Research article

The Effects of Land Restoration on Soil Fertility in Tsunami-inundated Farmlands of Miyagi Prefecture in Japan

KINGSHUK ROY*
College of Bioresource Sciences, Nihon University, Kanagawa, Japan
Email: roy.kingshuk@nihon-u.ac.jp

SATOKI IWATA
Graduate School of Agricultural Science, Tohoku University, Sendai, Miyagi, Japan

YURIKA KATO
Geosciences Department, University of Missouri-Kansas City, Missouri, USA

Received 3 February 2017 Accepted 5 May 2017 (*Corresponding Author)

Abstract In previous studies, a series of samples were analyzed to measure the salinity status of agricultural lands in Miyagi prefecture, where the extent of the seawater damage was the most severe among the tsunami-affected area in Northeast Japan following the Great East Japan earthquake in 2011. Since then, various restoration projects have been implemented by concerned agencies of the central and local governments. In the agricultural lands damaged by the earthquake and flooded with tsunami water, most of the technical tasks, such as the removal of debris and salts and the repair of irrigation and drainage infrastructures, were in the final stages of completion in 2016, and the efforts seems to have achieved their primary objectives. However, soil productivity in the restored farmlands remains a big issue for the local farmers. The present study was carried out in different farmlands in two adjacent towns in Miyagi Prefecture, Watari-cho and Yamamoto-cho. The major physicochemical and biological properties of soil were investigated, and the results show that the soil dressing used as topsoil in the restored farmlands had a low average cation exchange capacity (CEC) of <6 cmol(+)kg^{-1}, which ultimately contributed to lower average CEC values overall (<9 cmol(+)kg^{-1}). Moreover, carbon-to-nitrogen (C:N) ratios in the soil dressings and the restored lands showed a wider range (5 to 19), making the soil inconsistent in nutrient supply i.e., less fertile, compared to those in the farmlands where there was no top-dressing and in the farmlands at nearby inland sites. The study also suggests that issues concerned with rebuilding soil fertility and improving soil productivity in tsunami-inundated agricultural lands should be resolved through sustainable, soil-friendly methods and practices.

Keywords tsunami, farmland, soil salinity, soil fertility, soil dressing, land restoration

INTRODUCTION

The Great East Japan earthquake and tsunami disaster of 2011 caused massive damages to the coastal area. The earthquake damaged irrigation and drainage infrastructures severely, while the tsunami waves inundated large areas of agricultural land, causing excessive saline in the soil. Since the occurance, a lot of restoration efforts and studies have been carried out in the disaster-affected areas. Most notably, the central government of Japan announced a comprehensive recovery plan in the devastated area (Government of Japan, 2012), and accordingly, all concerned ministries, agencies, prefecture administrations, and non-governmental organizations (NGOs) started restoration projects in different sectors. In agricultural lands, salinity was a very big issue soon after the tsunami, especially in Miyagi prefecture, as this region accounted for nearly two-thirds of the tsunami-inundated agricultural lands (23,600ha) in northeast Japan (MAFF, 2011). The different stages and the order of execution related to the restoration, remedial, and reclamation works in agricultural lands consisted of mostly removing debris, puddling and leaching with freshwater and flushing away salts from the topsoil, and cutting away the top layer and dressing it with new soil carried from a nearby mountain area along with the rejuvenation of irrigation/drainage infrastructures. Roy et al. (2014, 2015) monitored the spatiotemporal changes in soil salinity in the tsunami-inundated agricultural lands in Miyagi prefecture from 2013 to 2015 and concluded that the salinity varied because of several physical factors, such as topography, soil texture, and water stagnation due to damage to drainage infrastructure. Research studies carried out by Tomomasa et al. (2013) and Toyama and Tajima (2014) specified the damage to underground infrastructures (i.e., buried drainage pipes) as an important factor responsible for water-logging, poor infiltration, and high salinity. As the restoration works progressed and reached the final stages of completion in 2016, salinity levels in most areas had returned to pre-tsunami levels (electrical conductivity<1 dS m^{-1}). In addition, the area had enough precipitation (approximately 1,200mm/year) to help to mitigate the salinity level even in non-restored lands (NARO, 2013; Roy et al., 2015). However, when crops were cultivated, farmers started to face new problems related to soil productivity in the restored lands.

Soil productivity refers to the capacity of the soil in its normal environment to support plant growth, while soil fertility refers to the ability of the soil to provide nutrients in proper quantities for the growth of plants (Gruhn et al., 2000). Therefore, to better understand the potential productivity of soil in the restored area, it is important to examine key soil characteristics and indicators—such as soil texture, depth, pH, organic matter content, and fertility—that might be affected through human activities, such as the use of a soil dressing in restoration works, or by natural processes, such as the accumulation of salt due to seawater intrusion. A report published by the Miyagi Prefecture Furukawa Agriculture Resaerch Station (2013) showed that the parts of restored paddy fields with a soil dressing had a reduced average production (361 kg/10a) compared to that of non-restored lands (563 kg/10a). During prior field surveys from 2013 to 2015, restoration works and farming activities were observed, and local farmers were interviewed at random about these issues. It is not difficult to understand that, in the case of any sudden replacement of the topsoil with a new soil (soil dressing), the fertility of the new soil is a big factor that ultimately affects soil productivity. No reports were published to date indicating that any prior investigations or analyses were completed regarding the fertility status of the new soil used as the soil dressing in the restored lands in the studied area. This promted further study to determine the existing soil productivity in terms of the soil fertility in the area. In particular, field samples were collected from different farmlands in two adjacent towns, Watari-cho and Yamamoto-cho, in Miyagi prefecture, where samples were also collected from 2012 to 2014. Soil samples were collected from restored farmlands with topsoil dressing ("dressed land"); farmlands with no soil dressing ("undressed land"); new/mountain soil used in topsoil dressing ("soil dressing"); and inland farmlands ("inland") and analyzed for soil fertility.

