# SOIL CHARACTERISTICS ASSOCIATED WITH AGRICULTURAL ENCLOSURES (*MANAVAI*) ON RAPA NUI

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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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ABSTRACT

Some scholars argue that human-induced environmental changes on Rapa Nui (Easter Island) led to the collapse of the island's population and its culture. This project investigates changes to agricultural soils. Sediment samples were taken from several *manavai*, agricultural enclosures, at Maitaki Te Moa and Anakena. Samples were taken both inside and outside the *manavai* to test soils associated with agricultural use. Sediment samples were analyzed for several properties: pH, percent nitrogen (%N), percent organic carbon (%OC), and the cations phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). These data were indicative of changing soil properties and can show human alterations. I tested the null hypotheses to compare soils inside and outside *manavai*; in the event of a significant difference the hypothesis was rejected, indicating anthropogenic alterations. Overall trends indicate a major difference in soils from the two regions as well as human influences inside the *manavai*.

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# INTRODUCTION

Rapa Nui has long been considered a place of great mystery. It is a place of many names: Easter Island, Rapa Nui, or Te Pito o Te Henua, meaning the "Navel of the World." The island was likely colonized in a single migration around 1200 A.D. (Hunt and Lipo 2006). The isolation from the rest of Polynesia is marked by the unique developments in culture found on Rapa Nui. Since the first European discovery by the Dutch Explorer Jacob Roggeveen on Easter Sunday, 1722 foreigners have marveled at the island's archaeology. The first explorers saw the giant stone statues, or *moai*, and the debate continues to modern times of how they were transported from a major quarry to every corner of the island. Other recent debates surround Rapa Nui as well; some see it as a microcosm for the anthropogenic destruction of an ecosystem, and a lesson to be learned (Diamond 2004; Kirch 2004; Flenley and Bahn 2002). Others maintain that the lesson is in the destruction of a population and a culture at the hands of European ways and diseases; that the population, though small, was quite successful in scratching a living out of the now-treeless volcanic island (Rainbird 2002). Recent studies have brought to light even more questions. Hunt and Lipo's (2006) later chronology for Rapa Nui shows that even basic facts concerning the island's prehistory may be in error. The rapid population growth necessary to successfully colonize the island would have had immediate, drastic impacts on the natural environment and landscape, especially with the introduction of species, particularly the Polynesian rat (*Rattus exalans*) (Hunt and Lipo 2006). A rapidly growing population relied on the successful production of food.

The Rapa Nui people had several strategies to subsist in their environment. One agricultural device was the *manavai*: a stone structure, usually an enclosed circle and often sunk beneath the outer ground surface. It is known that these structures were used to grow the simple foods of the Rapa Nui diet. This study seeks to determine the effect human practices might have had on the soils inside used for agriculture. Soils were taken at several points from a small sample of six, out of about 2,100, manavai on the island, to be used for analysis and testing (Bradford, et al. 2005). The soil samples were analyzed for pH, total nitrogen percentage (%N), organic carbon percentage (%OC), and concentrations of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). General trends were discerned from this small sampling, and clear variations appear between the two areas of field research and remarkable results came from individual features as well.

# CHAPTER I: BACKGROUND

## *Environment and Geography*

Located 3,600 km (2,237 statute miles) west of continental Chile and 2,075 km (1,290 statute miles) east of Pitcairn Island, Rapa Nui is one of the most isolated inhabited islands in the world. It is located south of the tropics at 27°09′S 109°27′W, on a parallel slightly north of Santiago, Chile. The island is approximately triangular in shape, created by three primary volcanoes and numerous cones of tuff and scoria from later eruptions. The 171 $km^2$ (66 sq. miles) island supports a population of 3,791 (2002 census), 3,304 of which live in the town of Hanga Roa. The remainder of the island consists primarily of ranches and farmland, largely devoid of trees save for a forest of introduced eucalyptus in the center of the island.

Easter Island is recognized by ecologists as a distinct ecoregion: the Rapa Nui subtropical broadleaf forests. The original moist broadleaf forests are now gone, but paleobotanical analyses of fossil pollen, wood charcoal from archaeological deposits, and tree molds left by lava flows indicate that the island was formerly forested, with a range of trees, shrubs, ferns, and grasses. A large palm, related to the Chilean wine palm *(Jubaea chilensis)* was one of the dominant trees, as was the toromiro tree *(Sophora toromiro)*(Orliac 2000).

The location in the temperate southern latitudes creates a seasonal climate with an average temperature of 20°C (generally ranging 14-28°C) and the topography, though only 500 m at the highest point of Terevaka, creates a slight orographic rainfall effect over much of the year (Genz and Hunt 2003). There is only one weather station on the island, near sea level at Mataveri, where an average of 1,250 mm of precipitation is recorded yearly. Though the rainy season occurs during the southern winter months (May-August), winds and rainfall events can be short-lived and sporadic, allowing for high variability (Genz and Hunt 2003). Despite the orographic rainfall caused by the mountains, no permanent streams exist on Rapa Nui.

*Anthropological History*

Rapa Nui represents a complex society of monument builders and agricultural subsistence. The downfall of the civilization has several theoretical origins, and has recently been popularized as a model for the human-induced destruction of an environment and subsequent collapse (Diamond 2004, Kirch 2004, Flenley and Bahn 2002). The recently introduced later chronology has implications for the ability of a group to sustain itself and grow into a culture dominated by monument building in such a brief period of time (Hunt and Lipo 2006). The examination of the prehistoric agricultural potential and sustainability of the Rapa Nui people is vital to understand such phenomena.

The population of Rapa Nui was estimated at 2,000-3,000 when the island was rediscovered in 1722 by Dutch explorer Jacob Roggeveen (Forster 1996). The second European visit to the island, by Spaniard Felipe Gonzalez in 1770, reportedly also found a population numbering in the thousands (von Saher 1992, Forster 1996). Members of Captain Cook's expedition in 1774, however, estimated only 700 inhabitants, of whom only about fifty were women (von Saher 1992). Introduced diseases likely spread among the susceptible Polynesians, who lacked the immunities necessary to combat the illnesses. These events combined with the forced removal of islanders for the slave trade beginning in 1862 reduced the number of native inhabitants to a mere 111 by 1877 (McCall 1994).

The questions addressed as objectives for this project involve the ability of the original population of thousands to sustain itself on such a seemingly inhospitable island.

