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Recovery of Tsunami-Affected Paddy Soil Using Calcium Materials for Sustainable Agriculture

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exchangeable sodium percentage,
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Abstract

The tsunami attacked the regions along Pacific coast and caused severe damage to the lowland farmlands with topsoil outflow and salt disorder. In most of the tsunami-affected farmland, desalinization work was carried out by irrigation, resulting in sufficient removal of water-soluble salt of the tsunami-affected soils. However, according to the monitoring surveys of the soil where the farmland recovery projects had been completed, some fields had a poor nutrient balance. To solve the problem, we examined the effectiveness of applying calcium-silicate materials (steel-making slag fertilizers) in alleviating Na disorders using model desalinated tsunami-affected soil in 2013. We found that the fertilizer made of steel-making slag was effective in restoring the productivity of desalted tsunami-affected soils containing high amount of Na.

Introduction

The 2011 Japan earthquake triggered a great tsunami. Many lives were lost and tremendous damage was caused by the Great East Japan Earthquake and tsunami disaster of March 11, 2011. The tsunami attacked the regions along Pacific coast and caused severe damage of topsoil outflow and salt disorder to the lowland farmlands. About 15,000 ha of paddy fields had been damaged in Miyagi Prefecture alone. Of the damaged agricultural lands, about eighty-five % was paddy field. Most of the tsunami-affected farmland were desalinized by irrigation and water-soluble salt was effectively removed from the tsunami-affected soils.

However, according to the monitoring survey of the soil where the farmland recovery projects had been completed, some fields had a poor basic cation balance (Ito, T., 2015). Some of the exchangeable calcium (Ca) ion had been displaced by sodium (Na) ion derived from seawater during the desalinization process. As a result of the exchange reactions between Na and Ca in the soil, some of Na ion had remained in the exchange sites of soils and exchangeable Ca had been reduced. In soils with high concentration of exchangeable Na, crops sometimes show poor growth due to the excess uptake of Na, Na disorder (Anil *et al*., 2005; Gong *et al*., 2006; Matoh *et al*., 1986). In order to mitigate Na disorders and restore soil productivity, it is essential to optimize the basic cation balance in the soils where desalinization has been implemented. According to IRRI report (Dobermann and Fairhurst 2000), in soils where exchangeable sodium percentage exceeds 20%, rice yield may begin to decrease. According to Gupta and Sharma (1990), rice yield decreased to 50% in the soil with ESP of more than 80%. When rice absorbed sodium excessively, uptake of potassium (K) and Ca was inhibited and rice growth was limited (Kinraide, 1999).

To solve the problem, we examined the effectiveness of applying calcium materials (steel-making slag fertilizers) in alleviating Na disorders. We conducted the cultivation experiment using model desalinated tsunami-affected soil in 2013.

Materials and methods

In order to clarify the effectiveness of calcium materials such as a steel-making slag fertilizer and gypsum in alleviating Na disorders of rice plant, the cultivation experiment was conducted using a model desalinated tsunami-damaged soil in 2013.

Preparation of desalinated tsunami-affected soil

An alluvial soil (clay content: 18%, total carbon content: 1.8%) was collected from normal paddy field without tsunami attack. The soil was submerged by seawater and was then desalinated by flooding and draining repeatedly with fresh water. The prepared soil (desalinated soil) showed low electric conductivity of soil suspension (soil:deionized water =1:5) of 0.20 dS m^{-1}, exchangeable Ca of 3.5 cmol $_{(c)}$ kg^{-1} and exchangeable Na percentage of 46%. The EC value is lower than the critical value causing rice salinity injury (Nakada, 2011). Exchangeable Ca contents decreased and exchangeable Na contents drastically increased with sea water immersion and washing by fresh water.

Cultivation experiment

Rice cultivation experiment was conducted in the paddy field of Field Science Center of Tohoku University in 2013. We packed the desalinated soil with a plastic frame of 0.076 m^2 without bottom in the paddy fields after applying Ca materials. We set five treatments; no application of Ca material, steel-making slag fertilizer application of 200, 400 g m^{-2}, gypsum application (corresponding to slag 200 g m^{-2}), and original soil without sea water immersion and desalination treatments. Application rate of gypsum was determined so as to be similar to the slag fertilizer of 200 g m^{-2} for the applied amount of Ca. The steel-making slag fertilizer used in this study contains 114 g kg^{-1} total silicate, 426 g kg^{-1} total CaO and 190 g kg^{-1} total iron (Gao *et al.*, 2016). We transplanted two seedlings with six leaves of rice (*Oryza sativa* L., Hitomebore) to each experimental plot made by a plastic frame after applying chemical fertilizers with application rates of $N\text{-}P_2O_5\text{-}K_2O$ of 4-6-6 g m^{-2} to packed soils. Cultivation experiments were conducted with three replications.

