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Acidification of Volcanic Ash Soils From Maui and Hawaiʻi Island for Blueberry and Tea Production

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Recent interest in the production of "acid-loving" specialty crops such as tea (*Camellia sinensis)* and blueberries (*Vaccinium spp.)* has created a need to determine acidification recommendations for Hawaiʻi soils. Many of Hawaiʻi's arable soils are slightly acidic to very acidic, and the liming requirements for the major agronomic crops are well studied. However, there is no information on the acidification of these soils for novel crops such as tea and blueberry. Although recommended pH ranges vary with variety and soil type, most blueberry plants grow best when soil pH is maintained between 4.0 and 5.2 (Williamson et al. 2006), and recommended soil pH is 4.5–5.0 for continental soils (Hanson and Hancock 1996). Tea also prefers acidic soils with pH between 4.5 and 5.0 (Zee et al. 2003). Acid-loving plants grown in soils with higher pH ranges can suffer from nutrient (i.e., iron and zinc) deficiencies that result in poor growth.

Tea is growing in popularity as a specialty crop in Hawaiʻi, but it requires a more acidic soil than the majority of the crops presently grown in the Islands.

The purpose of this publication is to 1) provide some background on soil acidity in relation to plant growth, 2) present approaches to acidifying soils, and 3) provide guidelines for the acidification of some volcanic soils on Maui and Hawaiʻi Island that are potential sites for tea and blueberry production. It is important to understand, however, that given that tea and blueberries for commercial production are new introductions to the Islands, there is no evidence yet that acidifying Hawaiʻi's soils will increase yields.

Soil Acidity and pH

Acidity in soils is a measure of hydrogen ion concentration (H^+) in the soil solution, and it is expressed as pH. A soil with a neutral pH has a pH value of 7. As (H^+) increases, the pH drops below 7. Acid soils typically occur in areas that receive high rainfall; for example, the red soils found on the wet windward uplands of the islands of Oʻahu, Molokaʻi, and Maui may have soil pH values less than 5.5. These soils are acid because the high rainfall leaches out basic, or alkaline, compounds (carbonates and minerals such as calcium and magnesium), leaving the soil rich in acid-forming minerals like aluminum. In addition to the natural acidification of soils due to precipitation, soils can become acidic with the prolonged use of ammonium-containing nitrogen fertilizers such as urea.

Figure 1. A) An iron-deficient blueberry plant has chlorotic new leaves and green veins. B) A healthy blueberry plant that is receiving sufficient iron owing to an appropriately acidic soil has dark green leaves and lighter veins.

Many plants, including most vegetables, grow best in soils with pH between 6 and 7; therefore, liming the soil is a common practice implemented to correct the negative effects of soil acidity and ensure good plant growth. However, an acid-loving plant such as tea or blueberry is not adapted to soils with this pH range. As soil pH approaches 7, iron (Fe), which is an essential element for plant growth, becomes less soluble. Thus its availability for plant uptake is limited. Blueberry plants are especially susceptible to Fe deficiency and often show interveinal chlorosis of new leaves and shoots with green veins, characteristic of Fe deficiency (Figure 1A).