*Agriculture and Manavai*

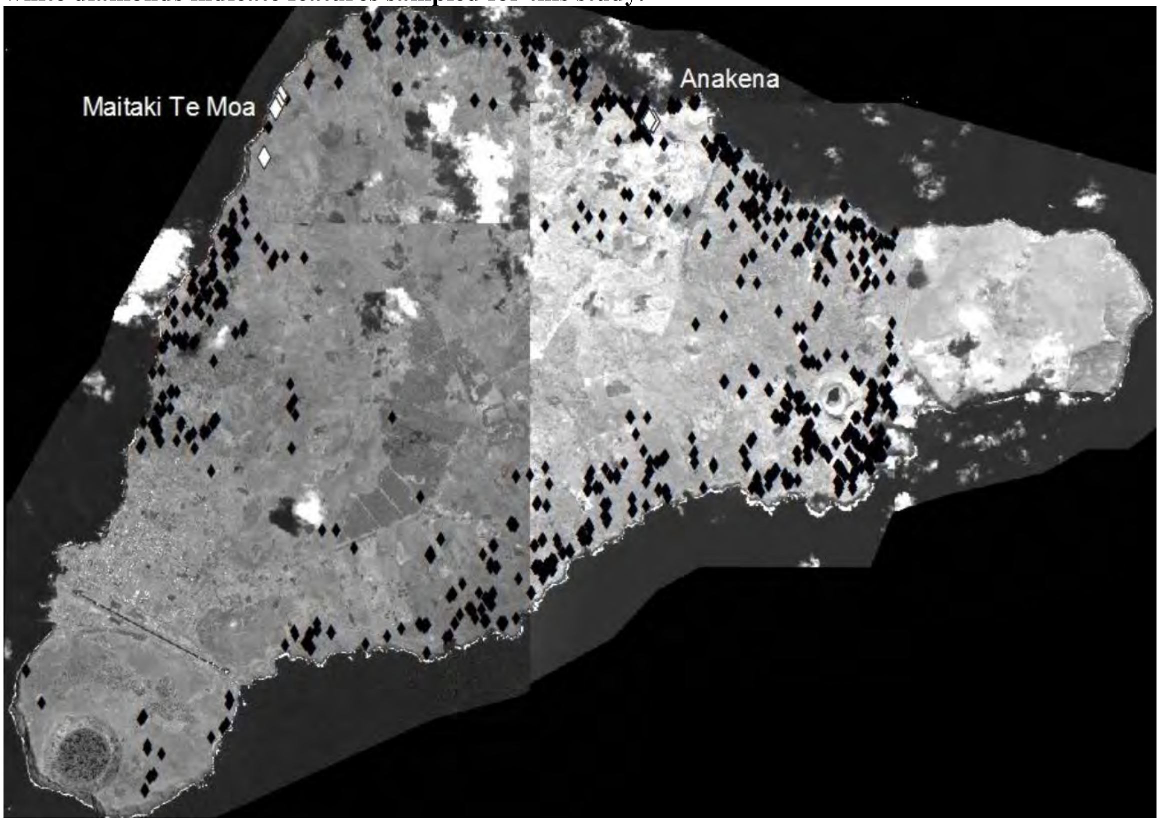
The Rapa Nui are known to have employed several strategies to maintain agriculture in the difficult environment. Introductions included the Polynesian rat as well as chickens which were maintained for food, but horticulture dominated the Rapa Nui diet (Wozniak 2000). Sweet potatoes, bananas, coconuts, sugar cane, and taro were all cultivated by the Rapa Nui. Six discrete agricultural practices defined by Stevenson et al. (2002) were used to reduce erosion, protect plants, and retain moisture:

1) Soils mulched with lithics
2) Veneer surfaces of small rocks to provide higher moisture levels due to increased permeability and decreased evaporation.
3) Stacked boulders to form windbreaks, often used in combination with veneer surfaces.
4) Steep-sided depressions, or *pu*
5) Planting circles, or smaller rings of stone, often containing a single plant
6) *Manavai* to reduce evaporation, protect fragile plants, and decrease erosion.

With deforestation and subsequent increases in erosion, all of these methods would be useful for retaining intermittent rainfall and protecting both plants and soils from wind and water erosion (Wozniak 2000, Stevenson, et al. 2002). The naturally rocky, boulder-strewn landscape makes identification of some features difficult, but recently satellite images have been used to identify habitation and subsistence features, notably *manavai* (Bradford et al. 2005).

Remote sensing with satellites offers the ability to survey individual features on an island-wide scale. Ground survey is made difficult on Rapa Nui due to the volcanic terrain and inaccessibility (Bradford, et al. 2005). Its isolation makes getting to the island difficult, and even four-wheel drive vehicles can not reach much of the island. Bradford et al.'s (2005) survey of *manavai* using satellite images likely identified features 4-6 of Stevenson's listed agricultural formations. Her criteria focused on enclosed or bound areas as seen with the differing light/dark reflectance offered in the panchromatic images (Bradford et al. 2005). Thus stones surrounding the *pu* and/or planting circles may have been identified as *manavai*. In the 144 $km^2$ survey area, representing approximately 85% of the island, 2,117 enclosures were identified as potential *manavai* (Fig. 1) (Bradford et al. 2005). Ground-truthing continues to establish the true number of *manavai* and produce an accurate representation of cultivation on the island.

**Figure 1: Satellite image of Rapa Nui. Bradford et al.'s survey of *manavai* shown as black diamonds, white diamonds indicate features sampled for this study.**




*Soils*

Soils form over time in 'previously unweathered' sediment to create a complex environment at the interface between air and earth (Middleton 2004). Composition of soils is determined by the climate in which they form (moisture, temperature, etc.), parent material from which the sediment was originally derived, biota within the soil, relief on a macroscopic and microscopic level, and time allowing for formation. The soils of Rapa Nui are weathered from the basaltic lava flows and tephra ejected during eruptions. Both of the sampling sites for this project are in regions estimated to lie on flows from Mount Terevaka dating to 1900 kya to 300 kya (González-Ferrán et al. 2004; Ladefoged et al. 2005). Although much of the central part of the island consists of Terevaka basalt, smaller cones resulted in primarily tephra eruptions, forming andisols. These andisols develop out of volcanic ash or other volcanic ejecta. They are characterized by low bulk density, mostly silt loam or finer textures when formed from ash, but can sometimes be coarser (Louwagie and Langhor 2003). High organic matter content is common due to their ability to sequester organic matter, with variable charge surfaces, and a high capacity to retain phosphate (Louwagie and Langhor 2003). In areas of low rainfall, such as Rapa Nui, these soils tend to have neutral pH values, high organic carbon (OC) and nitrogen (N) content, and be rich in cations.

