3 Post-tsunami assessment and restoration of soil and water

Key points

- The level of salinity in tsunami-affected soils in Aceh and the rate of salt leaching was influenced by:
  - the length of time that land was inundated by sea water
  - soil moisture levels at the time of the tsunami
  - soil type—salt leaches faster from sandy and peat soils than from clay soils
  - the depth and type of sediment deposited by the tsunami
  - drainage in fields and the local catchment
  - access to irrigation water to flush salt from fields
  - rainfall after the tsunami.
- Salt can leach vertically through the soil profile and laterally across fields with surface waters.
- Three years after the tsunami, high salinity readings were still measured in Aceh, mainly linked to poor drainage.
- Construct in-field drainage to accelerate the salt leaching process.
- Assess results from soil salinity surveys carefully to avoid misinterpretation.
- Incorporate shallow sediments (<20 cm) that are not highly saline into the topsoil.
- Remove deeper or highly saline sediments from fields.

Photo: New South Wales Department of Primary Industries

Tsunamis can have a number of effects on coastal soils: increased soil salinity and sodicity, sediment deposition, and scouring and erosion of topsoil. The physical and chemical properties of tsunami-affected soils in Aceh are discussed in Agus et al. (2008), Hulugalle et al. (2009) and McLeod et al. (2010).

Particular requirements for the recovery of agriculture in Aceh included:

- assessing and managing soil salinity and other soil issues
- managing the sediments deposited by the tsunami
- assessing and managing water quality
- repairing drainage and irrigation structures.

This section includes:

- methods of salinity assessment
- soil salinity impacts
- soil and crop rehabilitation related to the commonly experienced post-tsunami problems
- observations of the physical and chemical impacts of the tsunami.