The aim of this study is to determine the soil fertility in tsunami-inundated farmlands in Miyagi prefecture, where restoration works have already been completed, as well as to investigate sustainable, soil-friendly methods for agricultural lands where salinity and soil recovery are big issues.

METHODOLOGY

Study Sites and Methods of Sampling

Two adjacent towns, Watari-cho and Yamamoto-cho, both of which accounted for the largest inundated areas in Miyagi prefecture, were selected as study areas for sampling, although the post-disaster statuses and recovery plans were different in these two sites (Watari-cho, 2015; Yamamoto-cho, 2015). Field samples were collected and interview surveys were conducted five times from

December 2014 to December 2015. Fig. 1 presents the sampling sites and sampling points (farmlands) in the study area. The location of each sampling point were traced by a portable GPS receiver (Garmin eTrex). It is notable that, in some cases, the land use of the surveyed farmlands (paddy fields/uplands) as shown in Table 1, differed before and after the tsunami. The sampling points of dressed and undressed lands were randomly selected based on the information gathered during interviews with the local farmers. Samples of soil dressing were collected with permission from construction workers at the study sites. In addition, soil samples were collected from inland farmlands within a distance of 1 km from the inundated zone (sampling point) to represent the pre-tsunami soil characteristics of the inundated farmlands. A total of 48 samples were collected from different farmlands in the two sampling sites: 17 from dressed lands (paddy fields:14, upland:3), 13 from undressed lands (paddy fields:4, upland:9), 6 from soil dressing, and 12 from inlands (paddy fields:6, upland:6). All soil samples were collected from the top layer of disturbed soil (upto a depth of 10 cm) by a diagonal sampling method, packed in polyethylene sacks, and brought back to the laboratory for analysis. Other related data about land use (paddy, upland, or mountain), land condition (dressed or undressed lands), plant growth, fertilizer uses, and yields were recorded during interviews with farmers.

A visual outlook of two adjacent farmlands, one a restored land with soil dressing and the other with no soil dressing, as presented in Fig. 2, points a clear difference in growth between the two farmlands.

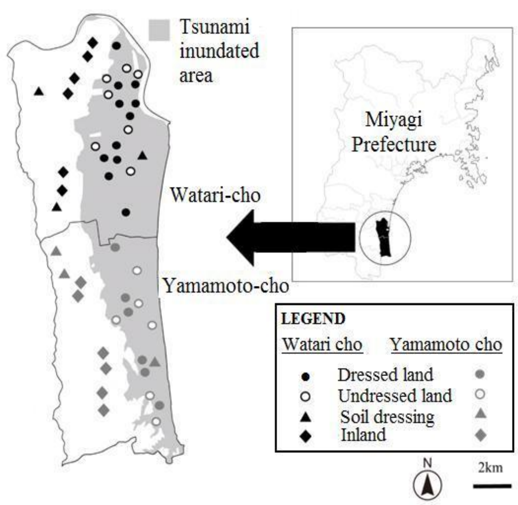


Fig. 1 Study sites with sampling locations Miyagi Prefecture, Japan

(Picture taken on June 22, 2015)

Fig. 2 Plant growth in two adjacent paddy fields in at Yamamoto-cho in Miyagi Prefecture

Analysis of Soil Samples

All of the soil samples were processed and analyzed in the laboratories of the College of Bioresource Sciences at Nihon University. The collected soil samples were air-dried and sieved through a 2 mm mesh, and then select parameters representing key indicators related to soil quality and productivity were measured. The parameters selected to represent the chemical properties were pH, electrical conductivity (EC), cation exchange capacity (CEC), and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+). The pH (H_2O) and the EC of the soil were measured with a pH meter (Twin pH B-212, Horiba, Japan) and an EC meter (B-173, Horiba, Japan), respectively. The ratio of soil to deionized water was 1:2.5 for pH, and 1:5 for EC. The CEC, estimated from soil cations (Ca^{2+}, Mg^{2+}, K^+, Na^+), was determined by ammonium acetate method (soil extracted in 1 mol L^{-1} ammonium acetate (NH_4OAc) at a pH 7) and measured with an atomic absorption spectrophotometer (AA-6680, Shimadzu, Japan). The concentrations of exchangeable cations, as well as the total exchangeable bases, were then expressed in terms of centi-mol per kg (cmol(+)kg^{-1}). Moreover, basic cation ratios—e.g., calcium-to-magnesium ratio (Ca:Mg), magnesium-to-potassium ratio (Mg:K)—and the percent base saturation were also calculated from the amounts of exchangeable cations analyzed. On the other hand, the selected physical properties were mainly particle size distribution and soil texture. In addition, gravel content (weight percentage) was also determined since the local farmers were worried about an excess of gravel in the soil dressing. The particle size distribution of the soil was measured using with the pipette method based on Stoke's theorem, and the soil textural classes were determined according to the IUSS (International Union of Soil Sciences) method. Gravel contents were calculated based on the remnants after sieving the air-dried soil through a 2 mm mesh. For biological properties, total carbon (TC), total nitrogen (TN), carbon-to-nitrogen (C:N) ratio, and organic matter content (OMC) were measured. The C:N ratio, TC, and TN of the soil were determined using an NC analyzer (Sumigraph NC-220F, Sumika Chemical Analysis, Japan), while the OMC of the soil was estimated using with the loss-on-ignition method and a muffle furnace (KBF-748, Koyo Thermos, Japan). All measured and calculated data regarding soil properties are listed in Table 1.

