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Salt removal from salt-damaged agricultural land using the scraping method combined with natural rainfall in the Tohoku district, Japan

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ABSTRACT

The tsunami that followed the Great East Japan Earthquake in 2011 caused catastrophic salt damage to agricultural lands in Tohoku district on the Pacific coast of Japan. Large amounts of water would be required to leach away the salt from the salt-damaged farmlands. In addition, the salt cannot be washed away by using natural water sources such as rivers and ponds because the irrigation infrastructure, such as water canals, was destroyed and has not yet been repaired. Therefore, it is important to develop new salt-removal techniques to restore agricultural lands without using large amounts of water. We tested a new technique for salt removal: scraping the soil, followed by exposure of the soil to natural rainfall. In the test plots, which were located in a paddy field, soluble salt in the soil accumulated on the soil surface through evaporation. Next, the top 2 cm of the soil surface was scraped away, and the scraped soil was placed in open-topped plastic boxes that were exposed to natural rainfall. Soil electrical conductivity, exchangeable sodium percentage, and ion content decreased exponentially as cumulative rainfall increased. In addition, soil electrical conductivity decreased below the upper threshold limit required for crop cultivation after cumulative rainfall surpassed 217 mm, about 50 days after the start of the experiment. Therefore, our technique may be used to remove salt from agricultural soils in a relatively short time.

1. Introduction

On March 11, 2011, the tsunami induced by the Great East Japan Earthquake flooded 24,000 ha of agricultural land in the Tohoku region along the Pacific coast of Japan (MAFF, 2011). As a result, these lands were damaged by salt and were no longer suitable for the cultivation of crops. Salt-removal programs were successfully implemented in some areas, returning production to normal within a short period.

However, a large amount of water is needed to leach the salt from the salt-damaged farmlands. Water from rivers or ponds cannot be used because the irrigation infrastructure, such as water canals, was destroyed and has not yet been repaired. Salt was removed successfully only from agricultural lands with free access to water resources. There has been no change in the conditions of almost all the coastal agricultural lands in the Tohoku region since 2011.

Future tsunamis may cause additional damage to farmlands in Japan and elsewhere. It is important to develop techniques to improve damaged agricultural land and to prepare for future disasters by improving our existing salt-removal technologies. For this reason, we developed and validated an efficient method of salt removal. The method is effective in locations with no easy access to water resources for salt removal by leaching.

Various techniques already exist to remove salt from agricultural land. If water resources are abundant, leaching (Chiba et al., 2012a, 2012b; MAFF, 2011) and flushing (FAO, 1988a) may be used. Alternatively, if water resources are scarce, surface aspiration elution (Inosako, 2012), capillary barriers (Endo and Hara, 2000; Sugi, 1997), or scraping (Qureshi et al., 2003) may be applied. The scraping method involves scraping off the surface soil after salt has accumulated on the soil surface through evaporation. Although scraping provides a temporary improvement in soil quality, sufficient to support crop growth, disposal of the topsoil containing the salts is a problem (FAO, 1988b) because the topsoil is rich in organic matter and humus. Hence, we advocate the selective removal of salts from the surface soil so that it may later be replaced on the farmland as topsoil.

Although baseline studies have confirmed that soil salinity levels are high in the surface layer of the soil after evaporation (Fukuhara and Sato, 1994; Gran et al., 2011; Jalili et al., 2011), few empirical studies support the effectiveness of the scraping method for restoration of farmland. Only recently did Endo et al. (2012) investigate the dynamics of soil salinity during evaporation in an application of the scraping method on land that had been affected by the tsunami after the Great East Japan Earthquake. In addition, Kang et al. (2013) investigated the cultivation of rice (*Oryza sativa* var. Tsugaru-roman) on the layer of

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lower soil that remained after the salt-damaged surface soil had been removed. In another study, Kanatsuka and Fujimaki (2010) investigated an increase in the salinity of surface soil by using the scraping method in agricultural land near Ismailia, Egypt.

In our study, the topsoil of agricultural land that had been flooded with seawater was artificially dried. Subsequently, the surface soil was removed by scraping and transferred to a different site where it was exposed to natural rainfall in order to leach the salt from the scraped soil layer. The purpose of this study was to establish and validate a technique that combined scraping with leaching by natural rainfall. We also sought to understand how differences between evaporation conditions (percolation of rainfall through the soil vs. inability of rainfall to percolate into the soil) affected salt accumulation on the soil surface. We report the results of our small-scale, water-efficient, desalination field experiment and recommend that this method of salt removal be used for salt-damaged agricultural lands.

2. Material and methods

2.1. Study area

The study site was a paddy field (40° 35′ 24.34″N, 141° 27′ 51.56″E) where salt removal had not been implemented since the tsunami. The field was located in a downstream basin between the Gonohe River and the Oirase River in Hachinohe City, Aomori Prefecture, Japan (Fig. 1). This research site is located 300 m from the Pacific coastline and was flooded by the tsunami that followed the Great East Japan Earthquake, which damaged about 53 ha of agricultural land in this region. The primary crops in this region are paddy rice, soybean, and strawberries cultivated in greenhouses. The region contains 83 strawberry greenhouses, which cover a total 1.96 ha and were all damaged by flooding. Because of water rights that govern the use of water in the area, there were no water resources that could be used to remove salt from the agricultural lands in the study area. Therefore, scraping is the only option for salt removal in this region.