## CHAPTER II: METHODOLOGY

### *Site Selection and Sampling*

Soil samples were taken from four manavai in the northwestern region of Maitaki Te Moa and two from Anakena on the northern coast (Fig. 1). One of the features at Anakena was a double manavai, forming a rough figure-eight shape, as seen later. The features were chosen from archeological survey databases compiled during the University of Hawai‘i field schools during the summers of 2004 and 2005. The feature numbers used to identify the *manavai* are from the pre-existing database of all archaeological features identified in the multi-year survey (Table 1). Samples were taken from each manavai along a transect oriented in a general north-south direction with bearings noted in relation to magnetic north. In general, ten samples were taken for each feature: three outside of the manavai to the north, three inside, three outside to the south, and one 100 m west of the final southern sample. The final sample offered a wider view of general soil conditions outside of the manavai. The exception to this procedure was the double manavai at Anakena. A single transect was positioned across both manavai, with three samples to the north, two inside each manavai, and three to the south with another taken 100 m to the west, as with the others. This sampling procedure resulted in a total of 61 samples for analysis, 42 from outside the features and 19 inside.

**Table 1: List of sampled *manavai* with feature number, condition, and modern vegetation**

| Feature # Region | Condition & Orientation | Modern Vegetation |
|---|---|---|
| 001 Maitaki Te Moa | Disturbed<br><br>Westernmost of manavai cluster | Taro inside N edge |
| 003 Maitaki Te Moa | Good condition<br><br>Western feature of double manavai, very deep | Banana |
| 57 Maitaki Te Moa | Possibly Disturbed | None |
| 219 Maitaki Te Moa | Good Condition | Banana inside N edge |
| 420 Anakena | Excellent Condition<br>Reconstructed | None, Bare interior |
| 421 Anakena | Good condition<br>Double manavai<br>Both surveyed | Dead tree in S Feature<br>Bare interior |

We collected soil at 15-20 cm below ground surface to avoid vegetation. All soil samples were air-dried, and a small portion of each was weighed before and after drying in an oven (105 degrees C) to determine moisture content. The soils were analyzed for pH, percent total nitrogen (N), percent organic carbon (OC), extractable phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Soil analyses were conducted at the Agricultural Diagnostic Service Center, University of Hawaiʻi at Mānoa.

*Analysis*

Soil pH was measured with a pH meter after a sample weighing 30-50 grams (g) was mixed with deionized water to make a saturated paste. The paste was then equilibrated for one hour with occasional stirring. Nitrogen and organic carbon percentages were measured using the LECO CN2000 analyzer (Hue et al. 1997). A combustion was performed and the gases then analyzed for N and $CO_2$. Given the generally basic nature of the soils, the Modified Truog procedure was used to extract P (Ayres and Hagihara 1952). An extracting solution of 0.01 M $H_2SO_4$ (sulfuric acid) + 0.02 M $(NH_4)_2SO_4$ (ammonium sulfate) in a soil-to-solution ratio of 1:100 with 0.5 g of soil was shaken for 30 minutes before measurements were taken. The samples were also analyzed for extractable ions $K^+$, $Ca^{2+}$, and $Mg^{2+}$. Ammonium acetate (1 M, pH 7.0) was used as the extracting solution with a soil-to-solution ratio of 1:20 with 2.5 g of soil shaken for 10 minutes. $Ca^{2+}$, $Mg^{2+}$, and $K^+$ in the filtrate were measured with an atomic absorption spectrophotometer (AA) (Hue et al. 1997). Analysis results are listed as raw data in the appendix.

# CHAPTER III: RESULTS and DISCUSSION

The data were evaluated to determine if evidence of human modification was present in the soils. Of primary interest was the potential for a significant difference between samples from inside and outside the *manavai*. I used the mean values of samples taken inside the *manavai* compared to those from outside to observe trends in the data. I compared values for the overall data, for samples from the two different regions: Anakena and Maitaki Te Moa, and for individual features themselves. The tests included the distant samples with the outside data to provide a better overall view of the surrounding landscape compared to soils inside the *manavai*.

Consistent differences in mean values were deemed to indicate human modifications, but I used a standard statistical t-test of the null hypothesis to evaluate the significance of the differences. The null hypothesis holds that no significant difference between chemical characteristics of samples inside and outside the *manavai* demonstrates a lack of discernible alteration of soils in the *manavai* as a consequence of ancient or modern agricultural use. Thus any significant difference would result in the rejection of the null hypothesis. Differences at confidence level of 95% ($p=0.05$ from the t-test) indicate only a 5% chance that the difference is due entirely to chance, and were considered significant. Though little of the data showed calculated significant differences, I considered trends and extreme values to be a notable sign of anthropogenic alteration.

### *Overall Data*

The pooled data for the entire study site revealed a general trend of higher values inside the *manavai* for pH, P, K, Ca, and Mg, as well as higher values outside for %N and

%OC (Table 2). With slightly more neutral soils found inside the manavai ($\bar{x}$ = 6.5) as opposed to lower, more acidic pH values found outside ($\bar{x}$ = 6.3), pH was calculated to differ significantly (p = 0.05). K also differed significantly in the overall data (p = 0.05) with much higher values ($\bar{x}$=770 µg/g) inside than outside ($\bar{x}$=414 µg/g). Though no other properties showed statistical significance in comparison of mean values, notable trends were evident. Percentages of N (inside $\bar{x}$=0.30%, outside $\bar{x}$=0.31%, p = 0.65) and OC (inside $\bar{x}$=3.99%, outside $\bar{x}$=4.32%, p = 0.48) were shown to differ very little, a factor that I attribute to variations in soils by region discussed below. The other variations, though not significant, demonstrated notably higher mean values inside the *manavai* than outside. Elevated concentrations of P (inside $\bar{x}$=1030 µg/g, outside $\bar{x}$=314 µg/g, p = 0.14); Ca (inside $\bar{x}$=2326 µg/g, outside $\bar{x}$=1714 µg/g, p = 0.06); and Mg (inside $\bar{x}$=1039 µg/g, outside $\bar{x}$=880 µg/g, p = 0.26) all point to more suitable agricultural soils inside the features, and indicate an improvement of soils by human action when compared to poor soils in the surrounding area.