Potassium, Ca, Na and silicon (Si) of rice straw, and brown rice yields were measured at the harvest time. The harvested rice grain was hulled and the brown rice of 1.7 mm or larger was collected using a multi-stage sieve apparatus. The brown rice yield was measured by correcting the water content to 15%. The Ca, Na and Si concentrations was measured using the harvested samples of rice plant dried at 70°C for 48 h. The dried plant samples were crushed and digested with sulfuric acid and oxygen peroxide, and the cation content was analyzed by atomic absorption spectrophotometry. The silicate content was analyzed by colorimetric method after being decomposed by HCl and HF.

During the cultivation period, Ca, Na and Si concentrations in soil solution water were measured. Soil solution water was sampled from a depth of 7 cm in the plow layer through a porous cup that was buried before planting. Exchangeable cations of soils in all treatments were determined after rice harvest to investigate the effect of applied Ca materials on cation balance of the soils. Statistical analysis was conducted by Tukey-Kramer test (0.05>p).

Results and discussions

Figure 1 and 2 show the changes of Ca and Na concentrations of soil solutions collected from plow layers in four treatments. Sodium concentrations showed about 3 to 10 times Ca concentrations in the control treatment. Calcium concentrations in soil solutions increased with applications of slag or gypsum and it was the highest in the gypsum treatment. Calcium concentration in the steel-making slag treatment with application rate of 200 g m^{-2} was lower than the gypsum treatment in spite of same total Ca input in the two treatments. It indicates that the steel-making slag dissolves more slowly than gypsum. On the other hand, there was no difference in Na concentrations among all the treatments. Increasing of Na concentration in the soil solution from 12, June to 3, July is considered to be due to progression of ferrous iron formation under submerged condition and ion exchange between ferrous iron in solution and Na ion in the exchange site of soil. These data show that the desalted soil supplies significant amount of Na to rice plant, and slag and gypsum can increase plant available Ca in soils.

Slag treatments with 200 and 400 g m^{-2} increased brown rice yields by 8 and 17% than the control treatment with significant difference for slag 400, respectively (**Fig. 3**). Gypsum treatment did not increase the rice yield in spite of increasing Ca and K contents and decreasing Na content in rice straw, as described below. This is considered to be due to injury of rice roots caused by hydrogen sulfide derived from sulfate reduction.

Calcium and K concentrations in rice straws increased with 10 to 18% and 3% by slag and gypsum applications, respectively (**Figs. 4 and 5**). On the other hand, Na concentrations in rice straws were reduced with 8 to 14% by slag and gypsum treatments compared with the control plot, respectively (**Fig. 6**). Slag treatments enriched silicate contents of rice straws at maturity stage with significant difference (**Fig. 7**). It suggests that the Ca-containing materials such

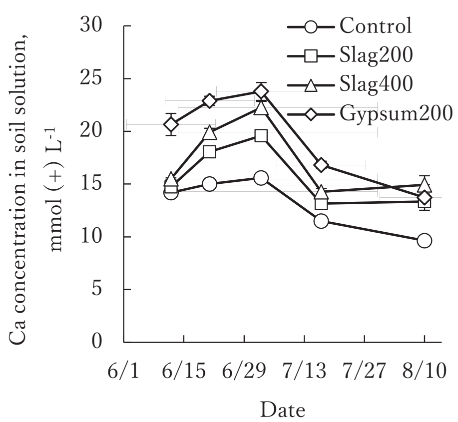

Fig. 1. Temporal pattern of calcium concentration in the soil solution.

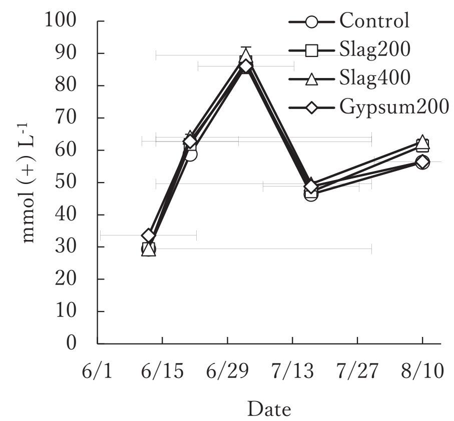

Fig. 2. Temporal pattern of sodium concentration in the soil solution.

