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Restoring agriculture after a tsunami:

the experience from Aceh, Indonesia

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New South Wales Department of Primary Industries

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Foreword

In 2013, the Australia–Indonesia Facility for Disaster Risk Reduction completed a national tsunami hazard assessment for Indonesia, which highlighted the vulnerability of the Indonesian coastline to tsunamis. There is a significant risk of a tsunami between 0.5 and 3 m high inundating parts of the Indonesian archipelago and affecting provincial capitals and important regions of agricultural production. Coastlines of a number of other countries share this vulnerability. The scale of the 2004 Indian Ocean tsunami, and the subsequent destruction and loss of life have highlighted the need for disaster-prevention programs and an understanding of the post-disaster recovery process.

The 2004 tsunami devastated coastal areas of the Indonesian province of Aceh, causing widespread destruction. The earthquake that triggered the tsunami dramatically altered land levels. Large areas of coastal farmland were inundated by sea water, some permanently, and many farms were covered in sediment scoured from the sea floor and the coast.

The Australian Centre for International Agricultural Research (ACIAR) recognised the need to assist the recovery of agricultural capacity and production in tsunami-affected Aceh, and established a series of projects in collaboration with the Indonesian Ministry of Agriculture.

This guide focuses on the lessons learned about agricultural recovery after the Aceh tsunami event. Farming is the principal source of livelihood for a large percentage of the population of Indonesia. Being prepared to assist tsunami-affected rural communities to recover their livelihoods is an important part of disaster response in Indonesia.

Nick Austin
Chief Executive Officer, ACIAR

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The ACIAR project partners were:

- BPTP for the province of Aceh, based in Banda Aceh
- BPTP for the province of North Sumatra (BPTP SUMUT), based in Medan
- Dinas Pertanian, Aceh's agricultural district administration
- Penyuluh Pertanian Lapangan, Aceh's on-ground farm advisers
- Indonesian Soils Research Institute (Bogor)
- Indonesian Centre for Rice Research (Sukamandi)
- New South Wales Department of Primary Industries.

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
BPTP	Balai Pengkajian Teknologi Pertanian: Assessment Institute for Agricultural Technology (one BPTP in each province of Indonesia)
EC	electrical conductivity
FAO	Food and Agriculture Organization of the United Nations
GIS	geographic information system
GPS	global positioning system
NGO	non-government organisation

Units

cm	centimetre
dS/m	decisiemen per metre
ha	hectare
km	kilometre
m	metre
mm	millimetre
t	tonne

Introduction

Many coastlines in the world are at risk from tsunamis. Records of large-scale tsunami events date back to the year 365 (Intergovernmental Oceanographic Commission 2013), and significant tsunamis occurred in the 20th century in Papua New Guinea, Indonesia, Hawaii, Colombia, Chile and Japan. Since the 2004 Indian Ocean tsunami, there have been significant tsunami events in the Philippines, Indonesia, Samoa, Solomon Islands and Japan. Apart from the tsunamis affecting the Indonesian province of Aceh (Slavich et al. 2006a, b), Solomon Islands (Jansen et al. 2007) and Japan (United Nations University 2012), little data and few observations are available on the impacts of tsunami events on agricultural land.

The focus of this guide is the lessons learned from post-tsunami agricultural recovery in Aceh since December 2004, during Australian–Indonesian projects funded by the Australian Centre for International Agricultural Research (ACIAR) between 2005 and 2012. The guide will complement comprehensive assessments of the post-tsunami reconstruction process in Aceh (Clarke et al. 2010; Masyrafah and McKeon 2010), which contain very limited discussion of agricultural recovery.

Consultations during development of the ACIAR projects highlighted the need to build the technical capacity of existing government agricultural services and non-government organisations undertaking agricultural projects. Needs identified during the consultations included soil and crop management strategies to restore productivity to at least pre-tsunami levels, and a communication strategy to promote regular exchange of information about agricultural recovery between governments, non-government sectors and farmers.

Photo: Food and Agriculture Organization of the United Nations

In 2005, ACIAR funded two projects to restore food crop production in tsunami-affected areas, and one project focusing on vegetable crops in the affected areas:

- SMCN/2005/004—Management of soil fertility for restoring cropping in tsunami-affected areas of Nanggroe Aceh Darussalam province, Indonesia
- SMCN/2005/118—Restoration of annual cropping in tsunami-affected areas of Nanggroe Aceh Darussalam province, Indonesia
- SMCN/2005/075—Integrated soil and crop management for rehabilitation of vegetable production in the tsunami-affected areas of Nanggroe Aceh Darussalam province, Indonesia.

Together, the three tsunami rehabilitation projects aimed to:

- strengthen and rebuild the technical capacity of extension services at provincial (Aceh), district and subdistrict levels to manage tsunami-affected soils
- develop and demonstrate soil management practices to restore the productivity of annual food and vegetable crops in tsunami-affected areas
- develop and implement a communication strategy to facilitate information exchange between government, non-government and community interest groups working on restoring agriculture to tsunami-affected land.

Project outcomes included:

- increased technical capacity of agricultural extension services
- technologies to reduce the impacts of soil and water constraints on production of rice and dry-season crops (palawija) in tsunami-affected areas
- communication strategies and packages to assist re-establishment of food production.

The projects also supported the Assessment Institute for Agricultural Technology in North Sumatra (BPTP SUMUT) to conduct farm trials in earthquake- and tsunami-affected communities on the island of Nias.

All projects worked with farmers through existing national and provincial government agricultural research and extension service networks.

Purpose of the guide

This guide comprises five main sections:

- **Section 1—The 2004 tsunami in Aceh** provides background information on the 2004 tsunami in Aceh.
- **Section 2—A timeframe for agricultural recovery** suggests a plan of activities after a significant tsunami, based on the Aceh experience.
- **Section 3—Post-tsunami assessment and restoration of soil and water** presents detailed information from experience and observations of tsunami impacts and recovery programs in Aceh. These experiences are also relevant to other regions of the world.
- **Section 4—Crop management** highlights the experiences of non-government organisations, government extension staff and farmers in Aceh in restoring farming activities in coastal Aceh.
- **Section 5—Aiding the recovery of agriculture and farmer livelihoods** emphasises the need for communication and coordination throughout the recovery process to ensure that governments and agencies work together with the farming community.

We hope that this guide proves useful in understanding how to help farmers recover their livelihoods as quickly as possible after a tsunami.

