11. Doerr, S. H., Shakesby, R. A. and Walsh, R. P. D., Soil water repellency: its causes, characteristics and hydro-geomorphological significance. *Earth Sci. Rev.*, 2000, **51**, 33–65.
12. Doerr, S. H. *et al.*, Extraction of compounds associated with water repellency in sandy soils of different origin. *Aust. J. Soil Res.*, 2005, **43**, 225–237.
13. Jaramillo, D. F., Dekker, L. W., Ritsema, C. J. and Hendrickx, J. M. H., Occurrence of soil water repellency in arid and humid climates, *J. Hydrol.*, 2000, **231–232**, 105–111.
14. Feng, G. L., Letey, J. and Wu, L., The influence of two surfactants on infiltration into a water-repellent soil. *Soil Sci. Soc. Am. J.*, 2002, **66**, 361–367.
15. Das, D. K. and Das, B., Characterization of water repellency in Indian soils. *Indian J. Agric. Sci*., 1972, **42**, 1099–1102.
16. Roper, M. M. and Gupta, V. V. S. R., Enumeration of wax-degrading microorganisms in water repellent soils using a miniaturized most probable number method. *Aust. J. Soil Res*., 2005, **43**, 171–177.
17. Anon., Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun, 2005.
18. Bhardwaj, S. P. and Singh, P. N., Soil, land capability, land use characteristics of soil conservation research farm, Dehradun. Technical Bulletin No. T-14/D-11, Central Soil and Water Conservation Research and Training Institute, Dehradun, 1981, pp. 4–8.
19. Blake, G. R. and Hartge, K. H., Bulk density. In *Methods of Soil Analysis, Part 1* (ed. Klute, A.), SSSA, Madison, WI, 1986, 2nd edn, pp. 363–375.
20. Chenu, C., Le Bissonnais, Y. and Arrouays, D., Organic matter influence on clay wettability and soil aggregate stability. *Soil Sci. Soc. Am. J.*, 2000, **64**, 1479–1486.
21. Hudson, R. A., Traina, S. J. and Shane, W. W., Organic matter comparison of wettable and non-wettable soils from bentgrass and sand greens. *Soil Sci. Soc. Am. J.*, 1994, **58**, 361–367.
22. Bond, R. D. and Harris, J. R., The influence of the microflora on physical properties of soils, I. Effects associated with filamentous algae and fungi. *Aust. J. Soil Res*., 1964, **2**, 111–122.
23. DeBano, L. F., Water repellent soils: a state of the art. Gen. Tech. Rep. PSW-46. Pacific Southwest Forest and Range Experiment Station, Berkeley, California, 1969, p. 21.
24. Dekker, L. W. and Ritsema, C. J., How water moves in a water repellent sandy soil. *Water Resour. Res*., 1994, **30**, 2507–2517.
25. Philip, J. R., The theory of infiltration. 1. The infiltration equation and its solution. *Soil Sci*., 1957, **83**, 345–357.
26. Lal, R., Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. Plant Sci.*, 1998, **17**, 319–464.
27. Dekker, L. W. and Ritsema, C. J., Fingerlike wetting patterns in two water-repellent loam soils. *J Environ. Qual*., 1995, **24**, 324–333.
28. Shakesby, R. A. D., Doerr, S. H. and Walsh, R. P. D., The erosional impact of soil hydrophobicity: current problems and future research directions. *J. Hydrol.*, 2000, **231–232**, 178–191.
29. Ferreira, A. J. D., Coelho, C. O. A., Walsh, R. P. D., Shakesby, R. A., Ceballos, A. and Doerr, S. H., Hydrological implications of soil water-repellency in Eucalyptus globules forests, north-central Portugal. *J. Hydrol*., 2000, **231–232**, 165–177.
30. Harper, R. J., McKissock, I., Gilkes, R. J., Carter, D. J. and Blackwell, P. S., A multivariate framework for interpreting the effects of soil properties, soil management and landuse on water repellency. *J. Hydrol*., 2000, **213–232**, 371–383.