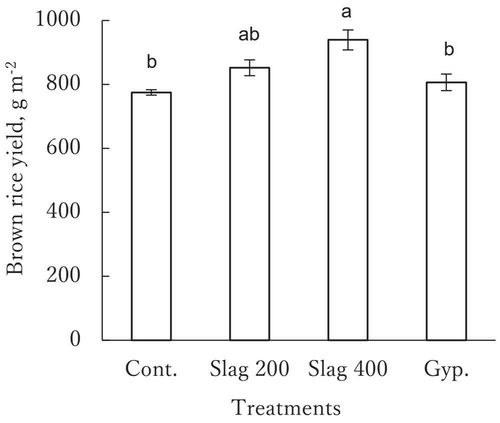

Fig. 3. Mean (±SE) brown rice yield in each treatment. Bars with the same letters are not significantly different ($P < 0.05$) according to the Tukey– Kramer test.

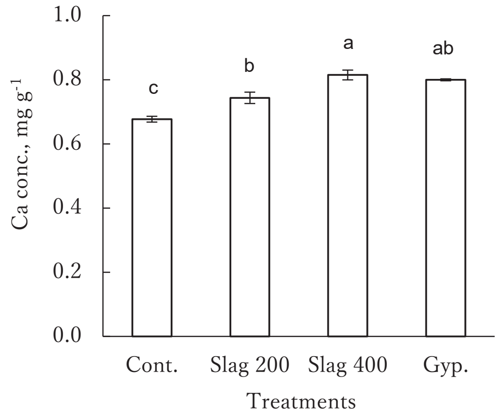

Fig. 4. Mean (±SE) calcium concentration in rice straw in each treatment. Bars with the same letters are not significantly different ($P < 0.05$) according to the Tukey– Kramer test.

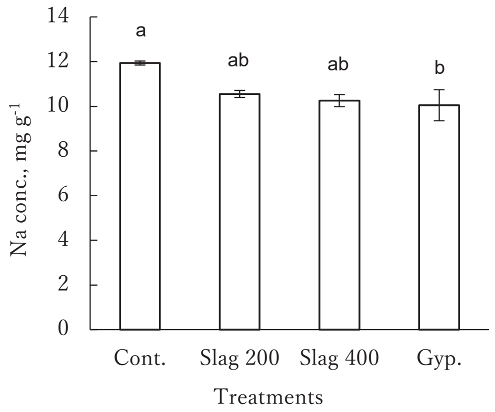

Fig. 5. Mean (±SE) sodium concentration in rice straw in each treatment. Bars with the same letters are not significantly different ($P < 0.05$) according to the Tukey– Kramer test.

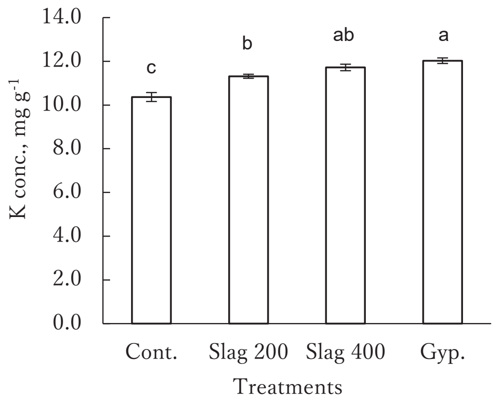

Fig. 6. Mean (±SE) potassium concentration in rice straw in each treatment. Bars with the same letters are not significantly different ($P < 0.05$) according to the Tukey– Kramer test.

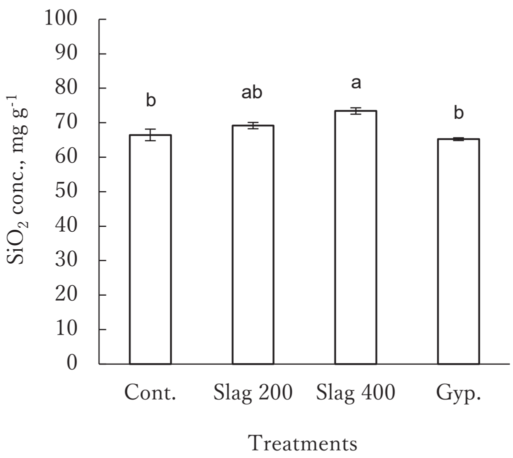

Fig. 7. Mean (±SE) silicate concentration in rice straw in each treatment. Bars with the same letters are not significantly different ($P < 0.05$) according to the Tukey– Kramer test.

as steel-making slag and gypsum suppress Na uptake and improve K nutrient condition of rice plant with accelerating Ca absorption.