1 The 2004 tsunami in Aceh

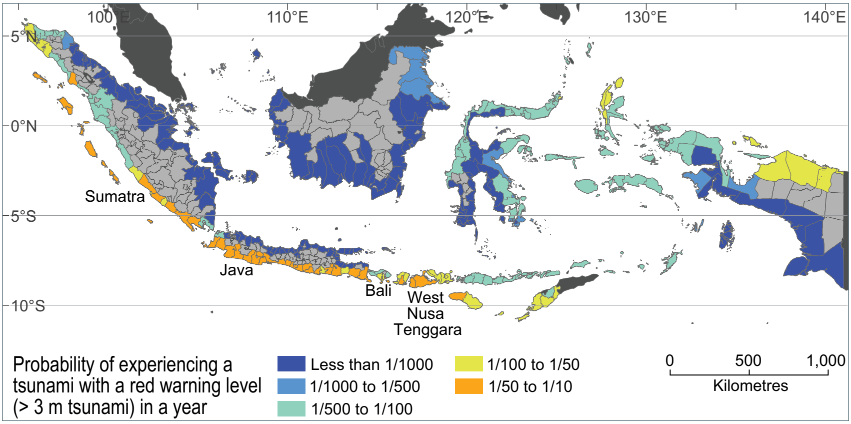
Key points

- The Indian Ocean tsunami was triggered by a 9.1 magnitude earthquake off the coast of Aceh, affecting 92,000 ha of agricultural land and plantations in Aceh, and farmland and farmers' livelihoods in Thailand, India and Sri Lanka.
- Wave heights were up to 30 m along Aceh's west coast and up to 5 m along the east coast.
- More than 330,000 people in Aceh required food and financial assistance as a result of loss of farming and fishing livelihoods.
- The Food and Agriculture Organization of the United Nations has developed a post-tsunami damage classification system to help determine where to concentrate land rehabilitation efforts.

Indonesia is prone to seismic activity, which can cause earthquakes, volcanic eruptions and destructive tsunamis. A large proportion of Indonesia's coastline is at risk from tsunamis (Horspool et al. 2013).

An assessment of tsunami hazards in Indonesia (Horspool et al. 2013) estimates at least a 1-in-100-year probability of a significant tsunami of 5–10 m for parts of west and central Indonesia, and a tsunami of 2–3 m for eastern Indonesia. The chance in any one year of a major tsunami (over 3 m) occurring somewhere in Indonesia is greater than 10%. Parts of the Indonesian coastline are particularly vulnerable, as a result of a focusing effect that magnifies tsunami height (Futurity 2013). Regions with the greatest chance of experiencing a major tsunami include the west coast of Sumatra and nearby islands, and parts of the south coasts of Java, Bali and West Nusa Tenggara (Figure 1).

Photo: Food and Agriculture Organization of the United Nations



Source: Horspool et al. (2013)

Figure 1 Risk map for a tsunami greater than 3 m in Indonesia

On Sunday 26 December 2004, at 7.58 am, an undersea earthquake measuring 9.1 on the Richter scale occurred off the west coast of Sumatra. The earthquake occurred in the subduction zone between the Indian and Indo-Australian tectonic plates (described in some texts as the Indian and Burma plates) and led to a massive 1,200-km-long fault slip along the boundary of the plates. The earthquake's upward thrust displaced enormous volumes of water, generating a tsunami that reached Aceh about 20 minutes after the earthquake.

The tsunami affected both the west and east coasts of Aceh (Figure 2). An International Tsunami Survey Team (Tsuji et al. 2005) documented wave heights of 5–12 m around Banda Aceh at the island's north-west end and found evidence that wave heights may have ranged from 15 to 30 m along a stretch of at least 100 km on the west coast. The United States Geological Survey measured wave heights of more than 30 m along the Lampuuk to Leupeung stretch of the west coast (USGS 2005a, b). A United Nations Educational, Scientific and Cultural Organization (UNESCO) team found wave heights of 10–15 m at Meulaboh on the west coast (Yalciner et al. 2005). Wave heights on the east coast were lower—around 5 m at Sigli and 2 m at Bireuen (USGS 2005a).

Source: Adapted from Dartmouth Flood Observatory

Figure 2 Coastal areas of Aceh inundated by the December 2004 tsunami

The earthquake raised the sea floor in front of the fault rupture and caused subsidence behind the rupture along Aceh's west coast. Observations of trees with their roots and lower trunks submerged in sea water indicated that coastal land subsided 1–2 m in some areas (USGS 2005a), while large sandy areas indicated significant uplift in other areas (Figure 3). Similar observations of uplift and subsidence of more than 1 m were made on the Andaman and Nicobar islands (Chand et al. 2013; Intergovernmental Oceanographic Commission 2013) and the island of Nias off the coast of Sumatra.

Photos: Kerry Sieh, Singapore Earth Observatory

Figure 3 Before and after photographs showing the dramatic uplift (right) caused by the 2004 earthquake on offshore islands along Aceh's west coast, contrasting with long-term subsidence before the earthquake (left)

Agricultural damage

The earthquake and tsunami resulted in great human loss in Aceh's coastal farming communities, inundated productive land with salt water, destroyed standing crops, eroded and scoured topsoil, deposited marine sediments and debris on fields, silted irrigation and drainage channels, destroyed field bunds, changed land levels and drainage patterns, and significantly altered parts of the coastline (Moore 2007). The type and nature of damage were highly variable—west coast settlements and agricultural land were more severely affected than those on the east coast—as a result of the location of the earthquake, and the height and power of the tsunami (Figure 4).

An estimated 70,000 ha of agricultural land and 22,000 ha of plantation crops were affected by the tsunami, and nearly 2 million livestock animals were lost (Alimoeso 2006). Other estimates are that the tsunami directly affected 92,000 farms and rural enterprises (Luther 2010), and more than 60,000 farmers (World Bank 2008). The livelihoods of 331,360 working people, mainly from fishing and agricultural enterprises, were affected to the extent that they required food and financial assistance in 2005 (FAO 2005a).

In Burma, similar effects were reported on agriculture from seawater inundation and sediments due to storm surges following Cyclone Nargis in 2009 (FAO 2009).

Photos: Food and Agriculture Organization of the United Nations

Figure 4 Aerial (top) and ground-level (bottom) images showing the tsunami's impact on low-elevation landscapes along the west coast of Aceh

Box 1 FAO post-tsunami damage classifications

After the 2004 Indian Ocean tsunami, the Food and Agriculture Organization of the United Nations (FAO) classified agricultural land damage in tsunami-affected areas into four main categories, based on field damage indicators (FAO 2005a). The classification system was primarily developed for Indonesia, where land damage was most extensive. The categories are as follows.

Class A: Minor damage—return to normal without intervention

This category includes fields where cultivation is achievable without major intervention.

Class B: Medium damage—return to farming depends on specific interventions

This category includes fields that require debris removal, salt leaching and levelling. This work means that it may be some months before the land can be cultivated.

Class C: Highly damaged areas—return to normal dependent on major interventions (C1) or not achievable (C2)

This category includes fields affected by erosion, debris, sediment and infrastructure damage, and fields flooded by brackish water for weeks or months after the tsunami, as a result of poor drainage. Methods for reclamation may have to be tested on pilot areas, and one or several cropping seasons will be missed. In some cases (C2), the damaged land may not be suitable for agricultural production, and other groundcover alternatives may need to be considered to protect soil and water.

Class D: Lost area

Along the west coast of Aceh, some fields and areas disappeared completely, covered by sea or brackish water. This category of land is permanently lost to agriculture.

The FAO provides further detail on assessment of post-tsunami damage, particularly with regard to salinity (FAO 2005b).

Assessments of the total area of agricultural land damaged in Aceh ranged from 65,000 to 85,223 ha. All assessments agreed that the amount of land lost to agriculture on the west coast was 15,000 ha. Agricultural damage to the east coast was divided evenly between categories A and B/C, established by the Food and Agriculture Organization of the United Nations (see Box 1).

In some rare cases on islands along the coast of Sumatra, uplift caused by the 2004 earthquake led to the establishment of new agricultural land (Figure 5).