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Salinity status of tsunami-affected soil and water resources of South Andaman, India

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The 2004 tsunami has created havoc and excessive devastation in terms of human lives and loss of infrastructure in coastal areas of Andaman and Nicobar Islands, and rendered the soil and water resources salt-affected. In order to assess the changes in the relevant soil characteristics, viz. pH, electrical conductivity, sodium adsorption ratio, soluble cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-), periodical soil and water sampling was done from selected soil series/locations of South Andaman. The results revealed that irrespective of soil series and water resources, the soluble salt concentration increased markedly post-tsunami (2005), making the soil highly saline/saline sodic. However, high rainfall during the subsequent years (3774 mm in 2005 and 3072 mm in 2006) has drastically reduced the salinity levels at these sites to almost close to the pre-tsunami levels. The results indicate the gradual recovery process of the salt-affected sites, which can be further augmented by adoption of appropriate location-specific engineering and agronomic management strategies.

Keywords: Soil salinity, soluble salts, tsunami, water resources.

SOILS turn saline generally due to weathering of parent materials (causing fossil or primary salinity), or from anthropogenic activities involving the improper management of land and water resources (contributing to man-made or secondary salinity). Until recently, the occurrence of large-scale soil salinity due to natural disasters like the tsunami was thought to be a rare phenomenon. However, nature's fury in the form of a massive tsunami triggered by the 26 December 2004 earthquake has created devastation not only in terms of human lives and loss of infrastructure in the coastal areas of the Andaman and Nicobar (A&N) Islands, but also caused complete submergence of adjoining agricultural fields and plantations, and rendered the soil and water resources, including ponds and dug wells salt-affected. The direct environmental impact of the tsunami varied according to different factors, notably bathymetry and geomorphology of the coastline[1]. Thus, areas adjacent to the relatively steep continental shelves

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were generally less damaged than coasts with excessive shallow continental shelf.

The coastal areas of A&N Islands affected by the tsunami present highly diversified human activities, from inland, freshwater, rice-based systems to mangrove and coastal strips used primarily for fishing. The tsunami also affected the cultivated lands surrounding the coastal areas, with severe impact on the eastern coast[2]. One of the main impacts of the tsunami is related to salt accumulation. This concern reflects an important fear within the agricultural sector and rural communities, of facing a strong decrease in soil fertility and productivity due high salinity resulting from sea intrusion. In saline soil, crop growth is severely restricted[3], when the salt concentration (measured as electrical conductivity of soil saturation extract, ECe) exceeds 4 dSm^{-1}. Soil sodicity has an adverse effect on the physical structure of the soil, causing problems of water uptake, transport and aeration of the soil, thus seriously hampering crop production[4]. In this context, soil and water sample collection cum analysis was undertaken at periodical intervals, i.e. immediately after the tsunami (February and March 2005), one rainy season after the tsunami (February and March 2006) and two rainy seasons after the tsunami (February and March 2007) in order to assess the changes occurring in soil salinity and water quality under situation I (sea water intruded the cultivated land during the tsunami and receded completely thereafter) and situation II (Sea water intrudes during high tide and recedes during low tide, especially during new moon and full moon days).

Soil sampling was done at periodical intervals in the tsunami-affected sites of South Andaman, viz. Lalpahar, Crikadabad, Chouldhari, Guptapara, Mithakhari, Loha Barrack and New Manglutan. The samples were collected from the surface layer (0–15 cm) and sub-surface layer (15–30 cm) using Edelmann corer (7 cm Ø, 60 cm length) from ten selected spots by making a transect walk across the slope under situations I and II. The soil samples were air-dried, powdered and sieved through a 2 mm sieve. The sieved samples (<2 mm) were analysed for ECe, pH, cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-) in the saturation extract using standard methods[5,6]. From the values of soluble sodium, calcium and magnesium, the sodium adsorption ratio (SAR) was derived[6].

The tsunami-affected agricultural lands from where the samples were collected belong to School line series (Guptapara), Tushnabad series (Mithakhari, Loha Barrack and New Manglutan) and Dhanikhari series (Lalpahar, Crikadabad and Chouldhari) of South Andaman and the pre-tsunami physico-chemical characteristics of the same soil series have been documented by Ganeshamurthy *et al*.[7].

