The role of potassium for the remediation of radioactive cesium contaminated agricultural land – Fate aftermath in Fukushima

#4454

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Abstract

Effect of radioactive compounds (131I, 134Cs and 137Cs are in concern) to the agricultural products and agricultural field has been evaluated in Fukushima. Radioactive compounds were scattered and distributed based on wind, precipitation, geographical and geometrical factors from the FDNPP after East Japan Great Earthquake on March 11th, 2011. Evergreen plants (tea), winter crops (winter wheat, pasture) and orchard plants were directly contaminated by fall out. As in the case of paddy and upland crops, most of them are before the cultivation and only the soil surface was contaminated. The countermeasure was mainly dependent on how the plant and/or field was contaminated. Removal of attached radionuclides from the plant body was effective to reduce the harvest radioactivity and a large area of tea and fruit orchard were treated by mid place cutting and bark removal by high water pressure machine, respectively. On the other hand, in the case of grass land, as the transfer factor (radioactive Cs concentration in shoot / radioactive Cs concentration in soil) of pasture is relatively high, appropriate countermeasure (i.e. reversal tillage) was required. In paddy field and most of upland crop fields, regardless of top soil removal, it is required to mitigate the radioactive Cs transfer from soil to plant by maintain the exchangeable K level high during the growth (Kato et al. 2015). By these countermeasures, the radioactive Cs contamination the brown rice is greatly decreased (Table 1).

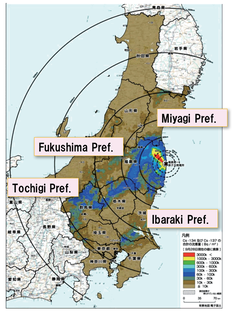

Fig. 1 Radioactive Cs (134Cs + 137Cs) distribution map of soil after FDNPP (September 2011). MEXT accident. Data was corrected to September 2011.

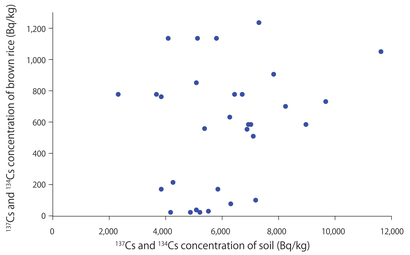

Fig. 2 Relationship between ^{137}Cs and ^{134}Cs concentration of soil and brown rice in 2011. (Fukushima pref.)

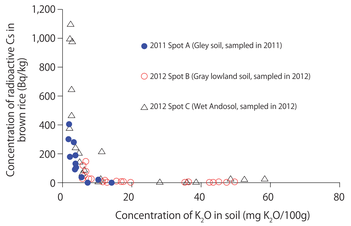

Fig. 3 Relationship between exchangeable potassium concentration in soil and ^{137}Cs and ^{134}Cs concentration of soil and brown rice in 2011. (Fukushima pref.)

http://www.maff.go.jp/j/kanbo/shosaigai/s_seisan_

Results and Discussion

When the data were collected from many paddy field in Fukushima prefecture in 2011, and it was confirmed that there was no clear relationship between soil radioactive Cs concentration and brown rice radioactive Cs concentration (Fig. 1). As K fertilizer has been considered the plausible compounds to mitigate the transfer of cesium by its similar chemical characteristics. Several researchers have been reported the effectiveness of application of K application under K deficient soil (Lebmrechts 1993, Nisbet 1993, Smolders et al. 1997). We have plotted the relationship between soil Exchangeable K2O and radioactive Cs concentration (Fig. 2). Which shows a very clear negative relationship between them. Based on these data we have determined that maintaining 25mgK_2O/100g soil throughout the growth stage is essential to keep the transfer factor lower than 0.01. As the standard value for brown rice radioactive Cs concentration was updated to 100 Bq/kg from 2012, this countermeasure has been introduced not only in the Fukushima prefecture but also surrounding prefectures as the official countermeasure to mitigate radioactive Cs from soil to brown rice. By applying this countermeasure, the ratio of exceeding standard value decreased dramatically and those brown rice produced in FY 2015 showed no sample which has higher than the value after more than 10 million all bags inspection for 30 kg brown rice bag (Table 1).However, additional application of K fertilizer and/or equivalent K resource (e.g. zeolite, manure, etc.) before the ordinary fertilization required additional labor for farmers and additional budget (ca. 15 billion JPY).