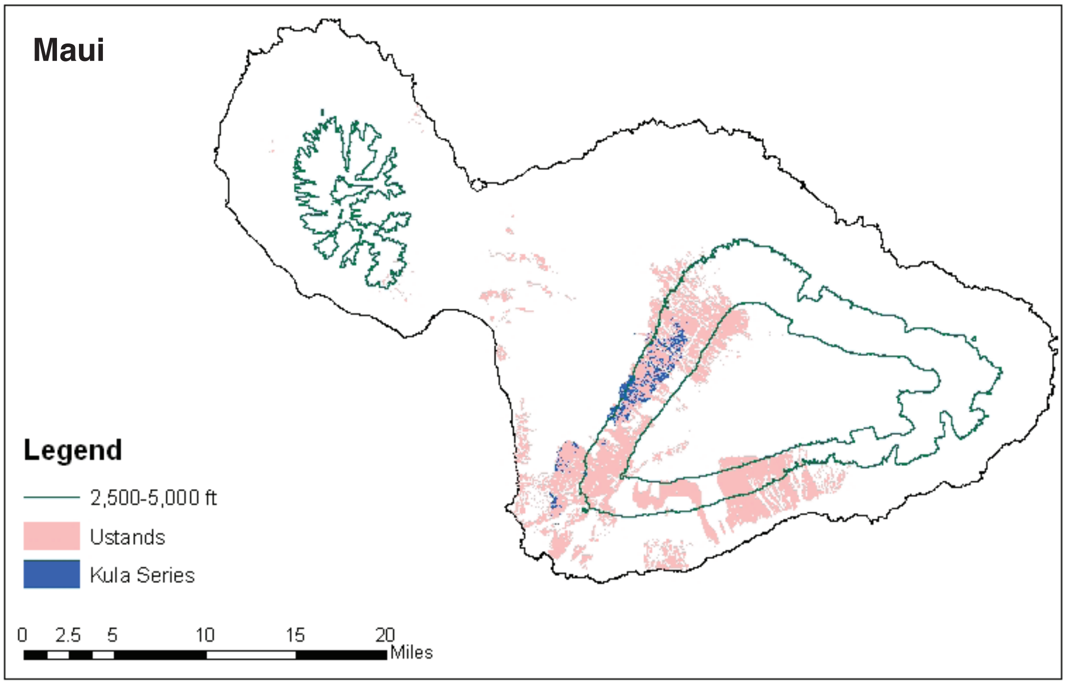
In a sub-tropical environment like Hawai‘i, blueberry production is best suited to intermediate-elevation sites where temperatures during the winter months satisfy these plants' chilling requirement for flowering. Given these environmental constraints, potentially productive areas for blueberry cultivation are limited to intermediate elevations (2,500–5,000 ft) on the slopes of Haleakalā on Maui and Mauna Kea, Mauna Loa, and Hualālai on the Big Island (Figure 2). Such areas are also suitable for tea production (Zee et al. 2003). Two soil types formed from volcanic ash dominate these geographic areas. Highly weathered soils (Udands) with low phosphorus (P), calcium (Ca), and potassium (K) are dominant in the high-rainfall areas (> 60″ per year), while moderately weathered soils (Ustands) rich in Ca and K prevail in the lower-rainfall areas (≤30″ per year). The pH of the surface horizon (0–6″) of highly weathered soils typically ranges from 5.0 to 6.0, but it can drop below 5.0 in soils that were under intensive sugarcane production (these soils are most common below the 2,000-ft elevation on the Hāmākua Coast). On the other hand, the moderately weathered ash soils of the drier areas have surface soil pH values that range from 6.0 to 7.0. To lower soil pH for blueberry production both soil types would require an acidification program to lower pH below 5.0.

Acidifying Soils

Acidifying soils requires the addition of materials capable of producing H^+ ions, which lower soil pH. There are a number of materials that have the ability to acidify soils, including ammonium (NH_4^+) fertilizers and organic matter (peat moss), but finely ground (prilled) elemental sulfur (S) is the most effective acidifier. The acidification occurs when soil bacteria (e.g., *Thiobacilli*) oxidize S to obtain energy to fix carbon, a biochemical process described by the following general reaction:

$$CO_2 + S^0 + \frac{1}{2}O_2 + 2H_2O \rightarrow CH_2O + SO_4^{2-} + 2H^+$$

The rate of this biological reaction depends on the properties of the S source (i.e., particle size), as well as environmental factors such as soil temperature and moisture that control bacterial life processes. Thus, warm, moist soils with an active bacterial population will enhance the speed of the reaction. Additionally, soil texture plays an