Soils of the School line series are Tropofluvents, used mainly for cultivating rice, coconut and arecanut. The texture is sandy clay loam with medium organic carbon content (0.55%) in the upper 25 cm. The soil reaction is acidic (pH: 5.9) and the soil ECe was found to be 0.32 and 0.04 dSm^{-1} in 0–15 and 15–30 cm depths, respectively. Exchangeable calcium and magnesium content was 1.8 c mol (p+)/kg soil in 0–12 cm depth and increased to 3.3 c mol (p+)/kg soil at 55 cm depth. The soils do not possess any salinity or sodicity hazards.

The soils of Dhanikhari series are Fluventic Sulfaquents with saline phase, formed from alluvium from the surrounding hills and marine deposits, and are used for rice cultivation and shrimp farming. The soil texture is clay loam in nature with very high organic carbon content (4%) in the upper 25 cm. The soil reaction is highly acidic (pH: 4.7) and the soil EC is 4.8 and 5 dSm^{-1} in 0–15 and 15–30 cm depths, respectively. Exchangeable calcium and magnesium content was 2.7 c mol (p+)/kg soil in 0–12 cm depth and increased to 3.9 c mol (p+)/kg soil at 24 cm depths and decreased further to 2.1 c mol (p+)/kg at 105 cm. The soils are highly saline/sodic.

The soils of Tushnabad series are Umbric Fluventic haplaquepts, formed from shales and are used for cultivation of coconut, arecanut, spices, banana, papaya and vegetables. The soil texture is clay loam in nature, with high organic carbon content (1.5%) in the upper 25 cm. The soil reaction is acidic (pH: 5.9) and the soil EC was found to be 0.02 and 0.05 dSm^{-1} in 0–15 and 15–30 cm depths, respectively. Exchangeable calcium and magnesium content was 14.5 c mol (p+)/kg soil in 0–23 cm depth and increased to 16.4 c mol (p+)/kg soil at 88 cm depth.

The analytical results of soil samples of the above-mentioned said soil series collected at periodical intervals are given in Table 1.

The pH (of soil saturation extract) of surface soil (0–15 cm) under situation I, varied between 4.7 and 6.8, and ECe from 7.2 to 22.9 dSm^{-1}, which indicates that there were several changes in pH and soluble salt content between pre-tsunami and post-tsunami conditions. Results from surface soil-sampling under situation I also revealed that irrespective of soil series, the surface soil has become saline. But the subsurface soil (15–30 cm) had comparatively lesser amount of soluble salts (Table 1). This trend clearly indicates that sea water intrusion during the tsunami did not affect the subsurface soil (15–30 cm), because the waves intruded in a flash and receded completely, leaving a layer of sodium and other soluble salts on the surface soil. The distance of the sampling site from the seashore and inherent soil salinity may also be responsible for the variation in the level of soluble salt concentration in different locations. Similar findings were reported by Rachman *et al*.[8] on the effect of the tsunami on a farmland in Aceh, Indonesia.

Under situation II, the results revealed that irrespective of soil series and initial salinity level, the surface soil (0–15 cm) has become highly saline, with ECe ranging from 7.6 to 34.4 dSm^{-1} and pH ranging from 5.3 to 6.9 (Table 1). The increased level of soluble salt concentration in the subsurface resulted in increased salinity (ranging from

