Effects of land use on soil properties in a Hawaiian volcanic ash soil

Amy Saunders* and Michael Robotham, USDA – NRCS Pacific Islands Area

Introduction

Soils on the eastern slopes of Mauna Kea on the Island of Hawaii (Hamakua coast) developed from volcanic ash parent material in a warm, humid climate (Figure 1). Northeasterly trade winds carry abundant moisture in from the ocean, resulting in favorable agricultural conditions.

For approximately 100 years between the late 1800s and the 1990s, large scale sugar cane production was the predominant use for soils along the Hamakua coast at elevations below 650 m above sea level (asl) (Figure 2). The sugar cane industry became fully mechanized in the 1950s in an effort to combat higher labor costs and increase yields. Eventually, international competition drove sugar cane production outside of Hawaii, leading to the closure of the last sugar cane plantation on the Island of Hawaii in 1996.

Historically, pasture and forest were the major land uses for Hamakua soils at higher elevations. Cattle ranchers established pastures for grazing. Forests included plantings of eucalyptus and other exotic species for timber, as well as isolated remnants of native forest, both which remain today.

Current land uses on the Hamakua coast include pasture, timber plantations (Eucalyptus spp.), native forest, small farms, rural housing, and unmanaged weedy fallow (Figure 3).

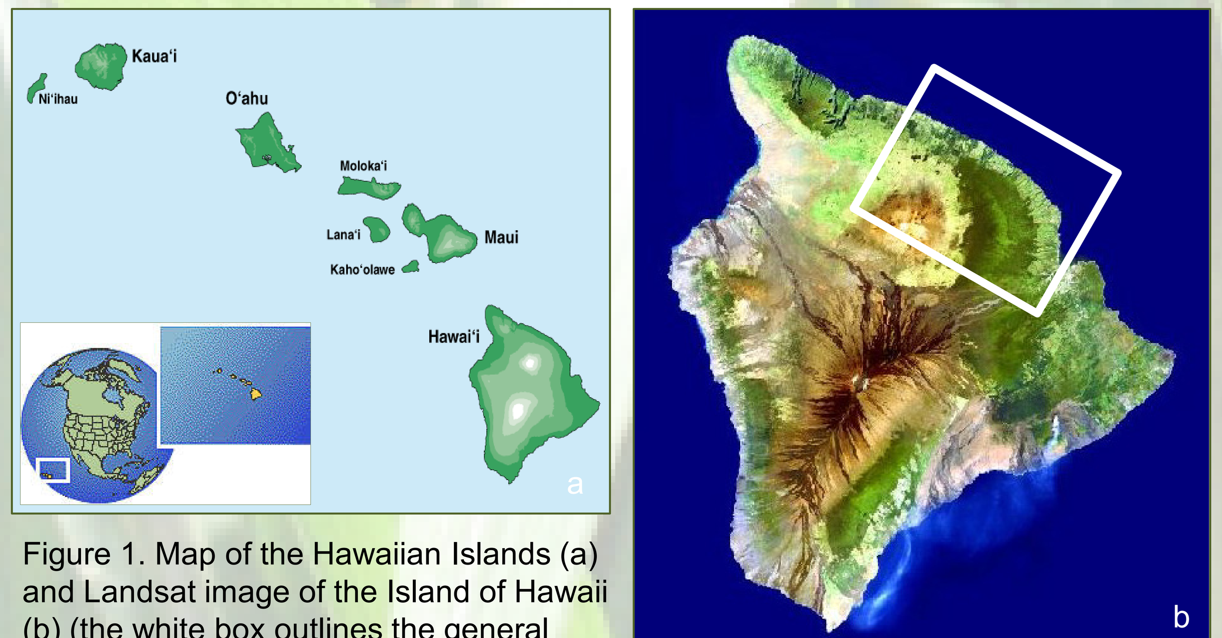


Figure 1. Map of the Hawaiian Islands (a) and Landsat image of the Island of Hawaii (b) (the white box outlines the general area of the Hamakua Coast).

