Challenges in remediation of agricultural soil contaminated by radioactive substances – Agricultural Engineering for Earthquake Disaster Reconstruction –

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Abstract

On March 11, 2011, a massive earthquake struck the eastern region of Japan, causing widespread devastation. Agricultural engineers in Japan are currently working on a variety of restoration projects and combining their previous experiences. However, we now face the new problem of soil contamination by radioactive substances. In this keynote lecture, I propose several methods that can effectively decontaminate soil contaminated by radioactive cesium based on the findings of clay science.

***Keywords**:* earthquake disaster reconstruction, remediation of agricultural soil, radioactive cesium, agricultural engineering, field monitoring system

1. Introduction

The damage caused by the massive earthquake and resulting tsunami that struck Japan on March 11, 2011 was particularly severe in Miyagi, Iwate, and Aomori Prefectures, where numerous coastal embankments were broken and large areas of farmland, including paddy fields, were flooded with sea water. In addition, as a result of the consequent accident at the Fukushima Daiichi Nuclear Power Plant, soil in some municipalities in Fukushima Prefecture was contaminated by radioactive substances. The entire East Japan area is now in need of massive and rapid reconstruction and Japanese agricultural engineers are working towards this goal by combining their previous experiences.

Are there countermeasures for the contamination of soil by radioactive substances? In this keynote lecture, I will speak as a specialist in soil physics and agro-informatics, and propose several methods that can be used to effectively decontaminate radioactive cesium in soil based on the findings of clay science.

2. Nature of the clay

Soil is composed of soil particles, water and air. Soil particles smaller than 2 μm (micrometers) are defined as clay. Clay becomes muddy when it contains a lot of water and becomes hard when it is dry. If we put a large amount of water and a small amount of soil into a plastic bottle and shake it for a minute and then place it on a table, we can see that the sand, which consists of larger particles, sinks to the bottom of the bottle faster than the clay, which is composed of smaller particles, and the muddy water gradually becomes transparent. This shows that the muddy water contains clay.

The chemical structure of some clay minerals has been analyzed at the nanoscale. Clay mineral surfaces are negatively charged and adsorb hydrated cations. In general, these cations are easily exchanged with other cations, such as potassium. However, the cesium that was released during the Fukushima nuclear accident has become trapped in the holes of clay surfaces.

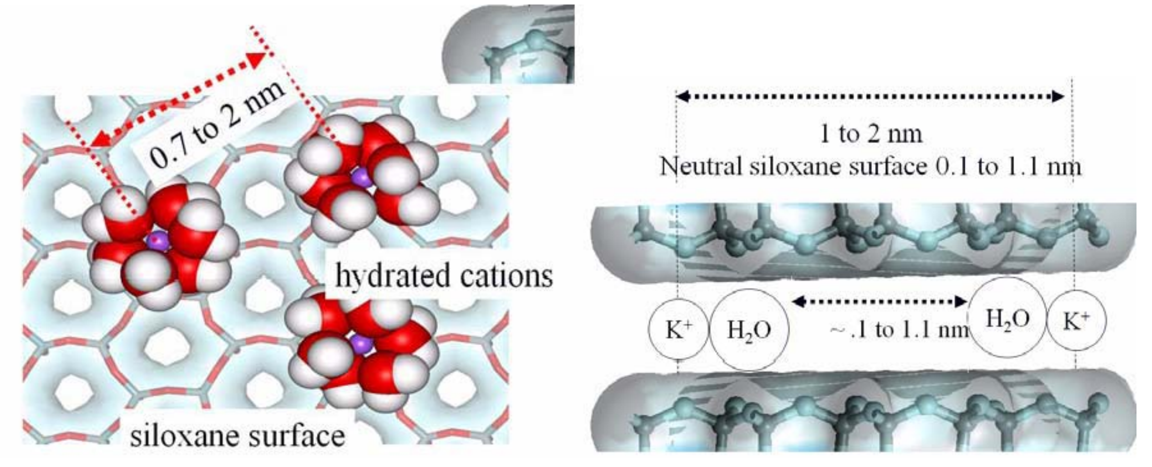

Fig. 1 Hydrated cations adsorbed by clay mineral surfaces (after C. T. Johnston, 2011).