Table 1. Salinity status of tsunami-affected agricultural lands of South Andaman

Parameter	Situation I: Surface soil (0–15 cm)	Situation I: Subsurface soil (15–30 cm)	Situation II: Surface soil (0–15 cm)	Situation II: Subsurface soil (15–30 cm)
Soil salinity immediately after tsunami (February and March 2005)				
pH	4.7–6.8 (6.3 ± 0.74)†	5.6–6.9 (6.5 ± 0.42)	5.3–6.9 (6.3 ± 0.69)	5.3–6.8 (6.2 ± 0.59)
ECe (dSm^{-1})	7.2–22.9 (15.5 ± 6.27)	5.7–16.6 (11.0 ± 4.00)	7.6–34.4 (21.7 ± 9.87)	9.7–28.4 (19.6 ± 7.05)
Na^+ (meq l^{-1})	67–211 (142 ± 58.1)	51–152 (101 ± 36.8)	68–293 (191 ± 81.5)	89–248 (174 ± 59.9)
$Ca^{2+} + Mg^{2+}$ (meq l^{-1})	13–37 (26 ± 8.7)	15–30 (23 ± 6.4)	18–42 (32 ± 9.5)	17–39 (30 ± 8.0)
SAR	23–51 (39 ± 11.1)	18–39 (30 ± 8.2)	23–65 (46 ± 14.9)	31–56 (44 ± 10.0)
HCO_3^- (meq l^{-1})‡	0.4–2.9 (2.0 ± 1.02)	0.8–2.8 (1.4 ± 0.80)	0.8–3.1 (2.4 ± 0.97)	1.2–3.1 (2.4 ± 0.71)
Cl^- (meq l^{-1})	43–158 (107 ± 45.6)	41–114 (80 ± 28.3)	56–218 (147 ± 57.6)	79–194 (138 ± 42.9)
SO_4^{2-} (meq l^{-1})	31–81 (56 ± 20.8)	21–62 (40 ± 15.6)	26–118 (75 ± 34.8)	30–101 (67 ± 26.3)
Salinity status of tsunami-affected soils after one rainy season (February and March 2006)				
pH	5.1–6.5 (6.0 ± 0.49)	5.5–6.6 (6.0 ± 0.41)	5.1–6.6 (6.0 ± 0.56)	4.8–6.4 (5.8 ± 0.64)
ECe (dSm^{-1})	3.9–11.9 (7.8 ± 2.99)	2.3–8.4 (5.9 ± 2.19)	4.5–14.1 (9.5 ± 3.12)	6.2–11.3 (8.7 ± 1.90)
Na^+ (meq l^{-1})	32–99 (67 ± 26.2)	19–75 (51 ± 20.6)	38–131 (82 ± 30.7)	57–102 (76 ± 17.6)
$Ca^{2+} + Mg^{2+}$ (meq l^{-1})	12–31 (21 ± 6.5)	11–24 (18 ± 4.7)	13–33 (24 ± 6.3)	14–26 (21 ± 4.1)
SAR	13–28 (20 ± 5.9)	8–23 (16 ± 5.5)	15–27 (24 ± 6.7)	20–26 (24 ± 4.5)
HCO_3^- (meq l^{-1})‡	0.2–1.4 (0.8 ± 0.57)	0–1.2 (0.4 ± 0.43)	0–1.8 (1.0 ± 0.70)	0–1.4 (0.9 ± 0.51)
Cl^- (meq l^{-1})	28–88 (57 ± 24.3)	21–64 (43 ± 17.7)	36–106 (67 ± 22.6)	48–88 (61 ± 15.9)
SO_4^{2-} (meq l^{-1})	18–37 (29 ± 7.5)	11–28 (20 ± 6.5)	17–45 (34 ± 10.0)	21–41 (32 ± 7.2)
Salinity status of tsunami-affected soils after two rainy seasons (February and March 2007)				
pH	4.2–6.5 (5.6 ± 0.71)	4.9–6.3 (5.7 ± 0.45)	4.9–6.7 (5.9 ± 0.62)	4.4–6.8 (5.7 ± 0.80)
ECe (dSm^{-1})	0.6–5.9 (3.9 ± 2.22)	0.4–5.3 (3.3 ± 1.95)	3.9–8.3 (6.2 ± 1.57)	3.7–7.6 (5.6 ± 1.33)
Na^+ (meq l^{-1})	4–46 (31 ± 17.8)	3–41 (27 ± 15.9)	31–75 (53 ± 15.6)	28–68 (47 ± 12.9)
$Ca^{2+} + Mg^{2+}$ (meq l^{-1})	6–24 (16 ± 7.2)	6–19 (14 ± 5.4)	10–19 (15 ± 3.0)	12–19 (15 ± 2.8)
SAR	2–15 (10 ± 5.2)	2–14 (10 ± 5.2)	14–27 (19 ± 4.2)	12–23 (17 ± 3.5)
HCO_3^- (meq l^{-1})‡	0–0.2 (0.1 ± 0.10)	0–0.4 (0.2 ± 0.17)	0–0.5 (0.3 ± 0.19)	0.1–0.8 (0.4 ± 0.26)
Cl^- (meq l^{-1})	5–43 (27 ± 15.0)	5–34 (23 ± 12.1)	24–55 (42 ± 10.4)	28–51 (38 ± 8.8)
SO_4^{2-} (meq l^{-1})	3–26 (15 ± 8.4)	3–22 (12 ± 7.1)	13–36 (25 ± 7.3)	13–30 (21 ± 6.4)

†Values indicate minimum – maximum (mean ± standard deviation) across locations; ‡CO_3^{2-} was absent in all the places.