**Table 2: Mean, minimum, and maximum values and t-test results comparing samples from inside and outside *manavai* for overall data. n=number of samples in each category. p-value ≤ 0.05 considered significant**

| Soil Property | Minimum | Maximum | Mean Inside ($\bar{x}$) | Mean Outside ($\bar{x}$) | n In | n Out | p-value |
|---|---|---|---|---|---|---|---|
| pH | 5.40 | 7.4 | 6.49 | 6.27 | 19.00 | 42.00 | 0.05 |
| %N | 0.07 | 0.84 | 0.30 | 0.31 | 19.00 | 42.00 | 0.65 |
| %OC | 1.40 | 10 | 3.99 | 4.32 | 19.00 | 42.00 | 0.48 |
| P (µg/g) | 46.00 | 6985 | 1030.21 | 313.64 | 19.00 | 42.00 | 0.14 |
| K (µg/g) | 24.00 | 2374 | 770.11 | 414.43 | 19.00 | 42.00 | 0.05 |
| Ca (µg/g) | 588.00 | 5672 | 2326.11 | 1713.71 | 19.00 | 42.00 | 0.06 |
| Mg (µg/g) | 284.00 | 2364 | 1039.16 | 880.29 | 19.00 | 42.00 | 0.26 |

*Anakena vs. Maitaki Te Moa*

The comparison of the means from the overall data from the two regions proved to be the most statistically notable of the evaluations. A t-test assessing the differences in data from the two areas of study showed every property to differ significantly except for P ($p = 0.61$) and Ca ($p = 0.14$) (Table 3). As Table 3 shows, analyses revealed the soils at Anakena to be more acidic, with significantly lower pH values averaging 6.1 as compared to 6.5 at Maitaki Te Moa ($p = 0.00$). N ($p = 0.00$) and OC ($p = 0.00$) percentages were both much higher at Anakena: 0.39% versus 0.27%; and 5.3% compared to 3.6%, respectively. The cations $K^+$ (Anakena $\bar{x}$=203 µg/g, Maitaki Te Moa $\bar{x}$=694 µg/g, p= 0.00), $Ca^{2+}$ (Anakena $\bar{x}$=1680 µg/g, Maitaki Te Moa $\bar{x}$=2021 µg/g), and $Mg^{2+}$ (Anakena $\bar{x}$=612 µg/g, Maitaki Te Moa $\bar{x}$=1096 µg/g, p = 0.00) all proved to be present in far lower concentrations at Anakena than Maitaki Te Moa. The notable difference between the two regions led me to investigate the individual features separately and divided by region, for comparison to local trends rather than the overall data set.

**Table 3: Mean values and t-test results comparing data from Anakena (Ana) and Maitaki Te Moa (MTM). n=number of samples in each category. p-value ≤ 0.05 considered significant**

| Soil Property | Mean Ana ($\bar{x}$) | Mean MTM ($\bar{x}$) | n Ana | n MTM | p-value |
|---|---|---|---|---|---|
| pH | 6.10 | 6.47 | 21.00 | 40.00 | 0.00 |
| %N | 0.39 | 0.27 | 21.00 | 40.00 | 0.00 |
| %OC | 5.33 | 3.63 | 21.00 | 40.00 | 0.00 |
| P (µg/g) | 457.62 | 578.43 | 21.00 | 40.00 | 0.61 |
| K (µg/g) | 203.43 | 694.15 | 21.00 | 40.00 | 0.00 |
| Ca (µg/g) | 1680.67 | 2021.95 | 21.00 | 40.00 | 0.14 |
| Mg (µg/g) | 612.29 | 1096.45 | 21.00 | 40.00 | 0.00 |

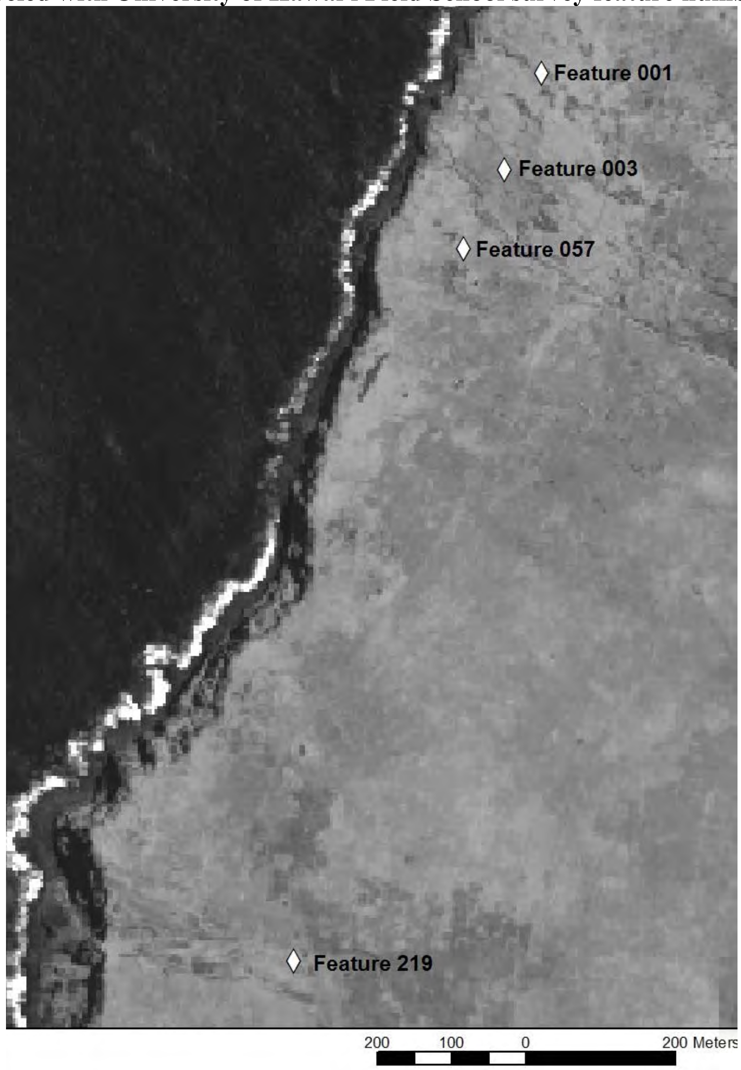
*Features by Region: Maitaki Te Moa*

Maitaki Te Moa is a rocky region on the northwestern slope of Terevaka, sloping east to west from the peak down to steep sea cliffs. Features 001, 003, and 057 are oriented parallel to the coastline approximately 100 m from the top of the cliffs and each approximately 130 m apart (Fig. 2). Feature 219 is positioned further south and approximately 250 m from the cliffs (Fig. 2). All transects for sampling were oriented perpendicular to the slope and parallel to the coastline to maintain consistent north-south transect bearings and procedures. The area in modern times is used for ranching, and cattle and horses roam the hillsides. Some modern vegetation is present, but not with the use of modern fertilizers or growing aids. The overall samples from Maitaki Te Moa only showed significant differences between inner and outer samples for pH (p=0.04) and K (p=0.02). Unlike the pooled data, all seven properties were higher inside the *manavai* at Maitaki Te Moa, indicating a clear trend of improved soils (Table 4). Separate evaluation of data from individual features reveals further notable differences.