Layered silicate is a typical clay mineral that is formed from the adhesion of two kinds of sheets, Si-tetrahedral and Al-octahedral, by dehydration synthesis. In the process of its formation, a negative surface charge is generated which electrically attracts cations such as hydrated potassium on the surface of the layered silicate. The surface of a Si-tetrahedral sheet has holes composed of six-membered rings, and because they happen to be the same size as cesium, it is difficult to remove the cesium once it binds to the sheet.

3. How to remediate soil contaminated by radioactive substances

Radioactive cesium only accumulates in the surface layer of topsoil (Shiozawa et al., 2011). Cesium is absorbed into the clay surface so strongly that normal exchange with other cations is limited and the cesium is seldom eluted into the surrounding soil water. Therefore, cesium can only move downward when muddy water containing cesium-contaminated clay particles seeps through cracks in the soil. This is why cesium has been retained within the topsoil for as long as seven months after the accident. However, the difficulty associated with removing cesium from the clay provides us with an important hint for removing cesium from the soil: that is, we should not think of removing the cesium, but removing the clay. We can thus effectively remove radioactive cesium from the topsoil if we remove clay that has adsorbed cesium. Although the problem of treating the collected clay remains, we can consider the following methods for the remediation of soil contaminated by radioactive substances.

(1) Soil puddling method

Paddy water becomes muddy due to soil puddling. As described above, large amounts of clay particles exist within the muddy water. Therefore, if we can flush out the muddy water after soil puddling, then we can reduce the number of clay particles in the paddy field. Farmers usually puddle the fields before planting in the spring. However, if they repeat soil puddling several times a year, then they can remove a large amount of clay, along with the bonded radioactive cesium, from their paddy fields. Figures 2 and 3 show our experiment in a paddy field in Fukushima Prefecture.

(2) Method for stripping the topsoil after soil puddling

If we puddle the soil in the dry season after harvesting, a skin of dry clay will form on the surface of the topsoil as the puddling water is lost by evaporation or underground seepage. This dry clay contains high concentrations of cesium. If we can develop a method to collect this dry clay, we could effectively remove the radioactive cesium from the paddy soil.

(3) Deep plowing method to replace surface soil with subsoil

The collected cesium-contaminated clay should be buried under non-contaminated soil. Although it depends on the moisture condition of the cover soil, the gamma-ray radiation at the soil surface is estimated to become approximately 1/10 and 1/100 from the contaminated soil at a depth of 25 and 50 cm, respectively (Miyazaki, 2011) The characteristic of soil that allows it to absorb gamma-rays is useful for developing a deep plowing method. From a practical point of view, it would be worth considering a method to replace the topsoil with subsoil deeper than the root zone in situ.

(4) Other methods

According to a batch test performed using soil from Fukushima, approximately 20% of the radioactive nuclides were extracted from the soil by water treatment; however, the remaining nuclides were not extracted by further water treatment (Nogawa et al., 2011). This result shows that all of the cesium is not always strongly adsorbed onto clay particles, but that some cesium might be loosely bound to the soil organic matter. In order to reduce the cesium eluted from the soil, it may be effective to add clay mineral powder such as bentonite, which readily adsorbs cesium, to the soil.

In addition, we could use the phytoremediation methods, which allows plants such as sunflowers to take up residual cesium from the soil after the physical removal of high concentrations of cesium.