ECe 9.7 to 28.4 dSm^{-1}) due to the percolation of soluble salts downward from the surface soil.

The analytical results of tsunami-affected soils after one rainy season revealed that irrespective of soil series and the conditions, there has been appreciable reduction in soluble cation and anion concentration, which in turn resulted in reduced ECe values. The surface-soil ECe of School line series (Guptapara) has come down to 3.9 from 7.6 (immediately after the tsunami) under situation I, and to 6.8 from 11.2 under situation II. In case of the Dhanikari series a similar trend was observed under both situations. With respect to Mithakhari, Loha Barrack and New Manglutan (Thushnabad series), the ECe of surface soil decreased to 11.9, 7.2 and 4.1 from 22.9, 16.1 and 7.2 under situation I and 14.1, 9.4 and 4.5 from 34.4, 20.2 and 7.6 under situation II respectively. Similar trend was observed in the subsurface soil irrespective of soil series and conditions. The reason for appreciable reduction in soil salinity in surface and subsurface soils may be attributed to the leaching of soluble salts by the high rainfall (3774 mm against average rainfall of 3075 mm) received during the 2005 rainy season. This has facilitated the removal of soluble salts in horizontal and vertical directions. Reports on the positive impact of monsoon rainfall in leaching of soluble salts are already available[9–12]. Though the salinity level has reduced from the initial value (immediately after the tsunami), it has remained above 4 dSm^{-1} in all the locations except in Guptapara (School line series). This may be attributed to the soil texture of the School line series (sandy clay loam), which might have facilitated the removal of soluble salts through leaching, as against the clay loam texture of Tushnabad and Dhanikari series, which does not allow leaching of soluble salts. Minhas[13] has reported that lower water-holding capacity of coarser soils leads to higher pore volumes of displacing solutions consequent upon similar rainfall. A larger fraction of rainwater also tends to either run-off or to evaporate from stagnant water on the surface of the soil due to the low infiltration rates of fine-textured soils (having a high clay content). This reduces the water available to displace the salts. Though enough information on soluble cations and anions was not available for the pre-tsunami condition of the above soil series, the analytical results of post-tsunami samples revealed that there has been appreciable involvement of sodium cation, and chloride and sulphate anions in surface and subsurface soils. It also revealed that the involvement of carbonate and bicarbonate anions was negligible. This may be

Table 2. pH, EC and soluble salt concentration of water samples of tsunami-affected ponds and wells of South Andaman

Source	Location	pH	EC (dSm^{-1})	Soluble cations (meq l^{-1})		Soluble anions* (meq l^{-1})	
				Na^+	$Ca^{2+} + Mg^{2+}$	Cl^-	SO_4^{2-}
Immediately after tsunami (February and March 2005)							
Pond	Lalpahar	6.9	4.9	38.4	14.1	40.4	16.9
	Chouldhari	7.8	4.4	33.7	8.7	36.2	11.3
	Crikadabad	7.6	11.8	88.3	36.2	83.7	25.4
	Guptapara	6.2	3.1	17.1	11.4	21.9	7.6
	Manjeri	6.6	2.3	13.7	9.7	15.4	4.2
Well	Sippighat	6.6	4.5	37.5	12.6	41.2	7.1
	Chidiyatappu	7.2	2.9	22.3	13.9	24.4	6.9
	Mithakhari	7.4	9.4	75.8	27.5	69.1	21.8
One year after tsunami (February and March 2006)							
Pond	Lalpahar	7.1	4.2	28.6	11.5	33.6	12.8
	Chouldhari	7.4	4.5	36.2	12.9	40.3	7.3
	Crikadabad	7.3	6.3	46.5	22.1	43.0	18.8
	Guptapara	4.5	1.3	8.3	6.8	10.7	1.4
	Manjeri	6.1	0.8	5.9	2.0	6.8	2.6
Well	Sippighat	7.0	2.5	19.0	10.5	22.1	5.9
	Chidiyatappu	7.5	1.32	9.5	4.9	11.9	4.1
	Mithakhari	8.2	2.9	21.4	13.7	26.9	5.7
Two years after tsunami (February and March 2007)							
Pond	Lalpahar	7.5	2.1	16.4	9.4	19.2	4.8
	Chouldhari	7.9	2.7	18.9	14.1	23.5	7.3
	Crikadabad	6.9	3.2	23.0	16.7	27.8	8.4
	Guptapara	4.3	1.4	9.8	5.8	11.1	1.3
	Manjeri	6.5	0.4	3.7	2.1	3.4	1.7
Well	Sippighat	7.9	1.7	12.6	8.6	14.3	5.2
	Chidiyatappu	7.0	1.0	7.8	5.8	9.5	2.9
	Mithakhari	7.1	1.5	11.5	7.2	12.8	3.4