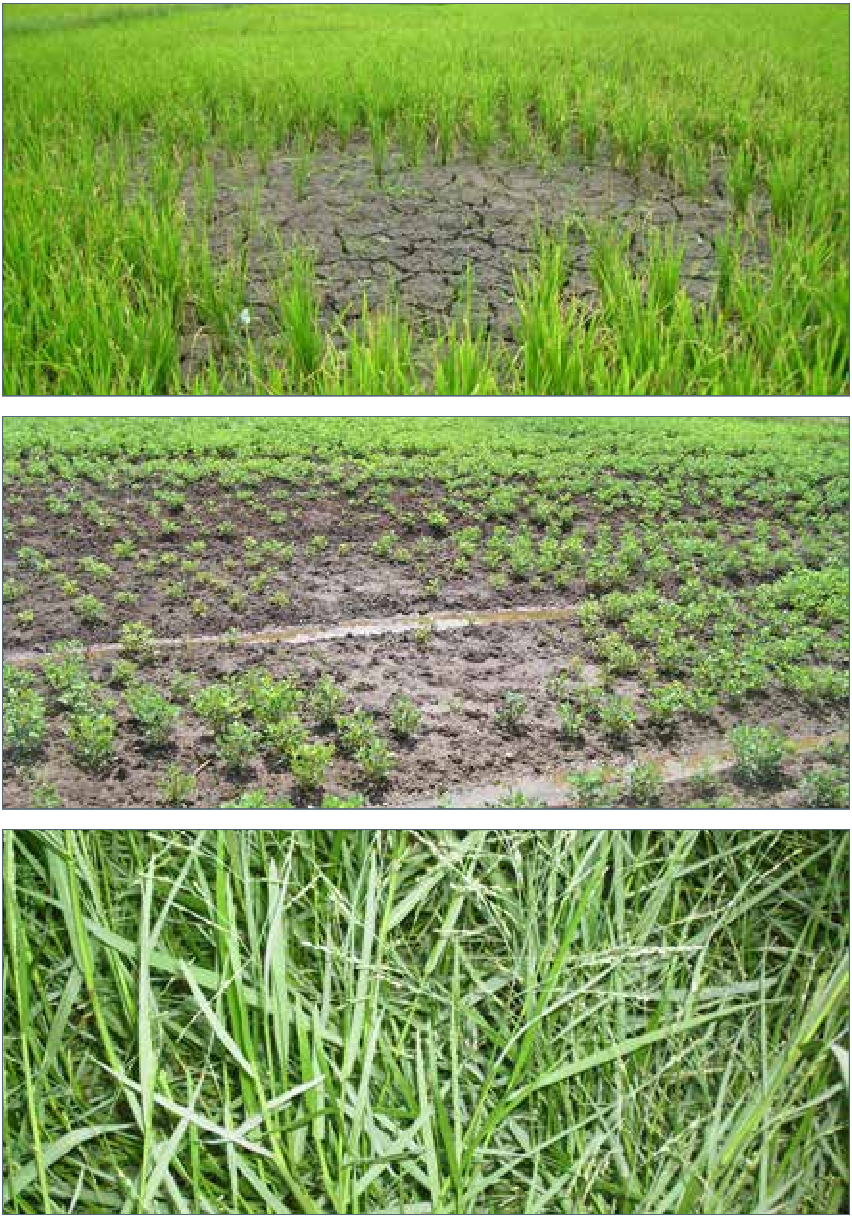
Soil salinity

Although there may be visual signs of soil salinity, the most commonly used method to estimate soil salt content is to measure the electrical conductivity (EC) of a soil solution in the laboratory. Soil salinity can also be measured in the field using a portable salinity meter or by assessing the apparent EC (ECa) using an electromagnetic induction soil conductivity meter, such as an EM38 or EM31 instrument.

Salinity assessment methods

Visual assessment

Visual indicators of soil salinity (Figure 7) include patchy plant growth; bare soil; salt crystals on the soil surface; puffy, dry soils; and appearance of salt-tolerant plant species. However, if the soil has been cultivated, there may be no visual indicators of the degree of soil salinity.



Photos: New South Wales Department of Primary Industries

Figure 7 Visual indicators of soil salinity: patchy growth, bare soil and salt-tolerant plants

Laboratory measurement

Laboratory methods to assess soil salinity involve measuring the EC of water extracts of soil samples using either a mixture of one part of soil to five parts of deionised water (EC1:5) or saturated paste (ECe). Different ratios of soil to water may also be used. Care must be taken when interpreting laboratory data because the different ratios of soil to water will give different results. The ratio used by the laboratory should be specified in the results.

Field assessment

Portable salinity meter

Soil salinity can be measured directly in the field by mixing dried, crushed soil with five parts of rainwater, shaking, allowing the mixture to settle, and then measuring the water with a portable (field) salinity meter.

Electromagnetic induction method

Soil EC can be assessed indirectly using electromagnetic induction instruments such as an EM38 or EM31. The EM38 instrument (Slavich et al. 2006a) measures the average ECa of the soil in situ to a depth of approximately 1 m. EM38 surveys are a fast and reasonably accurate method of determining bulk soil salinity levels in the field, particularly across large areas. Measurements across 23 sites in Aceh showed a high correlation between ECa values obtained from using the EM38 and EC1:5 values, to a depth of 40 cm. Given the high variability of soils in tsunami-affected areas, this provides a high degree of confidence in salinity assessments using the EM38 survey method.

ECa readings obtained using the EM38 instrument are influenced by clay content (texture), moisture content, and the presence of metals around the site or on the operator. Using raw figures from an EM38 survey as the basis for salinity action can be misleading, so training is needed in interpreting the results.

EM38 surveys can be used to:

- classify soil salinity risk as low, medium or high
- evaluate the effects of salinity on crop production
- monitor the extent of salt leaching through the soil profile
- identify locations suitable for sampling saline soils for laboratory analysis
- provide a guide to the level of salinity of different texture classes of soils.

Both EC1:5 and ECa can be converted to the EC of a saturated soil (ECe) using a site-specific calibration and a conversion factor based on soil texture (Rhoades et al. 1989; Slavich and Petterson 1993). ECe provides the most reliable measure of salinity for making comparisons between different soil types. Soils are considered saline when the ECe is greater than 2 dS/m.

Monitoring tsunami-affected soils is necessary to assess salinity levels and the rate of leaching, to determine the productive capacity of soils. After the Aceh tsunami, salinity monitoring under the Australian Centre for International Agricultural Research (ACIAR) projects provided information about:

- the impact of the tsunami on crops and yields
- movement of salt through the soil profile
- the rate of return to pre-tsunami conditions.