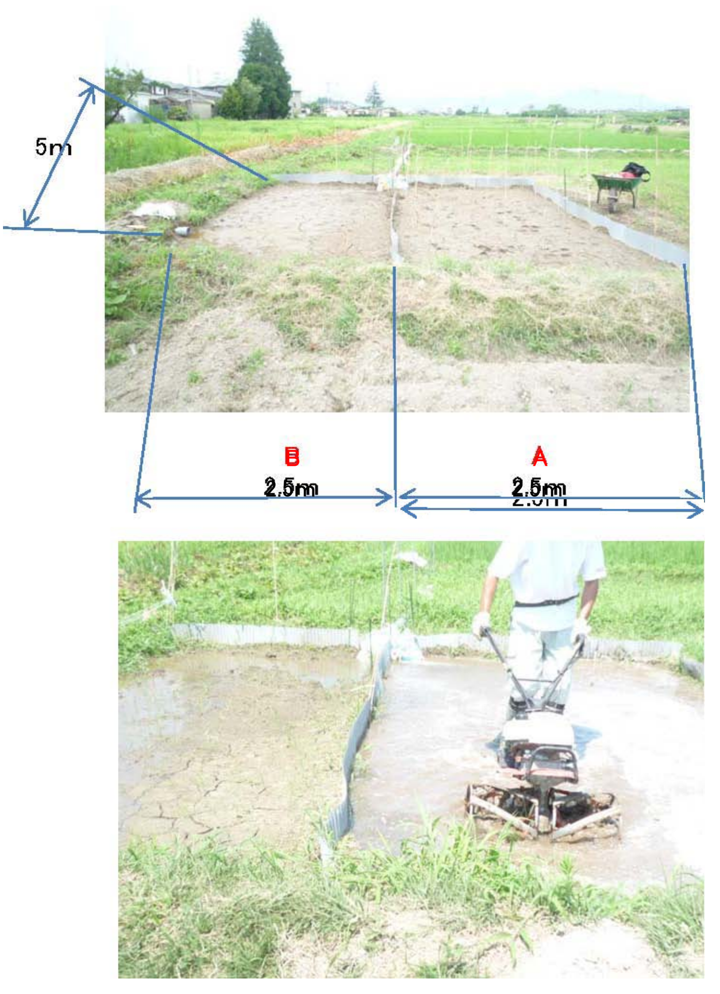

Fig.2 Demonstration of the soil puddling method in a small paddy field in Fukushima.

The study site was divided into two sections, A and B. After soil puddling, the muddy water was immediately drained from section B, and the topsoil was stripped after drying in section A. After a week, radiation levels were measured at the ground surface at 15 points in each section.