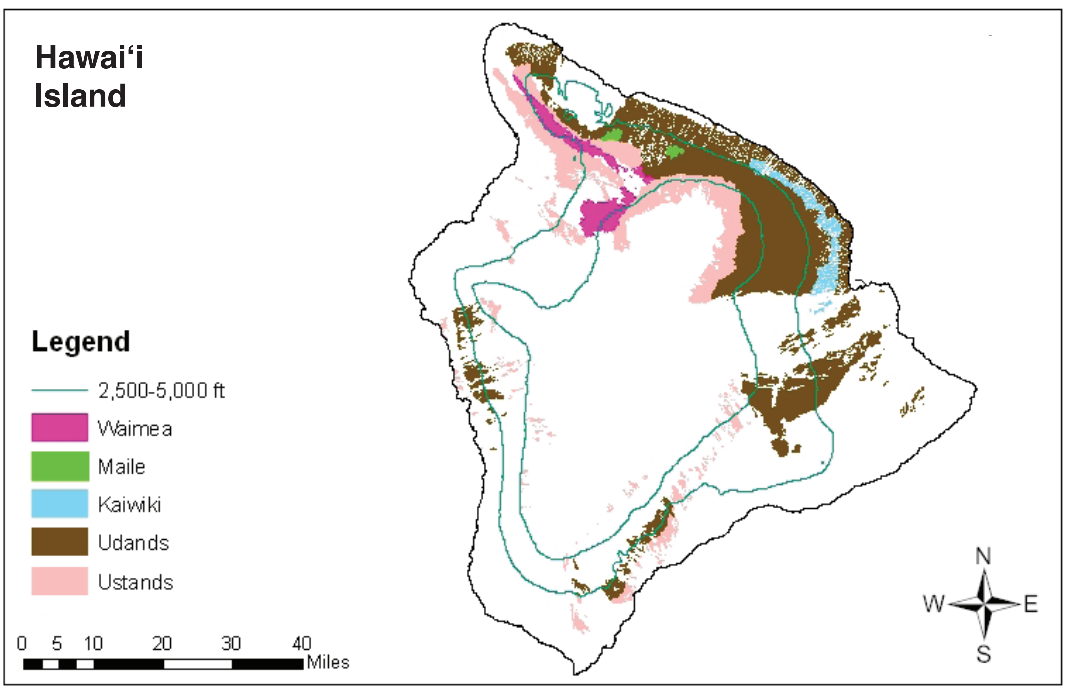


Figure 2. Maps depicting the distribution of soils developed in volcanic ash in Maui and Hawai‘i that are potentially suitable for blueberry production. Soils falling within the 2,500- and 5,000-ft contour lines meet the climatic requirements to satisfy blueberry and tea growth (maps created in ArcMap by J. Deenik).

