福島県飯舘村の放棄林地内の不かく乱土における放射性 Cs 分布の特徴
Characterization of radioactive Cs distribution in undisturbed soil at abandoned forest in Iitate, Fukushima

ダン クォック トゥエット，辰野 宇大, 井本博美，濱本昌一郎，西村 拓[1]
Dang Quoc Thuyet, Takahiro Tatsuno, Hiromi Imoto, Shoichiro Hamamoto, and Taku Nishimura[1]

1. Introduction

Environmental fate of radioactive Cs in soil greatly varies depending on not only Cs concentrations but also soil characteristics. *In-situ* K_d ranged from 300 – 1200 L/kg (Mahara 1993). Cs strongly bounds to soil, clay minerals, and mainly deposits to top 10-cm surface soil, however its interaction with soil organic matter is not well understood. Forest covers more than 70% of ground surface in Fukushima, and most of forest areas are covered by litter. The interaction of Cs and organic carbon may significantly change Cs fate. In a field inventor in 2013, we found that Cs distribution in surface soil was heterogeneous, and greatly varied from place to place just in two years after the Fukushima fallout in March 2011. Because of ^{137}Cs long radioactive half-life, its migration may greatly affect adjacent environment. Therefore, the mobility of Cs in-situ should be well monitored and controlled to prevent any unexpected pollution may occurred. The study presents three consecutive years of monitoring (2013-2015) of Cs concentrations at 12 plots in an abandoned forest located 40 kilometers northwest of the Fukushima Daiichi NPP. We aims to identify the parameters associated with the prediction of Cs concentrations in undisturbed soil in Iitate.

2. Materials and methods

Top 30-cm surface soil samples were collected from 12 plots in an abandoned forest in Iitate village in Fukushima from 2013 to 2015. The soil samples were first divided into 14 layers at 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22.5, 25, 27.5, and 30 cm, then dried at 110ºC for 24 hours prior analysis. Water content (wc), soil bulk density (db), cesium concentrations (^{137}Cs and ^{134}Cs), total carbon (C), and total nitrogen (N), C/N ratio (CN), were measured for each layer respectively. The additional data were also recorded such as soil sampling depth (mid), latitude (lat), longitude (lon), height (DEM) (hig), slope, and litter. Litter is not a measured parameter, but it was score of litter amounts observed in the field. Litter scores ranged from 1 (less litter) to 10 (thick litter layer). We use multivariate statistical analysis such as principal component analysis (PCA), multiple regression model, and Bayesian model averaging (BMA) to reduce dimensionality of the data and to identify the important parameters in the prediction of Cs concentration in soil.

3. Results and discussion

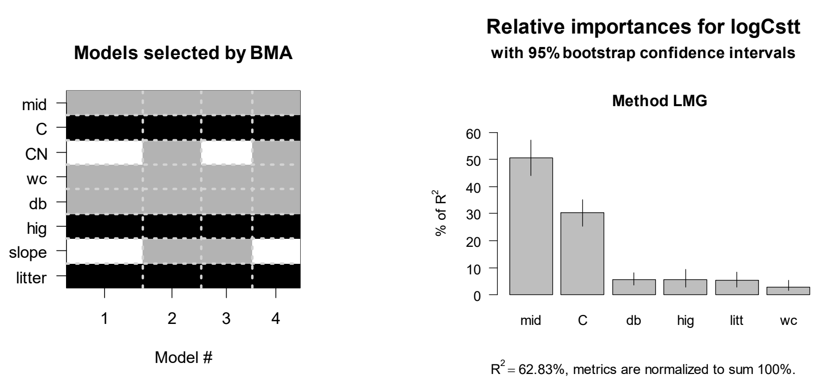

Fig. 1 Four selected models from Bayesian model averaging method; black, grey and white colors are positive, negative and unused variables in the models, respectively. LMG is Lindeman, Merenda, and Gold method recommended in Kruskal, 1987.

[1] 東京大学大学院農学生命科学研究科，Graduate School of Agricultural and Life Sciences, The University of Tokyo.
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PCA indicates that properties of soil samples can be characterized by three principal components (PC1-3) that account for 65.6 % of total variance. PC1 (27.8 % of total variance) includes latitude, longitude and DEM that indicate the geo-information of samples. PC2 (24.0 % of total variance) consists of Cs concentration, total carbon, carbon nitrogen ratio, and soil sampling depth. It indicates the chemical composition and distribution pattern in soil samples, and shows a tight relationship among these parameters. PC3 (13.80 % of total variance) is a group of water content, slope and litter. There parameters express the physical condition of study area, and they may indirectly influence the parameters in the PC2.

We used BMA in linear regression model method for variable selection. BMA suggests 4 possible models that well predict Cs concentrations in soil. Model #1 (Fig. 1) consists of six variables i.e. soil depth, total carbon, water content, dry bulk density, DEM and litter. The model has good prediction performance for Cs concentration and requires less variables (Fig. 1).

LMG (Lindeman, Merenda, and Gold) method (Kruskal, 1987) followed by 1000 times of bootstrapping were used to estimate the relative importance of each variable and its 95 % confidence interval (Fig. 1). The most important parameters in the regression model are soil sampling depth and total carbon that account for 50% and 30 % of total explained variance, respectively (Fig. 1).

Table 1 linear regression models.

$$\log_{10}(Cs) = a_1(carbon) + a_2(soil\_depth) + a_3$$

Plot	R^2	BIC*	a_1	a_2	a_3
1	**0.84**	**76.6**	**0.05**	**-0.05**	**3.87**
2	**0.86**	**57.6**	**0.13**	**-0.06**	**3.51**
3	0.49	95.0	0.12	-0.05	2.66
4	0.53	112.6	0.14	-0.06	2.15
5	0.50	98.9	-0.07	-0.08	3.36
6	**0.89**	**88.5**	**0.04**	**-0.09**	**3.73**
7	0.70	60.9	0.22	-0.03	1.74
8	0.57	133.2	-0.06	-0.11	3.97
9	0.67	96.9	0.15	-0.05	2.19
10	0.60	161.5	0.01	-0.12	3.97
11	0.62	104.0	0.05	-0.09	3.47
12	0.40	110.4	0.14	-0.04	2.93
All plots	0.54	1479.5	0.06	-0.07	3.21

*Bayesian information criterion (BIC)

If we consider two variables i.e. soil sampling depth and total carbon in the prediction of Cs, the model well simulated Cs concentrations in plot 1, 2 and 6 where total carbon was significantly higher than other plots (Table 1). The decrease in R^2 values was proportional to the amount of available litter and total carbon contents in each plot (Table 1). It indicates a strong association of Cs and organic carbon in soil. In other plots where less litter was available and total carbon content was low, Cs may highly associate with soil clay content.

4. Conclusions

The chemical characteristics and distribution pattern of soil samples were expressed by Cs concentration, organic carbon, carbon nitrogen ratio and soil sampling depth. Soil sampling depth and total carbon were two important parameters for the prediction of Cs concentrations. The prediction of Cs has high accuracy in the plot where more litter was available and total carbon content was high.

Reference

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