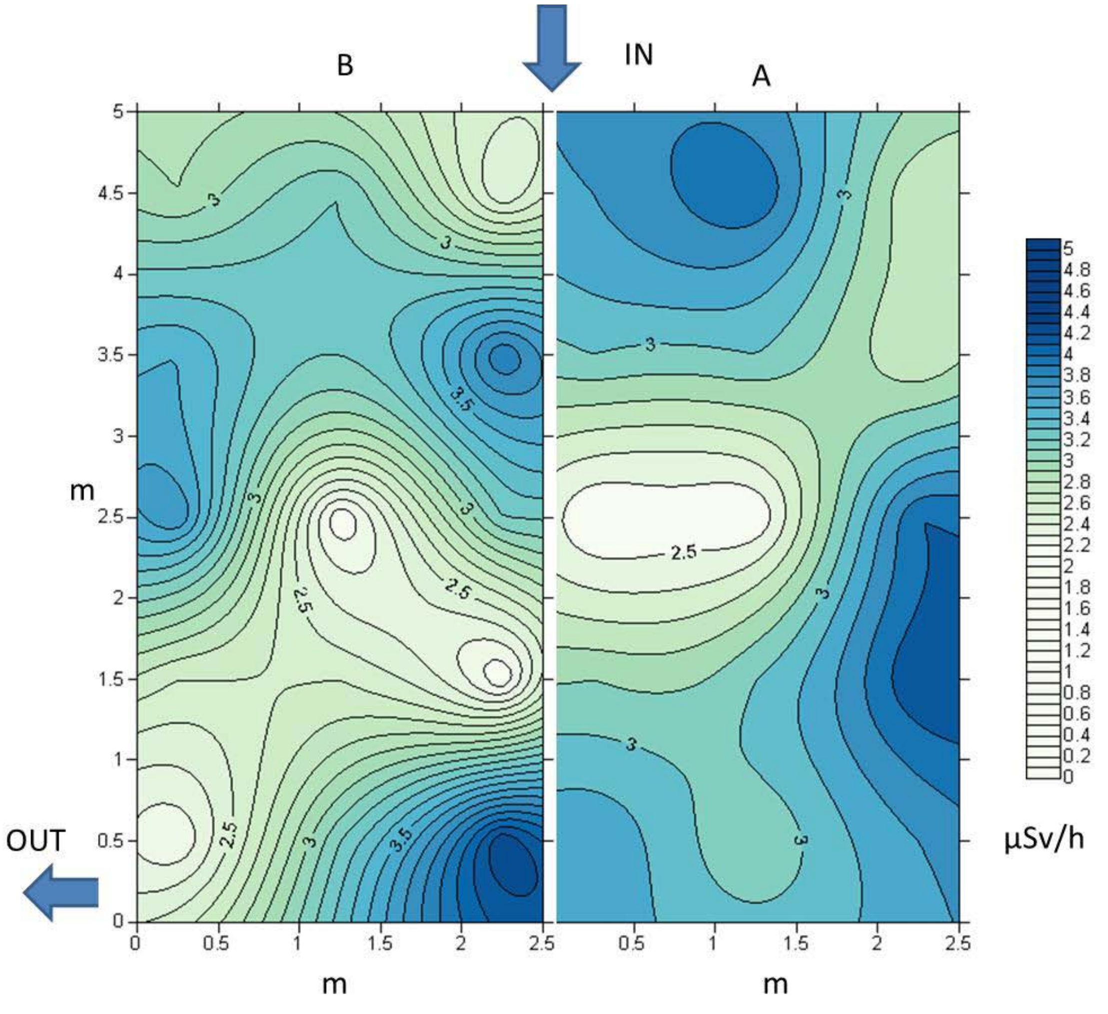

Fig.3 Map showing radiation levels. Irrigation water is supplied from the top of the field (IN) and drained from the left of the field (OUT) after soil puddling in section B.

4. Current status of soil in Iitate Village, Fukushima Prefecture

Over a weekend in June, my friend and I brought a Geiger counter and drove around Iitate Village and Namie Town, which are designated as planned evacuation zones. On the road, we passed only police cars that had come from outside of the prefecture, and this alone demonstrated to us the true scale and tragedy of the accident. We measured the gamma-ray radiation dose at three points on the surface of a soil slope and found that the radiation dose was higher at the bottom of the slope than at the middle or at the top of the slope (Fig. 4). This observation showed that clay is washed downwards on the slopes by rain. In other words, radioactive cesium accumulates on the surface soil and is moved downwards along with the clay particles by the rain. These are the results that we had expected.