Box 2 Protocols for using an EM38 instrument to monitor soil salinity

EM38 surveys were very useful in rapid assessment of salinity in Aceh. They showed that the effect of the tsunami on soil salinity was highly variable from one site to another and within a site. Therefore, protocols need to be developed and followed to ensure that readings are taken from representative locations, are reliable and are comparable over time (Slavich et al. 2006a, b). The steps below were used as a standard guide in Aceh:

- Identify sites for surveys based on guidance from local farmers.
- Identify areas of good, medium and poor crop growth, and establish representative sampling transects for each area.
- If more than one soil type is identified, treat each soil type separately, and identify areas of good, medium and poor crop growth on each soil type.
- Determine the start and end of each transect, clearly identify or mark its extent, and record the location and/or the GPS coordinates to enable transect monitoring over time.
- Establish the frequency with which measurements will be taken. This could be a regular interval (e.g. monthly or 3-monthly), after significant rainfall events, or before crop planting and after harvest.
- Follow the instructions for using the EM38 instrument and conduct site-specific calibration using the methods described in Slavich and Petterson (1990).
- Remove metal jewellery and footwear containing metal to avoid affecting the EM38 readings.
- Record visual site conditions at every survey date. Records could include crop stage, recent cultivation, and conditions of the soil surface or crop. Record anything that may affect EM38 readings.
- Record readings in both the vertical (EMv) and horizontal (EMh) orientation at each transect measurement point on each measurement date.

Box 2 *continued*

Photos: New South Wales Department of Primary Industries

Field measurements of salinity using an EM38 instrument under three different conditions: dry soil surface (top left), flooded (top right) and saturated (bottom)

Box 2 *continued*

- In flooded sites, measure the depth of water above the soil surface. The height of the instrument held above the surface of the water should be recorded and consistently used between sites and over time. This is needed to enable interpretation of the results—EMh is sensitive to height above ground (EMv is less sensitive).
- Determine the random error of EM38 readings by taking one reading across a full transect and repeating it four times, and then calculating the standard errors of the means. Do this under the three different conditions shown in the photographs: dry soil surface, saturated soil surface and standing water (flooded). This exercise only needs to be done once. It will ensure more accurate interpretation of the site survey data over time.
- Do spot EM38 checks in areas with low growth or yield potential, to identify crop losses that are related to salinity.
- Treat transect locations with very different EM38 readings separately. This will build up the dataset, and enable interpretation of EM38 survey results over time, particularly in relation to movement of salt through the profiles. The ideal time to do this is at the end of the wet season or at the end of harvest.
- Take soil water levels into account when interpreting data. Increased EM38 values during the wet season could be due to increased soil water content.
- Manage EM38 data through project leaders to ensure that only interpreted data are published.

Field observations in Aceh

Changes in field soil salinity between August 2005 and December 2007 were monitored on 23 sites across Aceh Besar, Pidie, Bireuen and Pidie Jaya districts by measuring ECa using an EM38 instrument. ECa values were calibrated using measured EC1:5 data obtained from samples across these sites, and converted to ECe using a factor of 8.6 (Slavich and Petterson 1993), which represents the dominant soil in Aceh's lowland agricultural areas. The ECa readings in both vertical (EMv) and horizontal (EMh) dipole orientations were recorded during each measurement to allow assessment of both the level of soil salinity and the direction of salt movement.

Monitoring soil salinity using an EM38 instrument (see above, under 'Field assessment') helped local agricultural extension agencies identify sites that were too saline for crops and determine when they were suitable for cropping again. This technique can be used following a storm surge or tsunami that leads to agricultural areas being inundated with sea water.

Seawater inundation after the tsunami introduced salinity into areas where it had never been a problem. Eight months after the tsunami, ECe values at the 23 sites varied from 1.6 to 22.6 dS/m (McLeod et al. 2010). Rainfall soon leached salt from most sandy soils. However, clay soils that were inundated for 1–3 days after the tsunami had low to moderate salinity 8 months later, and soils that were inundated for 6 days had higher salinity levels.

Salinity was a significant constraint to crop production during the dry season, and many farmers and extension workers reported declines in yield of around 50%. Three years after the tsunami, ECe values at the same sites ranged from 1.4 to 13.0 dS/m, even though 3,000–7,000 mm of rain had fallen during that period. Likely reasons for the slow leaching of salt are the loss of functional drainage systems and the generally low relief of the affected areas. Salinity tended to be higher in rice paddies that had compacted subsoils, which trapped saline tsunami sediments and held saline water for longer. Salinity also persisted in poorly drained, low-lying areas; in these areas, salinity fluctuated with the seasons. Salts slowly leached from the soil by both vertical displacement through the soil and horizontal movement in surface waters.

