Properties of tsunami-affected soils and the management implication

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Introduction

The forces of the waves and the mud brought by the waves, during the December 2004 tsunami, changed the soil profile and nutrient balance in the upper soil layer. The affected land underwent either one or combination of two to three changes (Agus, 2005): deposition of mud, silt, sand or coarser materials; increase in soil and water salinity; and desurfacing and compaction of topsoil.

The sea mud contains various salts and organic matter and its accumulation on soil surface changes soil physical and chemical properties. The sea water containing mud with an EC of >40 dS m-1 went as far as five km inland from the coastline (EC of the seawater is usually around 60 to 80 dS m-1). The seawater inundated the land for about five hours before it receded, except in some concave lagoons where it flooded the soil for longer time period causing a more severe salinity. The desurfacing of topsoil was caused by serious erosion from the waves' passage and by the clearing of debris by heavy machinery. The latter also caused soil compaction.

Considering the complexity of the process and the change in soil management it may imply, documentation of the properties of tsunami affected soil and their change overtime will be an important scientific and policy assets.

The objectives of this research were to evaluate the profile of tsunami affected soil and the change in the soil properties.

Materials and methods

We described four soil pits in May 2005 (five months after the tsunami) in Aceh Besar District, Nanggroe Aceh Darussalam (NAD) Province, Indonesia. One of the pit (NAD 3) was from the unaffected, while the other three (NAD 1, NAD 2, and NAD 4) were from the affected areas. In August 2007 (32 months after the tsunami) soil samples were taken adjacent to (within 10 m) Profiles NAD 1, NAD 2, and NAD 4 using a soil auger at depth increments in accordance with the soil horizon depths. The site description of the four soil pits is provided in Table 1.

In June 2005 a survey of soil electric conductivity was conducted in four coastal districts of NAD Province. Observations of electric conductivity of soil, ground water, and surface water was also conducted at several points in West Aceh District in June 2006.

Soil salinity was measured using the Electric Conductivity (EC) meter using a 1:5 soil : water suspension and water samples were measured directly without dilution. Other soil properties follow the standard protocol of routine soil analyses (e.g. Jones *et al.*, 1991).

Results and discussion

Properties of the soil profile

The unaffected NAD 3 profile shows the typical characteristics of acid upland soils. Its organic matter, total nitrogen, phosphorus and exchangeable bases were only slightly higher in the Ap horizon compared with those in the lower horizons (Table 2).

For the tsunami affected Profiles NAD1 and NAD 2, soil pH, organic carbon content, exchangeable cations (potassium, calcium, magnesium and sodium) and total phosphorus were significantly higher in the tsunami formed 'O' horizon than in the underlying layers. However, for Profile NAD 4, where the O layer was dominated by sand fraction, this increase was not observed, except for soil pH.

The Ap horizons of NAD 1 and NAD 4 underwent a sharp increase in sodium to >7 cmol (+)

kg^{-1} compared to those in the underlying layer which were only <1.5 cmol (+) kg^{-1}. This ncrease is believed to be resulted from sodium leaching from the O horizon.

Thirty two months after the tsunami, the depth of the O horizon decreased because of incorporation into the Ap horizon and the difference in soil properties between the O and Ap horizons became rather unclear. Sodium concentration has practically returned to the pre-tsunami condition.

Salinity

Soil salinity is the property describing the concentration of salts in soils. Table salt (NaCl) is the dominant one in coastal areas, but other salts, including Na_2SO_4, $MgSO_4$, $NaHCO_3$, Na_2CO_3, $CaSO_4$, and $CaCO_3$, also determine soil salinity. The higher the salt concentration the higher the electric conductivity (EC) of the soil is. Crops have different tolerances to salinity levels. Sensitive crops such as mung bean, common bean, asparagus, string bean, and spinach can only grow well on soils with EC from 0 to 2 dS m^{-1}. Rice, taro, and onion can tolerate EC of 2 to 4 dS m^{-1} (Djaenudin *et al*., 2003).

