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Developing a Salt-Removal Plan to Remedy Tsunami-caused Salinity Damage to Farmlands: Case Study for an Area in Southern Thailand

Tetsuo NAKAYA*, **Hajime TANJI, Hirohide KIRI and Hiromasa HAMADA**

Department of Geotechnical and Hydraulic Engineering, National Institute for Rural Engineering, National Agriculture and Food Research Organization (Tsukuba, Ibaraki 305–8602, Japan)

Abstract

We developed a salt-removal plan to reduce tsunami salinity damage based on the results of field surveys of soil salinity levels in southern Thailand after the 2004 Indian Ocean tsunami. Although salinity greatly exceeded the maximum for crop growth (4 dS m^{-1}) immediately after the tsunami, the soil's electrical conductivity was high only in the surface layer (1 to 2 cm deep) and decreased sharply in lower layers, rapidly falling below 4 dS m^{-1}. Long-term field surveys indicate that the soil's salinity was removed almost completely by rainfall during the rainy season, but that salinity had long-term effects on local crops. We propose a simple method for estimating the risk of salt damage based on meteorological observations and develop a method for calculating the amount of water required to reduce salinity based on the amount of salinity invasion for an argillaceous soil. Stripping the salinized surface soil so that the surface salt can be flushed out through drainage canals by rainfall or irrigation is an effective salt-removal measure that farmers can implement. Based on our results, we describe a plan farmers can use to rehabilitate their farmland and that can be modified for use elsewhere.

Discipline: Agricultural engineering
Additional key words: rehabilitation of salinized sites, salt injury to crops

Introduction

The tsunamis caused by the earthquakes that occurred west of Sumatra on 26 December 2004 brought disaster to Thailand, particularly in the southern coastal areas of Phang Nga Prefecture, leaving 5,000 people dead and 3,000 people missing. When a tsunami occurs, tourist resorts and the social infrastructure are generally reconstructed quickly, but almost no activities are carried out to investigate and remedy salt damage to farmland. Because the damage to agriculture only appears to affect crops, public interest in this damage is less than the interest in more obvious human losses. However, because most people in the stricken area earn their livelihood by farming, it is crucial to monitor this damage and to perform restoration work in some areas. Figure 1 illustrates the damage to farmland in southern Thailand.

Because the invasion of salt water caused by a tsunami represents a short-term phenomenon, the damage can be greatly reduced compared with the damage that occurs through salinization of dry land and polders, where salt damage can last for a long time.

In this paper, we develop a salt-removal plan to reduce tsunami damage caused by salt deposition, based on field surveys of salt damage in southern Thailand after the 2004 Indian Ocean tsunami.

Materials and methods

We performed field surveys from January 2005 to March 2006 to outline the dimensions of the tsunami damage. The main study areas are shown in Fig. 2; these included farmland in Pa Lai (an upland field) of Phuket Prefecture, along the western coastline of Phuket Prefecture, and farmland in Lam Kaen (a compound orchard), Bang Niang (a compound orchard), Nam Khem (a rubber plantation), and Leam Pakarang (a coconut palm plantation) in Phang Nga Prefecture. Here, a compound orchard means an orchard with two or more crops. Although we considered data from all of these areas in calculating the range of salinization impacts, we focused our analysis on the areas with the best available data: Bang Niang, Nam Khem and Pa Lai.

*Corresponding author: e-mail tnakaya@affrc.go.jp
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Fig. 1. An illustration of the damage to farmland in southern Thailand that was observed immediately after the 2004 tsunamis

We measured the electrical conductivity of the soil at each site using an electrical conductivity meter (model CM-210P, DKK-TOA Corporation, Tokyo, Japan), since this parameter is commonly used as an indicator of the salt concentration and to assess the level of salt damage, which is the main cause of the long-term crop damage that results from tsunamis. We used a 1:5 ratio of soil to water for this measurement[8]. We collected samples of undisturbed soil using DIK-110B soil samplers (Daiki Rika Kogyo Co., Ltd., Saitama, Japan).