A lack of familiarity with soil salinity problems in Aceh resulted in crops being planted in saline soil or irrigated with saline groundwater. This led to failed crops and despair in farmers who were already traumatised by the tsunami. Timely assessments of salinity can help farmers avoid growing crops in saline areas and indicate when management practices are needed to alleviate salinity.

Factors affecting salinity levels after the tsunami

Table 1 presents salinity risk factors for crop production after the tsunami, based on information collected from local farmers and field extension officers during site visits and EM38 surveys in Aceh's eastern districts. Some of these risk factors are discussed below.

Table 1 Salinity risk factors for crop production

	Risk of soil salinity affecting crop production		
Risk factor	**Low**	**Medium**	**High**
Duration of inundation with sea water	Less than 0.5 days	0.5–3 days	More than 3 days
Soil permeability	Low (e.g. puddled clays with shallow watertable)	Moderate (e.g. non-puddled loamy soils)	High (e.g. sandy soils)
Inundation by tidal water	Information not available	Tidal water only moderately saline	Irregularly covered by tidal water of high salinity
Number of irrigated rice crops since the tsunami	Information not available for more than two rice crops	1–2	0
Depth and salinity of shallow watertable	No data, but likely to be low risk if below 2 m in dry season and EC < 2 dS/m	No data, but likely to be medium risk if 1–2 m from surface in dry season and EC = 2–4 dS/m	Less than 1 m from surface in dry season, and EC > 4 dS/m

EC = electrical conductivity

Source: Slavich et al. (2006a)

Duration of seawater inundation

The length of seawater inundation after the tsunami determined the level of salinity risk for crop production. Highest salinity levels occurred where sea water stayed on the soil for weeks after the tsunami, allowing salts to penetrate the soil and attach to clay particles. Land inundated for more than 3 days was usually too saline for most crops to yield well in the first 12 months (Table 1).

Soil texture

Soil texture plays a crucial role in soil salinity. The level of clay in soils can be estimated using hand texture tests in the field, or measured using the standard particle size analysis method in the laboratory. In the hand texture test, a handful of soil is mixed with water to form a small ball about 2 cm in diameter. The ball is then pressed between fingers and thumb to form a ribbon; the longer the ribbon, the more clay is in the soil.

Sandy soils tended to be less saline after the tsunami because salts do not attach to sand particles and so are easily leached through the soils. Peat soils also leached salt relatively quickly through surface drainage networks. Clay soils drain more slowly than sandy or peat soils, and salts tend to attach to clay particles, so clay soils remained saline for longer. In heavy clay soils around Bireuen on the east coast of Aceh, where rainfall is relatively low (~1,600 mm/year), salinity persisted for more than 12 months, reducing crop yields. In poorly drained soils, salts are mainly lost via surface flow of water rather than by leaching through deeper layers (Nakaya et al. 2010).

Sediment type

Sandy sediments leached salts easily, whereas clay sediments held salts more tightly. The organic matter in peaty sediments tended to buffer the salt concentration so that the salt did not affect plant growth. However, the underlying soil type is more important than sediment type for predicting soil salinity levels. If the soil underneath the sediment is sandy, leaching will occur; if it is clay, the salts will tend to remain, even if the sediment is sandy.

Availability of fresh water for leaching salt from the soil

Sea water is more likely to infiltrate dry soils than wet soils. When assessing soil salinity after seawater inundation, knowledge about rainfall just before the tsunami will provide information on the soil moisture conditions and therefore the likelihood of infiltration by sea water. Knowledge about rainfall after the tsunami will provide information on the likelihood of salt leaching after the event.

Although no rainfall data for Aceh were available before the tsunami, it is likely that the soil was wet because the tsunami occurred during the wet season (the rice-growing season). At sites with similar rates of drainage, the leaching of salts from the soil profile is principally affected by the annual rainfall. The higher the rainfall, the faster salt is leached out. The average rainfall on the west coast of Aceh is 2,300–3,300 mm/year, compared with 1,365–1,889 mm/year on the east coast. It is likely that greater salinity occurred on the east coast than the west coast because of the slower rate of leaching.

