

Characteristics of water quality and stable isotopes in spring water, groundwater and artesian well at Minamisoma City and consideration of the water quality change after Tsunami.

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After the Great East Japan Earthquake occurred, the investigation near the coast area in northern part of Fukushima prefecture has been carried out to clarify the groundwater flow and residence time in this area. The measuring of EC, pH, water temperature, ORP and water sampling of groundwater, spring water and river water have been carried out several times. In this presentation, we will report the result of investigation which was carried out on December, 2016.

The investigation was carried out on 29-30 December, 2016 at Minamisoma City and Soma City. As a result of investigation of four spring sites and six groundwater sites (including the five artesian wells), the following were revealed.

- 1) As a result of chemical analysis for dissolved inorganic matter in spring water and groundwater, Na-(Cl+SO₄) type, Ca-HCO₃ type and Na-HCO₃ type were indicated. The spring water which shows the Na-(Cl+SO₄) type may be affected by the Tsunami. The investigation of this spring water has been performed regularly. Thus, the EC in this spring water decrease gradually (from 100 mS/m in December, 2012 to 30 mS/m in December, 2016), the influence of the Tsunami may decline. In the other sites, there is no tendency that was affected by the Tsunami.
- 2) If the water quality shows the Na-HCO₃ type, the groundwater flow might be more deeper and residence time might be relatively longer. In the investigation of December, 2016, Na-HCO₃ type was recognized at 2 sites (groundwater in Minamisoma City and artesian well in Soma City). Since the stable isotopes of oxygen and hydrogen in these water is relatively low, it is assumed that the recharge area is more higher latitude. As a result of calculation by using the altitude effect ($\delta^{18}\text{O}$: -0.29‰/100 m, δD : -2.0‰/100 m), recharge area of groundwater that water quality is Na-HCO₃ type is estimated about 300 m higher than the site where the water quality is Ca-HCO₃ type.
- 3) There is multiple groundwater flow near the coast area of northern part of Fukushima prefecture.
- 4) The concentration of trace element of manganese and iron is relatively high in the part of Minamisoma. The origin of manganese and iron might be Earth (soil or rock).
- 5) Because of the stable isotopes of strontium are different by geology, it is highly possible to grasp the difference of recharge area of groundwater. In future, we will measure the strontium isotopes and consider about the more detailed groundwater flow.

Keywords: Minamisoma City, groundwater, spring water, artesian well, water quality, Tsunami

Quantitative estimate of ^{137}Cs load characteristics in Kuchibuto river watershed

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^{137}Cs has major impact on the environment due to its long half-life (30.1 years). To understand ^{137}Cs load characteristics in the watershed, we estimated the effective ^{137}Cs half-life in the Kuchibuto river watershed by calculating the ^{137}Cs load in the river. Watershed area is 22km^2 , elevation is from 329m to 1,050m. Annual precipitation and average temperature is 1,158mm and 14°C respectively. The research watershed was covered with forest (74%), agricultural land (17.4%) and paddy field (7.6%). And, soil types are brown forest soil (51%) and Andosol (49%).

During the period from 6 July 2014 to 24 August 2015, we measured river discharge, SS, and ^{137}Cs concentration. Utilizing measured data, we attempted to estimate the ^{137}Cs load during non-observed period. First, Soil and Water Assessment Tool (SWAT) was utilized for river discharge estimate. Model warmup period was from 2008 to 2010. For the calibration, 2000 times simulation was conducted with Latin Hyper-cubic method from 1 October 2014 to 31 May 2015. Validation was also conducted from 6 July 2014 to 30 September and from 1 June 2015 to 24 August 2015. The model performance was assessed by Nash-Sutcliffe efficiency (NSE) and regression coefficient (R^2). Particulate ^{137}Cs concentration was calculated by regression curves between discharge and suspended solid (SS), and SS and ^{137}Cs concentration. Regression curves were constructed from observed discharge [$\text{m}^3 \text{s}^{-1}$], SS [g L^{-1}] and ^{137}Cs concentration [Bq L^{-1}], and bias was compensated. Dissolved ^{137}Cs was also calculated by using the partition coefficient which was ratio of particulate and dissolved ^{137}Cs in the river. For uncertainty analysis, 95% confidential interval of ^{137}Cs load was estimated by using the composition of Gaussian distribution of each regression curves from 1 October 2014 to 31 May 2015. Discharge uncertainty was estimated by the sequential uncertainty fitting (SUFI).