EC of the affected soil was > 7 dS m^{-1} five months after the tsunami (Table 1), although it varied spatially. The depth and duration of inundation by sea water and the initial soil water content seemed to determine the salinity. Thirty two months after the tsunami, none of the soil layer of the three affected soil profiles had EC any higher than 0.3 dS m^{-1} (data not shown). Table 2 consistently shows that Na concentration of the top soil layer has returned to normal (<2 dS m^{-1}) 32 months after the tsunami.

Salinity analysis in West Aceh District conducted in June 2006 (1.5 years after tsunami) indicated that, the salt content in soil, soil water and surface water, in general, had decreased to <2 dS m^{-1}, (Subiksa *et al.* 2006) the level most crops tolerate.

The level of salinity, in general, quickly decreased from up to 40 dS m^{-1} in the fresh tsunami mud to about 8 dS m^{-1} in 5 months and further to less than 4 dS m^{-1} in less than a year, especially in areas with high rainfall and coarse textured soils. Currently the EC of >2 dS m^{-1} are only concentrated in newly formed lagoons, in low annual rainfall (<1500 mm), and poor drainage areas.

Implication on soil management

Lowland rice affected by the tsunami has been producing empty grains while in other areas significant yield increase has been observed. The former has been occurring in fields inundated by sea mud while their irrigation and drainage systems have not been restored. The unfilled grain in rice crops seem related to nutrient imbalance and micronutrient deficiencies. The latter seemed related to nutrient enrichment by tsunami mud.

In other affected areas, peanuts' vegetative growth thrived, but the pods were empty. This seems to be caused by calcium deficiency due to imbalance of calcium relative to magnesium and sodium and/or micronutrient deficiency. In general, the ideal proportion of cations on the exchange complex is 65% calcium, 10% magnesium, 5% potassium and 20% hydrogen (McLean 1977). Table 2 shows that concentrations of magnesium in the tsunami-affected soils were relatively high, while that of potassium and calcium were relatively low. This imbalance may have lead to potassium and calcium deficiencies, because not only the total amount of cations determine plant uptake, but also the proportion of the exchangeable cations. Calcium is especially important for pod filling of peanuts. Again micro nutrients unavailability may be another factor of the empty pods.

Conclusions

The deposition of tsunami mud on top of the original soil profile changed the soil properties, but the changes in general, were temporary especially for the salinity. The change of basic cations composition stays longer. The yield of food crops such as rice in the poorly drained areas and peanuts have been affected in the tsunami affected areas. These may be attributed to imbalance and/or unavailability of macro and micro nutrients that require further research.

Tree crops seem more resilient to cope with the change in soil nutrient status.

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Table 1 Description of the soil profile observation points

Item	Soil Profile			
	NAD 3	NAD 1	NAD 2	NAD 4
Village	Beradeun	Nusa	Beradeun	Surah
Coordinate	05°30'09"N; 95°16'28"E	05° 30' 03"N; 95°16'17"E	05° 30' 06" N; 95°16' 21" E	05° 32' 25" N; 95°16'05" E
Phisiography	Peneplain	Fluvio-marine plain	Peneplain	Fluvio-marine plain
Slope	Undulating, 5%	Flat, 3%	Undulating, 3-5%	Flat, 0-3 %
Elevation (m asl)	33	5	18	5
Parent material	Clay stone	Mud and clay sediment	Clay stone	Mud and clay sediment
Drainage	Well drained	Poor	Well drained	Poor
Water table (cm)	160	160	165	160
Land use	Upland agriculture	Upland agriculture	Upland agriculture	Upland agriculture
EC of top soil (dS m^{-1})	<0.2	7.6	8.3	7
Soil classification	Typic Dystrudept	Typic Endoaquepts	Typic Eutrudepts	Typic Endoaquepts