Based on the results of our field surveys, we developed a plan to rehabilitate farmland that has sustained salt damage as a result of the tsunami.

Results and discussion

1. Outline of the salt damage in Thailand

The tsunami damage in tourist resorts mostly resulted from the collapse of buildings, but injuries and deaths were also common. In farmland, the salt damage from seawater was far more serious than physical damage such as the lodging of crops due to flooding. Most crops withered and died in all of the study areas[6]. According to the FAO[2], the area of farmland affected by the tsunami in southern Thailand totaled 1,556 ha. Virtually all of the damage (86%) occurred in farmland in coastal areas of western Phang Nga Prefecture. Figure 3 shows the area of damaged land in Phang Nga using GIS data provided by the Land Development Department of Phang Nga Station. Figure 3 shows that most of the affected farmland was compound orchards, followed by coconut palm plantations and rubber plantations. Most of these farmlands are on argillaceous soils with low hydraulic conductivity. Although most of the farmland lies within an area of about 2.3 km from the coast, land farther inland was also inundated by the tsunami, which traveled upstream along rivers. Based

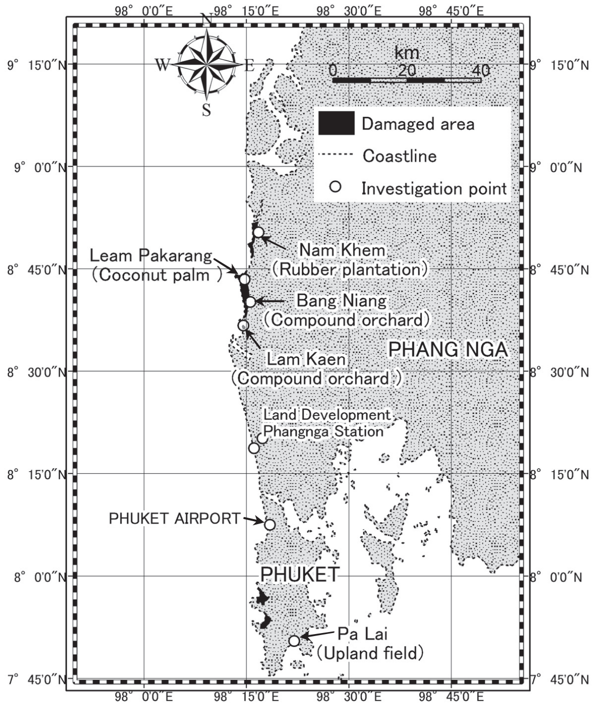

Fig. 2. Map of the study areas in southern Thailand

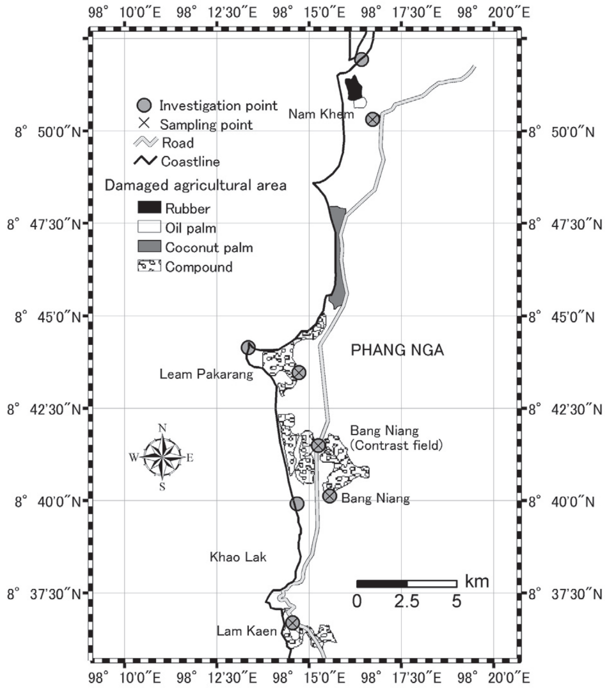

Fig. 3. Areas of farmland damaged by the 2004 tsunamis in Phang Nga Prefecture

Data provided by the Thailand Land Development Department's office in Phang Nga Prefecture.

on observations of materials deposited by the flood, the flood water appeared to reach a depth of about 2 m above the farmland. The thickness of sediment deposited by the tsunami in farmland was about 4-5 cm.

