Using EM38 to assess the progress and mechanism of salt leaching from tsunami affected soil in Aceh, Indonesia

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Abstract

A portable electromagnetic induction instrument (EM38) was used in both the horizontal (EMh) and the vertical (EMv) dipole orientations, to monitor changes in soil salinity in the tsunami affected areas of Aceh. The relative changes EMh and EMv over time were used to assess leaching progress and mechanism in both lowland irrigated and rainfed rice fields, and rainfed palawija (dry season crops) fields.

Time series data from EM38 surveys indicated that leaching of salts from the tsunami affected soil occurred slowly by both vertical displacement and horizontal movement in flood waters. However, the vertical leaching was more restricted due to the presence of a claypan layer in the lowland rice fields. Faster removal of salts should be facilitated by providing adequate surface drainage and irrigation channels to allow good water circulation.

Key Words

Sea water inundation; apparent electrical conductivity; salt; ECa.

Introduction

The Indian Ocean tsunami in December 2004 salinised and damaged agricultural soil in low-lying coastal areas around the Indian Ocean (Chaudhary *et al.* 2006; Rengalakshmi *et al.* 2007; Chandrasekharan *et al.* 2008; Raja *et al*. 2009), and damaged irrigation, drainage and road infrastructures. After the tsunami, farmers in Aceh reported crop failure, prompting the need to monitor the changes in soil salinity and to find ways to increase the leaching of salts out of farmlands.

Field instruments for measuring the apparent electrical conductivity (ECa) of soils using electromagnetic induction (EM) have been widely used to assess soil salinity. A portable ground-based EM instruments such as the EM38 (Geonics Pty Ltd) can provide a rapid measure of ECa to a maximum depth of 1.5 m. The ground placement of the EM38 determines the shape of the primary electromagnetic field emitted from the instrument into the soil. This determines the zone of sensitivity of the measurement in the soil profile. When the instrument is placed on the ground horizontally, the primary field (EMh) is strongest at the soil surface and declining with depth, while the primary field for the vertical placement (EMv) is strongest at 0.35 m depth and declining in sensitivity to a depth of 1.5 m (McNeil 1980). Slavich (2002) suggested that the average of profile ECa or (EMh+EMv)/2 provides a better representation of the root zone salinity compared to the value of EMh or EMv alone, and the relative value between EMh and EMv can be used to estimate the distribution of soil salinity in the soil profile. If the measurement is conducted over time, the relative values of EMv and EMh can be used to assess the salt leaching mechanism. This could guide management to enhance salt leaching from agriculture soils that are salinised due to tsunamis or cyclones.

Leaching of surface salts can occur either by horizontal movement as a result of surface flooding and movement of water or through vertical displacement of salts by water percolating and draining through the root zone. Figure 1 represents a simplified model of vertical leaching of salt leaching after seawater inundation (Slavich *et al*. 2006). It was assumed that shortly after the tsunami, the soil salinity of the affected areas was highest near the surface soil. Therefore at this stage EMh is expected to be greater than EMv (leaching progress stage 1). This assumption is based on: (1) the December 2004 tsunami occurred in the middle of the wet season and the soils were likely to have been close to or at saturation; (2) most soils in the tsunami affected areas area are used for lowland paddy which contain a dense claypan at about 0.2 m below the surface; and (3) sediment deposited at the soil surface would have had a high concentration of salt. High soil moisture and the presence of the impermeable claypan layer are likely to restrict deep percolation of sea water.

The vertical leaching of surface salt should cause a decrease in soil salinity at shallow depths (decrease in EMh) and a corresponding increase in subsoil salinity (increase in EMv), and lower average profile ECa.

This assumes there is potential for vertical drainage and that no further salinisation occurs at the soil surface. During lateral movement of salts from the surface soil by flood waters, subsoil salinity would be expected to change very little. Therefore, under this process EMh readings would be expected to decrease and EMv would either not change or decrease slightly, so that the average ECa would decrease.