During the observed period (6 July 2014 - 24 August 2015), particulate and dissolved ^{137}Cs load was calculated at 6.1×10^8 and $1.5 \times 10^6 \text{ Bq km}^{-2}$ and these values were equal to 0.26% and 0.00065% of total ^{137}Cs deposition on the watershed (5.13TBq , 28 December 2012 at present). Through the hydrological simulation by SWAT, total load of ^{137}Cs from 2013 to 2015 were estimated. For about the model performance, NSE and R^2 for calibration and validation were 0.75, 0.76 and 0.50, 0.54 respectively. Especially, in September 2015, large scale rainfall event (165mm day^{-1}) was occurred and this event contributed to huge amount of ^{137}Cs discharge in 2015. Annual total ^{137}Cs load excluding this rainfall event in September 2015 was $2.41 \times 10^8 - 2.86 \times 10^8 \text{ Bq yr}^{-1} \text{ km}^{-2}$ which was equal to about 0.1% of total ^{137}Cs deposition. Otherwise, annual particulate and dissolved load including the large scale rainfall event in September 2015 were estimated at $2.41 \times 10^8 - 6.8 \times 10^{10} \text{ Bq yr}^{-1} \text{ km}^{-2}$ and $8.7 \times 10^5 - 5.76 \times 10^7 \text{ Bq yr}^{-1} \text{ km}^{-2}$ respectively and these values were equal to 0.1 - 29% of total ^{137}Cs deposition in this watershed. However, it needs to be paid attention that the estimation of this huge scale rainfall might have large uncertainty because our observed period did not cover such large event. Lastly, effective ^{137}Cs half-life with consideration of ^{137}Cs load was calculated at 4.33 years according to our point estimation, and it appears that total amount of ^{137}Cs in the watershed is decreasing to 0.82% of initial ^{137}Cs amount within next 30 years. However, according to our uncertainty analysis, uncertainty range of ^{137}Cs load was crossing over 2 - 3 orders, thus, effective ^{137}Cs half-life is also probably highly uncertain. Thus, to obtain more accurate estimate, we need to improve the model performance during the extremely high flow events.

Keywords: Fukushima Dai-ichi Nuclear Power Plant accident, Cesium137 load, SWAT

Monitoring of radioactive Cs in stream discharge from small un-decontaminated forest in Fukushima

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Huge amount of radioactive materials were emitted by the accident of Fukushima dai-ichi nuclear power plant following to the Great East Japan Earthquake on March 2011. Five years have passed and decontamination has been proceeding at residential area and agricultural fields. Some evacuated areas are planning to accept return of former residences. However, especially in Fukushima, forest covers large area of the polluted region. A 70% of the area in Fukushima is covered by forest and most of them are still un-decontaminated. For returning village people, effects of polluted forest is important issue. From May 2016, we set monitoring and water sampling facility at the outlet of a small un-decontaminated forest. Water sampling was conducted when water level of the stream exceeded a threshold. Stream data and climate data at neighbor were transfer to the data storage by Field Reuter (X-ability, Inc.).

Water level-flow rate relationship and turbidity-suspension concentration relationship were determined, separately. Discharge of radioactive Cs was estimated by using those equations. Estimated discharge was 1470 MBq for 6 months since May till November, 2016. The number was 0.1 to 0.4% of the initial deposit (1 to 3 MBq m⁻²) of radioactive Cs at the nuclear power plant accident on March 2011.

Suspended sediments filtered by 0.45 μ m mesh membrane filters were subjected to imaging plate analysis. When suspended sediments seemed to be inorganic particles such as silt, sediments evenly contained radioactive Cs while when most of the sediments were consisted of organic matter, only several strongly radioactive Cs holding particles contributed most of radiation of the sediments. This suggested radioactive Cs in a sediment flowing a stream may variate temporarily depending on watershed conditions.

Keywords: radioactive cesium, forest, discharge

Effects of Soil Organic Matter on Transport of Cesium in weathered granite soil

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To grasp migration of radiocesium (Cs) in soil is an important issue after the accident of Fukushima Dai-ichi nuclear power plant, Japan. The soil organic matter (SOM) is one of the components to affect Cs transport. There are two possible cases for SOM-induced Cs transport. First, SOMs in solution carry Cs to deeper soil layer. Second, SOMs sorbed on the soil solid surface inhibit Cs fixation, resulting in enhancement of Cs mobility. Cs concentrations in soil water are also one of important factors to affect Cs transport. In this study, we experimented effects of organic matters, dissolved organic matter (DOM), humic acid (HA) and fulvic acid (FA), on the Cs transport in the soil by laboratory column experiment using different concentrations of Cs solution.