2. Outline of crop damage in Thailand

Figure 4 shows the vertical distribution of electrical conductivity values in the soil in areas that sustained salt damage between February 2005 and March 2006. Although the sediment accumulation that resulted from the flooding was 4 to 5 cm thick, the electrical conductivity of the soil during the dry season (February 2005) was high only in the surface layer (1 to 2 cm deep) and decreased sharply in lower layers, falling to values below 4 dS m^{-1}, the point at which salinity prevents the growth of most crops. This is an important finding to support measures against salt damage because it indicates that to remove enough salt from the affected farmland, there is no need to remove all of the soil and sand that was transported by the tsunami or to remove the original surface soil. Our observation that the salt concentration of the soil was high only in the surface layer (the top 1 to 2 cm) was also observed in other study areas. The detectable effects of the seawater invasion reached depths of 20 to 30 cm at all three sites, but the salt concentration was low (< 1 dS m^{-1}) at these depths.

However, the period during which increased soil salinity persisted depended strongly on the amount of rainfall during the rainy season. After 1,000 mm or more of rain had fallen, a soil salinity of 4 dS m^{-1} or more was not detected in any of the farmlands of Phang Nga Prefecture or Phuket Prefecture. At this time, soil salinity in the Phang Nga or Phuket farmland was 1 dS m^{-1} or less between the surface and a depth of 90 cm or more. These results show that most of the salt that accumulated during the dry season flowed out from the surface soil due to rainfall at the beginning of the rainy season. We expect the remaining salinity to be removed by subsequent infiltration.

Table 1 shows the results of our long-term observations of farmland damage. Salinity had been mostly removed from all farmlands by the end of the rainy season. Our investigation of the relationship between rainfall and soil salinity revealed that salt deposition resulting from tsunami-induced flooding was nearly completely removed by rainfall of 1,000 mm or more (Fig. 5). Dead and dying rambutan trees were removed from the Bang Niang plantation, and oil palms were planted (Fig. 6). Because oil palms require 6 years before their oil can be harvested, cucumbers were grown between the trees to provide an interim crop. The oil palms and cucumbers have grown well (i.e., comparable to their growth at sites not affected by the tsunami). Most rubber trees were felled by around 11 months after the tsunami, as most of these trees experienced reduced growth and the quality of their sap was considered to be poor by the farmers. These results indicate that although the soil salinity was almost completely removed by rainfall during the rainy season, the salt damage continued to influence crops for considerably longer. This suggests initial physical or physiological damage that must be repaired over time.

3. A simple method for predicting long-term salt damage based on climatic conditions

The salt damage created by tsunamis differs from the damage that occurs as a result of salinization in dry areas that undergo irrigation, which lasts longer. Our results show that after a tsunami, the salinity can be removed in the short term by rainfall. On this basis, we propose a simple water-balance estimation method based on meteorological data and demonstrate how this model can be