Table 2 Selected soil profile properties, five and 32 months after tsunami

Horizon	Depth (cm)	Texture		pH	Org	Total	Exchangeable cations (NH_4OAc 1N, pH 7)				
		Sand	Clay	H_2O	C	P	Ca	Mg	K	Na	CEC
		%			%	mg kg^{-1}	cmol(+) kg^{-1}				
NAD 3 (Unaffected soil, May 2005)											
Ap	0-16	47	20	5.2	13.5	90	4.0	1.2	0.07	0.1	11
Bw_{1-2}	16-40	52	19	5.2	4.5	30	1.8	0.7	0.00	0.2	9
$2Bw_{1-2}$	40-95	35	34	5.2	2.6	20	2.8	1.4	0.04	0.3	15
$2BC_{1-2}$	96-146	4	64	7.0	1.3	30	17.0	7.7	0.04	2.8	27

NAD 1 (May 2005; five months after tsunami)

O1	0-5	9	48	7.9	6.1	730	39.9	20.9	1.44	7.6	35
O2	5-11	84	10	8.0	0.8	390	33.8	5.6	0.28	7.4	10
Ap	11-25	28	31	6.1	1.1	120	5.8	3.7	0.28	7.2	13
Bw	25-42	27	43	7.1	0.3	60	9.8	4.7	0.07	1.5	16
Bwg	42-98	31	41	7.7	0.2	50	8.2	4.5	0.06	1.1	15
BC	98-147	22	39	8.1	0.1	360	9.6	5.4	0.07	1.7	16

NAD 1 (Aug 2007; 32 months after tsunami)

O	0-5	69	19	8.1	1.5	430	19.5	4.5	0.30	1.2	8
Ap	5.-20	28	43	7.6	0.7	90	7.4	3.5	0.12	2.3	10
Bw	20-37	17	51	7.6	0.4	60	10.5	4.7	0.12	3.2	9
Bwg	37-90	21	48	7.8	0.1	80	10.7	4.8	0.12	2.0	8
BC	90-142	21	48	8.2	0.1	170	9.4	4.2	0.09	1.5	12

NAD 2 (May 2005; five months after tsunami)

O1	0-9	42	35	8.0	9.8	360	27.8	12.8	0.49	3.6	32
Ap	9-29	22	37	5.8	1.5	80	7.6	2.6	0.09	2.1	16
Bw1	29-52	20	43	5.0	0.6	50	7.2	3.2	0.07	0.9	17
Bw2-3	52-83	17	59	6.0	0.3	20	14.8	6.7	0.09	1.4	28
BC	83-149	44	32	6.7	0.1	50	6.7	3.3	0.04	0.8	12

NAD 2 (Aug 2007; 32 months after tsunami)

O1	0-2	33	28	7.8	3.0	270	27.4	4.5	0.32	1.1	16
Ap1	2.-16	25	29	7.2	1.9	110	9.8	2.8	0.12	0.7	11
Ap2	16-27	26	35	6.3	1.0	70	6.8	2.7	0.09	1.2	8
Bw1	27-50	30	35	5.9	0.6	50	6.1	3.1	0.09	1.4	9
Bw2-3	50-83	40	33	6.5	0.4	60	9.0	4.8	0.12	1.6	10
BC	83-140	49	30	6.5	0.4	60	8.5	4.5	0.11	1.5	9

NAD 4 (May 2005; five months after tsunami)

O	0-17	93	5	8.4	0.1	1100	5.4	2.1	0.22	1.7	7
Ap	17-24	21	37	6.3	1.1	450	11.0	11.9	0.45	8.0	27
Bwg1	24-43	17	31	6.6	0.4	840	18.6	16.5	0.15	1.5	26
Bwg2	43-83	30	20	7.4	0.2	950	16.9	15.6	0.11	0.5	25

NAD 4 (Aug 2007; 32 months after tsunami)

O	0-5	73	14	7.7	1.1	890	10.3	4.5	0.88	0.5	10
Ap	5.-13	27	42	7.6	0.8	140	12.6	8.5	0.65	1.1	14
Bwg1	13-30	19	48	7.6	0.2	130	16.5	14.5	0.54	1.9	17
Bwg2	30-70	11	59	7.4	0.3	180	19.5	17.8	0.49	1.8	24