Photos: Kerry Sieh, Singapore Earth Observatory

Figure 5 Dramatic uplift following the 2004 earthquake (top), which exposed coral reefs and created new land suitable for the establishment of coconuts (bottom) on Wungga Island

2 A timeframe for agricultural recovery

Key points

- Immediate activities (within 6 months) after a tsunami:
  - Clean up waste and debris.
  - Survey land levels.
  - Train agricultural staff in soil and water assessment and observation.
- Short-term activities (3–12 months) after a tsunami:
  - Communicate with local farmers, especially women.
  - Coordinate advice and planning.
  - Repair irrigation and drainage infrastructure.
  - Train agricultural staff and farmers in rehabilitation methods.
  - Avoid establishing crops on saline land.
  - Incorporate shallow sediments into the soil.
  - Remove deep or highly saline sediments.
  - Use irrigation water (or rainfall) to flush salt from the soil.
  - Investigate other methods of producing income in rural areas.
  - Establish home food gardens.
- Long-term activities (> 12 months) after a tsunami:
  - Transfer technology and knowledge to farmers.
  - Maintain training programs for agricultural staff and non-government organisations.
  - Monitor plant nutrition and crop health.
  - Monitor the long-term health of tree crops, which might be affected by seasonal fluctuations in saline groundwater levels.
  - Expand support and training to surrounding areas less affected by the tsunami.

Photo: Kerry Sieh, Singapore Earth Observatory

Following a tsunami, some issues will require immediate action, some will take 12 months or longer to address, and others will need managing in the long term. The recovery timeframe for agricultural production outlined in this section is based on experiences in Aceh. Under different conditions, the timeframe may differ from the one presented here. Details about specific tasks relating to assessment and restoration of soil and water, crop management, and other activities to aid the recovery of agriculture can be found in Sections 3, 4 and 5 of this guide.

Immediate activities: 0–6 months

Clean up

Restoring public health and safety is the top priority in the aftermath of a major disaster (Waste Management World 2013). Sustainable management of disaster debris involves:

- collecting debris
- determining the constituents of the debris
- determining the potential toxicity of the debris and waste
- sorting the debris
- recycling
- disposing of residual wastes.

Large amounts of debris similar to construction and demolition waste are generated in disaster events in urban areas; in rural areas, debris is more likely to contain natural materials and organic matter.

In Aceh, the bulk of the waste on agricultural land (Figure 6) consisted of sediments of various origin (see Section 3), organic matter and, on fields closer to urban centres, building debris.

In Japan, the three prefectures most affected by the tsunami on 11 March 2011 accumulated 22.5 million tonnes of tsunami waste (Jakarta Post 2013). Japanese authorities established temporary storage sites before separating the waste and incinerating combustible material.

Photos: Assessment Institute for Agricultural Technology, Aceh

Figure 6 Deep layers of sediment and debris, which covered farmers' fields in the worst affected areas

Survey land levels

When a local earthquake triggers a tsunami, land levels can be altered. Surveys may be needed to establish the land levels, and direct the rehabilitation of drainage lines and irrigation channels. Some coastal areas may no longer be suitable for agriculture as a result of subsidence and increased frequency of tidal inundation.

The earthquake that produced the Aceh tsunami had a significant effect on the topography of the Aceh coast—land levels dropped 1–2 m in some coastal areas (FAO 2005c). Areas that were previously inhabited became permanently flooded, and drainage patterns and river flows changed, particularly in estuarine areas. In West Aceh, farmers reported that sand dunes disappeared, the river mouth clogged up and drainage channels changed, making land unsuitable for dryland crops. Restoring agriculture in such areas without adapting to these changes can lead to inappropriate management and wasted resources, and can be dispiriting for farmers who are already traumatised by the tsunami. Indonesia's Soils Research Institute mapped tsunami-affected land on Aceh's west coast using the Food and Agriculture Organization of the United Nations classification system (see Section 1), and GIS-referenced data and mapping software.

This enabled assessment of the suitability of land for certain crops in tsunami-affected areas.

Topographic changes were not a problem in tsunami-affected countries such as Sri Lanka, India and Thailand, which were further from the earthquake zone. The combination of earthquake-induced changes in topography and the high inundation force of the tsunami led to more complex impacts in Indonesia than in other countries.

Assess soils, and train agricultural staff and farmers

The degree of soil salinity resulting from seawater inundation will depend on the soil conditions at the site, the duration of inundation and subsequent rainfall. Tsunami-affected agricultural soils need to be tested for salinity, physical condition and nutrient levels to ensure that farmers avoid sowing crops in unproductive soils. Farmers should be closely involved in these soil assessment processes to improve their understanding of soil conditions in the area and build their soil management capacity.

Details about how to assess soil salinity, water salinity and soil nutrient status are provided in Section 3.

Short-term activities: 3–12 months

Communicate with the farming community

Participatory surveys with the rural community will indicate immediate and longer-term needs of farmers and their families, and help avoid misdirected and wasted aid efforts. Participatory rural consultations in Sri Lanka following the 2004 tsunami provided a valuable opportunity for communities to prioritise their needs (Koralagama et al. 2007).

Coordinate advice and planning of rehabilitation activities

Tsunami-affected farmers need consistent advice about how to manage sediment and soils, and the suitability of their land for farming. Government agencies and non-government organisations (NGOs) need to work together to provide this advice. Aid organisations should work closely with local agricultural extension staff and farming groups in any land rehabilitation effort.

Train agricultural staff and farmers

Since government officers, NGO staff and farmers may have limited experience with the post-tsunami soil and crop conditions, training may be needed in assessing soil salinity and nutrients, reducing soil salinity, propagating and supplying seeds, and making compost.

Repair irrigation, drainage and other farming infrastructure

The 2004 tsunami deposited debris and sediment over farming land, and destroyed irrigation and drainage canals, aquaculture ponds and pumps, sheds and other equipment. In Aceh, it was evident that successful agricultural restoration could not occur before physical infrastructure was repaired and restored. This included removing debris and sediment; restoring roads and tracks; and replacing fences, agricultural machinery (such as hand tractors, ploughs, rice milling equipment and pumps) and buildings (such as milling and storage sheds, field shelters and latrines).

Assessment and repair of irrigation and drainage infrastructure are a priority for successful agricultural recovery. In some areas of Aceh, agricultural production was limited long after the tsunami by inadequate drainage and irrigation. The recovery effort focused on rebuilding infrastructure, such as roads and housing, and often overlooked irrigation and drainage systems. Communities in Sri Lanka ranked the reconstruction of irrigation channels as their top priority for post-tsunami recovery (Koralagama et al. 2007).

Incorporate shallow sediments

Where the sediment layer deposited by the tsunami is shallower than 15–20 cm and not highly saline, it can be incorporated into the soil below. Clay sediments may contain high levels of organic carbon and nutrients (Chaudhary et al. 2006) that can improve the water-holding capacity and fertility of sandy soils. In Aceh, sandy sediments were generally shallower than clay sediments and could be incorporated into the soil.

Remove deep or highly saline sediments

Where sediment removal is an option, sediment that is deeper than 20 cm or contains high levels of salt should be removed. Salty sediments can be stockpiled at the edges of fields and spread back onto the fields after rainfall has leached the salts.

Flush salt from agricultural soils

Where supplies of irrigation water are available, soil salinity levels can be reduced by flushing the salts from the top of the catchment. This can only occur if there is sufficient drainage infrastructure and irrigation capacity, and land levels have not been significantly altered by earthquakes.