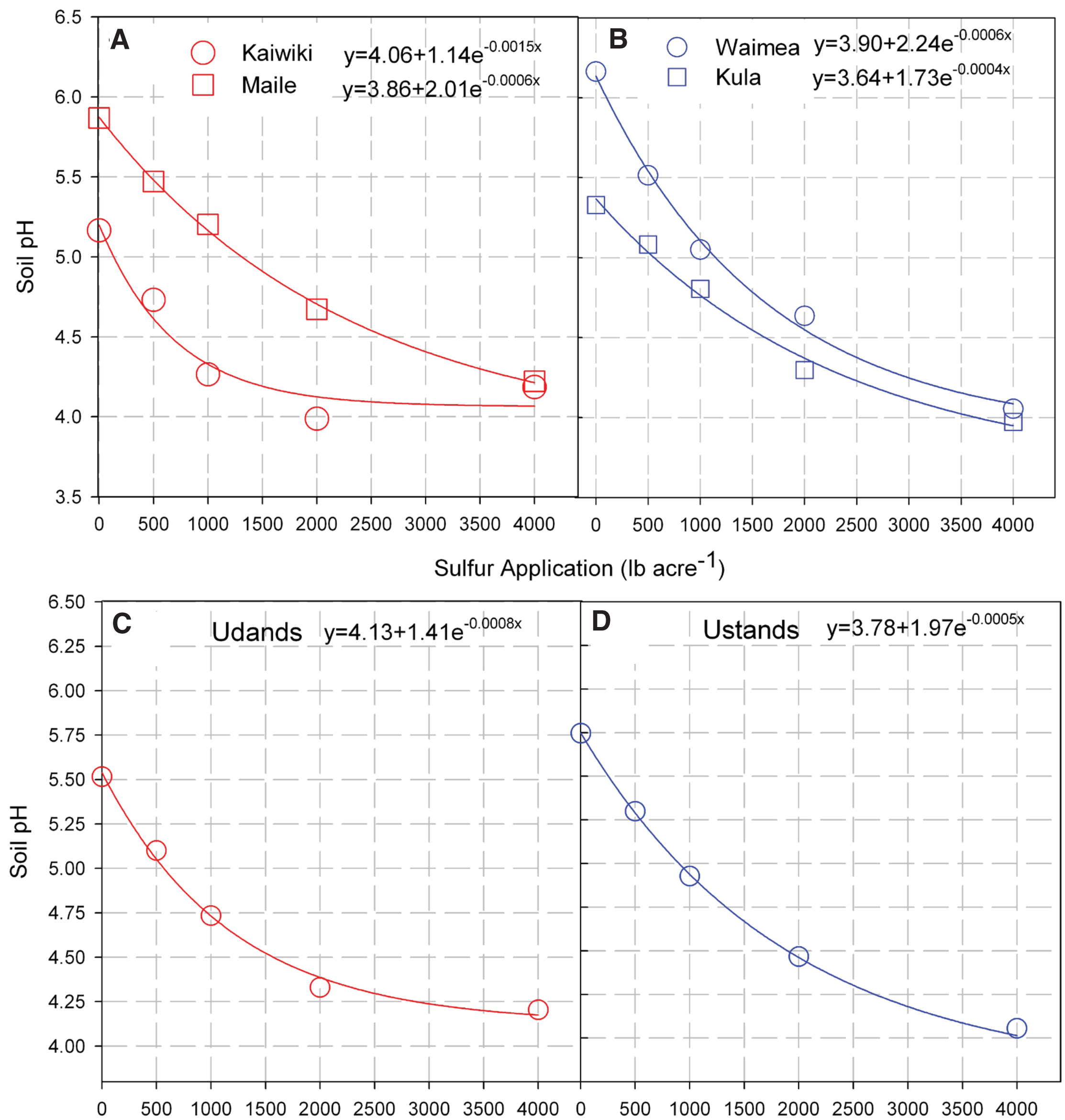


Figure 3. Acidification curves for the A) Kaiwiki and Maile soils and B) Waimea and Kula soils, and general curves for soils in C) Udands and D) Ustands sub-orders. The data points were fit with a first-order exponential decay model to predict pH change with increasing S additions.

important role in regulating the acidification reaction. Sandy soils with a low cation exchange capacity (CEC) require less S to lower pH, whereas soils with high clay content and high CEC require larger quantities of S to achieve the same pH change.

To determine how much S is required to acidify the volcanic soils of Maui and Hawai‘i Islands, we incubated two Ustands and two Udands with increasing amounts of elemental S. A Kula series from uncultivated land at the Kula Research Station (elev. 3,000 ft) on Maui and a Waimea series from the Lālāmilo Research Station (elev. 2,500 ft) in Waimea on the Big Island were chosen to represent the Ustands. The Maile series from the Mealani Research Station (elev. 2,800 ft) and the Kai-

Table 1. Calculated amounts of S^0 required to reach selected target pH values for the volcanic ash soils studied.