Rice soils are compacted and clay based to hold water. As a result, they do not leach salts vertically, and required flushing with rainfall or irrigation after the tsunami to remove salt laterally. Lower salinity levels were observed in areas where there was plenty of fresh water for irrigation and flushing. Rainfed paddy fields were more likely to be saline for longer because the salts could not be flushed away until the wet season. In some areas, the tsunami increased salinity levels in well water and groundwater, which meant that irrigation added additional salt to the soil.

Soil tended to be more saline in the centre of the rice paddies than in the outer sections, because the centre section was often a drainage basin for the rest of the site and difficult to flush out. Through-flow of surface water is particularly important when establishing rice on tsunami-affected land.

In Sri Lanka, upland fields and home gardens relied on rainfall to remove salt from the soil. Finding methods to flush salt from soils in low-rainfall zones was important for restoring productive home gardens (Weligamage et al. 2005). Rehabilitation of ponds and other water storages was vital to collect irrigation water to leach salts from field soils.

The research of Nakaya et al. (2010) in upland fields and plantations of Thailand proposed a method to calculate the amount of water needed to remove salt from soil with poor drainage. If farmers were provided with rainfall gauges, and trained in measuring and recording rainfall, they could learn to correlate rainfall with the rate of return of healthy crops. Combined with the removal of highly saline sediment and construction of shallow drains to facilitate salt leaching, this method could easily be converted into an extension package for advisers to help farmers determine when salinity risk has dropped to an acceptable level.

Salinity monitoring

In Aceh, sites selected for monitoring had all been inundated by sea water. They covered a range of soil types and were located in different agricultural areas of the province. Background information was gathered for each site to make sense of monitoring results; this involved answering the following questions:

- How long did sea water cover the site?
- What type of sediment was left behind?
- How deep was the sediment?
- How was the sediment treated?
- Was topsoil eroded and, if so, to what depth?
- Is the site now affected by tidal water?
- Is there good drainage at the site?
- Is the site dryland or irrigated?
- Is fresh irrigation water available?
- Are there problems with irrigation or drainage at the site?
- Before the tsunami, what crops were grown and what were their yields?
- What is the cropping history and yield since the tsunami?
- Does the site have any other special characteristics?

Monitoring criteria

The ACIAR projects in Aceh monitored 23 permanent sites every 3 months for:

- soil salinity
- soil texture (salt movement differs in clay and sandy soils)
- depth of water above the ground at flooded sites (this is important when interpreting EM38 salinity readings)
- soil nutrients (nitrogen, phosphorus, potassium, organic matter)
- soil pH
- salinity and pH of surface water and well water
- crop performance in the ground (leaf appearance, grain or fruit appearance, potential yield, yield).

Sampling protocols for soil, water and crops

Projects in Aceh adopted the following protocols for sampling:

- Assign and clarify responsibilities for sampling, analysing soil and plant samples, and analysing and interpreting data.
- Train field technical staff to collect and process soil samples. In Aceh, the field technical staff were from the Assessment Institute for Agricultural Technology (BPTP) Aceh.
- Take one soil profile at each site to a depth of at least 60 cm, with samples divided into 0–20 cm, 20–40 cm and 40–60 cm depths. Keep each sample in a bag that is clearly labelled to show location, date and depth of sample. Samples should be air dried and ground to pass through a 2 mm sieve before they are sent to the designated soil laboratory for analysis. The soil laboratories in BPTP Aceh and the Indonesian Soil Research Institute (ISRI), Bogor, were the designated laboratories for soil chemical analyses.
- Sample well water and surface water at each soil and crop assessment site, whenever possible. Record the sample depth and field EC. Submit well water samples to the laboratory to confirm the EC and pH. Note the water colour, particularly indicators of soluble iron after storage (oily surface and yellowing).

- Monitor the EC1:5 at selected points in the trial area. This should be done without combining samples, because soil EC is spatially variable. Sampling points could be based on visual indicators of plant growth (e.g. poor, medium and good growth).
- Take plant tissue samples where there is evidence of crop nutrition or soil fertility problems.

Record keeping

Records of soil and water measurements at each trial site—including a dedicated field diary of EM38 survey measurements—showed salt movement over time, and built a database of post-tsunami soil recovery. Notes on crop growth and performance at each site helped to determine whether salinity was an issue.

Salinity management

The ACIAR projects in Aceh developed several strategies, described below, to help advisers and farmers deal with salinity.