Purpose

The purpose of this analysis is to:

1) Correlate available laboratory data for the Honokaa soil series to past and present land use;

2) Evaluate data to determine whether historical land use affected soil physical and chemical properties; and

3) Identify data needs for further investigations of land use and soil change relationships in Hawaii.

By understanding the effects of land use on soil properties, we will be able to guide present day management of these soils more effectively.

Figure 2. Photos of sugar cane production. (a) Sugar cane (b) Field after harvest (c) Harvest machinery (d) Preparation for replanting. Photos courtesy of USDA-NRCS PIA and G. Uehara, University of Hawaii at Manoa.

Figure 3. Photos of current land uses on the Hamakua coast. (a) Timber and pasture (b) Timber plantation (c) Unimproved pasture (d) Native forest. Photos courtesy of USDA-NRCS and Forest Solutions, Inc.

Study Area

Honokaa soils (Hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands) are found on mid-elevation windward slopes of Mauna Kea at elevations from 335 to 1222 m asl, along the Hamakua coast of Hawaii Island (Figure 4). Steep and narrow drainage gulches dissect the landscape. These soils formed in basic volcanic ash over 64,000 to 300,000 year old lava flows. The mean annual rainfall ranges from 2000 to 3800 mm and the mean annual soil temperature is 18 to 22 C.

Honokaa soils were previously used for sugar cane cultivation at elevations from 335 to 650 m asl and pasture and forest at elevations from 650 to 1222 m asl. The 1973 Soil Survey of the Island of Hawaii identifies a break between two phases of the Honokaa soil series at 650 m asl, thus differentiating areas by their suitability for sugar cane production. Currently, dominant land uses are timber plantations, pasture, and native forest. Due to their diversity of past and present land uses, Honokaa soils provide a unique environment for studying the effects of land use on soil properties.

Figure 4. Study area. The extent of the Honokaa soil series is outlined in pink, the locations of the soil pedons studied are marked with stars, and 650 m asl elevation is shown in teal.

Methods

In order to analyze former sugar cane, pasture, and forest soils of the Honokaa soil series, we:

1) Gathered and evaluated all of the available laboratory data from the National Soil Survey Laboratory and selected six soil pedons of the Honokaa series;

2) Identified historical and current land uses for each pedon site; and

3) Summarized laboratory data of soil pedons by horizon for the following soil properties:
   a. Bulk density at 33 kPa (gcm^{-3})
   b. Organic carbon content (% of <2mm)
   c. Effective cation exchange capacity (ECEC) (cmol(+)kg^{-1})

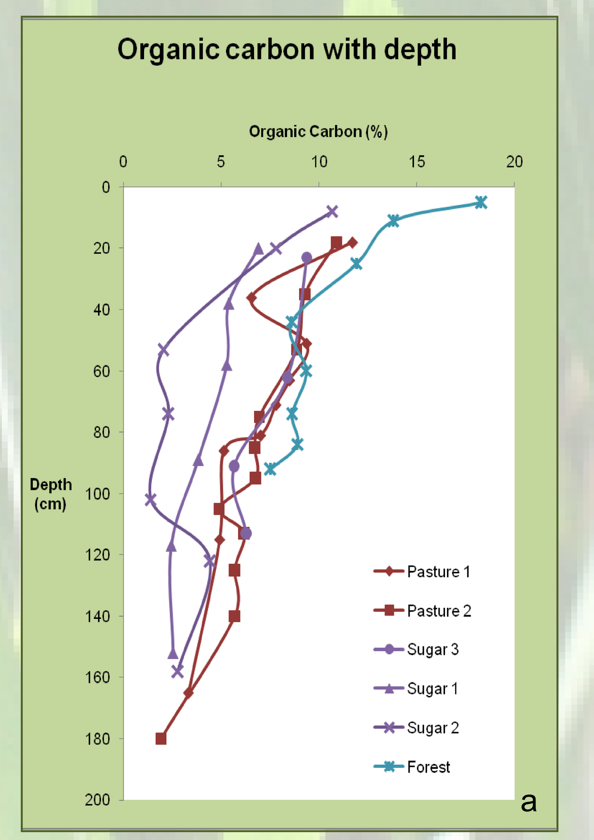
Table 1. Land use and sample date of pedon sites.