In Aceh, irrigation water was used to flush salt from rice paddies. Because the tsunami occurred in the wet season, most fields were already moist; most rice paddies around Banda Aceh contained water, which limited infiltration of saline water into the soil. Wet-season rainfall and the availability of irrigation water helped to flush salt from the soil, except where impediments to drainage were present.

In rainfed areas, ponds and reservoirs may need to be pumped empty of saline water and refilled with rainwater to accelerate leaching.

Avoid farming saline land

Successful crops are an important part of the recovery process after a tsunami, but most crops struggle to be productive in saline soils. Early salinity surveys can identify areas unsuitable for farming, and periodic monitoring will determine when these areas are ready for planting.

Section 4 provides further details on selecting suitable sites for cropping.

Provide high-quality planting material

Supplies of seed and planting material may be scarce, but it is vital that only certified quality seed is supplied to farmers, to ensure that post-tsunami crops do not fail (see Section 4). Before distribution, aid groups should test the quality of seed and other materials intended for farmer use. Sperling (2008) provides a useful guide to assessing the local seed supply and security situation. Farming implements may also be needed to ensure successful establishment of crops.

Grow salt-tolerant crops, where necessary

While salt could be present in the soil, varieties of rice and other crops that can be grown in saline soils must be identified and recommended to farmers (see Section 4). The crops must be matched to the soil salinity levels.

Establish income-producing opportunities for the farming community

In the short term, it may not be possible to generate income from farming activities. During this period, it is important to employ farmers and their families in assessing and repairing drainage and irrigation infrastructure, assessing soil salinity and nutrients, and composting organic waste. These activities will provide income, return farming land to production and encourage independence from food aid. Microfinance to help groups of farmers re-establish may be appropriate once farming activities recommence.

Establish home food gardens

For farmers and villagers who were not displaced by the impact of the tsunami, there is the opportunity to restore home gardens and encourage food growing while agricultural land is rehabilitated. The 2004 tsunami affected local employment, increased inflation as basic commodities became scarce and destroyed local ecosystems that people relied on for survival. These impacts particularly affected poor rural communities. Food-growing programs can be extended into more severely affected areas once housing and infrastructure have been restored.

A number of projects established in Aceh and Sri Lanka (Porteus 2008) focused on backyard food production and developing livelihoods for poor rural communities. A feature of the program in Sri Lanka was collaboration among local community-based organisations, with a longer-term goal of increasing food production and diversity in the affected region.

Establishing home gardens in disaster relief camps is also recommended. Food gardens based on indigenous plant knowledge maintain a connection to tradition, especially for displaced rural people, and reduce dependency on food aid. They can also contribute to improving the wellbeing of displaced people through activity and improvements to camp aesthetics and environment, helping to ease social tensions. Displaced people in Aceh remained in shelters and camps for up to 3 years. Opportunities to support small-scale food production and improve nutrition in camps and temporary shelters were missed by relief agencies in Aceh (Adam-Bradford and Osman 2009).

Consult women farmers and establish women's farming groups

The Aceh tsunami was followed by great social trauma and isolation. Until affected areas were rehabilitated, many women had limited access to employment and activities outside their homes. Women's farming groups provide important social outlets, extra income for the family and farming knowledge.

Long-term activities: 12 months onwards

Transfer technology and knowledge to the farming community

As information on farming on tsunami-affected soils becomes available, it needs to be passed on to farmers as quickly as possible to ensure that they receive up-to-date information. Farm demonstrations, field days and training for extension staff will all show farmers what methods work best.

Continue to build the capacity of farmers, extension staff and non-government organisations to manage soils

The Aceh experience showed that important relationships and networks were established though training and extension activities after the tsunami. These networks need to be strengthened over time to build farming knowledge and expertise, and to maintain contact between farmers, agronomists and NGOs. Training can focus on the agronomic and ecological aspects of farming in existing and new agricultural areas, and the importance of protecting natural ecosystems, such as peat land, wetlands and forest. Demonstration sites (see Section 4) are important for bringing groups together for updates on farming practices and rehabilitation efforts, and for possible collaboration.

In many cultures, women comprise the majority of the workforce in agriculture. All consultation processes should involve women farmers (see Section 5). They should assess issues such as education, the contribution of home-based food production to local food security, improved family nutrition provided by a diverse diet, income-generating activities, and equitable and secure access to land.

Expand support programs to unaffected areas

Areas unaffected by the tsunami may miss out on the support and training provided to farmers in tsunami-affected areas. In Aceh, for instance, the unaffected inland areas have higher levels of poverty than the coastal areas, and an even greater need for information and training.

Monitor plant nutrition

Although crops may be re-established relatively quickly after a tsunami, the loss of organic matter, and residues of salt and sediment can contribute to longer-term nutritional disorders affecting growth, flowering and fruiting, or grain filling (see Section 4). Monitoring plant nutrition over the long term is therefore essential.

Monitor tree crops

Tree crops are an important part of coastal farming systems in many areas. The post-tsunami condition of tree crops should be monitored over the longer term. Saline water can severely affect commonly grown tree crops, including rambutan, mangosteen and rubber. Although soil and groundwater salinity declined rapidly with wet-season rainfall, groundwater salinity in West Aceh continued to fluctuate (Marohn et al. 2012), and recurring episodes of elevated salinity damaged rubber tree crops and reduced coconut yields. New plantings of deep-rooted tree crops may be affected some years after the tsunami where groundwater levels and salinity continue to fluctuate.

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 2mm 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

4 Crop management

Key points

- Identify the types of farming systems present before the tsunami, including crops and yields, and management of inputs such as fertilisers.
- Make important resources such as soils or landscape maps available to all organisations and groups working to restore agriculture.
- Establish crops at sites where the tsunami impacts are minimal and the soil is least affected by salinity.
- Test water sources, especially groundwater, for salinity levels before using the water for irrigation.
- Consider using raised beds, which are useful to establish crops in salinity-affected soils and areas prone to waterlogging.
- Where available, use salt-tolerant varieties of crops.
- Assess the local seed supply situation:
  - Distribute viable, certified seed of crops and varieties that farmers are familiar with.
  - Provide training in the production of seed crops, and quality assurance, storage and distribution of seed.
- Monitor changes in weed species. Encourage coordination between farmers to control pests and weeds.
- After planting, monitor growth, yields and any symptoms of nutrient deficiencies or plant stress, to identify trends and develop site histories.
- Test soils for major nutrients before planting and fertilising.
- Use organic fertilisers, such as manure, composts, crop residues and mulches, to improve soil health and fertility.
- Develop trials to demonstrate new production systems and practices, and compare them with existing farmer practices.

Photo: New South Wales Department of Primary Industries

The first rice crops after the tsunami often failed or achieved very low production. The second crops were better, possibly as a result of the leaching of salt by irrigation of the rice paddy for the first crop. As salinity levels declined, vegetative growth improved. However, problems occurred with fruit, grain and nut production, indicating nutrient deficiencies, possibly caused by the tsunami removing organic matter from the soil. Lack of organic matter proved to be a major issue for crop production, particularly in the sandier soils. Some vegetable crops were affected by the quality of groundwater used to irrigate the crops.

