SOIL CHEMISTRY AND AGRICULTURE: ANALYSIS OF FIVE ARCHAEOLOGIAL SITES ON THE ISLAND OF HAWAI'I

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INTRODUCTION

In 1981, the Bernice P. Bishop Museum conducted an extensive archaeological survey and excavations in the Waimea-Kawaihae region of the District of South Kohala, Hawai'i Island (Clark and Kirch 1983). A key research problem addressed during that project centered on the exploration of the nature and variability of prehistoric Hawaiian agricultural practices. It became important, therefore, to be able to identify agricultural soils. To this end, we undertook limited chemical analyses of soils from selected archaeological sites and associated control areas. These sites ranged from clearly identified agricultural fields to hypothesized farming areas. The results of these analyses, summarized in this paper, suggest a pattern of chemical differentiation between agricultural and non-agricultural areas.

RESEARCH AREA

The Waimea-Kawaihae region of the western portion of Hawai'i Island (Fig. 1) is one of marked contrast. Kawaihae, a village on the leeward coast at the bay of the same name is situated at the juncture of the ocean, the Kohala Mountain slope, and the lower portion of the Waimea Plain. The present village of Waimea lies 15 km inland, where the southern base of the Kohala slope meets the northern edge of the Waimea Plain. Kawaihae, and the area for several kilometers inland are extremely arid, hot, and rocky. Much of the region has undergone extensive erosion and exposed bedrock is a common occurrence. As one moves inland (east) from Kawaihae, increasing elevation is accompanied by several environmental shifts. By the time one reaches Waimea the surroundings are cool and moist

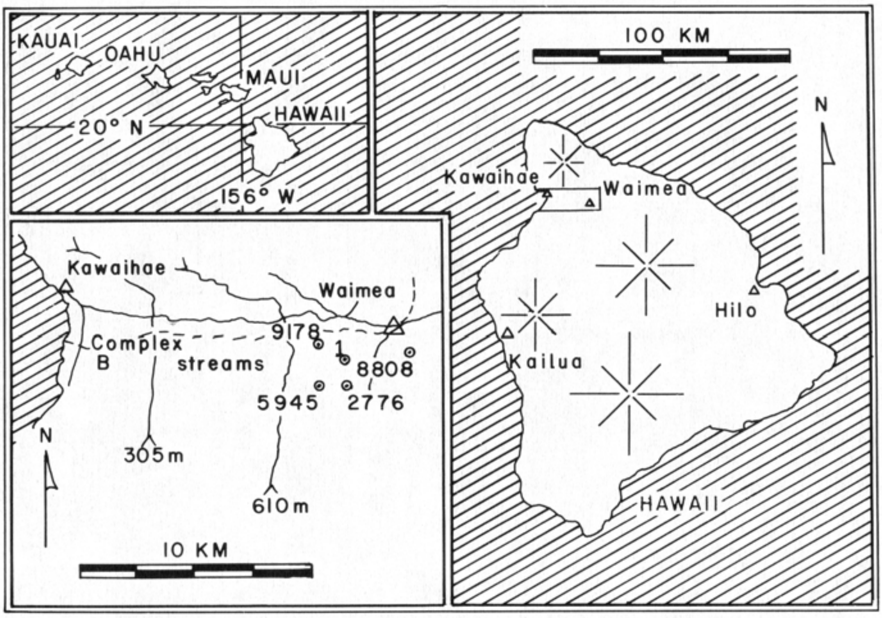

Fig. 1. HAWAI'I ISLAND AND PROJECT AREA.

with verdant vegetation, deep soils, and only occasional outcrop knolls or small ridges. Perhaps the contrast between Kawaihae and Waimea can best be expressed in the following passage from G. T. Allan who, in 1847, reported on his journey from the coast to the uplands:

> The whole face of the country around {Kawaihae} is barren in the extreme, and even destitute of fresh water, and the natives appear to have almost abandoned it... The heat during the day is so oppressive that there is no going out, but the sea breeze, which sets in about 9, A. M., keeps the house pleasantly cool, and bathing in the evening, is delightfully refreshing.....we set out for {Waimea}. For nearly half the distance, the heat and dust was disagreeable in the extreme; the former skinning our lips and noses, and the latter filling our eyes; but the last part of the ride proved pleasant enough, the ever bracing trade wind coming down in our face, wonderfully revived us, and led us to believe that we scented snow on Mauna Kea, which was now in sight. The scenery, which had thus far resembled the environs of Kawaihae, now entirely changed, and the hills began to look pleasantly green and wooded-The climate throughout the year is cool and invigorating (Allan 1847).