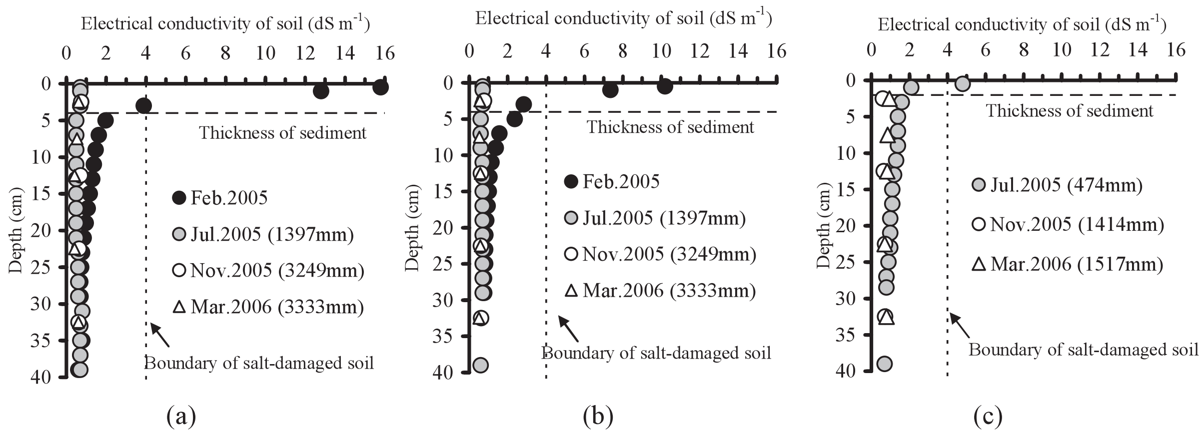

Fig. 4. Distribution of the electrical conductivity of the soil as a function of depth in (a) a compound orchard (two or more crops) at the Bang Niang site, (b) a rubber plantation at the Nam Khem site, and (c) a site with field crops at the Pa Lai site

Table 1. Results of long-term investigation of salinity damage to crops in southern Thailand after the tsunamis of December 2004

	Phang Nga (Nam Khem)			Phang Nga (Bang Niang)		Phuket (Pa Lai)		
	Kind of crops	Rubber		Mangosteen, rambutan		Field crops		
	Total rainfall (mm) after the tsunami	State of the crops	EC of surface soil (dS m^{-1}, 1:5 soil to water)	State of the crops	EC of surface soil (dS m^{-1}, 1:5 soil to water)	Total rainfall (mm) after the tsunami	State of the crops	EC of surface soil (dS m^{-1}, 1:5 soil to water)
Jan.2005	-	Sap production decreased	12.2	Completely killed by salt injury	7.1	1.2	Completely killed by salt injury	5.5
Feb.2005	-	Sap production decreased	10.2	Completely killed by salt injury	15.8	5		
Jul.2005	1,397	Sap production increased	0.70	Transplanted new crops after cutting down the damaged trees	0.70	474	Completely killed by salt injury	4.8
Nov.2005	3,249	The trees were felled because the quality of their sap was poor	0.77	Recovery almost complete	0.75	1,414	Growth was slowed	0.6
Mar.2006	3,333	–	0.55	Recovery almost complete	0.61	1,517	Growth remained low	0.95

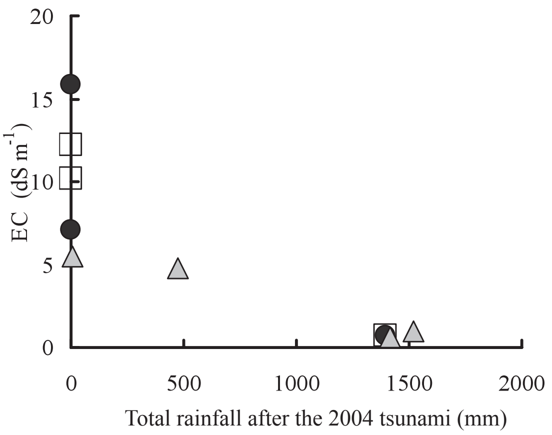

Fig. 5. The relationship between the total amount of rainfall after the 2004 tsunamis and electrical conductivity (EC, 1:5 soil to water) of the soil
● : Bang Niang, □ : Nam Khem, △ : Pa Lai.

Fig. 6. At Bang Niang, dying rambutan trees were removed and oil palms were planted 6 months after the 2004 tsunamis

used to predict the duration of salt damage based on the data we collected after the 2004 Indian Ocean tsunamis in southern Thailand.