Statistical Analyses

Descriptive statistics, correlation analyses, and one-way analyses of variance (ANOVA) among the physicochemical and biological parameters in this study were executed using a Microsoft Office Excel 2013 add-in application.

RESULTS AND DISCUSSION

Chemical Properties of Soil

As presented in Table 1, the average soil CEC values in dressed lands were 8.7 cmol(+)kg^{-1} and 7.8 cmol(+)kg^{-1} in Watari-cho and Yamamoto-cho, respectively, whereas those values in undressed lands were 17.5 cmol(+)kg^{-1} and 14.9 cmol(+)kg^{-1}, respectively. The inland soil at these two sites had similar average CEC values at 18.4 cmol(+)kg^{-1} in Watari-cho and 16.7 cmol(+)kg^{-1} in Yamamoto-cho. However, average CEC values were much lower for soil dressings at these two sites—5.9 cmol(+)kg^{-1} and 5.5 cmol(+)kg^{-1} in Watari-cho and Yamamoto-cho, respectively. Soil from several dressed lands at both sites (sample numbers 14 to 18 and 34 to 36 in Table 1) showed comparatively lower pH values (4.5 to 5.6) and percent base saturation (17% to 55.4%). However, $EC_{1:5}$ values in the respective lands were comparatively higher than in other farmlands. Although CEC and percent base saturation are essential indicators of soil fertility, the overall balance in exchangeable ions that can be estimated from the nutrient ratios is more important for the nutrient supply to the plants. Fig. 3 and Fig. 4 present the basic cation ratios (Ca:Mg, Mg:K) in the studied farmlands. The suitable values as recommended by MAFF (2007) are 2 to 6 for Ca:Mg and 2 to 4 for Mg:K. The nutrient ratios from different farmlands, as presented in Table 1 and graphed in Fig. 3 and Fig. 4, indicate that, while most of the farmlands' soils were within the MAFF-recommended limits, some soil samples collected from the dressed lands (sample 8 and 13 through 18 for Watari-cho, and samples 35, 36, and 39 for Yamamoto-cho in Table 1) had either higher or lower values than the recommended ranges. Such a situation indicates an imbalance in nutrition supply in the dressed lands at both Watari-cho and Yamamoto-cho.

Physical Properties of Soil

As presented in Table 1, most of the soil samples (42 out of 48 samples), including each type of lands in both of the studied areas, were sandy (sandy loam (SL), sand (S), or loamy sand (LS)). The textural

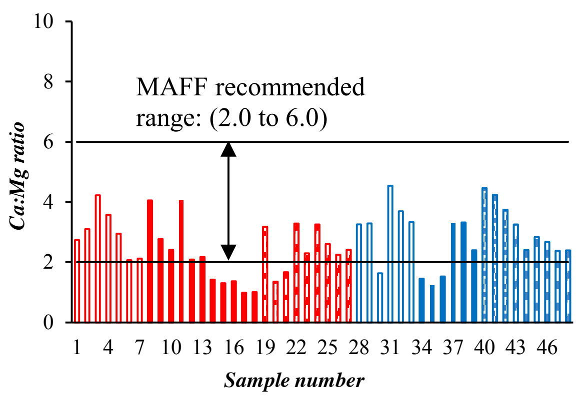
Table 1 Surveyed and analyzed data of soil samples collected from farmlands located in Watari-cho and Yamamoto-cho in Miyagi Prefecture