**Table 4: Mean values and t-test results comparing data inside and outside *manavai* at Maitaki Te Moa. n=number of samples in each category. p-value ≤ 0.05 considered significant.**

| Soil Property | Mean In ($\bar{x}$) | Mean Out ($\bar{x}$) | n In | n Out | p-value |
|---|---|---|---|---|---|
| pH | 6.67 | 6.39 | 12.00 | 28.00 | 0.04 |
| %N | 0.29 | 0.26 | 12.00 | 28.00 | 0.52 |
| %OC | 3.90 | 3.52 | 12.00 | 28.00 | 0.55 |
| P (μg/g) | 1355.17 | 245.54 | 12.00 | 28.00 | 0.16 |
| K (μg/g) | 1098.33 | 520.93 | 12.00 | 28.00 | 0.02 |
| Ca (μg/g) | 2645.67 | 1754.64 | 12.00 | 28.00 | 0.06 |
| Mg (μg/g) | 1280.00 | 1017.79 | 12.00 | 28.00 | 0.16 |

**Figure 2: Satellite image of Maitaki Te Moa survey region with sampled manavai denoted by white diamonds and labeled with University of Hawai'i Field School survey feature numbers.**




Feature 001 (Fig. 3) is the western portion of a double manavai partially made up of natural rock formations. Again, we found every soil property to have higher values inside the *manavai*. Notably, the raw data for Feature 001 had highest values for every property at the exact center point of the transect, taken in the middle of the *manavai* (Fig. 4). This cannot be explained by surface micro-topography, as the inside of the manavai slopes continuously east to west (Fig. 5). However rocks and modern plant growth may contribute to higher values at 20 cm depth in the center of the structure.

**Figure 3: Field map plan view of Feature 001 from 2004 field school. Western *manavai* sampled with sampling transect added. At time of sampling banana plants were not present.**

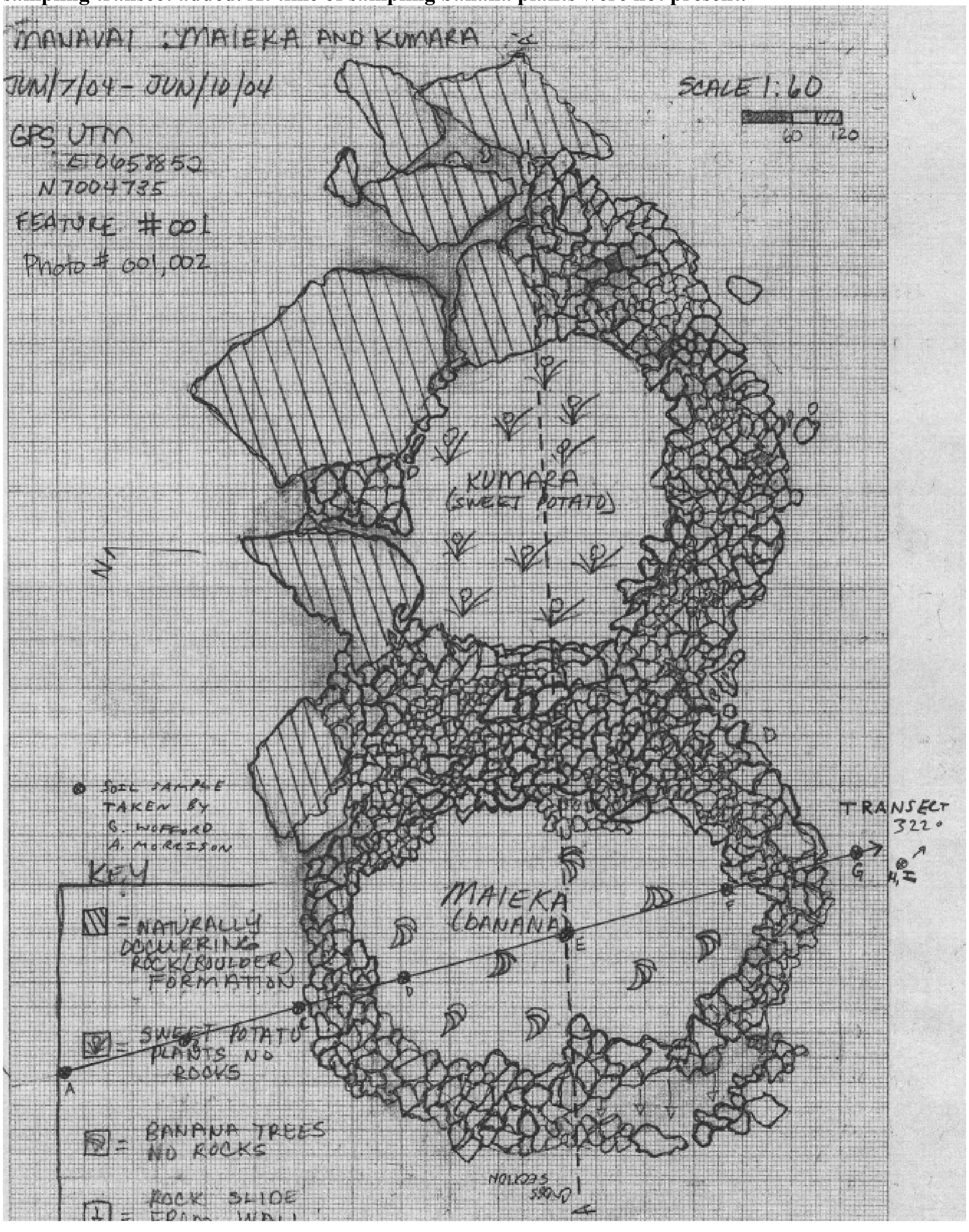


**Figure 4: Graph of extractable nutrients P, K, Ca, and Mg for Feature 001. Sampling sites A,B,C are outside to the north; D,E,F are inside *manavai*; G,H,I are outside to south; J is distant sample (See fig. 3 plan view). Concentrations expressed in µg/g.**