To restore cropping quickly, it was useful to know the types of farming systems at the site before the tsunami, including crop types, animal input, fertilisers used and yields. This information, in association with soil assessment and analysis of leaf tissue after the tsunami, helped identify agronomic issues specifically caused by the tsunami (e.g. crop failures, poor growth, low yields, empty pods and husks, change in weeds, waterlogging).

Aceh's experience highlighted the need for good records about district cropping practices, seasons and seed sources. This information could be collated and held by agricultural organisations at local, provincial and national levels, and even at an international level, to enable aid organisations to provide locally appropriate agronomic assistance after seawater inundation.

Site selection

Since cropping on highly saline areas is a waste of resources, it was important to grow crops where tsunami impacts were minimal and soil fertility was relatively unaffected. Avoiding saline areas was relatively easy using EM38 surveys (see Section 3) to identify saline soils. Farmer knowledge and experience of tsunami flooding levels and the duration of inundation, soil and plant indicators of salinity, and soil tests also helped with salinity assessment.

The Aceh experience showed that salinity levels were related to the permeability of the soils, the duration of seawater inundation and the physical location. For instance, crop failures occurred in low-lying areas near tidal creeks after inundation during high-tide events. Crops grown in coastal soils, such as peanut, were more affected by seawater inundation than crops grown on better soils further inland, such as soybean. Sandier soils close to beach dunes appeared to be the most saline following the tsunami. Peanut crops on the dunes showed patchy growth or leaf yellowing. The patchiness was associated with salt that accumulated on the soil surface following evaporation of salty, shallow groundwater. The yellowing appeared to be a related nutritional problem, or possibly a disease problem.

Raised crop beds were useful in saline soils because the beds could be irrigated to leach salt before crops were planted. Raised beds were also useful in areas prone to waterlogging.

Use of salt-tolerant varieties

Aceh's high rainfall meant that salinity was not a long-term problem in most areas, so there was not a great need for salt-tolerant varieties of crops. However, it was useful to have access to seed or planting material of salt-tolerant varieties, particularly in the early months after the tsunami and where salinity problems occurred in rainfed rice fields. Although no rice varieties are truly salt-tolerant, some varieties in Indonesia—Mendawak, Sunggal and Banyuasin—appear to be more salt-tolerant than others. Rice variety AT354 outperformed a variety that was not salt-tolerant (AT362) in trials on tsunami-affected land in Sri Lanka (Reichenauer et al. 2009).

Many salt-tolerant tree crops are recommended for revegetating coastal areas and re-establishing income-producing tree crops. Chaudhary et al. (2006) recommend a range of varieties of salt-tolerant field and tree crops specific to Tamil Nadu, India.

Following the 2011 tsunami in Japan, researchers investigated the use of salt-tolerant varieties of rice. However salt-tolerant cultivars were not adopted by farmers because the taste was not comparable with rice varieties available in the Japanese market. Instead, farmers selected alternative salt-tolerant crops, such as sunflower and rapeseed.

The salt-tolerance thresholds for a large range of different crops are presented in Tanji and Kielen (2002).

Seed supply and quality

Disasters can have a severe impact on the availability of seed for local food crops, and the recovery process may include seed assistance. Obtaining good-quality seed was a major problem after the tsunami in Aceh. Demand was so high that the main seed producers could not supply enough good-quality seed. Not all farmers used certified seed, and so crop establishment was unreliable. Many farmers who were given seed by aid groups found that the seed was not viable or that the varieties were unsuitable for the local market, resulting in loss of income and a waste of farmer time and resources.

The shortage of seed after the tsunami revealed the need to develop and maintain local seed breeding through local farmers' groups. An assessment of the local seed supply situation (Sperling 2008) is an important step in disaster recovery. In Aceh, seedbanks were constructed after the tsunami in rural areas to store locally produced seed. If seed storage facilities are available, farmers can be trained to select plants for mother seed and produce seed crops. Training can also be provided for seed quality assurance, storage and distribution.

The Aceh experience showed the importance of providing agricultural aid appropriate for the area, soil type, season, and local markets and tastes. Access to familiar varieties is important in the initial stages of recovery.

Pests and weeds

After the tsunami, rats and pigs were a problem because there were fewer people to control shrubland where the animals sheltered. Pest control for mice and rats requires coordination between farmers to make a difference (ACIAR 2001). Preventing and controlling pest and disease problems of crops was particularly difficult in Aceh because much knowledge was lost during the 30-year civil conflict in the province, which ended in 2005.

Many farmers commented on the changes in weed species after the tsunami. These changes possibly reflected increased salinity, changed nutrient status and lack of organic matter. Identification of the new weed species was useful because this could provide important information about soil nutrient status.

In one area, farmers did not weed peanuts once they flowered for fear of disturbing the roots, but the weeds competed with the crop for nutrients and moisture, reducing crop yields. Raised beds made it easier to weed between plant rows.

Plant nutrition

Agronomic trials in Aceh after the tsunami found a range of nutritional disorders, particularly lack of grain filling in rice and peanuts. Possible reasons for the nutrient problems included loss of organic matter and trace elements, high inputs of urea in relation to potassium, and lack of phosphorus and calcium in salinity-affected sandy soils.

Two years after the tsunami, most soil fertility problems in tsunami-affected areas were due to nutrient deficiencies and imbalances related to the loss of organic matter, and the effects of salts and sediments. Observations of the variation in crop performance highlighted the importance of monitoring growth, yields and nutrient levels to identify trends and develop site histories. Where there was potential to establish new production systems, such as different crops or rotations, trials were developed to demonstrate these new systems. For instance, the different soil treatments required for rice (compaction) and palawija (non-rice) crops (loose soil) led to trials using permanent beds for palawija crops, rather than alternate puddling and cultivation of one site to the detriment of soil health.

Pre-tsunami fertiliser recommendations were often found to be irrelevant or wrong after the tsunami because of the soil changes. It was therefore important to test tsunami-affected soils for at least the major nutrients before preparing the soil, fertilising or planting (Figure 11). Testing the soil ensured that the correct amount of fertiliser was applied; farmers learned that overfertilising is a waste of money because nutrients not used by the plants leach out of the crop root zone.

Photo: New South Wales Department of Primary Industries

Figure 11 Contents of the paddy soil test kit produced in Indonesia; kits are also available for dryland crops, vegetables and sugarcane

Crops initially grew well in peaty sediments as a result of the high nutrient levels of the sediment. Some coastal rice crops yielded very well within 12 months of the tsunami (Bradbury et al. 2005), probably as a result of a beneficial effect from tsunami-deposited peat sediments. The effects from these sediments were short lived—subsequent crops did not yield as highly without the addition of fertiliser. Inland peat soils offered cropping opportunities for farmers who lost land in the tsunami, but only if they were managed carefully to ameliorate the inherent high acidity. Phosphorus, trace elements and organic matter may be needed on salinity-affected sandy soils to help crops fill.

Case study: Empty peanut pods

Photo: New South Wales Department of Primary Industries

Empty seed pods in peanut crops; this was a common problem for farmers for up to 3 years after the 2004 tsunami destroyed farmland in Aceh

At Bireuen in Aceh, many peanut plants had empty pods in a crop harvested in February 2006. Farmers in the area reported that this was the first time these problems had been encountered. The peanuts were normally grown in deep, sandy soil (sand dunes) without fertilisers, and cropped twice per year, with weed fallows between crops. The plants had good vegetative growth and appeared to have enough nodules, but the root systems were very shallow. Weeds were well established in the crop and in bare areas. Measurements of soil salinity using an EM38 instrument showed low salinity. A possible cause of the empty pods was lack of calcium, which is essential for kernel development; calcium is absorbed directly from the soil through the pod wall. High soil magnesium can also reduce kernel quality and lead to empty pods.