First, we collected data on monthly (or daily) precipitation and monthly (or daily) evapotranspiration; in our example, we used monthly data from January to November 2005 in Phang Nga and Phuket Prefectures. We used the Penman equation to calculate the potential evapotranspiration, as described in detail by Miura and Okuno[4,5]. This equation uses the average daytime air temperature, relative humidity, wind velocity, and sunshine duration. When these meteorological data are unavailable, the actual measured evaporation can be used instead of the Penman equation. Matsui[3] demonstrated that the amount of evaporation (estimated using available data) remains useful even though neither the estimated nor measured evapotranspiration equal this reference value. Next, the estimated monthly (or daily) evapotranspiration is subtracted from the corresponding recorded monthly (or daily) precipitation. If the result is positive (i.e., precipitation exceeds evapotranspiration), salts are leached from the soil; if the result is negative, salt levels do not decrease. If this calculation is done for each month, the overall trends in the residual salinity throughout the year can be easily understood. Figure 7 shows the results of the water-balance calculations for the salt-damaged farmland (Thailand's Phuket Prefecture) after the Indian Ocean tsunamis of 2004.

To calculate the amount of evapotranspiration, we used meteorological data from Phuket airport (index station 48565; 8°7'N, 98°18'E). Because some solar radiation data were missing for October 2005, the amount of evapotranspiration in October was replaced by the measured amount of evaporation. Next, we grouped the water-balance calculation results to show how salinity changed at different times of the year (Fig. 8). In Group 1, rainfall was considerably larger than evapotranspiration, so salt was removed from the soil. Conversely, the amount of the evapotranspiration was considerably larger than the amount of the rainfall in Group 2, so salt persisted. In Group 3, the amounts of rainfall and evapotranspiration were almost equal, so salt concentrations remained unchanged. By adding the water-balance values for each month in Fig. 7, it can be seen that the net precipitation during months in Group 1 (1,732.5 mm) was greater than the net evaporation during months in Group 2 (727.62 mm), which suggests that the salinity created by a tsunami will not persist for long. Moreover, if the actual measured evaporation is used to estimate evapotranspiration, the total evapotranspiration decreases to 1,677 mm, and trends for this parameter throughout the year would roughly correspond to the evapotranspiration trends.

When salt accumulates in the surface layer of the soil and reaches a high concentration, as in the case of Thailand during the dry season, it can take considerable time for all of the salt to leach out of the soil, even if the soil does not tend to accumulate salt throughout the year. In such a case, it will be effective to remove the surface layer of soil (to a depth of about 3 cm) in which salt has accumulated at a high concentration. Because the electrical conductivity of soil below this layer is 4 dS m^{-1} or less, the soil in these layers can be considered to have sustained less salt damage from the perspective of its ability to support crop growth. Under most conditions, the remaining salt should leach out of the soil in response to heavy rainfall during the rainy season.

This analysis suggests that the magnitude of the salt damage and the need for mitigative measures can be predicted using a simple water-balance calculation.

4. Calculation of the amount of water required to mitigate the invasion of salinity

In our model field experiment[7], most of the salt that accumulated in the surface soil flowed out of this soil via surface runoff, and the remaining salinity was removed by infiltration (deep drainage). In our study area, the hydraulic conductivity of the soil is poor, and this may explain why salt does not seem to migrate into deeper soil layers and is instead lost primarily via surface flows. Apart from

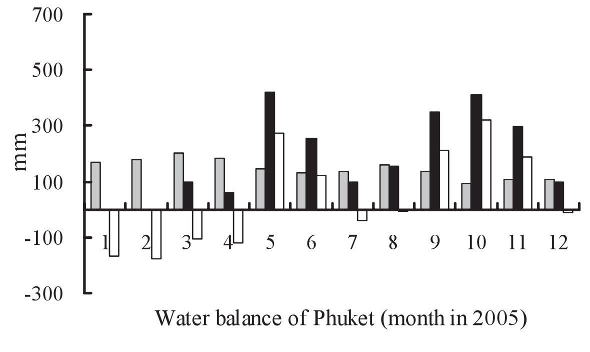

Fig. 7. Calculation of the water balance in Thailand's Phuket Prefecture after the 2004 tsunamis
Annual rainfall = 2,241 mm,
Annual evapotranspiration = 1,746 mm.
□ : Evapotranspiration (mm), ■ : Rainfall (mm),
□ : Net balance (mm).