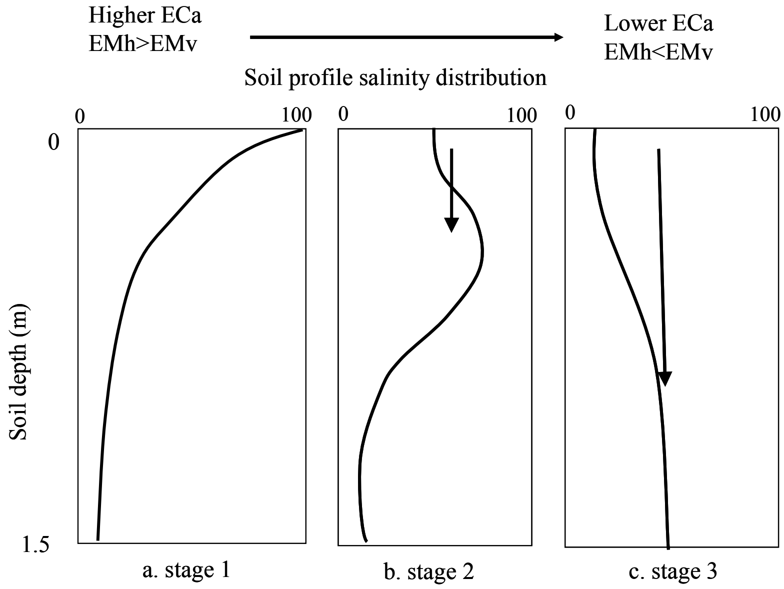

Figure 2. A conceptual model of soil profile salinity distribution and leaching after seawater inundation, with dissolved salts moving through the soil profile. Stage 1 shortly after seawater inundation (EMh > EMv); stage 2 after some leaching (EMh = EMv), and stage 3 after advanced leaching (EMh < EMv)

Methods

After the tsunami, agricultural research and extension staff in Aceh were trained in the use of EM38 to measure soil salinity levels (Figure 2). The first survey of tsunami affected sites was conducted in August 2005. Twenty three monitoring sites with a good field agriculture extension support were selected. Five EM38 measurements were conducted on these sites between August 2005 and December 2007. In each site, 1-3 fixed transects of up to 100 m each were selected based on visual assessment of crop performance (poor, medium, and good). The soil ECa was measured in both the horizontal (EMh) and the vertical (EMv) dipole orientations, at about 5 m intervals along each transect. Changes in EMh and EMv values of transects over time were used to infer stages of leaching based on Figure 1 and the direction of leaching.

Figure 3. Training of agricultural research staff in Aceh to use the EM38 instrument (left), using EM38 in a vertical dipole orientation (middle), and using the EM38 instrument in a horizontal dipole orientation (right)

Results and discussion

Leaching status based on the conceptual model (Figure 1) for each site through time (Table. 1) suggested that in August 2005, 15 of the 23 sites had been subjected to some degree of leaching (Stage 2 or 3). The number of sites at these stages of leaching was unchanged through to May 2006. The number of sites at stage 3 leaching increased to 17 sites only by January 2007 and to 21 sites by December 2007. Most of the changes in EM38 time series data were between stage 1 and stage 3 leaching. Stage 2 leaching was not detected very often and was only observed at site 16 in August 2005. This could have resulted because the time where EMh = EMv might have occurred between measurement times.

Table 2. Stage of leaching at each site from August 2005 to December 2007. S-1, S-2, and S-3 represent stages of leaching described in Figure 1.

Site	Aug-05	Jan-06	May-06	Jan-07	Dec-07
1	S-1	S-3	S-3	S-3	S-3
2	S-3	S-1	S-1	S-1	S-3
3	S-3	S-3	S-1	S-3	S-3
4	S-3	S-3	S-3	NA	NA
5	S-1	S-1	S-1	S-3	S-3
6	S-3	S-3	S-3	S-3	S-3
7	S-3	S-1	S-1	S-3	S-3
8	S-3	S-1	S-1	S-1	S-3
9	S-3	S-1	S-1	S-3	S-3
10	S-3	S-3	S-3	S-3	S-3
11	S-1	S-1	S-3	S-3	S-3
12	S-3	S-3	S-3	S-3	S-3
13	S-3	S-1	S-3	S-3	S-3
14	S-3	S-3	S-3	S-3	S-3
15	S-3	S-3	S-3	S-3	S-3
16	S-2	S-3	S-3	S-3	S-3
17	S-1	S-1	S-1	S-1	S-3
18	S-1	S-3	S-3	S-3	S-3
19	S-3	S-3	S-1	S-1	S-1
20	S-1	S-1	S-1	S-1	S-3
21	S-1	S-3	S-3	S-3	S-3
22	S-1	S-3	S-3	S-3	S-3
23	S-3	S-3	S-3	S-3	S-3

Leaching of salts was slow and was also likely to have been affected by the redistribution of salts during flooding events. The leaching status of 4 out of 8 sites that were at stage 1 leaching in August 2005, remained unchanged in January 2006, and only progressed to stage 3 leaching by December 2007. However, there were also five sites (2, 6, 7, 8, 12) that were already at stage 3 leaching in August 2005, but reverted back to stage 1 leaching in January 2006, before progressively being leached again. This might have been due to the severe flooding across these sites in December 2005, redistributing salts, so that the salinity of some sites increased, while some decreased. By the end of 2007 most of these sites were leached, except site 19 that was surrounded by a housing development blocking the drainage outlet.