The human settlement of this region can be thought of in terms of four main zones. The first is the coastal zone which is an area of intensive occupation centered on Kawaihae Bay. Residential, burial, and agricultural sites are scattered from the shoreline to an elevation of approximately 225 m above sea level (asl). From there to about 550 m asl is an intermediate zone where sites are comparatively few and scattered. Seasonal farming of small soil patches, bird catching, grass collection (for thatch and mulch), and overnight encampments for travelers were the principal activities carried out in this zone. Next comes the upland agricultural zone which stretches from about 550 m to 830 m asl and is the locus of the Waimea agricultural system (Clark 1981; 1983). An extensive prehistoric population is indicated by the many residential features dispersed over the knolls and ridges that separate stretches of agricultural fields. These fields were watered by an extensive set of irrigation ditches which form a complex, reticulate pattern. To the east of the agricultural system is the fourth zone, one of little or no prehistoric occupation. Settlement picks up again when one descends onto the windward slopes.

RESEARCH GOALS AND METHODS

A major research goal established for the Waimea-Kawaihae Archaeological Project was an exploration of the nature and variability of prehistoric Hawaiian agricultural practices (Clark and Kirch 1983:16-17). One of the means by which we sought to pursue that goal was soil chemistry analysis. Through this analysis we hoped to establish a means of distinguishing agricultural from non-agricultural soils, and at the same time provide a general assessment of soil fertility.

Five sites were selected for an examination of soil chemical properties. Of these, two sites (9178 and 8808) represented cases of clearly identifiable agricultural fields on the basis of numerous formal field features. Two others (2776 and 5945) appeared to represent farmed areas due to topographic considerations in conjunction with associated temporary residential structures and limited agricultural features. At the final site (2627), farming was inferred solely on the basis of topography and associated temporary residential structures. At each site, two or more locations within a suspected farmed area along with one or two control locations in areas which gave no indications of past agricultural activities were selected for the collection of soil samples. Control locations were established as near to the farmed area as possible so as to minimize the effect of other factors (such as different soils, rainfall, and vegetation) on the analysis.

At each sample location small units were dug (about 0.6 by 0.3 m), soil horizons identified, and soil samples collected. In the laboratory these samples were subjected to the following analyses: color, recorded both moist and dry (Munsell soil color chart); pH (paste in water); acid extractable phosphorus (P) (modified Truog method); exchangeable cations including potassium (K), calcium (Ca), and magnesium (Mg) (extracted with N NH40Ac at pH of 7); readily oxidizable organic matter (Walkley-Black method); and reaction to N HCL to detect free CaC03. Averages were obtained by using a weighted mean approach.

In carrying out these analyses we confronted two major problems. The first was the identification of adequate control locations. The absence of any surface features suggestive of farming is not completely satisfying but is the best we could hope for. In any case, while some form of farming may have occurred at some of the control locations, the nature of that activity would certainly have been much less intensive than at the suggested farmed areas, and it would have been accomplished without any form of irrigation.

The second problem relates to the fact that mass wastage has taken place at each of the sites examined. Agricultural layers have been particularly affected by this process. After the abandonment of agricultural activities, the combination of loose fine soil, high winds, and roaming cattle herds inhibited the regeneration of vegetation, leading to extensive erosion of the farmed soil layers. At some sites (e.g., 8808 and 9178), the former agricultural layers are now spotty in their occurrence. The importance of this factor will be made evident in the discussions which follow.