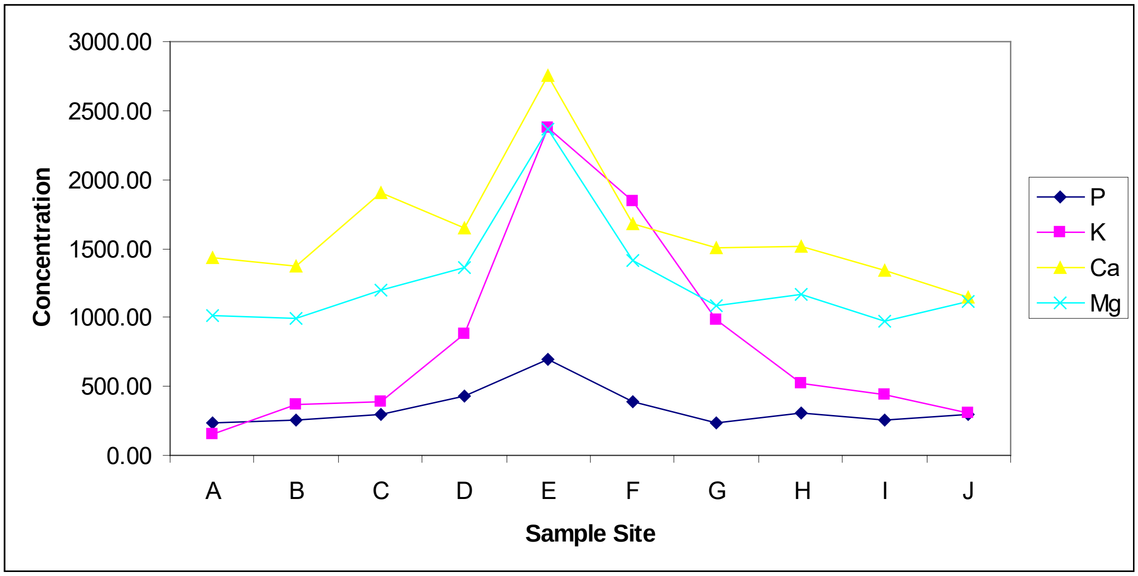
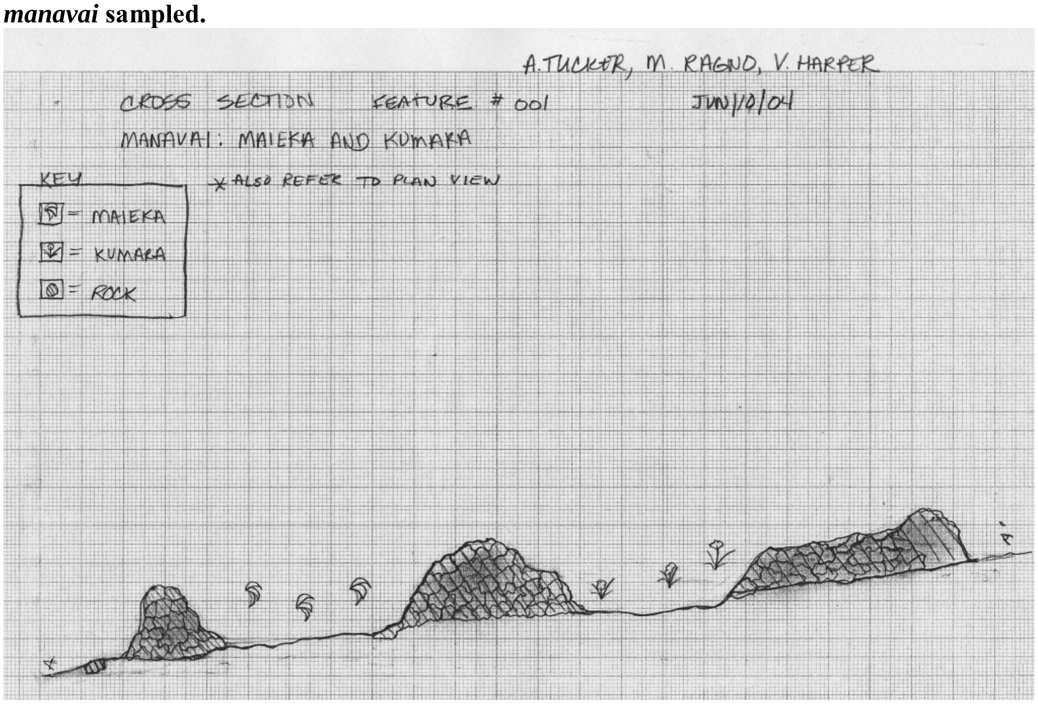



**Figure 5: Field map profile of Feature 001 from 2004 field school, looking north; western (left) *manavai* sampled.**




Feature 003 is a deep manavai (2.5 m) with a small circular feature (possibly another *manavai* or a *pu* connected to the east (Figs. 6 & 7). This feature had the most extreme values of any sampled features for two sites inside the *manavai* (Fig. 8) (See

Appendix A for raw data). These sites produced the highest measured concentrations of P (6985 μg/g) and Ca (5672 μg/g) and the second-highest for K (1,972 μg/g) and Mg (2314 μg/g) of all samples. This is most notable with P measurements of 6,495 μg/g and 6,985 μg/g, compared to 537 μg/g as the overall average of P. The soil inside Feature 003 also had the highest pH of all samples. The two samples noted above had pH of 7.2, two of only four samples from the overall data with pH greater than 7.0. The remaining sample inside was exactly neutral, ph 7.0. These samples were significantly more neutral than the acidic soils found outside this *manavai* (inside $\bar{x}$=7.1, outside $\bar{x}$=6.4, p = 0.00). Though existence of banana plants has possibly contributed to the improved quality as foliage falls and naturally fertilizes the soil, these unique values provide definite evidence of alteration of the soils.