Target Soil pH	Kaiwiki	Maile	Udand Mean*	Kula	Waimea	Ustand Mean*
	Initial pH					
	5.2	5.8	5.5	5.4	6.2	5.75
	Pounds Elemental S per Acre					
5	130	1,420	602	600	1,180	955
4.8	290	1,900	927	1,000	1,510	1,312
4.6	500	2,500	1,368	1,470	1,930	1,748
4.4	810	3,280	2,056	2,050	2,490	2,305
4.2	1,410	4,440	3,708	2,810	3,330	3,080

*Udand mean represents mean of Kaiwiki and Maile series. Ustand mean represents mean of Kula and Waimea series.

wiki series from uncultivated land in Nīnole (elev. 2,000 ft) on the Big Island are representative of the Udands. The equivalent of 0, 500, 1,000, 2,000, and 4,000 lbs of commercial-grade S per acre was applied to the soils, which were incubated at field moisture capacity. The soil mixtures went through three wetting and drying cycles to facilitate the S reaction in the soil; then after one month soil pH was measured (1:1 soil:water).

Figures 3A and 3B show the acidification curves for the Kaiwiki, Maile, Kula, and Waimea soils. The acidification reaction was complete within the first month after application, and the S was effective at maintaining an acidic soil environment for the 7-month incubation period—soil pH increased on average by only 0.2 units during the incubation. By fitting the data points in each curve with an exponential decay equation, we can estimate the amount of elemental S required to reach a target soil pH. Figures 3A and 3B provide a guideline for the amount of S required to decrease soil pH to desired levels for the four soil series. In Table 1, we provide calculated amounts of S to achieve target pH levels for the four soils tested. If your soil series is not one of the four listed above, you can use the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/) to determine your soil series (your local Cooperative Extension Agent or Natural Resources Conservation personnel can also assist you to determine your soil series). Once you have identified your soil series, find it in Table 2 to determine whether it falls into the Udands or Ustands soil group. Figures 3C and 3D are general acidification curves obtained by calculating the means for the two soils to represent Udands and Ustands. We provide calculated amounts of S that should be applied to reach specific target pH levels for soils in the Udands and Ustands groups in Table 1.

Alongside the elemental S incubation, we included a peat moss treatment applied in a 1:1 soil-to-peat ratio by volume (equivalent to 237 tons of peat per acre, assuming peat has a bulk density of 21.8 lbs per ft^3). Overall, peat was much less effective in decreasing pH than elemental S, and it was least effective in the Kaiwiki and Maile series, effecting only a 0.3- and 0.4-pH unit reduction, respectively. In the Kula and Waimea series, pH declined by 0.6 and 0.8 units, respectively (Figure 4). Furthermore, in contrast to S applications, the peat was not effective at keeping the soils acidic. In the Waimea and Kula soils, the pH increased by 0.3 and 0.4 units respectively, and the pH of the Maile and Kaiwiki soils returned to its original values after 7 months of incubation. The quantity of peat required to achieve these relatively small and temporary changes in pH is prohibitively expensive and impractical, especially at larger scales. However, peat additions increase soil organic matter levels with beneficial impacts on soil properties.

Applying Elemental S to Acidify Soils

Applying elemental S is an effective way to acidify the

Table 2. Soil series on Hawai'i and Maui that meet elevation requirement for blueberry production and fall within the Udands and Ustands sub-orders.

Soil Sub-Order	Island	Soil Series
Udands	Hawai'i	Akaka
		Alapai
		Hilea
		Honaunau
		Honokaa
		Honuaulu
		Kahua
		Kealakekua
		Kehena
		Maile
		Manu
		Moaula
		Ohia
		Piihonua
		Puaulu
		Punohu
		Puhimau
		Umikoa
Ustands	Hawai'i	Apakuie
		Hanipoe
		Kamaoa
		Kapapala
		Kikoni
		Laumaia
		Naalehu
		Palapalai
		Puu Pa
		Waiaha
		Waimea
	Maui	Io
		Kaipoipoi
		Kula
		Laumaia
		Oli
		Olinda
		Pane
		Puu Pa

volcanic soils suited to blueberry and tea production in Hawai'i. There are several commercial S products available in Hawai'i, which vary in both S composition and cost (Table 3). The elemental S can be broadcast over a field, but applying it in bands along the planting rows as wide as the diameter of the plant crowns will increase efficiency and reduce costs by concentrating the amendment near the plant roots (Table 3). The S should be incorporated via tilling to a depth of six inches and kept moist to insure that the acidification reaction proceeds normally. If the S is applied during the dry season, plans for irrigation must be included to keep the soils moist. Approximately two months after application, a pH test should be conducted to verify whether the target pH has been achieved. We emphasize that the results presented in this publication were developed in the laboratory, where conditions are optimized for the acidification reaction. We expect that higher quantities of S may be required to achieve similar pH changes in the field.