A trial investigating the effects of fertiliser, gypsum, and chicken and cow manures found that the best pod development was obtained by a soil treatment with combined chicken and cow manures, indicating a need for organic matter in the soil. Organic matter helps conserve soil moisture and improves the ability of peanut plants to absorb nutrients.

Organic fertilisers

Lack of organic matter in soils was identified as an important constraint to production in the tsunami-affected soils in Aceh. The tsunami's scouring action removed organic matter, leading to a drop in soil fertility. Organic amendments can substitute 25–100% of the nutrients of chemical fertilisers, depending on the kind, amount and content of the material. In Aceh, manure, composts, crop residues and mulches increased soil nutrient levels and generally improved soil health and long-term soil fertility. As well, they encouraged biological life, and improved soil structure and soil moisture-holding capacity. Farming systems that incorporated crop rotations and stubble management also increased soil organic matter.

A corn trial at the Assessment Institute for Agricultural Technology (BPTP) Banda Aceh grounds found that near-surface salinity was significantly lower when manure was incorporated beneath the corn row. Where organic matter was in limited supply, farmers incorporated compost or rotted manure in the planting row to provide nutrients close to the young plants, and encourage leaching of any salt in the soil.

Demonstration trials were useful for comparing crop production using fermented fertilisers, chemical fertilisers, no fertilisers, and a 50:50 mix of chemical and fermented products. It was important to keep records of fertilisers used and the fertiliser recommendations provided to farmers so that advisers and farmers could link fertiliser applications with crop production.

Compost

Making compost after the tsunami provided a source of organic matter for soil, created a useful product from organic debris and offered productive activity for farmers. Aceh farmer groups made a range of composted fertilisers. One group used rice husks, peanut pods, and cow or chicken manure; another made bokashi fertiliser from cow manure, rice ash, wood ash, rice stubble and micro-organisms; another group made liquid fertiliser from buffalo manure, lime and home-made fish emulsion.

Other soil amendments

Rice husk char (2 t/ha) and gypsum (1.5 t/ha) increased grain yields of rice grown on tsunami-affected soils in Sri Lanka (Reichenauer et al. 2009). Gypsum will ameliorate saline soils with a pH greater than 8.5 and exchangeable sodium percentage greater than 15. The soil pH is likely to increase during the leaching process (Chaudhary et al. 2006).

Rice husk char has shown potential as a soil amendment for wetland rice in Aceh, and for peanut and tree crops on sandy soils in dryland areas of Vietnam (Keen et al. 2013). Char derived from other waste organic materials may also be beneficial to the establishment of crops in tsunami-affected saline soils.

Manure

Approximately 2 million livestock animals (buffalo, cattle and goats) were lost in Aceh as a result of the tsunami. Smaller numbers of large livestock (beef and dairy cattle) were lost in the 2011 Japan tsunami, along with nearly 5 million poultry (Danone 2011). The loss of livestock in Aceh led to a shortage of manure, an important agricultural input in the sandy coastal soils. It is important to reintroduce poultry, goats and cattle as quickly as possible after a tsunami because their manure adds nutrients to the soil, builds organic matter levels and contributes to compost making. One water buffalo can produce about 2 t of manure per year.

The Aceh experience was that farmers would incorporate manures only if they could see a result and only for high-value cash crops, because of the cost of collection and transport of manure. Since it is financially difficult for many farmers to acquire livestock, a useful post-tsunami aid project could be replacing lost livestock, once there is sufficient food available for animals. Reintroduction of poultry where all birds have been killed is particularly useful; the birds' manure is an important nutrient source and organic soil amendment, and the birds also provide eggs and meat.

Grazing is a good use of land that is too waterlogged for cropping or does not have a reliable irrigation source. However, it was not an option for many Aceh farmers because the area of farming blocks is 1 ha or less, and this land is used to grow rice for food and income. A salt-tolerant grass

(*Diplachne fusca*) became more prevalent after the tsunami. Although the mature grass is not palatable to cattle, the grass is grown widely in Pakistan as a forage crop that is eaten when young. Aceh farmers confirmed that cattle will eat the young shoots.

Plant-based mulch

A mulch of dried organic matter such as coconut leaves will lower the soil temperature and hold moisture in the soil, both of which will make the soil more livable for soil organisms. Mulch also protects the soil from drying out and hardening—this is particularly useful for compacted rice paddy soils that are used to grow palawija crops during dry seasons.

The difficulty in Aceh was finding enough suitable organic material to use for mulch, because the local custom is to burn dead leaves to provide ash for use as fertiliser during planting. One option is to grow a green manure crop to act as mulch between crops, but for many farmers this will tie up productive land for too long. Another option is to grow stockfeed or a cash crop that can double as a green manure crop. However, caution needs to be used in growing green manure or stockfeed crops that could become weed pests.

It is important not to use peanut crop residues on soil to be used for peanuts, because of the risk of infecting the new crop with leaf pathogens. Peanut residues are better collected and composted before use.

Farm demonstrations

Demonstration trials comparing existing farmer practices, improved practices and scientifically tested practices provide some of the most useful training for Aceh farmers, especially when new practices or amendments are being introduced. Demonstration trials that actively involve farmers provide evidence of change, but may not be scientifically valid.

Scientifically designed field trials (Figure 12) are set up with a number of replicates to determine statistical differences between treatments. They require the input of trained researchers, and are therefore only possible if resources are available to employ researchers.

Photos: New South Wales Department of Primary Industries

Figure 12 Experimental trials established in Aceh (rice top row, peanuts and vegetables middle and bottom row) to determine the causes of crop problems

5 Aiding the recovery of agriculture and farmer livelihoods

Key points

Communication and coordination

- In emergency planning protocols, clearly allocate responsibilities and activities in agricultural areas among national, provincial and local government research and extension agencies, non-government organisations (NGOs) and farmer groups.
- Develop links and coordination between governments and NGOs.
- Coordinate urban recovery and agricultural rehabilitation to minimise impacts on agricultural land.

Capacity building

- Build the capacity of local agricultural extension staff, NGO workers and farmer groups:
  - by involving farmers in field trials and monitoring activities
  - by providing training in what to expect and how to overcome production problems due to seawater inundation and sediment.
- Rebuild technical and quality assurance capacity (especially laboratory facilities).

Social recovery

- Re-establish farmer and community groups, including groups for women.
- Encourage productive activity.
- Facilitate the establishment of food gardens in refugee camps, especially in rural areas where the majority of residents will be farmers.

Photo: New South Wales Department of Primary Industries

Communication and coordination

The magnitude of the humanitarian effort required after the 2004 tsunami inevitably led to duplications and gaps in rehabilitation activities in agricultural areas. Good communication is needed between all groups providing agricultural aid so that they can share successes and problems, and learn from each others' experiences.

