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Tongatapu post-eruption preliminary soil assessment

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Contents

Executive summary

Background and Objectives: The Hunga Tonga–Hunga Ha'apai volcanic eruption, which began on 20th December 2021, and the main eruption that led to the tsunami on 15th January 2022 affected the agricultural lands of Tongatapu. The extent of impacts associated with the deposition of volcanic ash and build-up of salts in soils (seawater ingression) were unknown. The work documented in this report was conducted to: (1) undertake a preliminary assessment of the soils in Tongatapu following these natural events, (2) determine the likely impacts on the soils' ability to grow crops, and (3) identify possible measures that may be undertaken to remediate affected soils.

Materials and Methods: A total of twenty-four soil and volcanic ash samples were collected from several locations in Tongatapu in February 2022, about 30 days after the tsunami event. The samples underwent chemical analyses at the CSIRO Laboratories at Black Mountain, using for this Australian Standards and ES-EPA analytical techniques and quality control procedures. Production constraints were assessed against changes in soil salinity and sodicity.

Key Results: In tsunami-affected soils, there were significant increases in soil salinity (electrical conductivity, EC) and sodicity (exchangeable sodium percentage, ESP), both of which exceeded crop tolerance, and there was also a significant increase in chloride content. About 80% of soil samples exhibited ESP values higher than 6 and thus classified as being sodic. Depending upon the clay content, soils with EC and ESP greater than 2 dS/m and 6%, respectively, may exhibit dispersion and structural collapse following rainfall. This may affect water infiltration rates leading to temporary surface ponding or increased risk of runoff. In ash-affected soils, there were no significant changes in salinity or sodicity. In all soils, changes in plant available phosphorus (P) were variable depending on sampling location, and there were no significant changes in metal contamination.

Key Conclusions: Minimise or avoid mechanical disturbance of soils affected by sodicity to improve soil structure and internal drainage (which will assist leaching of salts below the rooting zone). Application of ameliorants may be required to reduce sodicity, improve structural stability, and balance out soil pH. Mulching of crop beds with organic residue may prevent rapid evaporation and deposition of salts on the soil surface/within the rooting zone. May need to consider improving surface drainage by raising crop beds in low-laying areas or establishing drainage channels. Agronomic advice should be provided on nutrient management and bed establishment.

Recommendations: There is a need for ongoing monitoring and assessment of soil salinity and sodicity, particularly in tsunami-affected soil, to assist soil management decisions and implementation of corrective measures. This will require soil sampling and analysis at regular time intervals (e.g., twice per year). Samples will need to be collected from the same locations to a consistent depth, and GPS sampling points recorded. Following collection, samples need to be air-dried and stored until analyses could be conducted. Future work involving modelling of solute transport within the soil could be used to predict the time required for salts to leach down the profile (below rooting depth) and the rate of soil recovery. The number of samples available for this work (24 soil and 2 ash samples), and their geographical spread, limited the spatial analysis, and the generalisation and interpretation of findings. Therefore, future soil surveys that allow for increased sampling density will be beneficial.

1 Introduction

The Hunga Tonga–Hunga Ha'apai volcanic eruption ash fall and tsunami impacted the agricultural lands of Tongatapu. The Tongan Ministry of Agriculture, Food, Fisheries and Forestry collected 24 surface soils and 2 volcanic ash samples from sites in Tongatapu (Figure 1) to quantify soil related agricultural production constraints. The samples were collected in February 2022, less than two months after the eruption (recorded on 20 December 2021).

Figure 1. Approximate location of the tsunami and ash sites from where soil samples were collected.

2 Soil Testing

A description of the analytical methods employed in this work is provided in the Appendix. Soil electrical conductivity (EC) and exchangeable sodium percentage (ESP) are used to denote soil salinity and sodicity, respectively.