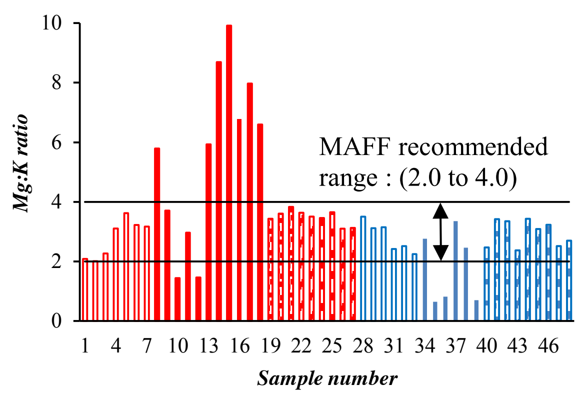
Study site	Sample	Land condition	Land use	Location		Elevation	pH	$EC_{1:5}$	CEC	Exchangeable bases (cmol(+)kg⁻¹)			Base saturation	TC	TN	C:N	Soil	Particle size distribution (%)			Gravel content
				Latitude	Longitude	(m)	(H_2O)	(dSm^{-1})	($cmol(+)kg^{-1}$)	CaO	MgO	K_2O	(%)	(%)	(%)	ratio	texture	Sand	Silt	Clay	(%)
Watari-cho	1	Undressed	Paddy	38°04'06.8"N	140°54'08.6"E	0.3	6.5	0.08	16.94	9.59	3.50	1.68	87.22	1.69	0.15	11.32	SL	66.3	25.0	8.7	2.5
	2	Undressed	Upland	38°04'15.9"N	140°54'01.9"E	1	6.8	0.11	23.11	10.85	3.51	1.74	69.69	2.68	0.22	12.16	CL	57.4	22.1	20.5	2.2
	3	Undressed	Upland	38°02'23.8"N	140°54'01.1"E	1.5	7.4	0.07	17.60	10.54	2.50	1.10	80.37	2.38	0.23	10.48	SL	81.7	11.9	8.4	2.0
	4	Undressed	Upland	38°01'44.4"N	140°52'57.9"E	1.2	6.6	0.09	13.53	8.16	2.28	0.74	82.57	1.09	0.10	11.42	LS	87.0	6.5	6.5	3.4
	5	Undressed	Upland	38°01'13.1"N	140°53'48.6"E	0.3	6.8	0.09	12.40	7.35	2.49	0.69	84.90	1.25	0.12	10.49	SL	76.2	16.2	7.6	2.9
	6	Undressed	Paddy	38°03'53.3"N	140°53'09.7"E	1	6.0	0.12	17.80	6.44	3.12	0.97	59.15	2.00	0.16	12.52	SL	73.1	18.8	8.0	2.4
	7	Undressed	Upland	38°03'36.6"N	140°53'11.1"E	0.7	6.1	0.13	21.42	7.46	3.52	1.11	56.42	1.76	0.16	10.99	CL	47.0	37.0	16.0	3.1
	8	Dressed	Upland	38°04'33.9"N	140°53'31.7"E	1	7.9	0.11	8.33	7.10	1.75	0.30	109.91	0.79	0.05	15.17	SL	73.9	20.0	6.1	4.6
	9	Dressed	Paddy	38°03'44.4"N	140°54'06.2"E	-0.1	6.8	0.11	7.30	3.78	1.37	0.37	75.59	0.58	0.05	11.84	LS	87.7	7.2	5.1	7.4
	10	Dressed	Paddy	38°03'43.1"N	140°53'38.1"E	-0.1	6.8	0.11	8.31	4.25	1.77	1.23	87.25	0.95	0.08	12.01	LS	88.2	6.7	5.1	5.2
	11	Dressed	Paddy	38°03'21.6"N	140°53'40.6"E	-0.3	7.2	0.12	7.32	4.49	1.11	0.37	81.58	0.92	0.07	13.53	LS	90.5	3.1	6.4	7.7
	12	Dressed	Paddy	38°03'21.7"N	140°54'07.4"E	-0.1	6.8	0.09	9.41	3.76	1.80	1.24	72.35	1.01	0.09	11.21	SL	82.6	13.7	3.7	9.7
	13	Dressed	Paddy	38°02'59.1"N	140°54'00.1"E	-0.3	6.6	0.13	9.38	4.42	2.04	0.34	72.47	1.04	0.09	11.95	SL	80.8	11.2	8.0	11.3
	14	Dressed	Paddy	38°01'47.0"N	140°53'20.2"E	-0.3	5.3	0.47	10.60	1.27	0.89	0.10	21.33	1.49	0.10	14.91	SL	79.4	15.5	5.2	9.0
	15	Dressed	Paddy	38°01'29.1"N	140°53'17.5"E	-0.3	5.5	0.46	10.50	0.97	0.75	0.08	17.02	1.50	0.09	17.45	SL	82.1	11.3	6.6	6.7
	16	Dressed	Paddy	38°01'30.1"N	140°53'04.5"E	-0.2	5.6	0.46	9.71	1.43	1.05	0.16	27.21	1.47	0.09	16.16	SL	82.9	9.6	7.5	9.3
	17	Dressed	Paddy	38°01'05.2"N	140°53'04.4"E	-0.1	4.5	0.59	7.16	0.52	0.53	0.07	15.67	1.57	0.09	18.42	S	89.2	6.1	4.6	9.0
	18	Dressed	Paddy	38°00'15.0"N	140°53'41.4"E	0.6	5.3	0.40	7.31	1.18	1.17	0.18	34.53	1.22	0.07	17.36	LS	86.3	5.8	7.9	5.8
	19	Soil dressing	Mountain	38°03'23.1"N	140°50'34.3"E	26.9	6.8	0.05	4.14	2.48	0.78	0.23	84.42	0.34	0.09	10.63	SL	77.3	16.9	5.8	14.1
	20	Soil dressing	Mountain	38°01'32.8"N	140°54'09.7"E	-0.1	6.0	0.06	8.35	2.74	2.03	0.56	63.96	0.95	0.11	5.67	SL	74.3	21.0	4.7	16.9
	21	Soil dressing	Mountain	38°00'06.0"N	140°51'01.5"E	44.7	6.0	0.06	5.24	1.22	0.73	0.19	40.80	0.53	0.10	6.40	S	89.2	9.2	1.5	12.7
	22	Inland	Paddy	38°04'56.5"N	140°52'41.8"E	2.3	6.2	0.10	23.31	12.74	3.88	1.07	75.85	2.82	0.28	10.07	L	58.2	26.9	14.9	2.1
	23	Inland	Upland	38°04'39.2"N	140°52'44.4"E	3.8	6.3	0.09	19.13	7.87	3.43	0.98	64.18	2.42	0.23	10.67	L	54.7	31.6	13.6	2.0