RESULTS

A brief description of each site will be given followed by a summary of the results of the soil chemistry analyses. Detailed site descriptions and excavation data (Clark and Kirch 1983) and soil chemistry data (Tamimi 1982) have been given elsewhere. Basic environmental data for each site are presented in Table 1.

Site 50-10-06-8808

This site is located on the extreme eastern (inland) edge of the upland settlement zone. It consists of a series of formal agricultural fields bounded by low soil ridges and watered by a set of irrigation ditches. The irrigation system used was a simple, supplemental form rather than the more common ponding. While farming may have taken place in this area earlier, the formal field units appear to date from the mid 1700s to mid 1800s A.D. The field complex is bounded on the south and west by stone walls presumably constructed to keep out marauding cattle.

Four locations within a single field were sampled although one of these consisted of only a single sample from the suggested agricultural layer. This fourth sample was collected in order to insure representation of this layer since we suspected that, due to erosion, the layer may not have been present in the first three columns. As

TABLE 1

SUMMARY OF ENVIRONMENTAL DATA

Site No. (50-10-)	Elevation (m)	Rainfall (mm)	Mean Range of Soil Temp. (°F)	Soil*	Dominant Vegetation
05-2627	80-95	<250	74-77	Kawaihae extremely stony very fine sandy loam. Moderate permeability, medium runoff, moderate erosion hazard.	Grasses and low shrubs with bands of *Prosopis pallida* along the gulches.
05-9178	695	450	69-71	Puu Pa; extremely stony very fine sandy loam. Moderately rapid permeability, medium run-off, moderate erosion hazard.	Grasses and low shrubs with an occasional tree, usually *Erythrina sandwicensis*.
06-5945	730	350	69-71	Same as Site 9178.	Grasses and low shrubs.
06-2776	760	375	69-71	Same as Site 9178.	Grasses, low shrubs, cactus.
06-8808	815	600	59-62	Waimea very fine sandy loam. Moderately rapid permeability, slow runoff, slight erosion hazard.	Grasses (pasture), primarily *Pennisetum clandestinum*.

*Source: Soil Survey of Island of Hawaii, State of Hawaii, by the U.S.D.A. Soil Conservation Service.

it turns out, this sample is indeed critical for our interpretation of the chemical analyses. A single control column was located a short distance to the south of the southern boundary wall.

On the whole, the farmed areas differentiate readily from the control by being lighter in color, more acidic, lower in P, K, Ca, and total cations, and higher in organic matter. When one focuses specifically on what has, on the basis of other criteria, been interpreted as the agricultural layer, the same differences hold, but with the important exception that P is higher in this layer relative to the control samples and to the lower levels of the field columns.

Site 50-10-06-2776

This site is located on the extreme southern margin of the Waimea agricultural system. it consists of a small (ca. 0.49 hectare) swale bounded by low rocky ridges and associated small temporary occupation sites. A primary irrigation ditch runs along the southern edge of the swale while a secondary branch can be traced for a short distance along the northern flank. A simple irrigation technique is represented, in which water was introduced to the planted swale as needed and allowed to flow through and seep into the soil. The temporary campsites on the rocky ground above the swale were occupied in the early 1800s A.D. and perhaps the late 1700s.

Two sample areas within the swale were examined along with two control columns, one each from separate swales to the southwest of the site. Neither of these control swales had associated residential or agricultural features.

In general, soil P and K are higher throughout the profiles of the farmed area than in the controls. Ca levels are more difficult to interpret. Within the suggested agricultural layer of the swale, Ca is slightly lower relative to the layers above and below, but is not significantly lower than the controls. The other parameters are inconclusive.

Site 50-10-06-5945

This site is similar in layout and type to site 2776 and lies on the extreme southern edge of the Waimea agricultural system. It consists of a small swale bounded by rocky ridges, and fed by a primary irrigation ditch along the southern edge and a secondary ditch on the north. Temporary residential structures associated with a slightly larger swale approximately 120 m to the west date to the first half of the nineteenth century, and possibly to the late eighteenth century A.D. A burial located on the ridge above the 5945 swale yielded a date of A.D. 1500 to A.D. 1800. Charcoal samples from a buried soil layer within the swale yielded dates between about A.D. 1300 and A.D. 1500. While the burning event represented by the latter dates is probably related to human activity, the relationship of this event to farming in the swale is not clear. In any case, there is evidence of human activity in this area substantially earlier than indicated by residential remains.