The results represent a single sample value; *CO_3^{2-} and HCO_3^- were absent in all the places.

attributed to the composition of seabed materials and sea water, which mainly contained chlorides and sulphates of sodium, brought by the tsunami into the agricultural lands[8].

After two rainy seasons, there has been a drastic reduction in soluble salt concentration of tsunami-affected agricultural lands. The surface soil ECe ranged from 0.6 to 5.9 dSm^{-1} under situation I and from 3.9 to 8.3 dSm^{-1} under situation II. Similarly, in the subsurface soil, the soil ECe ranged from 0.4 to 5.3 dSm^{-1} under situation I and from 3.7 to 7.6 dSm^{-1} under situation II. In addition, the soil pH is also approaching the pre-tsunami level in most cases. The reason for the reduction of soil ECe under situation II is due to the construction of bunds along the shore, which has prevented the entry of sea water into agricultural lands. However, this has also resulted in the problem of water stagnation in many places due to lack of drainage outlets.

The analytical results of the water samples collected immediately after the tsunami have revealed that the waves have contaminated both well and pond water, and that the ECe ranged from 2.3 to 11.8 dSm^{-1} (Table 2) and contained mainly chlorides and sulphates of sodium. However, the level has reduced after one rainy season. This may be attributed to the high rainfall received during the season, which has diluted or washed away contaminated water from the ponds and wells. The ECe level has further decreased after two rainy seasons, and in most of the places it is below 2 dSm^{-1}.

Soil salinity reclamation requires analysis of sensitivity parameters that affect interactions between salinity and crop yield[14]. Methodologies developed elsewhere for reclaiming saline and saline-sodic soils of arid and semiarid regions due to irrigation may not be suitable for the A&N Islands.

Hence rehabilitation and management of salt-affected soils of these islands require a combination of engineering and agronomic measures depending upon different situations. The first step towards reclamation of any salt-affected soil should be on the basis of assessment of the soil, including soil profile, which will in turn establish whether the soil is saline/saline-sodic in nature, or is not affected by salts. In the Andamans, the analytical results revealed that the $Na^{2+}/Cl^- + SO_4^{2-}$ and the $CO_3^{2-} + HCO_3^-/Cl^- + SO_4^{2-}$ ratios were less than one. Thus, application of amendments like gypsum is not required and leaching through rainwater impounding alone will be effective to reclaim the tsunami-affected agricultural lands[15]. Hence, agricultural lands under situation I can be easily reclaimed considering the higher annual rainfall (>3000 mm), which can be effectively used for leaching out the accumulated salts. However, the areas under situation II require construction of raised embankments along with sluice gates, which will regulate the ingress of sea water in these areas. It will restrict the entry of sea water into the field during high tide and will allow the drainage of rainwater from the field, which may collect during the rainy season during low tide. In case of situation III (Permanent stagnation of sea water and depth of impounding increases with high tide), it has been envisaged that brackish-water aquaculture would be an alternative livelihood option.

Besides these, a set of agronomic management practices as enlisted below may be followed for effective rehabilitation of salt-affected soils.