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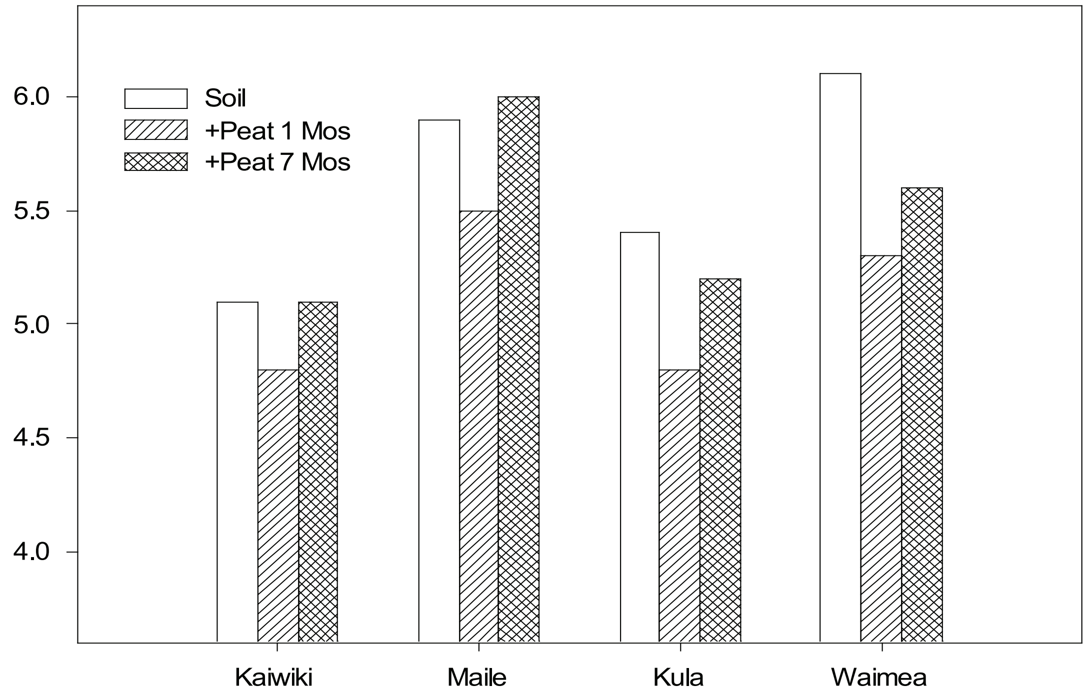

Figure 4. The effect of commercially available peat moss on the pH of 4 volcanic ash soils found on Maui and Hawai‘i.

Table 3. Estimated S costs for three different S products available in Hawai‘i, either broadcast or banded, to reach a target soil pH of 4.6 for the 4 volcanic ash soils.

S Product	Cost Per Acre to Reach Target pH of 4.6							
	Kaiwiki		Maile		Kula		Waimea	
	5.2		5.8		5.4		6.2	
	Initial pH							
	Broadcast	Banded[a]	Broadcast	Banded	Broadcast	Banded	Broadcast	Banded
Sulfur 90[1]	$325	$122	$1,354	$507	$797	$298	$1,045	$391
Drexel[2]	$818	$306	$4,085	$1,529	$2,402	$899	$3,153	$1,180
Kumulus[3]	$1,200	$449	$4,996	$1,870	$2,938	$1,100	$3,856	$1,443

[1]$24.00 per 50 lbs., 90% S; [2]$44.15 per 30 lbs., 90% S; [3]$48.00 per 30 lbs, 80% S
[a]These calculations were based on a planting density of 1,352 plants per acre and S applied to 3-foot-wide beds.

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