Two sample locations were selected within the swale and a single control column was collected approximately 60 m to the south.

Both pollen (Bennett 1983) and phytolith (Pearsall and Trimble 1983) analyses have indicated that the top layer in the swale is actually a pre-modern deposit, suggesting that extensive soil erosion has taken place at this locale. The impact of this process on our interpretation is not clear, but it seems likely that at least a portion of the old agricultural layer has been eroded away.

In any case, soil P, K, and total cations are substantially higher in the 5945 swale, particularly in the soil layer interpreted as agricultural. Mg also tends to be higher in this layer, although the differences are not as marked. Ca levels are variable.

<u>Site 50-10-06-9178.1</u>

Located in the heart of the Waimea agricultural system, this is clearly a site of agricultural activity. The area of our concern is a broad swale bounded on the north and south by low *rocky* ridges and divided into a series of rectangular fields by low, linear mounds of soil and stones. Irrigation ditches to provide supplemental watering run at the base of the ridges, perpendicular to the long axes of the fields. Small stone planting mounds are distributed throughout the fields. Six pondfields are located at the eastern end of the swale. These appear to be superimposed over earlier fields and probably represent relatively late farming activities. The fields fed by supplemental irrigation appear to date to sometime from the mid sixteenth to the very early nineteenth centuries

A.D., while the pondfields (paddy type irrigation) are probably from sometime in the nineteenth century.

Six sample locations were selected at this site, two from a single supplementally irrigated field, two from a pondfield, and two controls--one from a gentle soil slope north of the swale and the other from a soil patch atop the southern ridge. While dry planting may have occurred at the control locations, irrigation was not used and the intensity of planting would undoubtedly have been less than in the fields proper. We consequently set up a three part comparison at this site between unplanted (or at least unirrigated) areas, supplementally irrigated fields, and pondfields.

Mass wastage again presented a serious problem in interpreting our results since very little of the original farming soil remains in the fields. This was of particular concern with one of the pondfield columns leading us to give little consideration to the calculations from that column.

If comparisons of column results are made on the basis of unadjusted depth alone, P tends to be higher and Ca lower in the supplementally irrigated field than in the controls, while K and Mg levels vary. When we compensate for differential erosion in the fields and controls, and compare the suggested agricultural layer with what probably would have been a comparable depth in the controls, P is higher, K tends to be slightly higher, Ca is lower, and Mg is variable. When samples from the pondfield are compared with those of both the irrigated field and the controls, more striking differences emerge. Regardless of which comparison is made, P is higher, K and Mg are slightly higher, and Ca significantly lower in the pondfield. In addition, in the pondfield column the pH drops with depth indicating acidification--the normal pattern is for soils to become more alkaline with depth.

Site Complex B

A set of associated features initially designated as five separate sites compose this complex. The complex centers on two small alluvial flats adjacent to a small intermittent stream gulch. These flats are bounded on the east and west by low rocky ridges and on the north and south by the stream gulch and a smaller branch gully, respectively. Thin strips of alluvium along both of the water channels link the two alluvial flats. During the winter months, heavy rainfall further inland can send a flow of water down the gulch overflowing the banks and sending water and alluvium over the soil flats. Five small, temporary shelters and two rock piles are found on the ridges above the flats. Occupation of these shelters appears to have fallen between the early sixteenth and early nineteenth centuries A.D. The site complex is similar to complexes elsewhere in this region which have been described as "flood-water farming" areas (Rosendahl 1972). It is suggested that the alluvial flats of Complex B were exploited for seasonal (winter) cropping with the stone shelters being short-term frequentation sites for persons tending the crops. Presumably the permanent residences of the planters were at or near the coast.