Soil sample was collected at an abandonment forest in Iitate, Fukushima, Japan. Dissolved organic matter was extracted from a litter from university forest in Chichibu, Saitama. Two Cs solutions are used, high (30mg/L) and low (1000Bq/L) concentration. High concentration solution was stable CsCl solution, and low one was extracted from organic soils in Iitate. The acrylic plastic column having a diameter of 3-cm and a length of 7-cm was used for the experiment. Two different treatments were applied for the repacked soil (control and organic adsorbed soil columns). The control soil column was prepared by repacking air dry soil sample up to 5cm of height. The organic adsorbed soil column was prepared by flowing dissolved organic matter for 24 hours to the control soil column. In the column experiment, Cs or Cs-DOM mixed solutions were applied under a constant ponding depth. Effluent Cs concentration was measured. After the transport experiments, the column was sliced in 1-cm interval and the soil at each section was used for the sequential extraction of Cs.

As a result of preliminary column transport experiment where high concentration Cs solution was applied to the 10cm long soil column, Cs accumulated within surface 4cm thick layer, while Cs mixed with DOM solution could move into 10-cm deep soil layer. Sequential extraction suggested most of Cs at deeper layer was complexed with organic matter.

Keywords: Fukushima, cesium, dissolved organic matter, humic acids, fulvic acids

Effects of soil clay minerals on radiocesium transport in soil

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In 2011 the fallout of radiocesium, Cs-134 and Cs-137, originated from the Fukushima-Daiichi Nuclear Power Plant contaminated soils in the Pacific coast side of northern Japan. The most of the fallout-radiocesium on the soil surface was reported to be remained in the surface layer in Fukushima Prefecture. There are two major soils with different clay minerals in Miyagi Prefecture, a northern next neighbor of Fukushima Prefecture: (1) volcanic ash origin soil with allophane found in the northern part of Miyagi Prefecture, and (2) granite origin soil with vermiculite found in the southern part of Miyagi Prefecture. Column experiments were conducted in a constant temperature room. The soils were uniformly packed in the columns and saturated with distilled water supplied from the bottom of the columns. A 160 mL of KCl solution with 1.5 kBq/kg exchangeable radiocesium was supplied with a rate of 10 mL/h from the top of the soil columns. Effluent from the bottom of each soil column was collected every two hours and analyzed for the concentrations of Cs-134 and Cs-137, dD and dO-18, and KCl. After applying 800 mL distilled water with a rate of 10 mL/h from the top of the soil columns, the soil columns were dissected with 1 cm thick and analyzed for the concentrations of Cs-134 and Cs-137. No or less than the detection limit of Cs-134 and Cs-137 was found in the effluents of all the columns although the solution containing the radiocesium was completely drained out with 2 pore volumes of effluent. The distributions of Cs-134 and Cs-137 in the volcanic ash origin soil and the granite origin soil were very different. The radiocesium reached near the bottom of the column for the volcanic ash origin soil whereas the radiocesium stayed near the soil surface for the granite origin soil. This difference might be attributed to different clay minerals contained in the soils. Our results implied that the prediction of radiocesium transport in soil should be accounted for clay minerals.

Keywords: adsorption, advection, breakthrough curve

Effects of inorganic amendments on radiocesium behavior in grassland soil

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The accident at the Fukushima Daiichi nuclear power plant occurred in 2011, resulting in contamination of agricultural fields by radioactive substances such as ¹³⁷Cs (RCs). Potassium (K) fertilization is typically considered as an effective countermeasure for reducing RCs uptake by plants. However, in case of a pasture, K fertilizer application results in increase in pasture K concentration, causing a metabolic disease for cattle known as grass tetany. Therefore, in the grassland polluted by RCs, alternative countermeasures for reducing RCs uptake are required. In this study, we investigated the effect of adsorbent applications on the RCs behavior in grassland soil.