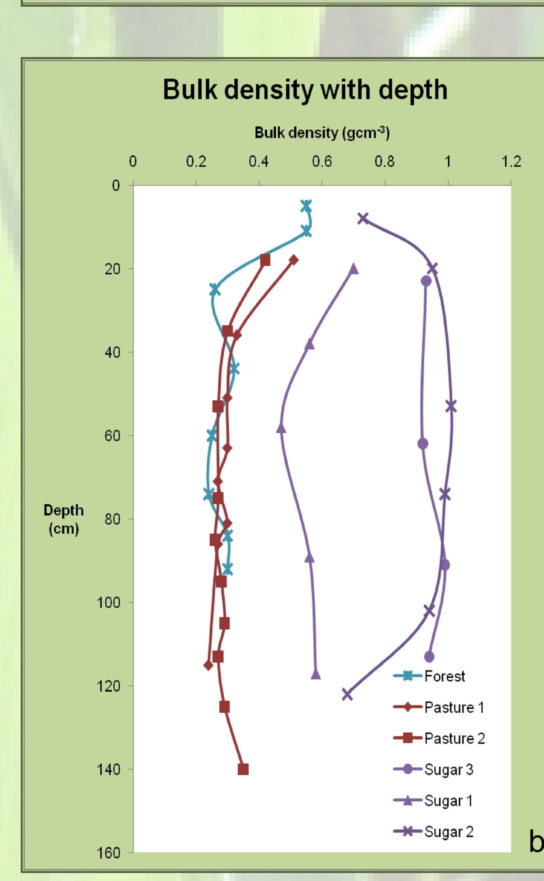
Pedon Name	Year Sampled	Past Land Use	Current Land Use
Sugar 1	1982	Sugar cane	Timber plantation
Sugar 2	1987	Sugar cane	Timber plantation
Sugar 3	2005	Sugar cane	Pasture
Pasture 1	1962	Pasture	Timber plantation
Pasture 2	1962	Pasture	Pasture
Forest	1999	Forest	Forest

Results and Discussion

The six selected pedons are distributed throughout the extent of the Honokaa soils (Figure 4). Sampling dates span 43 years and past and present land uses vary (Table 1). Three pedons were former sugar cane sites (Sugar 1, 2, and 3), two were pasture (Pasture 1 and 2), and one was native forest (Forest). Two of the former sugar cane sites (Sugar 1 and 2) and one of the former pasture sites (Pasture 1) are currently used for timber plantations (Eucalyptus spp.). One former sugar cane site (Sugar 3) is now used to graze dairy cows. Land use of the forest site (Forest) and the other pasture site (Pasture 2) did not change.

Data from the selected pedon samples indicate that former sugar cane areas generally have higher bulk density and lower surface organic carbon content than soils that were used for pasture or remained under natural vegetation (Figure 5 and Table 2). The higher bulk density values of the former sugar cane soils can likely be attributed to compaction resulting from the repeated traffic of heavy machinery. Organic carbon in the former sugar cane soils likely decreased as a result of repeated plowing as well as erosion (wind and water) of surface horizons when the soils were bare after harvesting and before replanting. Field investigations for the Hamakua coast agree with these findings, noting that former sugar cane soils are often compacted and surface horizons are thin with weak structure and low organic carbon when compared to pasture and forest soils (Figure 6). Effective cation exchange capacity (ECEC) was highest in the surface horizons and decreased with depth for all six pedons (Figure 5). Overall ECEC values did not vary noticeably amid land uses (Table 2).