Two sample locations were within the larger alluvial flat and two control locations were selected for analysis. The first control was situated on a low bench of the ridge to the north of the larger flat, but the shallow soil yielded only one soil layer (and sample). Deeper soil was found at the second control which was located in a small soil flat some distance to the south.

Relative to the controls, the soils within the alluvial flat show slightly higher P and K, but lower Ca and Mg. The pH of the middle layer soils drops to slightly acidic before again increasing in alkalinity.

CONCLUSION

When conducting studies such as this, several points must be kept in mind. It is important that soil scientist and archaeologist work closely together in the field during collection and initial description of soil samples. The selection of adequate controls is also of critical importance. In addition, an understanding of the depositional and erosional processes affecting both the site and the controls is necessary for the interpretation of the results. Vertical (stratigraphic) comparisons may be as important as horizontal control for interpretations, although the discrimination of agricultural layers within a profile is less likely to be successful than general distinctions between farmed and non-farmed. Our ability to identify, with reasonable probability, farmed areas on the basis of soil chemistry will depend on developing a general pattern of differentiation for a region. Nonetheless, specific site-control differences in soil chemistry will vary from site to site, even within a relatively small geographic area. Agricultural techniques, cultigens raised, soil formation processes, post-abandonment conditions, intensity of cultivation, moisture availability, water-borne nutrients, and other factors can all affect the results and interpretations of soil chemistry analysis.

In the Waimea-Kawaihae region our studies suggest a general pattern of distinction between farmed and non-farmed soils. Table 2 gives a simplified presentation of relative differences between the site and the control columns in the key parameters (i.e., P, K, Ca, and Mg). In some cases the differences are quite marked while in others they are rather small. At Complex B, for instance, the differences in quantities observed are not by themselves substantial enough to demonstrate agricultural activity. They assume greater significance, however, by virtue of the fact that they are in accord with a general pattern suggested for the area. While these results do not prove that the soil flat was farmed, they do provide us with a stronger argument that such was in fact the case.

Our data from Waimea-Kawaihae suggest that farmed soils tend to differentiate from non-farmed by way of higher levels of P and K, and to a lesser extent Mg, and lower levels of Ca. Pondfields differentiate from non-ponded fields and from controls by the same parameters, although the differences are more pronounced. In addition, acidification of soil takes place in pondfields and to a lesser extent in often-flooded areas. The more intensive the agricultural utilization of an area the more pronounced the differentiation is likely to be. And finally, at all sites examined the soil fertility was sufficiently high for good crop growth if adequate water was provided.

In future studies, additional analytical parameters such as soil mineralogy and particle size distribution in soil horizons should be investigated in conjunction with soil chemistry. Archaeologists have much to learn on the effects of agriculture on soil chemistry, and, conversely, on the effects of soil chemistry on agricultural practices.

The soil studies reported here constitute a feasibility study on the effectiveness of soil chemistry analyses in identifying farmed soils. We feel that the results are sufficiently positive to warrant further studies along these lines. At the same time, however, we recognize that soil chemistry

TABLE 2
SUMMARY OF CHEMICAL QUANTITIES IN
SUGGESTED AGRICULTURAL AREAS RELATIVE TO CONTROLS

	Site	Analytical Context	P	K	Ca	Mg
1.	8808	Site	-	-	-	?
	8808	Agricultural layer	+	-	-	+
2.	2776	Site	+	+	?	?
	2776	Agricultural layer	+	+	-	?
3.	5945	Site	+	+	?	?
	5945	Agricultural Layer	+	+	?	+
4.	9178.1	Field, general	+	?	-	?
	9178.1	Field, agricultural layer	+	+	-	?
	9178.1	Pondfiled, general and agricultural layer	+	+	-	+
5.	2627	Site	+	+	-	-

+, higher quantities than controls.
-, lower quantities than controls.
?, variable quantities relative to controls.

alone does not present a quick and easy means of clearly identifying agricultural soils. Rather, soil chemistry provides a potentially productive analytical tool that can be used in conjunction with other methods for the investigation of agriculutral sites.

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