3 Results and Discussion

Production Constraints: Salinity and Sodicity

Soil electrical conductivity (EC) clearly shows the impact of the tsunami on the Kanokupolu and ‘Ahua soils relative to the ash affected soils. At the time of sampling, the tsunami-affected soils were considered too saline for crop growth (Figure 2). The concentration of chlorine in the soil reflects that inundation of the land surface with salt water (Figure 3). In total, the tsunami affected soils potentially have had an additional 1.3 tonnes per ha of chloride added to system (Figure 4).

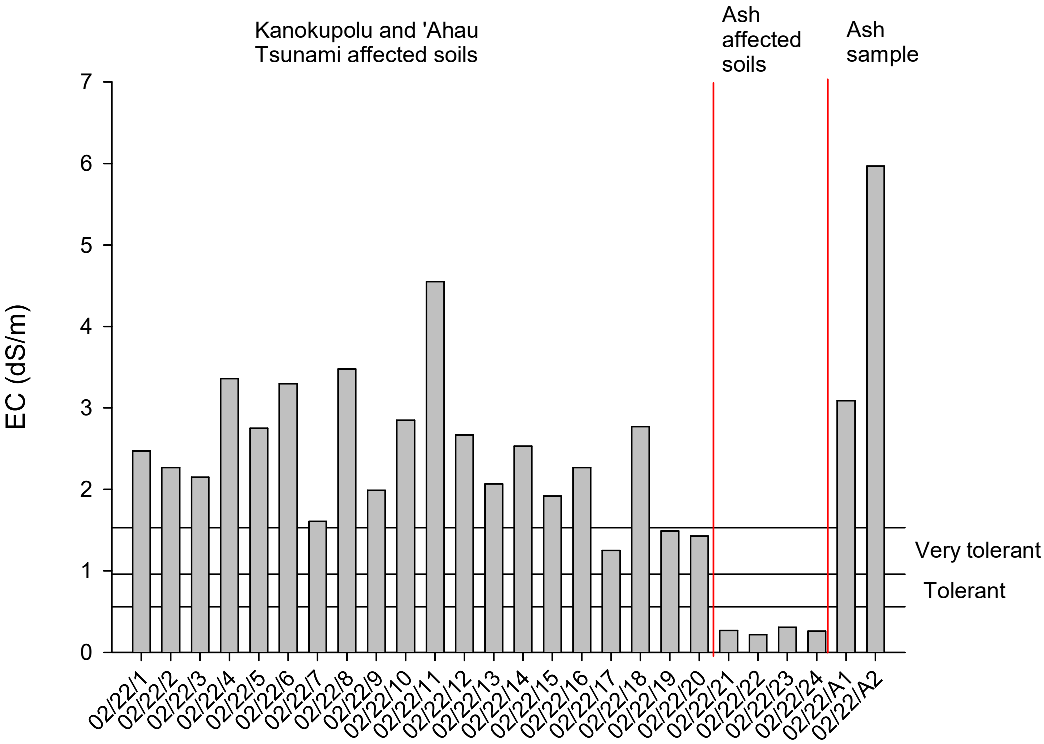

Figure 2. Soil electrical conductivity and corresponding plant salt tolerance groupings for soils with a 40%-60% clay content (Mass and Hoffman, 1977).