- Selection and raising of salt-tolerant varieties of crops like rice, sugarcane, sorghum, watermelon and forage crops like karnal grass (*Diplachne fusca*) and para grass (*Brachiaria mutica*), and green manure crop like *Sesbania* sp.
- Selection of suitable crop rotation like rice–watermelon, rice–maize, rice–sorghum, rice–vegetables, rice–sugar beet and rice–forage crops.
- Adoption of broad bed and furrow system of land manipulation in the affected areas
- Application of higher dose of farmyard manure (FYM) to improve the physical condition of the soil and drainage.
- In case of rice, transplanting of aged seedlings of salt-tolerant variety and increased number of seedlings (4–6) per hill.
- Sowing seeds in the furrows or two-thirds from the top of the ridge.
- For wide-spaced crops like vegetables, adoption of the pit system of planting by replacing the salt-affected soil with a mixture of normal soil and FYM.
- Adoption of frequent light irrigation.
- Adoption of drip irrigation or pitcher irrigation for high-value crops.
- Application of higher dose of NPK than the recommended dose, and
- Adoption of auger hole technique for planting tree species in salt-affected areas.

1. Navalgund, R. R., Sumatra tsunami of December 26, 2004. *J. Indian Soc. Remote Sensing*, 2005, **33**, 1–6.
2. Velmurugan, A., Swarnam, T. P. and Ravisankar, N., Assessment of tsunami impact in South Andaman using remote sensing and GIS. *J. Indian Soc. Remote Sensing*, 2006, **34**, 193–202.
3. Somani, L. L., *Crop Production with Saline Water*, Agro Botanical Publishers, Bikaner, 1991, p. 308.
4. Datta, K. K. and De Jong, C., Adverse effect of water logging and soil salinity on crop and land productivity in northwest region of Haryana, India. *Agric. Water Manage.*, 2002, **57**, 223–238.
5. Page, A. L., Miller, R. H. and Keeney, D. R. (eds), In *Methods of Soil Analysis, Part II, Chemical and Microbiological Properties*, ASA, SSSA, Madison, Wisconsin, USA, 1982.
6. USSL STAFF, Diagnosis and improvement of saline and alkali soils. *USDA Hand Book No. 60*, 1954, p. 147.
7. Ganeshamurthy, A. N., Dinesh, R., Ravisankar, N., Anil Nair and Ahlawat, S. P. S., *Land Resources of Andaman and Nicobar Islands*, Central Agricultural Research Institute, Port Blair, 2002, p. 134.
8. Rachman, A., Wahyunto and Agus, F., Integrated management for sustainable use of tsunami affected land in Indonesia. Paper presented at the Mid-term Workshop on Sustainable use of Problem Soils in Rainfed Agriculture, Khon Khaen, Thailand, 14–18 April 2005.
9. Gupta, I. C. and Abhichandani, C. T., Seasonal variations in salt compositions of some saline water irrigated soils of Western Rajasthan. *J. Indian Soc. Soil Sci*., 1970, **18**, 428–435.
10. Pal, B. and Tripathi, R. K., Physico-chemical characteristics of soils of a semi-desert tract of UP as affected by irrigation water quality. *J. Indian Soc. Soil Sci*., 1979, **27**, 240–248.
11. Manchanda, H. R. and Chawla, K. L., Soil profile variations and wheat growth under irrigation with highly saline waters in coarse loamy soils in South Western Haryana. *J. Indian Soc. Soil Sci*., 1981, **29**, 504–511.
12. AICRP, ICAR All India Coordinated Research Project on Management of Salt-affected Soils and Use of Saline Water in Agriculture, 1972–1993. Annual Reports, CSSRI, Karnal, 1994.
13. Minhas, Saline water management for irrigation in India. *Agric. Water Manage.*, 1996, **30**, l–24.
14. Zeng, L., Shannon, M. C. and Lesch, S. M., Timing of salinity stresses affects rice growth and yield components. *Agric. Water Manage.*, 2001, **48**, 191–206.
15. Gupta, S. K., Ambast, S. K., Gurbachan Singh, Yaduvanshi, N. P. S., Ghoshal Chaudhuri, S. and Raja, R., Technological options for improved agriculture in tsunami affected Andaman & Nicobar Islands and Maldives. Central Soil Salinity Research Institute, Karnal, 2006, p. 88.

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Intensity of shape preferred orientation in a granite and its tectonic implications

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The present study deals with the measurement of intensity of shape preferred orientation in the Palaeoproterozoic Malanjkhand Granite (Central India). This intensity is measured by calculating the strength of mineral lineation of biotite (κ_{bi}). The NE–SW striking Central Indian Suture (CIS) that was formed by the collision of the Bundelkhand and Bastar cratons lies to the north of the granite and κ_{bi} was calculated in 11 samples collected at varying distances from the

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