Soil samples were taken from a grassland polluted by RCs at the surface layer (from 0 to 5cm) in Fukushima prefecture. Zeolite and weathered biotite were selected as adsorbents. The soil was adjusted to different water contents (0.86, 1.2) and the adsorbents were added at 0.5, 2.5, 5g per 50g dried soil. Incubation was conducted in constant temperature (20°C) room. Incubation duration was 7, 28 and 112 days. After that, 1M ammonium acetate with soil: solution ratio of 1:4 (dried soil: solution) was added and shaken for 6 hours. Suspension was filtered by 0.45 μm membrane filter. Cs concentration (exchangeable Cs, Ex-Cs) in the filtrates were measured by a Ge semiconductor detector.

With increasing adsorbents added to the samples, the concentration of Ex-Cs decreased where more decrease in Ex-Cs was observed for the sample at higher water content. Zeolite decreased concentration of Ex-Cs more than weathered biotite in same soil: solution ratio.

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Keywords: Fukushima, cesium, inorganic amendments

Application of Soil Radioactivity Data to Environmental Contamination Recovery

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Response to an environmental disaster consists of three domains: Human perception of the event, the concerned environmental processes, and the data and analytical tools. Human perception of the event (cause, effect, future prediction) would affect the disaster recovery and mitigation planning. Building a proper plan requires an understanding of the physical landscape processes. To understand the landscape processes, field data and data analysis tools are utilized. Together, these three domains combine to present a whole aspect of the disaster situation which needs to be tackled.

During the summer of 2016, soil samples were collected in a village in Fukushima, Japan for radioactivity level assessment. Following the nuclear plant accident in 2011, environmental decontamination efforts, including surface soil scraping, have been taken place in the areas affected by the radioactive fallout. In this study, based on the collected soil radiation data, the relationship among the three domains (human perception, landscape processes, and data) in case of Fukushima is analyzed.

The challenge, which soil data presents, is the inherent geological and landscape heterogeneity, movability, and its three-dimensionality. The land types of the sampling site include natural forests on hills, the foot of the forests where the ground surface was decontaminated, and a rice paddy in the lowlands whose surface soil was replaced. In an effort to identify the storage and the subsurface movement patterns of radioactivity, numerical statistical analysis and two- and three- dimensional visualization analysis are attempted.

The preliminary results indicate a few issues in the three-domain model. With regard to human perception, decision makers' perception about the land processes pose enormous effects on the later implementation of recovery measures. Physical process modeling indicates that the forests are acting as a natural storage for elevated radioactivity, although the natural storage would work differently compared with a man-made storage. As for data handling, horizontally and vertically distributed soil samples impose challenges in visualization. Still, visualization attempts show the certain radiation 'sink' areas in the landscape.

Addressing shortcomings in each domain and filling gaps in the interconnection among them would present an insight which is relevant to disaster response and recovery in general.

Keywords: radiation, radioactivity, soil, decontamination, geography, GIS

Artificial Macropore Installation for Enhancing Vertical Transport and Fixation of Radioactive Cesium at Blueberry Farm.

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Artificial Macropore Installation for Enhancing Vertical Transport and Fixation of Radioactive Cesium at Blueberry Farm.

Keywords: artificial macropore, radioactive Cesium, infiltration

Potential of Bioenergy Crop Production in Decontaminated Farmlands in Fukushima

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The devastating accident of Fukushima Dai-ichi Nuclear Power Plant occurred due to Great East Japan Earthquake on March 11th, 2011. The projects of remediation lands and removal of radiocesium-contaminated soil from farmlands are still ongoing. Essentially, it is an important aspect to utilize those decontaminated farmlands for local farmers and communities. In Japan, the researchers have now been seeking how to start agricultural production from decontaminated farmlands, restructuring local communities, and economic activity in Fukushima. Globally, the research regarding the renewable energy resources, for example, *Miscanthus × giganteus*, have increased significantly. *Miscanthus × giganteus* has the high potential for a biomass energy crop, because of high biomass yield with low annual energy requirements and financial inputs, including tillage and planting practices and fertilizer, herbicide, and pesticide application. In addition, *Miscanthus × giganteus* can growth under severe soil condition such as dilapidated land or reclaimed mine land. Under *Miscanthus × giganteus* cultivation, their nitrogen recycles system is sufficient, because the nitrogen is recycled as it moves from the rhizosphere into the developing shoots during spring and summer, and is transferred to the rhizosphere in fall and winter. If shoots are harvested, the nutrients remain in the rhizosphere. It can be utilized for *Miscanthus × giganteus* shoot growth in the coming season. The previous research showed that the average biomass yield of *Miscanthus × giganteus* over 6 years was 25.6 Mg ha⁻¹ year⁻¹ in Northern Japan. In addition, our previous research revealed that carbon sequestration rates of *Miscanthus × giganteus* were 1.96 Mg-C ha⁻¹ year⁻¹ over the 6 years of this research trial. *Miscanthus × giganteus* generally increase SOC stocks due to the greater carbon inputs of above- and belowground biomass and no tillage. Therefore, the objective of this research was to estimate the potential of bioenergy production through *Miscanthus × giganteus* cultivation in decontaminated farmlands in Fukushima, Japan. The key findings are outlined below: (1) *Miscanthus × giganteus* can be the new insight for agricultural production from decontaminated farmlands, (2) due to the high carbon sequestration under *Miscanthus × giganteus* cultivation, the fertility of decontaminated farmlands can be improved, (3) more field experiments need to be done in order to develop the bioenergy crop production.