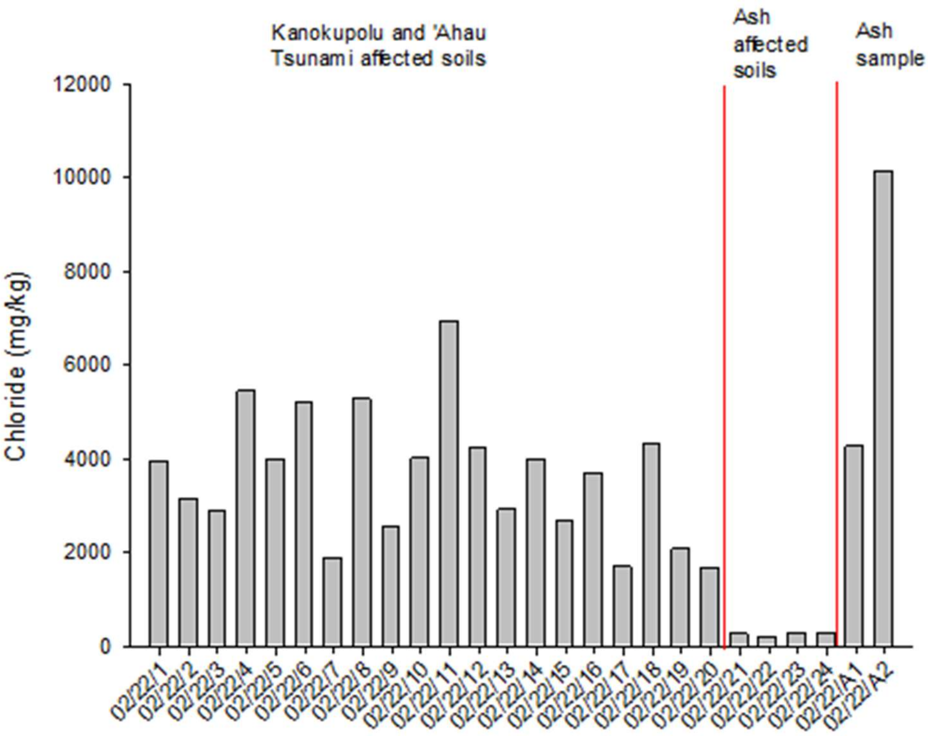

Figure 3. Soluble chloride concentrations in soil and ash samples.