Leaching and flushing of salt from soil

Aceh's naturally high rainfall encouraged leaching of salts down through the soil profile, especially in sandy soils (Slavich et al. 2006b). Leaching of saline sites can be encouraged by:

- raising crop beds to improve drainage (see below)
- constructing shallow drainage channels to encourage surface flushing of salt during rainfall
- mulching beds to prevent soil from drying out and bringing salts to the surface.

Flushing fields using irrigation water and natural rainfall is possible once drainage and irrigation channels are cleared of sediment and a through-flow of water is available. Pumps might be needed to remove saline water in low-lying areas. In Aceh, salt in rice soils was close to the ground surface because the soils were already flooded, and the compacted, puddled soils prevented the salt from leaching down through the soil. Where farmers had access to irrigation water and drainage was unimpeded, this surface salt was easily flushed away. Rice crops appeared unaffected by the tsunami 7 months later, even where tsunami deposits were present.

Farmers in rainfed fields may need to wait longer for salts to be leached from the soil if no local source of irrigation water is available. Nakaya et al. (2010) proposed a method in Thailand to predict the long-term impacts of salt, based on climatic conditions, and calculated the water requirements to mitigate soil salinity in rainfed farming systems. Their findings supported other observations (Raja et al. 2009) that salinity decreased with increasing rainfall, and only a shallow layer of surface soil may need to be removed initially to reduce salt levels in the short term.

Soil salinity at depth can remain an issue for longer, depending on the local hydrology and the extent of saline water intrusion into groundwater. This type of salinity may affect deep-rooted crops and tree crops. Studies in Thailand and Aceh (Nakaya et al. 2010; Marohn et al. 2012) observed long-term impacts from saline groundwater on mortality and yields of common tree crops in coastal areas.

Removal of saline water

Where poor drainage or post-tsunami damage impedes the flushing of salt-affected fields with fresh water, the removal of saline water with pumps is an option. In 2005 in the district of Pidie, rice in one bunded field failed, while crops in bunded fields on either side grew normally (Figure 8). The difference in management was that some farmers could afford to pump saline water from their fields, reducing the salinity levels at planting, and establish crops before the start of the wet season, whereas the owner of the failed crop waited for rain to plant. At the time the photo was taken, surface water EC readings were low (~0.2 dS/m) in both fields; however, they were probably higher in the failed crop at planting because no removal or flushing of surface salts was possible.

Photo: Assessment Institute for Agricultural Technology, Aceh

Figure 8 Failed rice crop (left) and successful crop (right); in the paddy field on the right, salt water was removed with pumps, helping to dilute the salinity of the water and avoiding crop losses due to high salt levels

Use of raised beds

Raised crop beds allow water to drain quickly from the soil, taking any salt with it. This is a useful technique in high-rainfall areas, but not as useful during dry periods when the demand for water is high. On more elevated sites, the construction of shallow drainage channels will help to leach salt from soils.

Use of calcium

Adding calcium to saline soils replaces sodium, effectively leaching the sodium from the soil. Calcium is commonly added in the form of gypsum. Where gypsum is unavailable, poultry manure, which is high in calcium, could be used. These options were rarely used in Aceh, mainly because of the high cost of gypsum and a scarcity of poultry manure.

Other soil issues

In the short term, soil salinity will be the main limiting factor for agriculture after a tsunami or seawater inundation event. However, salinity and sediments can also affect soil chemistry and nutrient availability. Particular attention needs to be paid to coastal peat soils, which can potentially become acid-sulfate soils if exposed by drainage.

Acid-sulfate soils

Tropical floodplains such as those in Aceh may overlie acid-sulfate soils. These soils are harmless while covered in water. However, when they are dry, they produce sulfuric acid, which acidifies soils and surrounding waterways (Sammut and Lines-Kelly 2004). The acidity produced by these soils is often so high that plants cannot grow. Indicators of acid-sulfate soils include red staining from iron particles on the soil surface and along stream banks.

On the west coast, farmers displaced by the tsunami moved inland onto peat soils. Farming in these areas had varying degrees of success, depending on the acidity levels that occurred when the soils were drained and dried out. Some soils became so acid that very little would grow. A basic pH kit can help farmers and advisers to assess acidity. Lime, mulches and organic matter can help reduce acidity levels, although lime can be expensive.