**Figure 6: Field map profile of Feature 003 from 2004 field school, looking south; western (right) *manavai* sampled. Note depth and banana plants.**

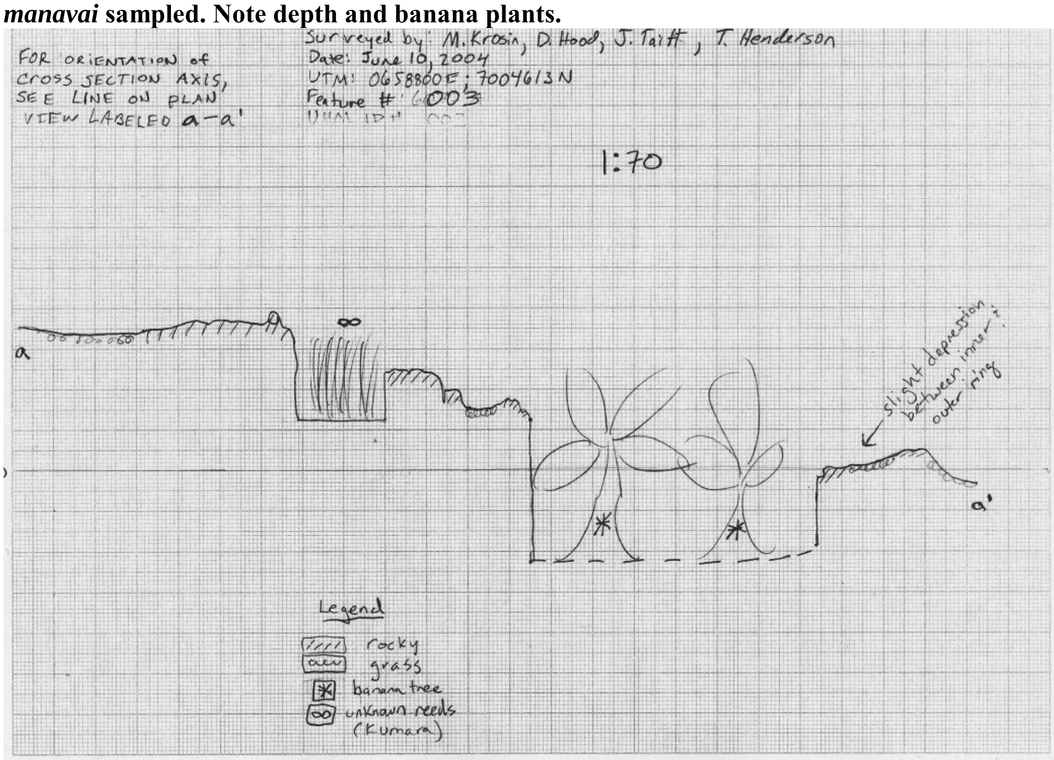


**Figure 7: Field map plan view of Feature 003 from 2004 field school. Western manavai sampled with sampling transect added.**

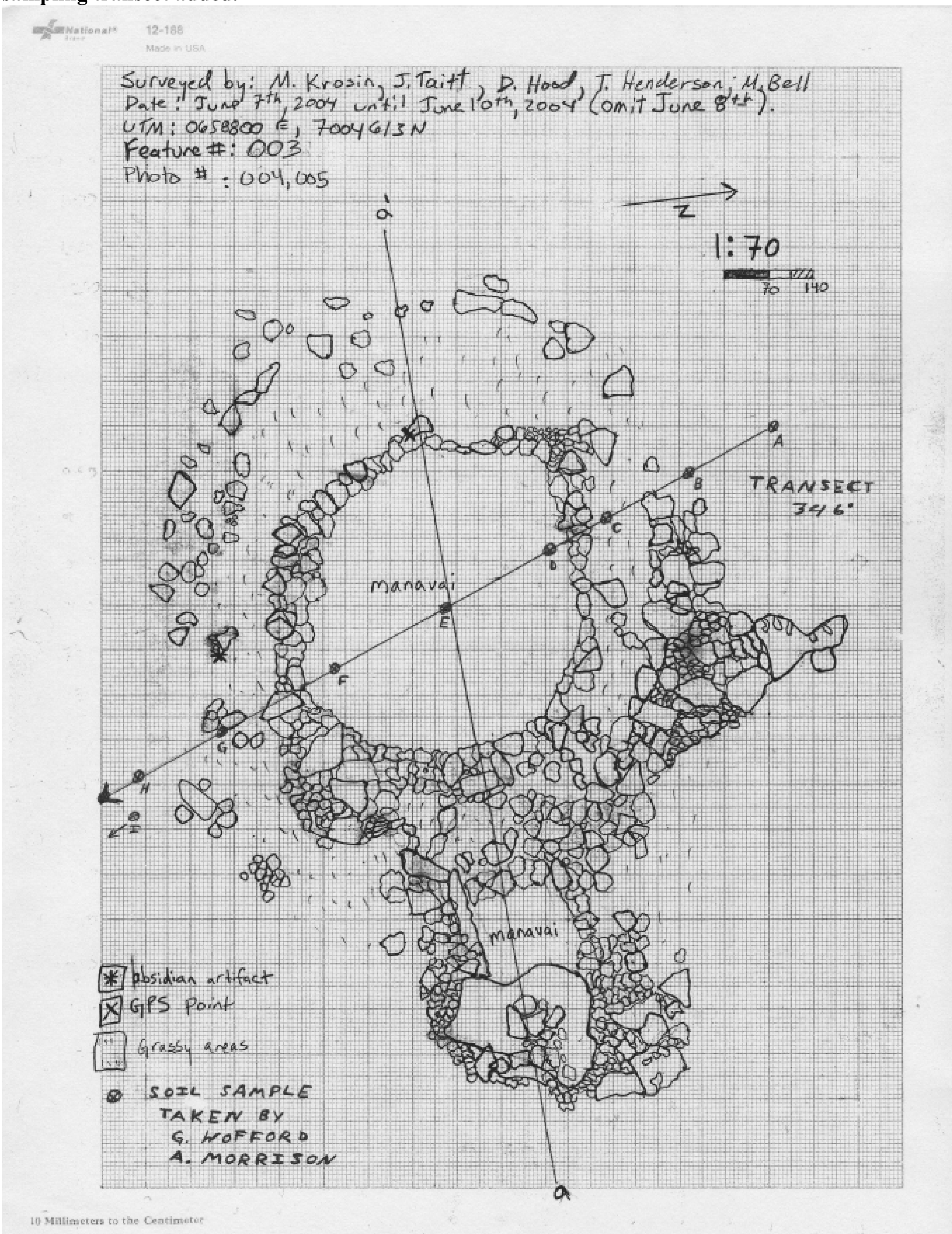
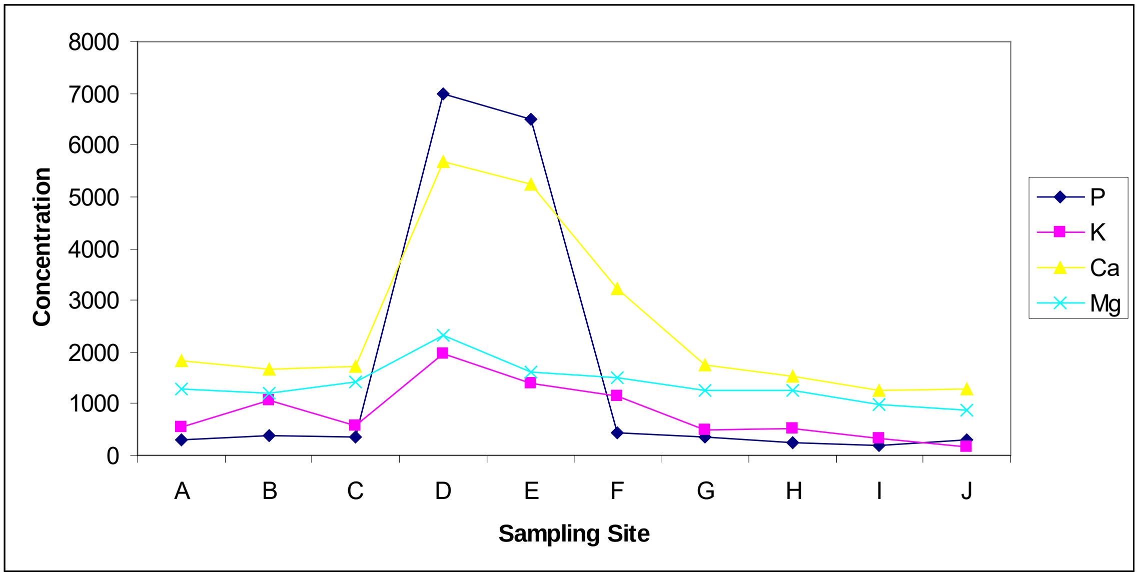