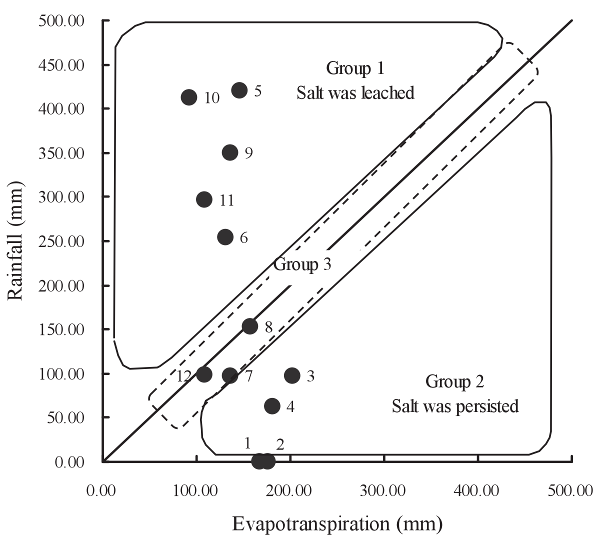

Fig. 8. A simple grouping of the results (numbers refer to the month numbers in Fig. 7) of the water-balance calculations to show annual trends

this difference, the experimental conditions were similar to conditions in the present study.

To apply these values to the damaged area in southern Thailand, we used the following procedure:

(1) We converted the electrical conductivity (EC, 1:5 ratio) into the EC of a saturated paste extract by multiplying the observed values by 9.7[1].

(2) We converted the EC of the resulting saturated paste extract into a salinity using the following equation[7]:

$$y = 0.0006\,x^2 + 0.0538\,x - 0.0077 \qquad 1)$$

where y is salinity (%) and x represents the EC of the saturated paste extract.

(3) We converted the salinity into an amount of salt (g) included in a unit volume represented by an area of 1 cm^2 multiplied by the sampling depth (cm), and totaled the results to calculate a total salinity to that depth for each unit area (1 cm^2).

(4) The amount of water (1,839 to 2,167 mm) required to remove a salinity of 0.5 g cm^{-2} is then multiplied by the value from step (3), and the amount of water required is then calculated by multiplying this result by (2).

We calculated the amount of water required to remove this quantity of salt using this method and the distribution of EC (1:5) values shown in Fig. 4. The detection limit depth for the infiltrating salinity (i.e., the depth at which salinity no longer changed significantly) was around 37 cm (Fig. 4). We therefore performed our calculations to a depth of 37 cm. The amount of salinity for each unit area (to this depth) equaled 0.46 g cm^{-2}, and the corresponding amount of water required was between 1,687 and 1,993 mm. It is possible to use these values to roughly estimate the thickness of surface soil that must be removed to achieve sufficient salt removal. Figure 9 shows the relationship between the thickness of removed surface soil and the amount of rainfall required for salt removal. If the total amount of rainfall after a tsunami is known, the thickness of surface saline soil that must be removed to achieve sufficient salt removal can be estimated from this figure.

After the surface saline soil has been removed, the leaching effect can be enhanced by creating small drainage ditches that carry away drainage water more efficiently (Fig. 10). Note that this approach will work best in areas where the water flow is primarily horizontal, as in our study area; in areas where deep infiltration occurs quickly, the method may have to be modified to account for migration of salt into deeper soil layers.

5. Proposal for a salt-removal plan to reduce salinity damage after a tsunami

Based on our calculations in the preceding sections, we propose a series of measures that can be taken to reduce salt damage. Large-scale farmland restoration after a tsunami is difficult because of the difficulty of obtaining government or other funds. Therefore, the proposal focuses on measures that can be implemented by individual farmers without such assistance.

First, we collect the meteorological data used in our calculations and a land-use map for the mitigation area. Next, we survey the flooded area and flood duration using the land-use map. Next, we check the amount of residual salinity in the damaged farmland. Next, we calculate the total amount of rainfall within 1 year after the tsunami based on past meteorological data. We then calculate the thickness of surface soil that must be removed using the techniques described in section 4. After stripping off the surface soil (the part of the soil that initially reaches the highest level of salinity), the leaching effect can be enhanced by creating small drainage ditches.