Sodicity

After the 2004 tsunami, soil scientists in Aceh expected sodium in the salt water to attach to clay particles, making the soil sodic and susceptible to erosion. However, soil sodicity proved infrequent, possibly because most soils were sandy, and the puddled and compacted clay rice soils prevented sea water infiltrating to any depth. However, sodicity may be a problem in clay soils that are not compacted. Saline sodic soils were detected on the Andaman and Nicobar islands after the 2004 tsunami (Nayaka et al. 2010).

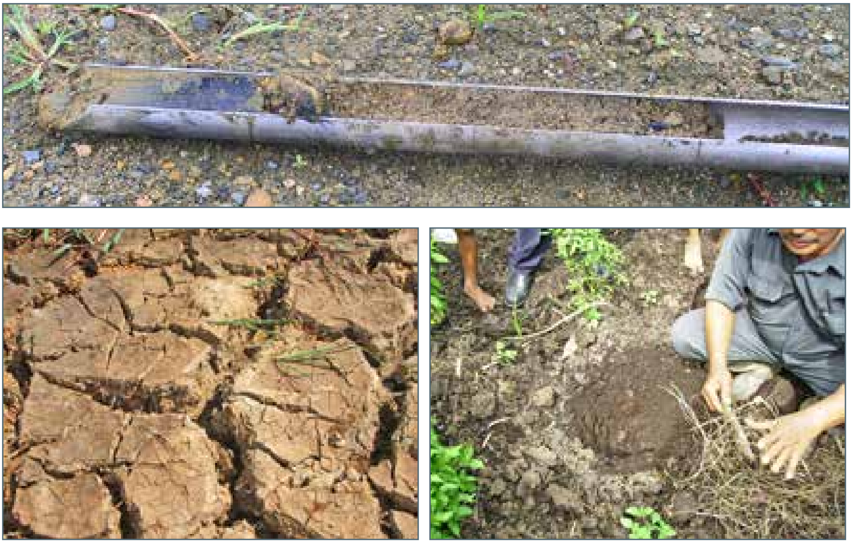
Tsunami sediments

In Aceh, the tsunami deposited sediment over floodplains, filling in irrigation channels, agricultural drains and rice paddy fields. In many areas, channels and paddy fields had to be restored before any crops could be established. Some agricultural land took months or even years to return to production because farmers could not channel irrigation water in the dry season or drain floodwaters in the wet season. Removing sediment from channels and drains is a high priority after a tsunami. This activity must be coordinated with land surveys, in case changes in land elevations have altered drainage patterns.

At workshops 2 years after the tsunami, farmers said that they would have liked information immediately after the tsunami on sediment removal techniques and how to prioritise which fields to work on first. However, managing sediment is a complex issue that needs site-specific assessment. Removing sediment is a labour-intensive and expensive operation, and may not be necessary in all instances. Some sediment deposits can be left in place or incorporated into the topsoil. In some areas in Aceh, sediments gradually merged into the soil without any intervention, mainly due to self-seeding vegetation that grew through the sediment into the soil below. Where sediment—particularly deep sediment—has to be removed, assistance from government reconstruction and aid groups may be needed. The decision to remove sediment from fields depends on the factors outlined below.

Sediment type

Aceh tsunami sediments ranged from sand and clay to peaty organic matter, coral fragments and seabed mud (Figure 9). Some sediments were highly variable in particle size, comprising mixed gravel, sand and clay. Peaty sediments originating from coastal wetlands proved to be fertile and productive, and so could be left in situ, although monitoring was necessary to ensure that they continued to be fertile.



Photos: New South Wales Department of Primary Industries

Figure 9 Sediments deposited by the 2004 tsunami in Aceh: sand (top), seafloor mud (bottom left) and organic peat (bottom right)

Clay sediments provided some nutrition to farmer fields once they were incorporated into the soil. In some cases, sediments over acid peat soils buffered the soil acidity, and the peat provided minerals to assist crop growth, so these sediments were initially very fertile.

Tsunami deposits on the Nicobar and Andaman islands consisted of organic matter, fine sand, coral boulders, granules and broken shell fragments (Sarkar et al. 2012). In India, clay and sand sediments were most common (Chaudhary et al. 2006), and were shallow enough to be incorporated into the soil by ploughing.