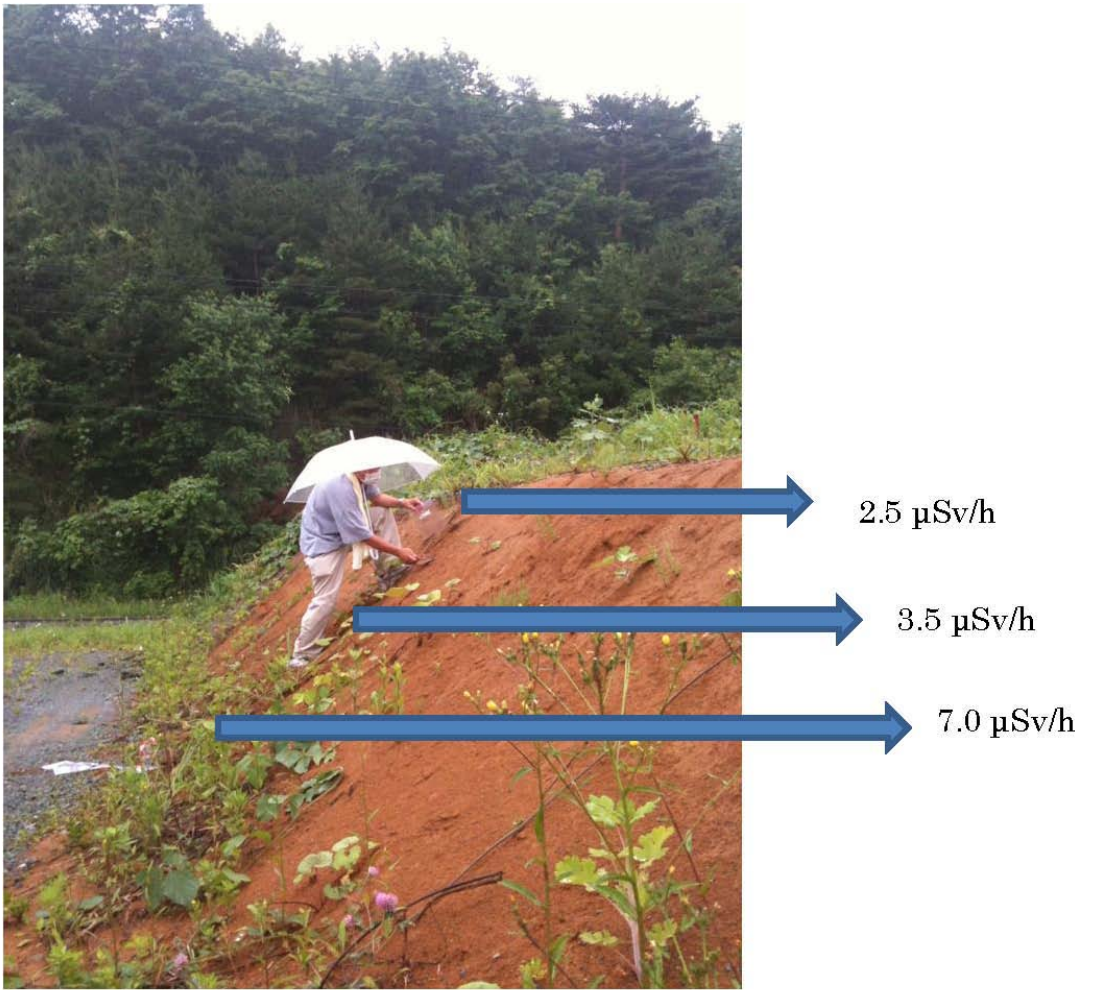

Fig.4 Measurement of radiation dose on a slope near the Iitate Village office (2011.6.25; Mizoguchi and Noborio)

However, when I visited Iitate Village again in July, I discovered another problem. There was a lot of summer grass growing in the uncultivated rice paddy fields. To conduct the soil puddling method proposed previously, we must first kill the grass with herbicide, till the soil, and then puddle the paddy field. Although I proposed the soil puddling method from the standpoint of clay science, the actual field conditions showed me that our task is not so easy. In order to solve these problems, we need to repeat various field tests and identify realistic and effective methods.

5. Decontamination of a village

Cesium does not move by itself, but rather moves along with clay particles, as described above. Since forests comprise 74% of the Iitate Village area, even if the farmland is cleaned up temporarily using the proposed method, clay particles will continue to flow into the farmlands from the forest every time it rains. Also, clay particles will travel as dust into living spaces from the forest on windy days. To keep the village clean, we should consider decontamination of the entire basin. One idea is to create a moat around the community, which may be useful in preventing the inflow of clay particles from the forest.

Fig.5 Setup of Field Monitoring System (FMS) at the corner of a house in Iitate village (2011.10.2).

The FMS measures the radiation dose at a height of 1.2 m above the ground at noon and sends the results to a data server in my laboratory together with hourly data for air temperature, relative humidity, precipitation, solar radiation, wind direction, wind speed, soil moisture, soil temperature, and electrical conductivity of soil.

6. Environmental monitoring of soil

After decontamination treatment on farmland or communities, we need to evaluate the effectiveness of the decontamination. For this evaluation, it is necessary to continuously monitor soil radiation at important points (hotspots). In particular, it is important to observe the relationship between radiation dose and weather, such as precipitation and wind. It is also important to observe the relationship between precipitation and runoff/turbidity of rivers.

However, radiation meters are expensive for the general public. People therefore need an economical radiation dose sensor that gives a relative value, even if it is somewhat rough in accuracy. Fortunately, a volunteer group has recently developed a Pocket Radiation Sensor in order to respond to this need (non-profit project "radiation-watch.org", 2011).

Recently, I have been developing a field monitoring system for quasi real-time data collection from a remote agricultural field in Asia (Mizoguchi et al., 2011). By adding this new radiation sensor to the monitoring system, I have just started in situ soil monitoring in Iitate Village in October of this year. Figures 5-8 show some of the results. I believe this monitoring system will be a powerful tool in the remediation of soil contaminated with radioactive substances, which will start in Iitate Village.