	24	Inland	Paddy	38°03'23.7"N	140°51'36.3"E	3	6.2	0.12	16.76	9.52	2.93	0.85	79.35	2.70	0.22	12.29	SL	68.1	22.8	9.0	1.5
	25	Inland	Upland	38°03'30.5"N	140°51'07.2"E	1.9	6.4	0.13	21.42	10.54	4.05	1.11	73.30	2.31	0.19	12.15	CL	47.0	37.0	16.0	1.4
	26	Inland	Paddy	38°01'25.0"N	140°51'43.6"E	3.6	6.3	0.07	15.54	6.88	3.06	0.99	70.32	2.42	0.15	15.80	L	60.1	31.0	8.9	1.9
	27	Inland	Upland	38°01'04.8"N	140°51'29.5"E	2.3	6.7	0.08	14.52	7.24	3.01	0.96	77.25	1.51	0.12	12.20	SL	79.6	15.2	7.2	1.8
Yamamoto-cho	28	Undressed	Upland	37°58'34.5"N	140°54'08.7"E	1.2	6.4	0.10	12.38	6.10	1.88	0.54	68.72	1.36	0.10	14.31	SL	82.4	10.4	7.2	6.4
	29	Undressed	Upland	37°57'31.0"N	140°54'19.6"E	1.3	6.8	0.11	13.42	7.86	2.39	0.77	82.07	1.41	0.12	11.72	SL	82.3	9.4	8.3	3.6
	30	Undressed	Paddy	37°57'40.1"N	140°53'51.5"E	1.4	5.9	0.13	15.57	4.99	3.07	0.97	58.01	1.89	0.17	11.34	SL	78.1	14.2	7.7	5.6
	31	Undressed	Paddy	37°57'25.2"N	140°53'23.2"E	2.4	7.4	0.14	14.43	10.27	2.26	0.93	93.25	1.79	0.18	10.04	SL	84.5	8.3	7.2	5.9
	32	Undressed	Upland	37°55'22.6"N	140°54'32.2"E	1.9	7.2	0.17	12.40	9.57	2.59	1.03	106.50	1.73	0.11	15.74	SL	75.2	17.6	7.2	4.2
	33	Undressed	Upland	37°54'44.0"N	140°54'48.9"E	7.6	7.0	0.14	21.17	12.47	3.75	1.67	84.49	2.75	0.19	14.19	SL	58.3	26.7	15.0	6.3
	34	Dressed	Upland	37°59'24.3"N	140°53'14.6"E	1.3	6.2	0.32	7.30	2.64	1.82	0.66	70.18	0.97	0.09	10.63	LS	85.3	8.8	5.9	13.2
	35	Dressed	Paddy	37°57'48.6"N	140°53'40.6"E	1.3	5.2	0.49	6.21	0.89	0.72	1.12	43.99	0.63	0.11	5.67	S	89.5	7.3	3.1	20.2
	36	Dressed	Paddy	37°57'39.6"N	140°53'48.5"E	1.3	5.4	0.48	8.29	1.87	1.23	1.51	55.49	0.61	0.10	6.40	S	90.3	5.6	4.2	21.1
	37	Dressed	Upland	37°56'18.7"N	140°54'30.6"E	1.4	7.1	0.10	7.32	5.09	1.55	0.46	97.09	0.65	0.06	10.88	SL	78.5	16.8	4.7	16.8
	38	Dressed	Paddy	37°56'01.3"N	140°54'30.5"E	1.1	6.8	0.13	7.31	3.39	1.02	0.41	65.97	0.79	0.06	12.33	SL	77.3	16.9	5.8	16.4
	39	Dressed	Paddy	37°55'18.3"N	140°54'47.2"E	0.9	6.4	0.16	10.41	3.26	1.36	1.97	63.32	0.94	0.06	15.23	SL	82.4	10.5	7.1	16.2
	40	Soil dressing	Mountain	37°59'01.4"N	140°51'21.4"E	52.3	7.4	0.03	4.02	2.77	0.62	0.25	90.66	0.43	0.03	14.90	S	88.5	8.5	3.0	16.7
	41	Soil dressing	Mountain	37°56'12.6"N	140°54'41.5"E	1.6	7.3	0.04	6.25	4.49	1.06	0.31	93.78	0.44	0.05	9.59	SL	84.6	12.7	2.6	19.9
	42	Soil dressing	Mountain	37°58'22.8"N	140°52'04.0"E	27.7	7.3	0.04	6.22	4.35	1.16	0.35	94.20	0.51	0.07	7.75	SL	85.3	10.3	4.4	25.8
	43	Inland	Paddy	37°58'14.8"N	140°52'14.2"E	11.9	6.9	0.04	16.69	8.44	2.59	1.10	72.69	1.55	0.15	10.12	SL	65.7	22.1	12.2	3.4
	44	Inland	Upland	37°58'08.2"N	140°52'05.6"E	17.3	6.4	0.02	16.76	8.41	3.50	1.02	77.13	1.60	0.15	10.82	SL	67.7	22.6	9.7	1.9
	45	Inland	Paddy	37°56'07.7"N	140°52'47.5"E	19.4	6.5	0.03	23.13	9.62	3.39	1.10	61.03	2.52	0.24	10.72	SL	68.2	18.3	13.5	1.3
	46	Inland	Upland	37°56'09.8"N	140°52'55.2"E	16.6	6.6	0.02	17.70	9.52	3.57	1.11	80.18	2.10	0.18	11.86	SL	77.8	14.5	8.7	1.6
	47	Inland	Paddy	37°55'07.0"N	140°53'08.9"E	13.6	6.5	0.04	13.60	6.82	2.87	1.14	79.62	2.02	0.19	10.82	SL	75.2	17.4	7.4	1.9
	48	Inland	Upland	37°55'10.6"N	140°53'04.0"E	14.4	6.5	0.04	12.52	6.58	2.75	1.02	82.76	1.85	0.18	10.22	SL	65.7	24.3	10.0	1.8