In the state of Tamil Nadu, India, a coordinating body was established for the post-tsunami recovery activities of some 500 non-government organisations (NGOs). The NGO Coordination and Resource Centre (NCRC) assessed damage to agricultural land and established a package of rehabilitation activities (Mohan 2008). The roles of the NCRC were to:

- facilitate communication between planners and affected communities
- inform NGOs about the importance of agriculture and the need for assistance
- link local NGOs with donors
- use a participatory process to allocate NGOs to affected communities
- develop a common vision for the post-tsunami recovery in Tamil Nadu.

The NCRC response was divided into three categories:

- immediate—desalinisation
- short term—restoration of soil fertility
- long term—ensuring the viability of agriculture.

Although a similar body was established in Aceh by the Indonesian Government, many NGOs involved in agricultural recovery operated in isolation and for short-term projects only, and communication and collaboration among organisations was limited. NGOs were required to document their projects and progress on a web-based registry of the Bureau of Rehabilitation and Reconstruction. This provided NGOs with an opportunity to make contact with other organisations working in a similar sector; however, progress reports provided limited information on post-tsunami soil and crop conditions, and re-establishment of farming.

Forums to share post-tsunami or post-disaster experiences can improve agricultural restoration processes. This was demonstrated by a regional forum convened by the Food and Agriculture Organization of the United Nations in 2006 (FAO 2006) and a workshop in Indonesia in 2008 (Agus and Tinning 2008).

The experience in Aceh showed a need for a clear allocation of responsibilities and activities in agricultural areas among national, provincial and local government agricultural research and extension agencies, NGOs and farmer groups. These responsibilities and activities are best defined in emergency planning protocols that can be implemented immediately after a tsunami. This is particularly important in regions such as Aceh where most of the coastal rural population relies on agriculture for livelihoods and employment.

Non-government organisations

After the tsunami hit, many NGO aid groups worked in Aceh's rural areas. Most of them worked independently and were not familiar with local agricultural practices, crops and seasons, and this led to some inappropriate plantings and failed crops. When farmers encountered problems and asked government advisers for help, the advisers were not familiar with the NGO programs. It is vital that NGOs work with local agricultural services to ensure the long-term sustainability of their agricultural work once the aid program finishes. Aid groups need to understand—by liaising with agricultural departments or local government—how agriculture is managed at a district or local level. They should then build links with local farmer groups, advisers and NGOs, to ensure good communication. Local knowledge of field staff and farmers is crucial to the recovery process.

The Aceh experience has shown that agricultural aid workers and government agricultural extension workers need to work together to:

- build relationships
- exchange knowledge
- plan work programs to ensure that all information provided to farmers is consistent
- share feedback from farmers about their needs.

Governments should treat NGOs as an opportunity, not as competition, and make it easier for them to assist farmers through collaboration with the government extension network.

The projects undertaken by the Australian Centre for International Agricultural Research (ACIAR) have shown that it takes some time to restore soil health in tsunami-affected areas. Consequently, it may be useful for agricultural aid projects to commit to 2–3-year projects, rather than projects that only address the emergency period.

Urban recovery impacts

Coordination between urban planning and agricultural rehabilitation is required to minimise impacts on agricultural land. For instance, drainage from new housing estates near Banda Aceh resulted in nearby agricultural land becoming a flood basin that could no longer be reliably used for crop production.

Capacity building

Building the capacity of extension staff, NGO workers and farmer groups was a crucial component of the ACIAR projects in Aceh. Technical knowledge gained by Aceh extension staff enabled them to diagnose constraints to the re-establishment of crop production and associated income generation after the tsunami, and improved the advice and information available to farmers.

One of the biggest challenges in restoring agriculture in Aceh was encouraging farmers to be independent, rather than dependent on external aid. In Aceh, only one-third of farmers could afford to plant rice three times per year after the tsunami. The rest planted only once per year because of poor infrastructure and lack of capital, and many consumed the profit from aid-assisted crops that was intended to support them for the next planting season. Farm production suffered as a result of lack of capital, which farmers used for restoring other aspects of their farms after the tsunami.

Involving farmers in field trials and monitoring activities was vital to the success of the ACIAR projects. The projects' emphasis on communication and information sharing through meetings, interactive workshops, newsletters and publications enabled rapid exchange of information on practices that could be used to recover from the tsunami and improve productivity. Productive crops motivated others to return to farming. Farmer-to-farmer learning visits enabled farmers to learn techniques of crop production in other areas and apply new ideas to their own farming systems. Aid-assisted farmer training in production management, compost making, crop rotations, soil management and stubble management could be useful in these cases.

Training

Immediately after the tsunami in Aceh, there was a need for training of farmers and agricultural officers in restoring inundated farmland. Major difficulties in delivering this training included lack of local agricultural staff because of the high death toll, and lack of information about post-tsunami agricultural management. Although aid groups were generous with seed, fertiliser and equipment after the tsunami, there was often little follow-up support or advice. This is not surprising, given the lack of knowledge about post-tsunami agronomic problems. Aid groups, local agricultural advisers and farmers need training in what to expect and how to overcome production problems caused by seawater inundation and sediment. If training activities are coordinated and delivered to a wide cross-section of aid and extension staff, a consistent message is distributed, ensuring that farmers and field staff receive the same information and the appropriate support.

The training topics could include:

- soil salinity, including operation of electrical conductivity (EC) meters and electromagnetic field measurement (EM38) equipment
- soil acidity, including operation of pH meters and pH kits
- soil sodicity
- soil texture, including use of the 'ribbon' test (see Section 3)
- soil structure, including visual assessment

- soil organisms, including visual assessment
- the importance of organic matter
- sampling protocols for soils to be used in laboratory analysis
- monitoring and recording of test results
- typical crop responses to salinity, nutrient deficiencies and waterlogging
- assessment of sites and crops for salinity and nutrient impacts, especially visual indicators
- remediation methods to improve crop production.

Demonstration trials to compare varieties and nutrient amendments could form part of the training.

Soil testing facilities

The 2004 tsunami destroyed the Assessment Institute for Agricultural Technology (BPTP) Aceh's soil laboratory. Restoring the laboratory was a high priority to enable rapid testing of tsunami soils for salinity and nutrient levels. Tests required included pH, electrical conductivity, chloride, and the major nutrients nitrogen, phosphorus and potassium. Basic equipment needed for BPTP's soil laboratory in the Banda Aceh laboratory included:

- end-over-end shaker for preparing soil extracts
- glassware
- chemicals for soil and plant analysis
- distilled water for preparing samples
- computer and printer
- power supply regulator.

Rebuilding technical and quality assurance capacity was crucial to ensure that testing and results were reliable. Partnering with an established quality-assured laboratory to analyse replicate samples would enable data checking and build confidence in the laboratory.

Participation

The Aceh projects showed that training sessions needed to include ample time for discussion, interaction and sharing of stories. Practical demonstrations of new practices or technologies were also needed, coupled with hands-on experience of techniques until participants were confident.

Social recovery

Rural communities faced significant challenges after the tsunami. Many villagers were killed, which fractured leadership and social structures, and resulted in loss of coordination and motivation among remaining villagers. People were severely traumatised by the loss of family members, villages and their way of life. There were fewer people to work on the land; initially, agricultural workers preferred to work in higher paid reconstruction work rather than agriculture. Many farmers were housed in emergency shelters and temporary housing, often far from their farms, so it was difficult for them to get to their land. As well, loss of agricultural staff made it difficult for farming to resume. As many as 30% of the staff of Dinas Pertanian (the agricultural district administration) in Aceh's west coast centres are reported to have died during the tsunami.