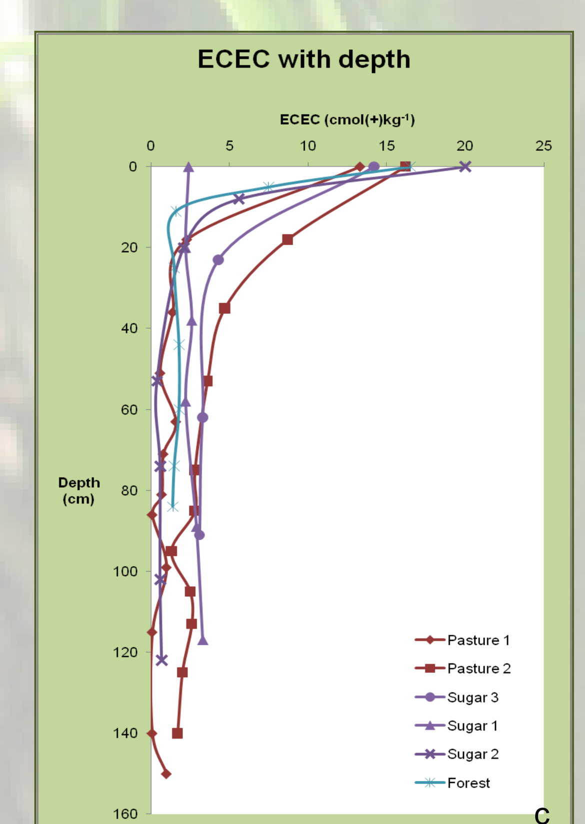


Figure 5. Graphs demonstrating trends in organic carbon (a), bulk density (b), and ECEC (c) with depth for selected Honokaa soil pedons. Data indicate that former sugar cane areas generally have higher bulk density throughout the profile and lower surface organic carbon content than soils that were used for pasture or remained under natural vegetation. ECEC was highest in the surface horizons and decreased sharply with depth, showing comparable values for all pedons.

Figure 6. Photos of Honokaa soils at former pasture (a) and former sugar cane (b) sites. Both sites are now used for timber plantations (*Eucalyptus spp.*). The surface horizon of (a) is slightly thicker and darker than (b). The horizons of (a) are more distinct than (b), which shows evidence of compaction and mixing. Photos courtesy of USDA-NRCS.

Table 2. Summary of surface horizon properties for each soil pedon.

Pedon Name	Depth	Bulk Density (33 kPa)	Organic C	ECEC	pH (H_2O)	pH (KCl)
	cm	gcm^{-3}	%	cmol(+)kg^{-1}		
Sugar 1	0-20	0.70	6.91	2.4	5.1	4.8
Sugar 2	0-8	0.73	10.68	20.0	5.3	4.7
Sugar 3	0-23	0.93	9.38	14.2	6.2	NA[2]
Pasture 1	0-18	0.51[1]	11.70	13.3	NA[2]	NA[2]
Pasture 2	0-18	0.42[1]	10.90	16.2	NA[2]	NA[2]
Forest	0-5	0.55	18.30	16.5	5.2	4.4

[1] 1962 bulk density samples were determined at field capacity. [2] Data not available.

Conclusions

Our analysis indicates that intensive land use, specifically sugar cane production, can change soil properties over short periods (<100 years) of time. Changes in soil physical properties (organic carbon, bulk density) seem to be more apparent than changes in chemical properties (ECEC). The changes we observe in soil properties between former sugar cane, pasture, and forest soils of the Honokaa series are important because of their impact on present day management of these areas. Understanding dynamic soil properties is important so that proper management of these soils can be suggested to land managers. Future investigations will explore if current land use has any effect on reverting soil properties of former sugar cane soils to a state similar to the pasture and natural vegetation areas.

References

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*Corresponding author:
Amy Saunders
USDA-NRCS PIA, Hilo, Hawaii
amy.saunders@hi.usda.gov

Michael Robotham, Ph. D.
USDA-NRCS PIA, Honolulu, Hawaii