The relative changes and value of EMv and EMh for the three main landuse systems across the assessment sites are presented in Figure 3. The salinity level at the rainfed rice field (Figure 3. middle) was much higher than the palawija (Figure 3 left) and the irrigated rice fields (Figure 3 right). This is because the rainfed rice fields do not have irrigation and drainage channels so the seawater was trapped for longer periods of time compared to the irrigated rice and palawija fields. In the rainfed palawija site, the EMh was slightly greater than EMv in August 2005, and by January 2006, EMh had decreased and EMv had increased. This suggests that vertical leaching of salts has occurred. In the rainfed rice field there was a large increase in EMh, but with a much smaller increase in EMv in May 2006, which suggests horizontal redistribution of salts. Both EMh and EMv then progressively decreased from May 2006 to the end of 2007, possibly due to a combination of vertical and horizontal leaching processes. The heavy rain from September to December 2005 and the flooding in December 2005 might have contributed to this.

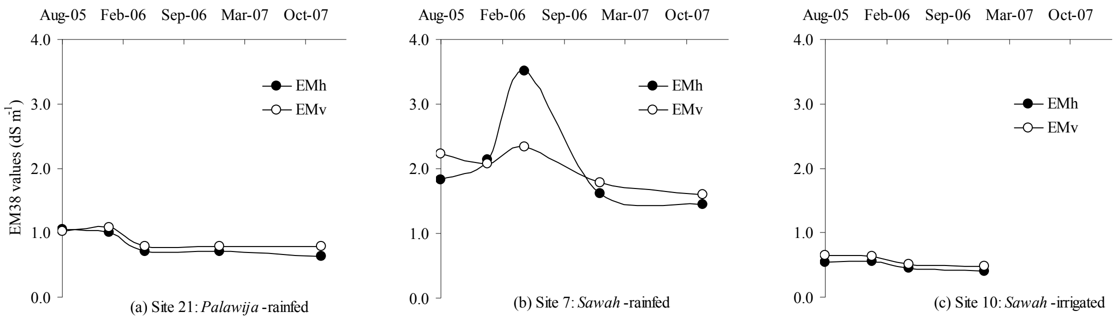

Figure 4. Changes in EMh and EMv over time in sites with different land use systems.

The impermeable claypan layers in the lowland rice fields are likely to have reduced the depth of infiltration of sea water and limited the rate of vertical leaching, so the reduction in salinity level is likely to have been by surface movement with irrigation or flood waters.

Conclusion

This study indicates that EM38 can be used to evaluate leaching progress and mechanism in tsunami affected soils. Leaching of salts occurred slowly by both vertical displacement and horizontal movement in flood waters. Given the low permeability of Aceh's lowland agriculture soils and the presence of the claypan layer in rice fields, the removal of salts from salt affected lowland rice fields should be conducted through horizontal flushing by providing a good drainage and irrigation infrastructure.

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References

Chandrasekharan H, Sarangi A, Nagarajan M, Singh VP, Rao DUM, Stalin P, Natarajan K, Chandrasekaran B, Anbazhagan S (2008) Variability of soil-water quality due to Tsunami-2004 in the coastal belt of Nagapattinam district, Tamilnadu. *Journal of Environmental Management* **89**, 63-72.

Chaudhary DR, Ghosh A, Patolia JS (2006) Characterisation of soils in the tsunami affected areas of Tamil Nadu for agronomic rehabilitation. *Current Science* **91**(1), 99-104.

McNeil JD (1980) Electrical conductivity of soils and rocks: Technical Note TN-5, GEONICS Limited, Ontario, Canada, 22p.

Raja R, Chaudhuri SG, Ravisankar N, Swarnam TP, Jayakumar V, Srivastava RC (2009) Salinity status of tsunami-affected soil and water resources of South Andaman, India. *Current Science* **96**(1), 152-155.

Rengalakshmi R, Senthilkumar R, Selvarasu T, Thamizoli P (2007) Reclamation and status of tsunami damaged soil in Nagappattinam District, Tamil Nadu. *Current Science* **92**(9), 1221-1223.

Slavich P (2002) Ground based electromagnetic induction measures of soil electrical conductivity. Applications and models to assist interpretation. In 'Electromagnetic Techniques for Agricultural Resource Management'. (Ed HG Beecher) pp. 1-7. Proceedings of a Conference, July 3-5, 2001, at Yanco Agricultural Institute, Yanco, NSW. (Australian Society of Soil Science Inc., Riverina's Branch)

Slavich P, McLeod M, Moore N, Iskandar T, Rachman A (2006) Rapid assessment of soil salinity in tsunami-affected areas. Experiences from Nanggore Aceh Darussalam province, Indonesia. NSW DPI Internet publication (January 2006). http://www.agric.nsw.gov.au/reader/salinity/assess-salinity-tsunami-areas.pdf