The emergency aid provided after the tsunami created aid dependency, so that survivors expected payment to return to farming. NGOs reported that the biggest hurdle was the lack of motivation of some farmers to return to farming, exacerbated by their personal trauma and the availability of food packages. A solution to this problem would be for the aid organisations to work with the pre-existing agricultural research and extension system, and with farmers who have already taken the initiative to restart cropping.

As a result of the social disruption, many crops were not sown at optimum times. This led to additional problems with pests, availability of irrigation water and waterlogging. In some areas, farmers were ready to go back to farming but were prevented by a thick layer of tsunami sediment on their fields. Overall, farm production suffered as a result of lack of capital, which was spent on farm equipment while no reliable seed supply was in place to allow planting.

The participation of farmers, including women, in the recovery process is very important. Capacity building and social recovery were particularly important in Aceh because of the impact of a 30-year civil conflict in the province, which led to large loss of life, in addition to the lives lost during the earthquake and tsunami.

Working with established farmer and community groups

In Aceh, rice farmers work in groups. Re-establishing these groups after the tsunami provided personal support, built relationships and networks, and shared the considerable workload involved in preparing land for cropping. Women's farming groups are also important—they offer opportunities for networking, interaction, learning new skills, growing food and making money. Before the tsunami, there were many such groups; afterwards, there were very few because of the collapse of village structures. A dynamic extension officer at Meulaboh trained women's groups in organic farming, including compost making and organic pest control. The women's groups grew fresh crops and made products such as sauces and preserves, which they sold locally to earn an income. One-third of the profit was kept in the group's account, one-third purchased inputs for the next crop, and the remaining third was shared equally between members. Other women asked for similar groups to be formed, as their only activity outside the house was helping their husbands in the fields.

A United Nations Development Fund for Women report on changes to gender attitudes in Aceh (UNIFEM 2009) provided some strategic recommendations from the post-tsunami experience in Aceh for gender-responsive disaster recovery, some of which are particularly relevant to agricultural recovery:

- Develop and strengthen local women's networks and organisations as partners in reconstruction.
- Ensure that disaster-affected women have safe, accessible and culturally positive spaces to meet, and to organise and conduct activities.

- Identify the promotion and realisation of women's rights—including women's land rights—as a key platform for long-term recovery.
- Collect and use age-sensitive, sex- and gender-specific data in program evaluation and monitoring.

The need for productive activity

Farmer workshops 2 years after the tsunami indicated that activities such as restoring drainage and irrigation channels, removing debris and replanting crops were important for farmers to regain a sense of control and purpose. Other activities could be sediment and salinity surveys by farmer groups, to assess where to begin planting crops, and the establishment of home garden programs to commence food production at a local level.

Farmers in Aceh stated that being active and focused on their work helped to distract them from trauma, and that it was important to stay optimistic and work together. They also asked for agricultural knowledge and expertise—not just one-off inputs or donations—to help them to continue farming.

Conclusion

Providing development assistance to disaster-affected communities requires a long-term commitment to fully realise its benefits. In the 9 years since the 2004 tsunami, projects by the Australian Centre for International Agricultural Research (ACIAR) in Aceh have worked with coastal farmers, extension officers, non-government organisations (NGOs), agricultural scientists and soils scientists to restore agricultural soils, and build skills in soil and water management, agricultural production and participatory research.

In that time, Aceh's agriculture has blossomed. Scientists and extension officers have learned new skills in agricultural science and communication, and farmers have increased their yields with improved crop varieties and management practices. Women's farming groups have also flourished, with women gaining production and marketing skills, social outlets and income.

ACIAR's long-term involvement has shown that helping farmers recover from a tsunami involves more than just fixing soil and water in the short term. Good communication and coordination between all aid parties involved in restoring the land are vital. Ideally, emergency management protocols are in place well before a tsunami, to ensure that farmers know what is happening and can return to productivity as soon as possible. In future tsunami events, farmers and local communities will have to deal with seawater inundation, saline soils and water, sediments of varying depth and composition, and damage to local infrastructure. The scale and timing of the tsunami event will determine what effect these factors will have on the productivity of agricultural land, and the duration of the impact. Similar impacts can be expected in low-lying coastal areas after severe tropical cyclones and the associated storm surges.

Farmers benefit most by being involved from the beginning in activities to restore their land. These activities include surveying boundaries, removing sediment, repairing infrastructure, and assessing soil and water quality before planting crops. Reliable, up-to-date information on the quality of soil and water can potentially save farmers time, effort and scarce funds spent establishing crops after a tsunami. In severely affected areas, leadership and social networks may need to be rebuilt, along with agricultural networks. NGO and government aid needs to be integrated into these networks.

The ACIAR projects have shown that, once agricultural production is under way again, agricultural networks are ideal mechanisms to introduce new management practices and new crop varieties to improve productivity. The productivity of tsunami-affected farmland can be higher following restoration and development assistance than before the tsunami, as has happened in Aceh. We hope that the information we have compiled in this guide will provide a useful benchmark for future post-tsunami restoration of agricultural land.

Glossary

EC (electrical conductivity)	The ability of a substance to conduct electricity. In soil, EC is a measure of the electrical current conducted by water and soil. EC is the most convenient method to measure soil or water salinity. It is commonly expressed in decisiemens per metre (dS/m). EC readings are affected by the concentration and composition of dissolved salts, so high EC values do not always mean high salinity values.
EC1:5	Electrical conductivity measured in a soil solution of one part of soil and five parts of deionised water. EC1:5 is the most commonly used method to estimate soil salt content.
ECa	Apparent electrical conductivity. A measure of bulk electrical conductivity of undisturbed soil in the field. ECa can be measured with an electromagnetic instrument (EM38 or EM31).
ECe	Electrical conductivity of a saturated soil. This is the most accurate measure of soil salt content and can be estimated by multiplying the EC1:5 by a conversion factor based on the soil texture group.
EM38	An electromagnetic induction instrument used to measure bulk ECa in the field. Readings from an EM38 instrument are sensitive to soil water content, soil texture and metal. They therefore require local calibration against electrical conductivity (ECe) measurements from a laboratory before use.

EMh	ECa value obtained when reading EM38 value in the horizontal mode. This is sensitive to soil salinity at the 0–0.35 m depth zone.
EMv	ECa value obtained when reading EM38 value in the vertical mode. The EMv value is sensitive to soil salinity at the 0.35–1.5 m depth zone.
exchangeable sodium percentage	The amount of sodium in the soil solution relative to the amount of total cations in the same solution; often used as an indicator of soil sodicity. A soil is considered *sodic* when the exchangeable sodium percentage is 6% or greater. Soil dispersion problems may occur at a higher or lower level than this, depending on clay type.
palawija	Non-rice food crops such as soybean, mungbean, peanut or maize grown on lowland rice fields during the dry season in Indonesia.
pH	The acidity or alkalinity of a solution, measured by the activity of dissolved hydrogen ions (H^+), on a scale of 1–14 (7.0 is neutral pH); most agricultural soils are in the pH range of 4.5–8.
sodic soils	Also referred to as dispersive soils. The chemical composition of sodic soils makes them more likely to dissolve when exposed to water and more vulnerable to erosion.

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