Changes of the radioactive Cs concentration of brown rice after 2011.3.11 (30kg bag) (Fukushima prefecture)

		≤ 50 Bq/kg	51~75 Bq/kg	76~100 Bq/kg	100 Bq/kg <	Monitored number
FY 2011	actual no.	20,295	364	219	311	21,189
	ratio(%)	95.78%	1.7179%	1.0338%	1.4677%	100%
FY 2012	actual no.	10,343,548	1678	389	71	10,345,686
	ratio(%)	99.98%	0.0162%	0.0038%	0.0007%	100%
FY 2013	actual no.	10,951,351	492	323	28	10,952,194
	ratio(%)	99.99%	0.0045%	0.0029%	0.0003%	100%
FY2014	actual no.	11,014,636	1	1	2	11,014,640
	ratio(%)	100%	0.00001%	0.00001%	0.00002%	100%
FY 2015	actual no.	10,498,325	4	0	0	10,498,329
(2016.10.01)	ratio(%)	100%	0.00004%	0	0	100%

It is because the exchangeable K_2O by 1M ammonium acetate method is considered to underestimate the plant available K of soils especially where the soil is rich in mica (e.g. Jackson 1985), because non-exchangeable K in the mica interlayer is also plant-available (Sparks 1987). Alternatively tetraphenylboron (TPB) extraction method (precipitation of K with TPB is considered to mimic the process of K uptake by plant root) has been proposed (Fanning et al. 1989), which have the ability to elucidate the K supply from the mica to plant. Though rice plant is also considered to have the ability to utilize nonexhangeable K of mica (eg. Nanzyo et al. 1999), it is not clear the influence nonexchangeable K of mica on the radioactive Cs uptake by rice. Evaluation of plant-available K by TPB extraction was applied to paddy rice. By using different mica and KCl to the paddy field, rice plant was grown to obtain brown rice in pot experiment. Relationship between the transfer factor (TF) and exchangeable K was plotted in Fig. 3(a). The relationship is not consistent when different type of mica was applied. It is considered that the ability to supply K from mica to soil solution is different among different mica types. On the other hand, when the soil K level was evaluated by using TPB extraction, the relationship indicates a very clear negative relationship with TF (Fig. 3(b)).

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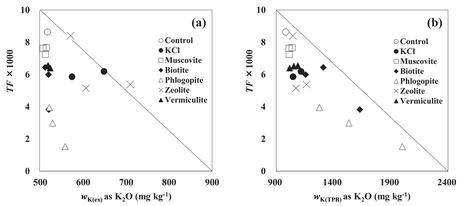

Fig. 4 Relationship between ^{137}Cs transfer factos for brown rice (TF) and (a) exchangeable K concentrations before planting and (b) sodium tetraphenylboron-extractable K concentrations before planting

Conclusion

After the East Japan Great Earthquake and subsequent Tokyo Electric Power Company' s Fukushima Dai-ichi Nuclear Power Plant accident, huge efforts have been paid for the countermeasure of the contaminated farmland. Besides the physical decontamination, far larger area is required to have mitigation of radioactive Cs transfer from soil to plant. K application is the most promising measure, but it is now coming to consider to apply it more efficiently in the meaning of labor and cost. In this study, TPB-extractable K concentration measured before planting was strongly negatively correlated with the ^{137}Cs TF, whereas exchangeable K concentration before planting was not correlated with the TF. Therefore, we conclude that TPB-extractable K is more reliable than exchangeable K as a basis of fertilizer recommendations for radiocesium-contaminated paddy fields.

References

[1] N. Kato et al. Soil Science and Plant Nutrition 61 (2015) 179-190.
[2] K. Tensho et al. Journal of the Science of Soil and Manure, Japan 30 [1959] 253-258.
[3] A. Tsumura et al. Bulletin of the National Institute of Agricultural Sciences
[4] S. Yanezawa and S. Mitsui Journal of the Science of Soil and Manure, Japan 36 [1965] 135-139
[5] M. Komamura et al. Radioisotopes 50 [2001] 80-93
[6] H. Tsukada et al. Journal of Environmental Radioactivity 59 [2002] 359-363
[7] S. Uchida et al. Radioprotection 40 [2005] S129-S134
[8] J. Lembrechts Science of the Total Environment 137 [1993] 81-98
[9] A. Nisbet Science of the Total Environment 137 [1993] 99-118
[10] E. Smolders et al. Environmental Science and Technology 31 [1997] 3432-3438
[11] B. Jackson New Zealand Journal of Experimental Agriculture 13 [1985] 253-262
[12] D.L. Sparks Advances in Soil Science 6 [1987] 1-63
[13] T. Eguchi et al. Journal of Environmental Radioactivity 147 [2015] 33-42
[14] M. Nanzyo et al. Soil Science 164 [1999] 206-214