class of 31 soil samples (of 48) was sandy loam (SL), according to the IUSS classification system. Therefore, the texture of the soil in the study area was generally sandy by nature, regardless of the presence or absence of top dressing. However, the average particle size distribution showed a tendency toward fewer fine fractions (silt and clay) in dressed lands than that in undressed and inland lands because of the abundant gravel contents in the soil dressing—averages of 14.6% and 20.8% in Watari-cho and Yamamoto-cho, respectively (Fig. 5).

Biological Properties of Soil

Fig. 6 presents the total C:N ratio of soil, a determinant of organic matter content and an important indicator for plants' nutrient availability, at different farmlands in the studied sites. Dividing the C:N ratios into four groups (Fig. 6) shows that most of the soil samples were within the range of 10<C:N<20.





Notes: 1) MAFF: Ministry of Agriculture, Forestry and Fisheries, 2007
2) Sample number: 1 to 27 denote Watari-cho, 28 to 48 denote Yamamoto-cho
3) Land use and condition: As presented in Table 1

Fig. 3 Soil Ca:Mg ratios at different farmlands in Miyagi Prefecture

Fig. 4 Soil Mg:K ratios at different farmlands in Miyagi Prefecture

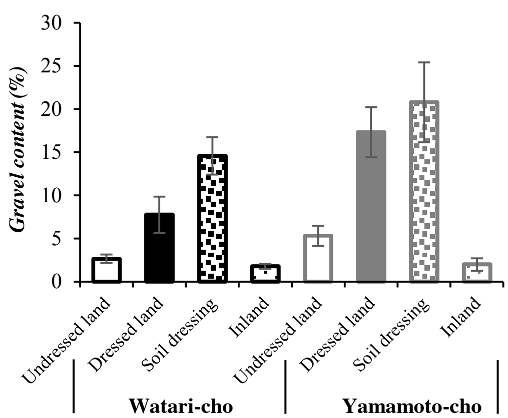


Fig. 5 Gravel contents in soils from different farmlands in Miyagi Prefecture

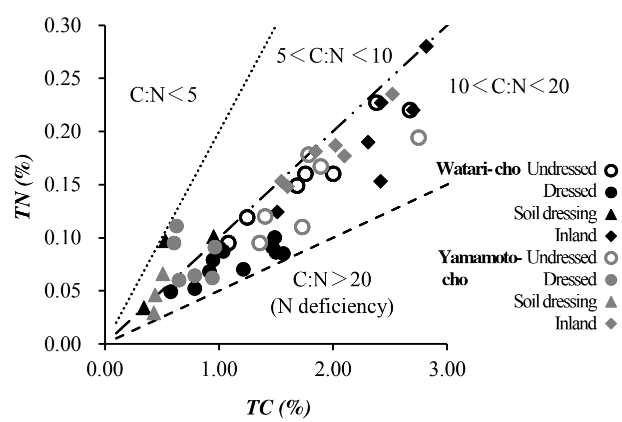


Fig. 6 Total C:N ratios of soils from different farmlands in Miyagi Prefecture

The C:N ratio in most agriculture soils remains more or less constant; Cleveland (2007) found a global tendency for the C:N ratio of overall soil to be 14.3±0.5. A soil with a C:N ratio greater than 20 indicates N-deficiency because of microbial growth (JSSSPN, 1998).Although none of the soil samples in this study had poor C:N values, however, the individual C:N values from the soil dressing and the dressed lands were highly irregular and scattered across a wider range (5.7 to 18.4) compared to those in the undressed (10.5 to 15.7) and inland soils (10.1 to 15.8). Moreover, the TC and TN values were also lower in soil dressings and dressed lands than that in undressed and inland soils. The average values for organic matter content (ignition loss) in the samples of the field soils (dressed, undressed and inland) ranged within 3.9% to 4.9%, whether the same in the soil dressings showed lower values of 2% and 2.1% in the two study sites.

Soil Properties and Their Correlations

Table 2 presents the correlations between the measured properties of the soil samples collected from different farmlands in Miyagi prefecture. The correlation matrix also includes the grain-yield factor as recorded during interviews with farmers at 15 paddy fields with different land conditions. From the table, the grain yield was found to have strongly correlated (positively and negatively) with soil CEC (r=0.794), clay content (r=0.813), and gravel content (r=-0.87). Moreover, significant correlations existed between the pH and the base saturation (r=0.889) and EC (r=-0.743); between the $EC_{1:5}$ and the base saturation (r=0.739); and between the CEC and the TN(r=0.884), clay (r=0.882), and gravel contents (r=-0.970). Except for the C:N ratio, most of the measured parameters of the soil samples that represent the productivity and fertility of the agricultural lands were found to have significantly correlated to one another ($p<0.001$, $p<0.01$, or $p<0.05$), as presented in the correlation matrix table.

Status of Soil Fertility and Productivity in Restored Lands

While the data and analyses presented above give an idea of soil properties, Fig. 7 shows the yield in 2015 at different farmlands in our study sites. As seen in the soil properties, the lands that were restored with soil dressing (dressed lands) are relatively imbalanced nutritionally and, therefore, less fertile compared to the undressed and inland fields, which ultimately negatively affects grain yields at paddy fields with soil dressing in both Watari-cho and Yamamoto-cho, as shown in Fig. 7. Although fertility does not always guarantee the productivity of soil, it (fertility) represents the productivity of agricultural lands. Data from Table 1 show that the soils' CEC and percent base saturation values were lower overall in dressed lands than in undressed lands, and the extent of variation widens when comparing the values from dressed lands with the inlands. The use of soil

