alkaline-earth elements. It is a metal and has oxidation state II.

The mobility of radionuclides in the soil and their availability to plants depend on the following soil properties:

- Mineralogical composition and soil texture.
- pH.
- Organic matter content.
- Cation composition of soil solution.
- Ca and K concentrations.

The fate of artificial radionuclides in soil is determined by general sorption processes. Radionuclides take part in the processes of ion exchange, physical adsorption, co-precipitation, etc. However Klechkovsky (Cigna and Durante, 2005) indicated that sorption of radionuclides is specific, e.g. takes place under conditions of very low concentrations of sorbed substance. Due to extremely low concentrations, the behaviour of artificial radionuclides depends considerably on natural isotopic and non-isotopic carriers – stable nuclides of the element or its chemical analogues. Changes in concentration of a macroelement (K, Ca) in the soil can influence the distribution of a radionuclide ($^{137}\text{Cs}$, $^{90}\text{Sr}$), while changes in concentration of a radionuclide do not influence the distribution of the macroelement in the soil. Indeed, even in very severe radiological situations, the mass concentration of radionuclides in soil is very low and equal to about 0.4-1.0 g km$^{-2}$.

Clay minerals with layered structures (such as montmorillonite and hydrous micas) considerably influence the stability of artificial radionuclides in soil. Minerals of this group determine exchangeable (on the surface) and non-exchangeable (in interlayer space) sorption of $^{137}\text{Cs}$. Sorption of $^{90}\text{Sr}$ is mainly exchangeable and therefore this element is more mobile in the soil-plant system than $^{137}\text{Cs}$.

Non-exchangeable fixation of $^{137}\text{Cs}$ in the interlayer space of clay minerals determines the long-term presence of this element in the root habitable zone, while its biological availability generally decreases. If there is K in the system, the sorption of $^{137}\text{Cs}$ may be decreased because macroelements displace radionuclides from exchange sites (Wauters et al., 1994; Nisbet et al., 2000). However rather high K concentrations are needed for the decreas-

### Table 36.1. NRN concentrations in raw phosphate materials in Russia.

<table>
<thead>
<tr>
<th>Deposit, mine</th>
<th>Number of samples</th>
<th>$^{238}\text{U}(^{226}\text{Ra})$ [Bq kg$^{-1}$]</th>
<th>$^{232}\text{Th}(^{228}\text{Th})$ [Bq kg$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apatite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kola</td>
<td>4</td>
<td>26</td>
<td>70</td>
</tr>
<tr>
<td>Seligdar</td>
<td>1</td>
<td>100</td>
<td>1,030</td>
</tr>
<tr>
<td>Belaya Zima</td>
<td>2</td>
<td>80</td>
<td>610</td>
</tr>
<tr>
<td>Phosphorite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kingisepp</td>
<td>9</td>
<td>190</td>
<td>40</td>
</tr>
<tr>
<td>Podmoskovnoe</td>
<td>1</td>
<td>410</td>
<td>17</td>
</tr>
<tr>
<td>Bryansk</td>
<td>4</td>
<td>140</td>
<td>11</td>
</tr>
<tr>
<td>Verhnemanskij</td>
<td>3</td>
<td>360</td>
<td>18</td>
</tr>
<tr>
<td>Gornaya Shoriya</td>
<td>2</td>
<td>440</td>
<td>35</td>
</tr>
<tr>
<td>Aktyubinsk</td>
<td>1</td>
<td>390</td>
<td>30</td>
</tr>
<tr>
<td>Sejbinskoe</td>
<td>1</td>
<td>410</td>
<td>6</td>
</tr>
<tr>
<td>Belkinskoe*</td>
<td>2</td>
<td>1,480</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Oshurkovskoe</td>
<td>1</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Telekskoe*</td>
<td>1</td>
<td>430</td>
<td>22</td>
</tr>
</tbody>
</table>

*Concentrated product after flotation

### Table 36.2. Average weighted NRN concentrations in selected Russian phosphorus fertilisers.

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>$^{238}\text{U}(^{226}\text{Ra})$ [Bq kg$^{-1}$]</th>
<th>$^{232}\text{Th}(^{228}\text{Th})$ [Bq kg$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorite concentrate</td>
<td>460</td>
<td>30</td>
</tr>
<tr>
<td>Superphosphate</td>
<td>24</td>
<td>44</td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>130</td>
<td>48</td>
</tr>
<tr>
<td>Phosphate slag</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Ammophos</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Nitroammophos</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>Nitrophos</td>
<td>330</td>
<td>26</td>
</tr>
<tr>
<td>Nitroammophoska</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>Nitrophoska</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Foreign fertilisers</td>
<td>400-4,000</td>
<td>15-440</td>
</tr>
</tbody>
</table>
ing coefficient of $^{137}\text{Cs}$ distribution in the solid phase-soil solution system. The influence of K is not significant if its concentration in the soil solution is 0.4 g l$^{-1}$, but the effect is 2-3 times stronger if the K concentration is 4.0 g l$^{-1}$. Therefore, when K concentration in soil is very high, an increase in availability of Cs for plants may be observed. However K fertilisers (within the range of agronomically reasonable doses) decrease Cs uptake 3-5-fold more in comparison with the control, because K competes with Cs for the sorption sites on the root surface (Drichko and Tsvetkova, 1990).

Competition between the chemical analogues Ca and Sr is also rather distinct in the soil-plant system. Liming decreases Sr accumulation in agricultural products 3-20-fold depending on biological characteristics of the plants and soil properties. Increasing pH, induced by lime, decreases the mobility of radionuclides. Thus neutralisation of soil acidification decreases accumulation of $^{137}\text{Cs}$ in harvested crops 2-4-fold (Aleksakhin and Korneeva, 1992). Yudintseva et al. (1980) observed an antagonism between Ca$^{2+}$ and Mg$^{2+}$ in lime and pollutant cations in soil solution. The application of lime decreased plant uptake of radionuclides belonging to the Periodic Table groups I and II, although the solubility of their hydroxides is very high.

Organic fertilisers should be applied to decrease accumulation of $^{137}\text{Cs}$ in the food chain. Organic fertilisers increase the sorption capability of the soil and this measure is most effective on light soils. For example, application of organic fertilisers to soddy podsolic sandy loam soil decreased Cs uptake by peas 3-fold, while organic fertilisers applied to the soddy podsolic light loam soil decreased Cs uptake 1.5-fold. However, radionuclides are weakly sorbed by organic matter and therefore their transfer from peat soils is more intense than from mineral soils (Drichko et al., 1996).

Low quantities of Sr are very well co-precipitated with Ca phosphates, which is why application of phosphorus fertilisers on soils contaminated by $^{90}\text{Sr}$ decreases Sr uptake by plants 5-8-fold (Firsakova et al., 2002). Nitrogen fertilisers should be applied carefully, as higher doses give higher Cs and Sr concentrations in plants. The selection of crops that accumulate relatively low amounts of radionuclides is also a very important measure for the management of contaminated territories. Cereals in this case are more preferable for cultivation than vegetables and root crops. Cultivation of technical crops and seed breeding are the safest activities on contaminated lands.
References


Chapter 36


References


Chapter 37