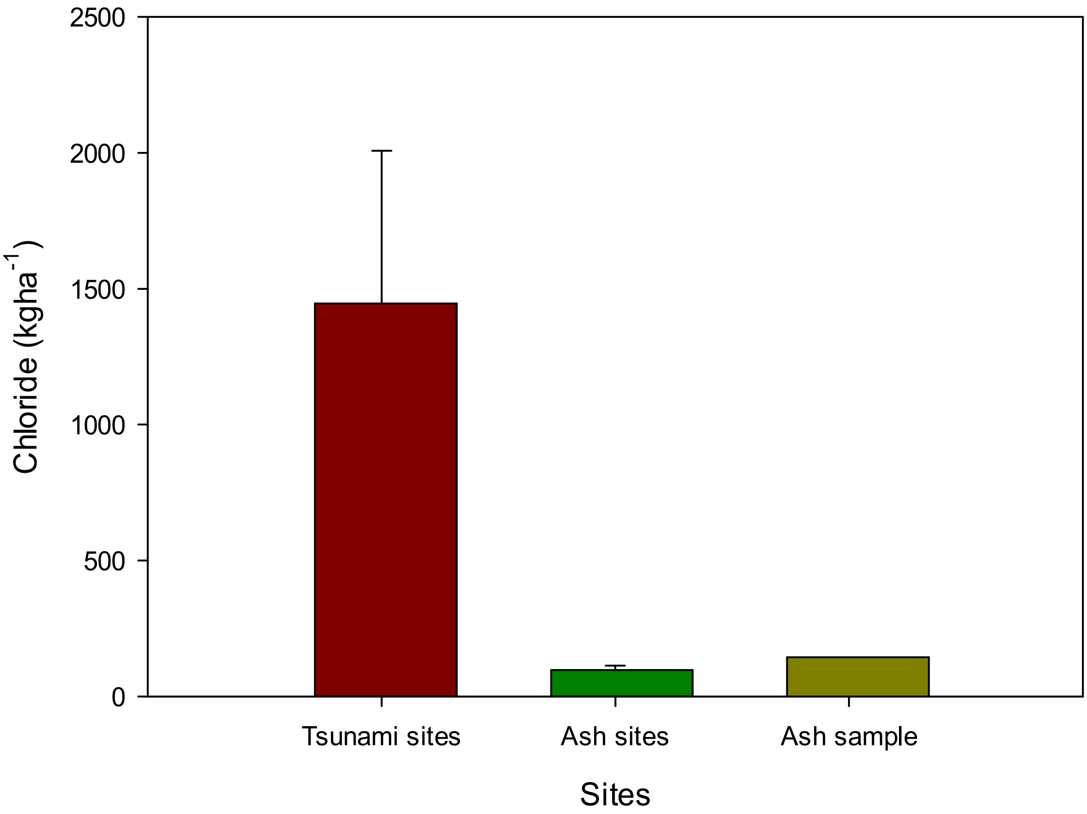

Figure 4. Total mass of salt in the top 0.05 m of the soil profile for the tsunami- and ash-affected sites. Total mass of salt potentially deposited in Tongatapu.

Seawater inundation has also changed the sodicity status of the soil (Figure 5), which may affect crop productivity in the short-term through changes in the physical and chemical status of the soil. In the short-term the soils may be more dispersive, thus, potentially reducing rainfall infiltration into the soil. This may lead to temporary ponding of water on the soil surface or increased risk of runoff. An increase in ESP may also lead to changes in soil pH and nutrient imbalances. Effort should be made to promote vegetation cover or the use of mulch to protect the soil surface and avoid mechanical disturbance.

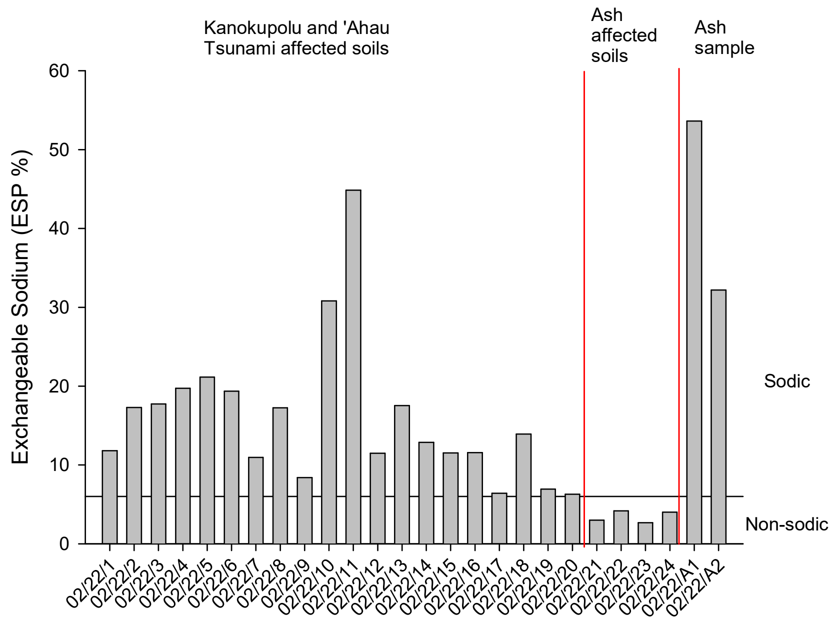

Figure 5. Exchangeable sodium percentage (ESP, %) and sodicity status. for the tsunami- and ash-affected sites.

The soils of Tongatapu are highly permeable (hydraulic conductivities >20 cm/h), and therefore, there is unrestricted movement of solutes from the soil surface to deeper in the profile (van der Velde et al. 2004, van der Velde et al., 2005). Going forward, the main solution is to allow the rainfall to leach the salt down from the topsoil. After the tsunami in Aceh Indonesia it was recommended by NSW DPI (2014) that leaching of saline sites can be encouraged by:

1. Mulching the beds or the land surface with organic residues (e.g., straw plant residues) to prevent soil from drying out and bringing salts to the surface.
2. Raising crop beds to improve surface drainage, especially in low lying areas
3. In low lying areas, the constructing of shallow drainage channels to encourage surface flushing of salt during rainfall.