Table 2 Correlation matrix between soil properties in Miyagi prefecture

	Grain yield (Paddy)	pH(H_2O)	$EC_{1:5}$	CEC	Exchangeable cations			Base saturation	TC	TN	C:N ratio	Sand	Silt	Clay	Silt+Clay	Gravel content
					CaO	MgO	K_2O									
Grain yield	1.0															
pH(H_2O)	0.275	1.0														
$EC_{1:5}$	-0.660 ***	-0.743 ***	1.0													
CEC	0.794 ***	0.037	-0.293 *	1.0												
CaO	0.790 ***	0.484 ***	-0.564 ***	0.837 ***	1.0											
MgO	0.853 ***	0.175	-0.484 ***	0.916 ***	0.868 ***	1.0										
K_2O	-0.157	0.116	-0.251	0.620 ***	0.576 ***	0.649 ***	1.0									
Base saturation	0.310 *	0.889 ***	-0.739 ***	0.077	0.560 ***	0.321 *	0.264	1.0								
TC	0.749 ***	-0.093	-0.125	0.902 ***	0.734 ***	0.806 ***	0.485 ***	-0.048	1.0							
TN	0.697 ***	-0.043	-0.257	0.884 ***	0.751 ***	0.817 ***	0.549 ***	0.042	0.904 ***	1.0						
C:N ratio	0.187	-0.113	0.325	0.011	-0.069	-0.102	-0.226	-0.235	0.201	-0.193	1.0					
Sand	-0.705 ***	-0.068	0.334 *	-0.792 ***	-0.659 ***	-0.797 ***	-0.450 **	-0.133	-0.704 ***	-0.693 ***	-0.002	1.0				
Silt	0.583 ***	0.079	-0.365 *	0.685 ***	0.580 ***	0.734 ***	0.382 **	0.165	0.606 ***	0.609 ***	-0.047	-0.970 ***	1.0			
Clay	0.813 ***	0.052	-0.217	0.882 ***	0.720 ***	0.791 ***	0.517 ***	0.050	0.789 ***	0.754 ***	0.102	-0.855 ***	0.707 ***	1.0		
Silt+Clay	0.706 ***	0.076	-0.340 *	0.801 ***	0.669 ***	0.805 ***	0.456 **	0.137	0.712 ***	0.702 ***	0.001	-0.999 ***	0.970 ***	0.857 ***	1.0	
Gravel content	-0.870 ***	-0.049	0.254	-0.734 ***	-0.660 ***	-0.725 ***	-0.302 *	-0.072 *	-0.757 ***	-0.647 ***	-0.320 *	0.535 ***	-0.454 **	-0.625 ***	-0.545 ***	1.0

Significance of correlations indicated by *, **, and ***, are equivalent to p=0.05, p=0.01, and p=0.001 (n=48; only except grain yield, where n=15) dressings with a low CEC (4.02 cmol(+)kg^{-1} to 8.35 cmol(+)kg^{-1}) in the restored lands can be said to be responsible for that. Because pH and base saturation are generally closely related to soil CEC (Turner and Clark, 1966; Huvlin et al., 2011), even a soil with a high CEC does not guarantee productivity if the pH is low. In the current study, comparatively lower pH values (4.5 to 5.3) and percent base saturations (15.67% to 55.49%) were observed in parts of the dressed lands at both study sites (5 lands out of 11 in Watari-cho, and 2 lands out of 6 in Yamamoto-cho), although the EC were comparatively higher (0.32 dS m^{-1} to 0.59 dS m^{-1}) in the respective areas. In such case, while soil pH needs to be rectified to increase the percent base saturation and thus to enhance the fertility and favor productivity, farmers were observed using overdoses of fertilizers in these fields, which might affect the C:N ratio and increase the $EC_{1:5}$ of the soil. As a result, while the C:N ratio in most of the agricultural soil is constant, as found in the inland soil (10 to 12), dressed lands showed inconstant and wider-ranged values (5 to 19) within the same type of land condition in both study areas. Lower cation ratios also indicate the inferiority of soil fertility levels in these dressed lands. All of these chemical properties were found to have strong correlations with the proportion of finer and the coarser particles from different soils in the study sites. While none of the inland fields had more than 3.4% gravel contents, the undressed fields contained 6.4% (although there is some possibility that undressed fields might have some gravel parts carried by the tsunami water), and soil dressings contained between 14.1% and 25.8%, resulting in maximum percentages of 21.1% gravel content in dressed lands. During the survey, many volunteers were observed periodically sorting out gravel at the restored farmlands. All of these factors and activities individually and jointly deteriorated the nutritional balance and fertility of the soil in these specific lands.

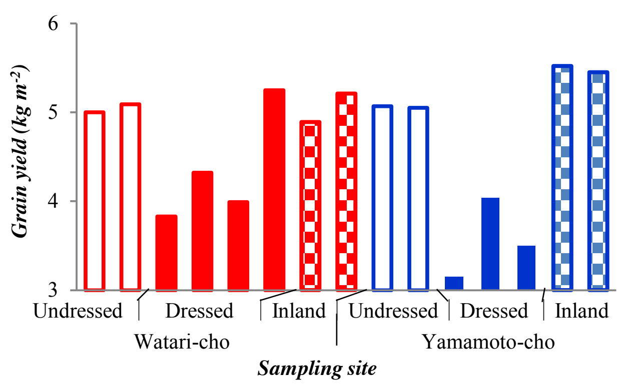


Fig. 7 Yields from paddy fields at different farmlands in Miyagi Prefecture (2015)

CONCLUSIONS

Several years have passed since the Great East Japan earthquake and tsunami disaster of 2011, and the tsunami-inundated farmlands have been influenced by many natural and anthropological activities. Therefore, to figure out the absolute status of fertility and productivity in the fields before and after the tsunami is very difficult. Soil samples from nearby inland fields were collected and analyzed of to provide an idea of the pre-tsunami soil quality in the area.

The analytical results indicate that soil in the restored (dressed) lands is inferior from the perspective of agricultural production compared to the non-restored (undressed) land. The extent of that inferiority becomes more distinct when compared with the soil inland, and the reason lies in the quality (or inferiority) of new soil used as a top dressing during the restoration. The findings of this study conclude that, in the tsunami-inundated agricultural fields, the presence of a soil dressing (i.e., mountain soil) with inferior physical properties (i.e., fewer fine fractions) contained poor and imbalanced chemical and biological constituents, making it less fertile, which ultimately affected soil productivity even after the restoration. It may take several years or even decades for the topsoil to regain its productivity, and the process can be accelerated only by proper fertility management after figuring out the specific cause(s) and extent(s) in the specific field(s).