Keywords: Decontaminated farmlands, *Miscanthus × giganteus*, Bioenergy

Supporting Greenhouse Cultivation Using Fertigation Control System ZeRo.agri

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In response to the request of a farmer in Iitate Village of Fukushima Prefecture in 2015, an old pipe greenhouse was refurbished and the ICT nutrient soil cultivation system "zero agri" was introduced as a prototype of the future agriculture in the village. Nutrient soil cultivation is a cultivation method in which liquid fertilizer is mixed with irrigation water and applied to plant stocks using drip irrigation tubes. Drip irrigation was first developed in Israel in the 1960s to save irrigation water. Meiji University and Routrek Networks Co., Ltd. developed the "Zero Agri" system to automate fertigation procedures in 2013 and market the system. The system consists of two components: (1) a control section and (2) a driving section. using sensors that simultaneously measure solar irradiance outside a greenhouse using a pyronometer, and soil temperature, soil moisture, soil EC (electric conductivity: strongly relates to nitrate concentration, which is a major fertilizer source) using a Hydro probe II. Data measured by the sensors are recorded with a data logger of the control section and transmitted to the cloud over the Internet, where the amount and concentration of liquid fertilizer to be applied and the supply time are calculated based on the data acquired via the Internet. The driving section consequently controls control signal parts to open and close solenoid valves to manage liquid fertilizer application. The liquid fertilizer is supplied to the field with an infusion irrigation tube. A thermometer/hygrometer, a web camera, etc. can also be installed along with the sensors.

As daily water and fertilizer requirements of crops are proportional to the amount of solar radiation, liquid fertilizer is applied in proportion to the amount of solar radiation per time. Moreover, by separately controlling the supply amount and the concentration of the liquid fertilizer, soil moisture and soil EC become constant values. It is possible to increase the demand of water and fertilizer according to growth stages of crops, thus to cope with a decline in the water demand of crops due to increases in water infiltrated into the rhizosphere from the lower soil layers in the greenhouse. It is possible for growers to change soil moisture and soil EC by observing growing conditions of the crops. In other words, this system is semiautomatic in cooperation with growers. Since a tablet terminal is used to change control procedures, all the data are stored in the cloud, and the "experiences and feelings" of the growers are digitized. These data can be used for cultivation in the following years, or it can be provided to growers with insufficient experiences. If the system is introduced in a certain area, comparison among good and poor growers can be used to improve all the growers' skills in the whole area.

In Iitate Village, before the earthquake, agriculture, mainly rice and dairy farming, was a major industry. Although villagers will return to the village from April 2017, there is no prospect of improvement in paddy rice price once collapsed by the nuclear accident. Also, since pastures are always exposed to the risk of radioactive pollution, there is no prospect of resuming dairy farming. Furthermore, due to the restriction of the topography, there is little possibility of agriculture utilizing large-scale upland fields. In such background there is a high possibility of protected horticulture that uses greenhouses. Based on our study in Iitate Village from 2015 to 2016, we concluded that a rotation of "spring summer pepper → autumn lettuce → autumn lettuce → two winter spring transplanted spinach" was fully applicable. "Zero Agri" adequately supported a commuter farmer, who is not reside in the village, to grow crops.

Keywords: Fertigation, Greenhouse Cultivation, Control System