2.2. Soil profiles and basic properties of soil in the paddy field

2.2.1. Sampling and measurement of soil physical properties

Soil samples obtained on June 12, 2012, revealed that the paddy field was composed of Arenosols (FAO, 1974). Three 100-mL core soil samples and three disturbed soil samples were collected at 5, 10, 20, 30, 40, and 50 cm. Soil particle density was measured using a pycnometer. The distribution of soil particle size was evaluated using a hydrometer and sieve analysis in order to determine soil texture. Dry bulk density and water content were determined using the gravimetric method. Saturated hydraulic conductivity was determined using the falling head method. The relationship between the matric potential and volumetric water content was evaluated using the pressure plate method to identify the soil water retention curve parameters.

2.2.2. Measurement of soil chemical properties

Soil pH and electrical conductivity (EC) were measured using the glass electrode method (HM-30V; DKK-TOA Ltd.) and electrical conductivity method (DS-14; HORIBA Ltd.), respectively. The EC was measured using the 1:5 soil:water extract method. To measure soil pH, a 1:2.5 ratio (distilled water:extracted water) was used. Water-soluble sodium and chlorine were measured using the ion electrode method (C-121; HORIBA Ltd.) and ion chromatograph method (PIA-1000; SHIMADZU Co.), respectively. The sample solution for measuring exchanged cations was extracted using pH 7.0 with ammonium acetate, after which exchangeable cations were measured using atomic absorption spectrophotometry (Z-2000; SHIMADZU Co.).

2.3. Field experiment

2.3.1. Installation of the experimental plots

Experimental plots were established in the paddy field on June 29, 2012 (Fig. 2). Each experimental plot was 2.0 m × 1.5 m and was partitioned using PVC-corrugated plates. First, disturbed soil samples were collected from all plots at depths of 1, 5, 10, 15, and 20 cm. Next, two plot conditions were established: (1) covered using a vinyl film (V-plot) and (2) bare (B-plot) (Fig. 2; Table 1). The vinyl film caused soluble salts to accumulate on the soil surface. The plots were then irrigated at random by applying different initial amounts of water ($m_{wi} = 0$ L, 56 L, and 113 L) to the soil surface. The initial irrigation amount of 0 L represented extreme water-saving measures. After the irrigation, 1 m length of stands was placed on the soil surface of the V-plots, and the clear vinyl film was placed on them. The V- and B-plots experienced normal rainfall and evaporation conditions until September 21, 2012 (i.e., an 84-day period). On this date, disturbed soil samples were collected from the V- and B-plots at depths of 1, 5, 10, 15, and 20 cm. The vinyl film was then removed for the duration of the year.

To evaluate the salt content profiles, disturbed soil samples were collected from random plots at depths of 1, 5, 10, 15, and 20 cm on June 14, 2013 (350 days from the onset of evaporation and 266 days after the

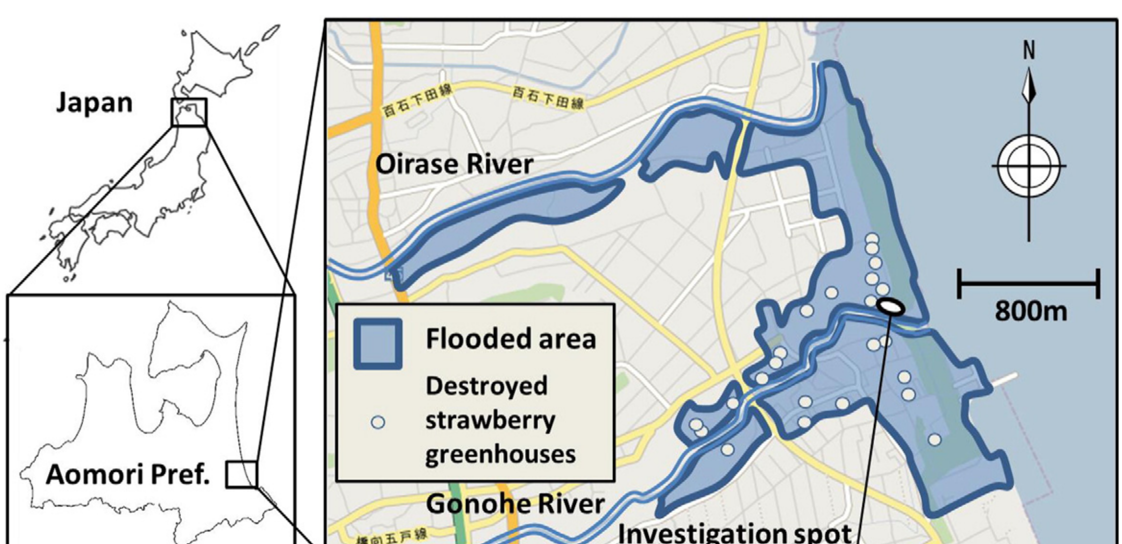

Fig. 1. The study area and region damaged by flooding.