This study also serves to remind that, in the case of agricultural practices with long-term histories and processes, rapid land restoration does not necessarily ensure land productivity, which is the most important to farmers and agriculturists. 'Slow but steady' mitigation processes, such as phytoremediation by using halophytes (Yaneshita, 2011), would be much more practical because the latter does not damage the inherent soil fertility in agricultural fields. Instead, over-fertilization will not only worsen the soil quality but also have drastic side-effects on soil and natural environment in the long run.

More detailed analyses considering more spatiotemporal data on soil humus, isotopes, and buried geology could give a clearer picture of the overall fertility and productivity in the area after the tsunami disaster. Future studies related to salinity mitigation in agricultural fields should include research using different inexpensive and locally originated materials, such as cotton waste, charcoal, fly ash, and halophyte species, all of which have salt removing potentials and are harmless to agricultural soils which is a precondition to sustainable agriculture.

ACKNOWLEDGEMENTS

The authors would like to express gratefulness to the local farmers in Miyagi prefecture, who were very kind and cooperative throughout the study period. Prof. Yukihiro Hayashi at the College of Bioresource Sciences at Nihon University in Japan provided valuable suggestions. Thanks are due to the students of the International Environment Conservation Lab at the College of Bioresource Sciences at Nihon University for their support in carrying out the experiments and sample analyses.

REFERENCES

Cleveland, C.C. and Liptzin, D. 2007. C:N:P stochiometry in soil: Is there a "Redfield ratio" for the microbial biomass? Biogeochemistry, 85 (3), 235-252.

Government of Japan. 2012. Road to recovery. Retrieved from http://japan.kantei.go.jp/policy/documents/2012/__icsFiles/afieldfile/2012/03/07/road_to_recovery.pdf, access date: August 11, 2016.

Gruhn, P., Goletti, F. and Yudelman, M. 2000. Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. Food, Agriculture, and the Environment Discussion Paper 32, International Food Policy Research Institute, Washington, DC, 1-31.

Huvlin, J.L., Tisdale, S.L., Nelson, W.L. and Beaton, J.D. 2014. Soil fertility and fertilizers (8th ed.). Pearson Prentice Hall, Upper Saddle River, N.J. , 550p.

JSSSPN (Japanese Society of Soil Science and Plant Nutrition). 1998. Glossary of soil science and plant nutrition (Fujiwara, S. et al. Ed.). Rural Culture Association Japan, Tokyo, 338p (in Japanese).

MAFF (Ministry of Agriculture, Forestry and Fisheries, Japan). 2007. Improvement of chemical properties. Retrieved from http://www.maff.go.jp/j/seisan/kankyo/hozen_type/h_sehi_kizyun/pdf/ntuti16.pdf, access date: September 1, 2015 (in Japanese).

MAFF (Ministry of Agriculture, Forestry and Fisheries, Japan). 2011. Estimated area of agricultural land by the Great East Japan Earthquake (tsunami). Department of Statistics, MAFF. Retrieved from http://www. maff.go.jp / j/tokei/saigai/pdf/shinsai.pdf, access date: September 1, 2015 (in Japanese).

Miyagi Prefecture Furukawa Agriculture Research Station. 2013. Characteristics of nitrogen mineralization at the restored paddy fields after tsunami disaster in Miyagi prefecture. Retrieved from http://www.naro.affrc.go.jp /org/tarc/seika/jyouhou/H25/kankyou/H25kankyou010.html, access date: November 1, 2016 (in Japanese).

NARO (National Agriculture and Food Research Organization). 2013. The EC transition by natural rainfall in the tsunami affected paddy fields (no cropping). Retrieved from http://www.naro.affrc.go.jp/org/tarc/seika/jyouhou/H23/kyoutuu/H23kyoutuu001.html, access date: August 29, 2015 (in Japanese).

Roy, K., Kato, Y., Sato, N. and Nagasaka, S. 2015. Post-tsunami salinity status of reclaimed and nonreclaimed farmlands in Miyagi Prefecture. J. Environmental Information Science, 43, 19-24.

Roy, K., Sasada, K. and Kohno, E. 2014. Salinity status of the 2011 Tohoku-oki tsunami affected agricultural lands in northeast Japan. International Soil and Water Conservation Research, 2 (2), 40-50.

Tomomasa, T., Kitagawa, I., Mineta, T. and Haraguchi, N. 2013. Restoration and desalinization of tsunami-damaged agricultural land. J. Japanese Geotechnical Soc., 61, 20-23 (in Japanese).

Toyama, K. and Tajima, T. 2014. Measures and issues for restoration and rehabilitation of farm lands and agricultural facilities destroyed by the Great East Japan Earthquake. Water, Land and Environmental Engineering, 82 (3), 201-204 (in Japanese).

Turner, R.C. and Clark, J.S. 1966. Lime potential in acid clayand soil suspensions.Trans. Comm. II & IV Int. Soc. Soil Science, 208-215.

Watari-cho (Maintenance team: Agriculture, Forestry and Fishery Division). 2015. Rice planting and reclamation in restored farmlands of Watari cho in 2015, Retreived from http://www.town. watari. miyagi.jp /index.cfm/ 9,30060,c,html/30060/20141128-091304.pdf, access date: September 10, 2016 (in Japanese).

Yamamoto-cho (East Infrastructure Promotion Office). 2015. Master plan for restoration of agricultural lands in Yamamoto cho. Retrieved from http://www.town.yamamoto.miyagi.jp/uploaded/attachment/5704.pdf, access date: November 2, 2016 (in Japanese).

Yaneshita, M. 2011. Restoration of agricultural land flooded by seawater from the Tohoku tsunami: salt-removal using seawater-tolerant plants. Report of Taisei Technology Center, 44 (20),1-4 (in Japanese).