Chemical and physical changes in tropical soils from seawater exposure and subsequent rainwater washes

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Abstract

There is little published information regarding the response of tropical island soils to periodic seawater intrusions. In this paper, we describe batch experiments where samples of three Hawaiian acidic upland soils (collected from western Oahu, Hawaii) were equilibrated for 16 h with simulated seawaters, ranging from 0.25-25 g L⁻¹ (or ppT) of total salt, and then washed three times with 20 µS cm⁻¹ solutions containing dilute concentration of NaCl (approx. 0.01 g L⁻¹) to simulate rainfall events. Solution data showed that the exchangeable sodium (ExNa) loads were high on all soils. While much of this ExNa was lixiviated with the rainwater washes, the soil exhibited significant remaining exchangeable sodium percentages (ESP). Consequences of the residual ESP after intensive washings were exhibited in the enhanced dispersiveness (i.e., increased settling time) of the soil colloids. In balance of the continuous sea spray and lower rainfall of the site, it is likely that high salt, high sodium effects would be manifested for extended periods of time in these soils.

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1. Introduction

While models are being developed to predict how global climate patterns may change with warming, there are limited studies on the impact these changes could have on soils. Most of the work to date has focused on changes in soil carbon dynamics. Yet, to our knowledge, very few studies have focused on the potential soil response to seawater intrusions from climate change-mediated sea-level rise. The available literature suggests that the effect of seawater intrusions on soils is potentially long lasting. For example, Blood et al. [1] showed that soils retained high concentrations of salt four months after a 5-8 m storm

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surge from the 1989 hurricane Hugo inundated a coastal pine forest in South Carolina. Others showed significant salinization problems in soils and groundwaters in India and Sri Lanka, following the devastating 2004 Indian Ocean tsunami [2] and the 2011 tsunami off the coast of Japan. Given the high salt and Na content of seawater, soils will likely develop either saline and/or sodic soil behavior from seawater intrusions. The implications of seawater intrusions on the development of saline/sodic soils are quite serious, causing potentially catastrophic damage to island agricultural industries and economies. High Na strongly deteriorates soil structure and thus its viability to support critical infrastructure (bridges, runways), native vegetation, and food production. Studies have shown that embankments made of sodic soils and rigid structures (e.g., culverts, bridges, pavements, etc.) were readily compromised, sometimes as short as 8 months after construction [3, 4], due to the ready dispersibility of the soil. In agriculture, sodic soils are readily dispersed or disaggregated, severely limiting water movement and gas exchange needed for crop growth [5]. As a result, sodic soils are either severely water limited (leading to dryland salinization), water logged, or highly erodible.

Most of the current information on sodic soils comes from areas of the world that are naturally high in natric (i.e. Na bearing) parent material, and generally in arid and semi-arid regions (e.g., Western and Mid-Western U.S.). Little information is available in the scientific literature regarding the potential impacts on soils developed in tropical/sub-tropical climates, particularly in the context of climate change-mediated ocean storm activity and sea level rise.

2. Materials and Methods

For these experiments, three acidic, Oahu soils were selected on the western side of Oahu, Hawaii, USA, facing the westward-blowing trade winds (called the windward lowlands). The soils were a Tantalus (TAE) silt loam (Medial over pumiceous or cindery, ferrihydritic, isothermic Typic Hapludands), a Leilahua (Le) silty clay (Very-fine, ferruginous, isothermic Ustic Kanhaplohumults), and a Wahiawa (Wa) silty clay (Very-fine, kaolinitic, isohyperthermic Rhodic Haplustox). Approximately 5 g of soil was placed in 50 mL PP centrifuge tubes containing approx. 30 mL of Instant Ocean solution, adjusted to total salt concentrations ranging from 0.25 to 25 g L⁻¹ and shaken for 16 h. After shaking, an aliquot of suspension was withdrawn from each tube, diluted by 1:10, and then pipetted 3 mL into a disposable cuvette. Soil settling rates were computed by measuring the change in suspension scattering at 600 nm light with time using a Varian Cary 50 UV-vis-NIR spectrometer as described previously [6]. The remaining suspension in the test tube was centrifuged at approx. 9500 rpm (approx. 3000 xg) for 10 min. The equilibrium solution was sampled and analyzed for total elemental concentrations by ICP-AES, pH and EC by potentiometric methods. Afterwards, sedimented soils were washed with a very dilute NaCl equivalent to 20 µS cm⁻¹ as measured by Accumet electrical conductivity (EC) probes. Soils were washed for a total of three times.

3. Results & Discussion

Table 1 presents the exchangeable cation composition for the three soils. Given the location of these soils, it seems the continuous sea-spray has resulted in a high amount of ExNa ranging from 1.6-2.7 cmol kg⁻¹, or 7-31% ESP. By USSL definitions [7], the Leilahua and Wahiawa soils are defined as sodic soils although sodic soil-like properties have never been reported. Given the drier climate that exists on the western side of the island, there is likely insufficient rainfall to match the sea-spray mediated loading of Na on the exchange phase.

Data obtained during the different seawater exposures and rainwater washes (not shown) indicated that all soils were highly loaded with ExNa, yet this was readily leached with successive rainwater washes – the magnitude of decrease depending on the initial seawater salt concentration. These decreases in ExNa corresponded with an increase in ExCa and ExMg (and decreased ESP), consistent with the shifting ionic
The physical consequence of seawater exposures on the dispersion potential of soils was investigated using simple settling studies. Typical soil settling data is presented in Figure 1. At equilibrium with 0.25 ppT seawater, the Wahiawa soil exhibited a slow settling behaviour compared to the higher salt concentrations (10-25 ppT). These outcomes are consistent with the collapse of the Debye screening length, as described for charged colloidal particles, which is modelled as proportional to the square root of the solution ionic strength [9, and references therein]. The shrinking double layer volume around individual aggregates, promotes higher proportions of successful interparticle collisions and faster aggregation. However, the settling behaviour of the Wahiawa soil was very different after the rainwater washes. Figure 1 shows that the settling curves “separate”, with soils that were exposed to the highest seawater salt concentration, exhibiting the highest turbidity throughout the settling period. Thus, this behaviour may be attributed to the residual soil ESPs.

Fig. 1. Example settling curves for the Wahiawa soil exposed to different concentrations of seawater. Curves are shown at equilibrium (following seawater exposure) and after washes 1-3.
4. Conclusion

This study demonstrates the impact of seawater salts on the chemical and physical properties of acidic tropical soils. Experiments demonstrated that these soils exhibited high loadings of ExNa. Classical ion exchange behaviours were exhibited with respect to solution ionic strength and heterovalent ion selectivity. Much of the ExNa was removed with rainwater washes, however, it is important to point out that at the particular soil collection site in western Oahu, the combination of continuous sea spray and low rainfall will prolong the time necessary to wash out the salts. Thus, the deleterious impacts of high salt-high sodium may be observed in soils for extended periods of time.

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