It is known that Ca or Si applications can mitigate Na disorder of rice. Supplementation of Ca decreases Na absorption and increases K absorption (Khan *et al*., 1992; Song *et al*., 2006). Also, it is well known that silicate is positively taken up by rice and increase photosynthetic capacity and resistance to insects and salt resistance (Ma, 2004). Silicate is deposited on the rice leaves and suppresses unnecessary transpiration from the cuticle, resulting in improvement of water utilization efficiency and photosynthetic capacity. Furthermore, the improvement of the physical strength of leaves and stems by absorption of silicate is known to be effective to increase rice standing uprightness and the light receiving posture. That can result in improving photosynthetic capacity of plant. Moreover silicate application reduces Na uptake in rice and alleviates Na injury (Matoh *et al*, 1986; Gong *et al*., 2006). Steel-making slag and gypsum applications did not accelerate Na leaching from plow layer soils but increased the contents of plant available Ca (exchangeable Ca) in soils (**Table 1**).

It is concluded that the fertilizer made by steel-making slag is more effective in restoring the productivity of desalted tsunami-affected soils containing high amount of Na, compared with gypsum. Slag can supply Ca and Si effective in alleviating Na disorder of rice and accelerating rice growth, and does not have a risk of increasing hydrogen sulfide injury to rice roots other than gypsum.

Table 1. Apparent exchangeable cations in the soils at the beginning and end of the cultivation experiment

Timing/Treatment	Ca	Mg	K	Na	ESP[1]
Beginning	6.7	7.3	1.0	12	43.6
End					
Control	7.0	5.3	0.72	3.2	19.5
Slag 200	8.5	5.7	0.66	3.4	18.7
Slag 400	9.9	6.2	0.70	3.5	17.1
Gypsum	8.8	5.0	0.68	3.0	17.2

[1] Exchangeable sodium percentage (ESP) = ex. Na / (ex. Ca + ex. Mg + ex. K + ex. Na) × 100

References

Veena, S. A., P. Krishnamurthy, S. Kuruvilla, K. Sucharitha, G.Thomas and M. K. Mathew (2005) Regulation of the uptake and distribution of Na+ in shoots of rice (Oryza sativa) variety Pokkali: role of Ca2+ in salt tolerance response. Physiologia Plantarum, 124: 451–464.

Doberman, A. and T. Fairhurst (2000) Rice: Nutrient disorders & nutrient management. IRRI (free PDF download), 139-144.

Xu, G., T. Ito, H. Nasukawa and S. Kitamura (2016) Application of Fertilizer Made of Steelmaking Slag in the Recovery of Paddy Fields Damaged by the Tsunami of 2011. ISIJ International, 56 (6): 1103-1110.

Gong, H. J., D. P. Randall and T. J. Flowers (2006) Silicon deposition in the root reduces sodium uptake in rice (Oryza sativa L.) seedlings by reducing bypass flow. Plant, cell & Environment, 29: 1970-1979.

Gupta, S. K. and S. K. Sharma (1990) Response of crops to high exchangeable sodium percentage. Irrigation Science, 11: 173-179.

Ito, T. (2015) Measures of desalinization in tsunami-hit farmland. 7. State of exchangeable bases in desalinized tsunami-affected farmland in Miyagi Prefecture. Japanese Society of Soil Science and Plant Nutrition, 86: 438-440.

Khan, H. R., K. F. Yasmin, T. Adachi and I. Ahmed (1992) Effects of gypsum, Zn and intermittent saline irrigation on the growth, yields and nutrition of rice plants grown in a saline soil. Soil Science and Plant Nutrition, 38: 421-429.

Kinraide, T. B. (1999) Interactions among Ca2+, Na+ and K+ in salinity toxicity: quantitative resolution of multiple toxic and ameliorative effects. Journal of Experimental Botany, 50: 1495-1505

Ma, J. F. (2004) Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Science and Plant Nutrition, 50: 11-18.

Matoh, T., P. Kairusmee and E. Takahashi (1986) Salt-induced damage to rice plants and alleviation effect of silicate. Soil Science and Plant Nutrition, 32: 295-304.

Nakada, H. (2011) Actual retention conditions of salts in paddy field soil subjected to seawater flood damage and a modeling analysis of water-washing salt-removal countermeasures. Bulletin of the Agricultural Research Institute, Toyama Prefectural Agricultural, Forestry and Fisheries Research Center, 2: 27-37.

Song, J. Q., X. R. Mei and H. Fujiyama (2006) Adequate internal water status of $NaCl^{-}$salinized rice shoots enhanced selective calcium and potassium absorption. Soil Science and Plant Nutrition, 52: 300-304.