Soil salinity assessment should be undertaken prior to any management invention to determine the most optimal option. Also on-going monitoring and evaluation of soil EC and sodicity (ESP) is required to ensure appropriate soil management decisions.

The soil analysis on the submitted samples indicates that the main production constraint is the salt loading and not metal contamination and acidification (Tables 1 and 2). There are phosphorus (P) limitations at some locations, and excess P levels in others due to historic fertilisation practice (Figure 6). Further agronomic advice should be provided on nutrient management and bed establishment.

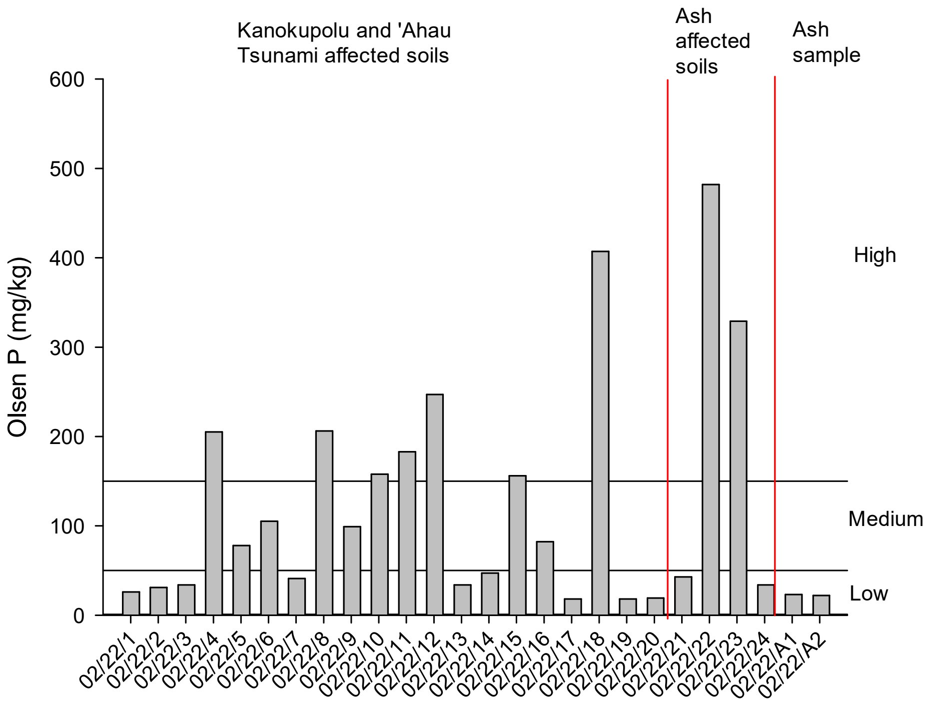

Figure 6. Soil P content and corresponding generalised interpretation guidelines (Moody and Bolland, 1999).

Table 1. Mean Soil and ash chemical properties. Std. Dev. is standard deviation (n = 20 for tsunami sites and n = 4 for ash sites).

Determination	Tsunami sites		Ash sites		Ash Sample
	Mean	Std. Dev.	Mean	Std. Dev.	Mean
pH	7.4	0.5	6.6	0.3	7.6
pH_{CaCl}	7.3	0.5	6.1	0.3	7.5
	Exchangeable Cations ($cmol_{(+)}$ kg^{-1})				
Ca	23.92	10.82	27.65	6.17	0.76
Mg	5.81	3.60	5.94	0.90	0.40
Na	4.96	2.07	1.24	0.09	1.34
K	0.88	0.69	1.64	1.07	<0.05
Total	35.57	14.92	36.46	6.44	2.51
	Water soluble anions (mg kg^{-1})				
F	<0.5	<0.5	<0.5	<0.5	<0.5
Cl	3618.0	1401.3	246.0	38.1	4250.0
Br	8.0	3.5	<2.5	<2.6	8.5
NO_3	78.6	41.8	83.4	52.4	<2.5
SO_4	531.0	246.1	60.8	8.4	1193.7

Table 2. Total elemental analysis of soil and ash. Std. Dev. is standard deviation (n = 20 for tsunami sites and n = 4 for ash sites).