Sediment depth

Farmers interviewed 2 years after the tsunami said that thin layers of sediment were not a problem for their farming because they could be incorporated easily into the soil below. Farmers did not attempt to grow rice in deeper sediments because their cultivation implements could not penetrate deeper than 20 cm. The Indonesian Bureau of Rehabilitation and Reconstruction found that sandy sediments deeper than 25 cm were too deep to grow rice, but that shallower sandy sediments away from the coast did not affect peanut crops. A sandy sediment deeper than 10 cm could be difficult to incorporate, especially where the underlying soil texture was coarse.

Another reason for shallow sediments being of less concern than deep sediments is that salt levels were observed to be low in shallower sediments, and plant roots could grow through the shallow layer to the soil below. Deep sand or clay sediments posed more of a problem because they were sometimes very saline, as well as being difficult for plant roots to move through. Rice paddies located a short distance inland from the west coast of Aceh were not subjected to the same rate of coarse sediment deposition as coastal paddies on the east coast.

Salinity levels in sediments

Following the 2004 tsunami, sediments varied greatly in their salinity levels, so site-specific assessments were required before any crops could be planted.

Underlying soil type

The soil under the sediment determines the rate of salt leaching from the sediment. Highly permeable sandy soils can leach sediment salts quickly. Clay soils, particularly compacted rice paddy soils, do not leach easily; there is a higher risk of salinity in these sediments, and they may need to be removed.

Farming options

When assessing whether to remove sediments, authorities in Aceh first checked whether villagers had other areas where they could grow crops. Sediment was removed only if the villagers had no other available land. The decision to remove sand or clay sediments was determined by the sediment depth and the underlying soil type.

Sediment removal programs

Two years after the tsunami, farmers identified physical activity as very important in regaining a sense of control. Small-scale sediment removal or incorporation programs provided a useful therapeutic activity, as well as a practical step in preparing fields for planting. Nakaya et al. (2010) proposed a salt removal plan for individual farmers in Thailand that incorporated sediment removal and other practical steps, where required. Mapping of sediment depths was also suggested as a possible activity for farmers. However, this requires resources and coordination that might be too time-consuming to achieve practical outcomes for farming groups.

Water quality and assessment

The 2004 tsunami caused major changes to Aceh's water systems. Coastal drainage patterns changed, particularly on the west coast, which was closer to the earthquake epicentre and hence more affected by the tsunami. Some land rose, other areas subsided, and the scouring action of the tsunami altered the coastline dramatically. Changes in coastal drainage closed estuaries in some areas; attempts to dredge them open to allow drainage were not successful, possibly because of changed land levels from subsidence or uplift. In many areas, former freshwater catchments became affected by high tides, saline groundwater or waterlogging, making them permanently unsuitable for agriculture (Figure 10).

Delays in reconstructing irrigation and drainage channels meant that areas remained waterlogged or were unable to access irrigation water. There was a general shortage of irrigation water in dry areas, and a lack of local rainwater storage for rainfed rice production. Some sites needed pumps to remove saline water from storages and to pump fresh river water into dams; some dams needed cleaning and deepening.

A common problem was poor growth due to salinity in low-lying fields. These 'basins' accumulated salts that would dissolve into the first irrigation water. Farmers therefore needed to drain water and accumulated salts away from the fields.

In some areas, salt water entered freshwater aquifers, and water testing was needed to ensure that salt water was not used on crops. Groundwater salinity in West Aceh fluctuated markedly—it declined rapidly after the tsunami, then rose repeatedly in response to seasonal variation in rainfall and the intrusion of saline water during flooding (Marohn et al. 2012). In the district of Bireuen, irrigated rice experienced more problems than dryland rice, possibly because of salt in the water used for irrigation. Water with an EC greater than 3 dS/m may cause significant crop damage.

In areas with poor drainage, improving the irrigation and drainage systems was an important priority for local government and non-government organisations. Irrigation was vital to ensure that farmers could plant and finish rice crops through flowering and seed set. On the east coast of Aceh, rice crops that were well established in August 2005 failed to yield well in October. A lack of sufficient irrigation water reduced salt leaching, leading to increased soil salinity and plant water stress. Irrigation systems must be surveyed to ensure that levels have not been affected by earthquake or tsunami damage.

The New South Wales Department of Primary Industries has produced guidelines for testing the salinity of water (NSW Agriculture 2000).

Photos: New South Wales Department of Primary Industries

Figure 10 Use of a portable meter to identify salinity levels in irrigation water and ensure that crops are not affected by high concentrations of salt