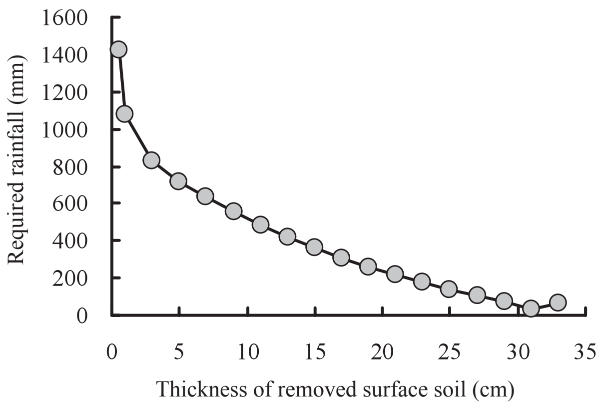

Fig. 9. The relationship between the thickness of surface soil that must be removed and the amount of rainfall required for salt removal

Fig. 10. Example of a small drainage ditch that has been dug near Bang Niang to enhance salt removal through drainage

Conclusions

We identified the following key points based on our investigation of salt damage in farmland soils in our case study area in Thailand:

(1) The initial soil salinity value greatly exceeded the maximum salinity for the growth of most crops (4 dS m^{-1}), and salt damage to crops ensued.

(2) The salinity in the top 1 to 2 cm of the surface soil is highest even if the sediment deposited by the tsunami forms a relatively thick layer, and salinity decreases rapidly with increasing depth below this layer.

(3) Long-term field surveys indicated that the soil salinity had been almost completely removed by rainfall of 1,000 mm or more during the rainy season, but the salt damage continued to influence crops for a longer time.

To develop a salt-removal plan capable of reducing tsunami damage to farmlands, the following points should be considered:

(1) A simple, long-term damage-forecasting technique such as the one in the present study can be developed based on the time (season) when the tsunami occurs.

(2) The amount of water required to remove the salinity can be calculated.

(3) Based on the results of these analyses, it is possible to propose a simple series of steps that describe how to rehabilitate the farmland using measures that are feasible for farmers, without requiring large amounts of government or other funding.

References

1. Ahmed, A. et al. (2006) Soil salinity assessment by some destructive and non destructive methods in calcareous soils. *J. Jpn. Soc. Soil Phys*., **104**, 27–40.
2. FAO/MOAC (2005) Report of joint FAO/MOAC detailed technical damages and needs assessment mission in fisheries and agriculture sectors in tsunami affected six provinces in Thailand. FAO in cooperation with MOAC, pp.20.
3. Matsui, H. (2003) Estimation of mean monthly pan evaporation based on Hargreaves equation. *J. Japan Soc. Hydrol. & Water Resour*., **16**(6), 589-594 [In Japanese with English summary].
4. Miura, T. & Okuno, R. (1993a) Detailed description of calculation of potential evapotranspiration using the Penman equation. *Transactions of the Japanese Society of Irrigation, Drainage and Reclamation Engineering,* **164**, 157–163 [In Japanese with English summary].
5. Miura, T. & Okuno, R. (1993b) Ideas for easy calculation of Penman equation. *Transactions of the Japanese Society of Irrigation, Drainage and Reclamation Engineering,* **164**, 165–170 [In Japanese with English summary].
6. Nakaya, T., Tanji, H. & Kiri, H. (2006) Long-term field survey of damage in rural area of Southern Thailand due to the 2004 Indian Ocean tsunami. *Ann. J. Coastal Eng., JSCE*, **53**, 1381–1385 [In Japanese].
7. Nakaya, T. et al. (2007) Planning method on salt exclusion for the reduction of salt damage of farmlands by tsunami. *Ann. J. Coastal Eng., JSCE*, **54**, 1386–1390 [In Japanese with English summary].
8. Soil Environment Analyzing Method Editing Committee, ed. (2002) Soil environment analyzing methods. Hakuyusha, Tokyo, 202–204 [In Japanese].