Determination	Tsunami sites		Ash sites		Ash Sample
	Mean	Std. Dev.	Mean	Std. Dev.	Mean
	Total (mg kg^{-1})				
Ca	88775	63480	5825	1212	9810
K	1561	618	1670	721	298
Mg	5682	1208	2165	97	1410
Na	3522	1322	526	22	3610
S	870	187	620	107	557
Al	52620	16567	81900	1273	16100
As	21	9	<10	<10	<10
B	<9	<10	<10	<10	<10
Cd	<10	<10	<10	<10	<10
Co	24	7	52	6	<10
Cr	15	2	22	5	<10
Cu	80	28	161	5	16
Fe	46725	15133	91875	5917	4570
Mn	1199	460	3583	647	73
Mo	<10	<10	<10	<10	<10
Ni	15	3	21	1	<10
P	1000	976	1778	785	<40
Pb	<10	<10	<10	<10	<10
Sb	56	23	<20	<20	<20
Se	<10	<10	<10	<10	<10
Zn	68	24	153	12	<10

Appendix: Soil Testing

Soil pH and electrical conductivity of soil

Were determined using a 1:5 soil/water extract. 10 g air-dried soil was shaken with 50 mL water for one hour and left to settle for 20 minutes. Electrical conductivity (EC) was determined and a subsample for chloride taken. Soil pH in water was then determined before calcium chloride added, sample re-agitated, re-settled before reading for calcium chloride pH. Soil pH was then determined using an Metrohm 815 Robotic Processor and Metrohm 854 glass electrode. Electrical conductivity was determined using a Metrohm 815 Robotic Processor and standardised conductivity cell (Rayment and Lyons 2011).

Total carbon and total nitrogen

Total carbon (C) and total nitrogen (N) were determined by high temperature combustion in an atmosphere of oxygen using a LECO TruMAC. Carbon was converted to CO_2 and determined by infrared detection. Nitrogen was determined as N_2 by thermal conductivity detection (Rayment and Lyons, 2011).

Extractable phosphorus

Extractable phosphorus (P), which represents the plant available fraction, was determined by segmented flow colorimetry (Lachat QuikChem 8500 series 2) following Olsen extraction using 0.5M $NaHCO_3$ at pH 8.5 (Rayment and Lyons, 2011).

Exchangeable cations

Exchangeable cations were determined using NH_4Cl solution at either pH 7.0 or pH 8.5 dependent on soil pH. Non-calcareous soils use extraction solution pH 7.0 and alkaline soils use extraction solution pH 8.5. Samples were pre-treated for soluble salts prior to extraction. Exchangeable cations Ca, Mg, Na and K were analysed by ICP-OES (Rayment and Lyons, 2011).

Soluble anions

Soluble anions were determined using a 1:5 soil/water extract. Five grams of air-dried soil was shaken with 25 mL water for one hour. Fluoride, chloride, bromide, nitrate and sulphate were analysed using a Shimadzu IC system (Rayment and Lyons 2011).

Total metals

Total metals were determined by microwave assisted acid digestion following US EPA method 3051A (1998). The finely ground sample was digested in a microwave oven using a mixture of nitric acid and hydrochloric acid. The solution was then analysed for a wide range of elements by inductively coupled plasma optical emission spectrometry (ICPOES).

Salt mass calculations

The mass of salt in the soil samples was calculated assuming a uniform soil density of 0.8 Mg m^{-3} and a sampling depth of 0.05 m. The salt input from the ash was calculated assuming a uniform density of 0.4 Mg m^{-3} and a depth of 0.005 m. The salt mass in 1 ML of seawater was calculated using the seawater chemistry characteristic from Stumm and Morgan (1996).

Funding and Acknowledgement

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