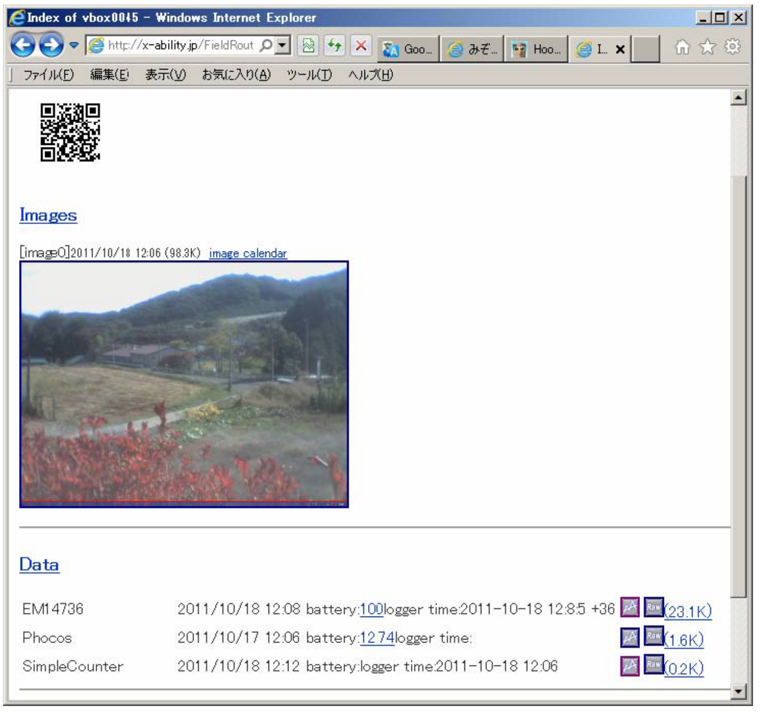

Fig.6 The FMS website for the Iitate Village monitoring program.

In addition to images, all sensor data can be downloaded from the website (http://www.iai.ga.a.u-tokyo.ac.jp/mizo/edrp/) as numerical or graphical data.

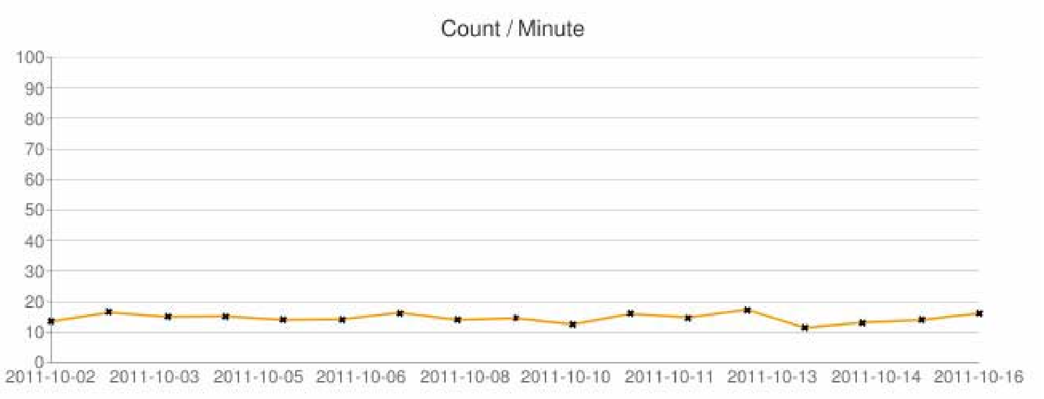

Fig.7 Changes in the radiation dose at a height of 1.2 m above the ground at noon from October 2, 2011.

Fig.8 Hourly data of air temperature, relative humidity, soil temperature and electrical conductivity of soil at the corner of a house in Iitate village.

7. Conclusion

Historically, agricultural engineers have resolved numerous problems in rural areas using a variety of engineering solutions. However, Japan now needs new and innovative agricultural engineering for the restoration after the earthquake. In this keynote lecture, I focused on the nature of clay, which adsorbs radioactive cesium, and proposed several methods to remove the radioactive cesium-adsorbing clay from the soil. It has not been proven whether these methods are effective in actual fields, as field testing has just started. However, the remediation of agricultural soil contaminated with radioactive substances is urgent, and we cannot afford to wait for the results of research: we must think on our feet to solve this problem. I only want to say one thing in this keynote, and that is the importance of clay in the decontamination of radioactive cesium.

Acknowledgments

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