**Figure 8: Graph of extractable nutrients P, K, Ca, and Mg for Feature 003. Sampling sites A,B,C are outside to the north; D,E,F are inside manavai; G,H,I are outside to south; J is distant sample (See fig. 7 plan view). Concentrations expressed in µg/g.**




Feature 057 is a shallow, incomplete or possibly disturbed, circular structure with large boulders to the southwest (Fig. 9). This is the only feature which shows higher mean values for all seven properties outside the *manavai* instead of inside (Table 5). Again, a single point displayed higher values in every category than the others, but in this case it was a point immediately outside the southern boundary of the *manavai* (Sample G), not inside. Aside from this unique sample, the other samples show little difference comparing inside and outside values, with relatively inconsistent values along the transect (see Appendix A). This is also the only feature at Maitaki Te Moa which does not have modern vegetation growing inside beyond short grasses (Table 1). The unique nature of the isolated sample at Feature 057 again indicates some kind of alteration, but the location and individuality point to the effects of animals on the landscape or localized anthropogenic activity near the *manavai*. The data for this feature are inconclusive in terms of comparing soil quality inside and outside the *manavai*.

**Figure 9: Field map plan view of Feature 057 from 2004 field school with sampling transect added. Note disturbance or incompleteness of northeastern quadrant.**

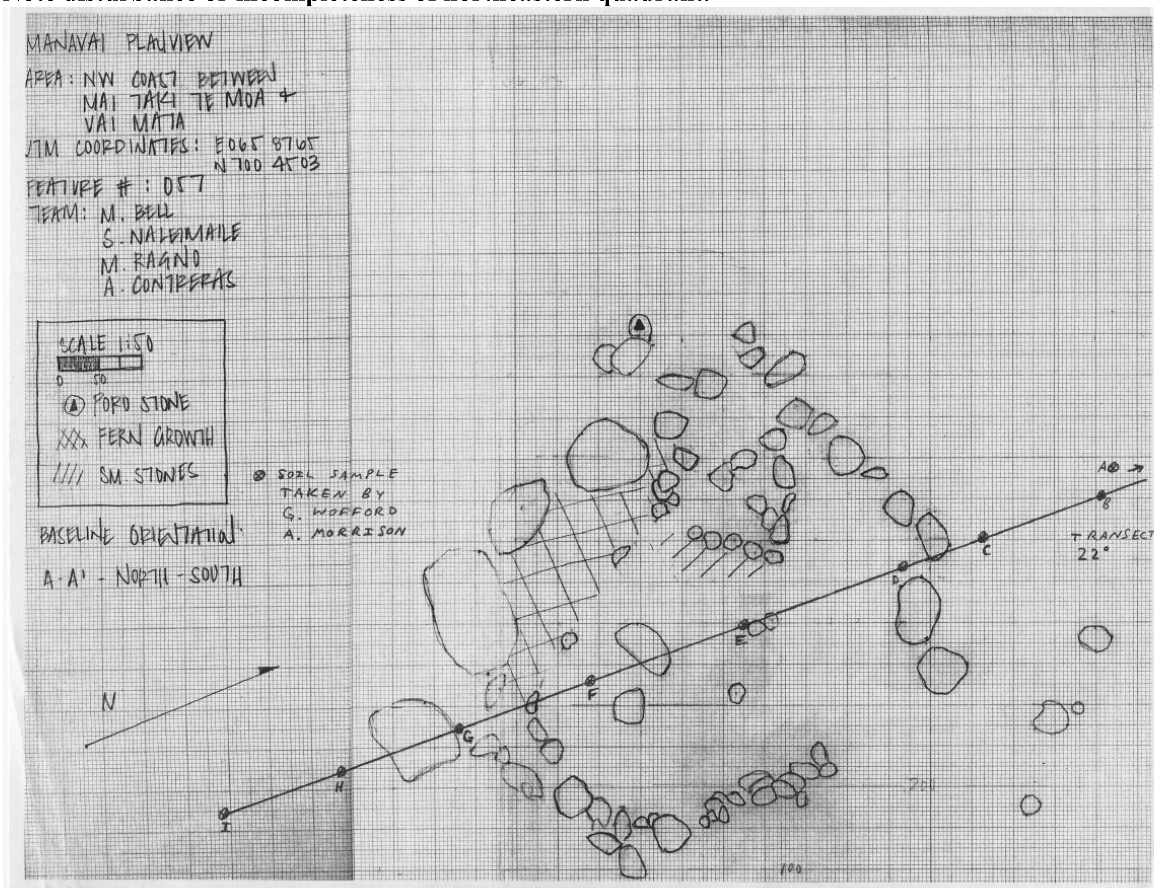
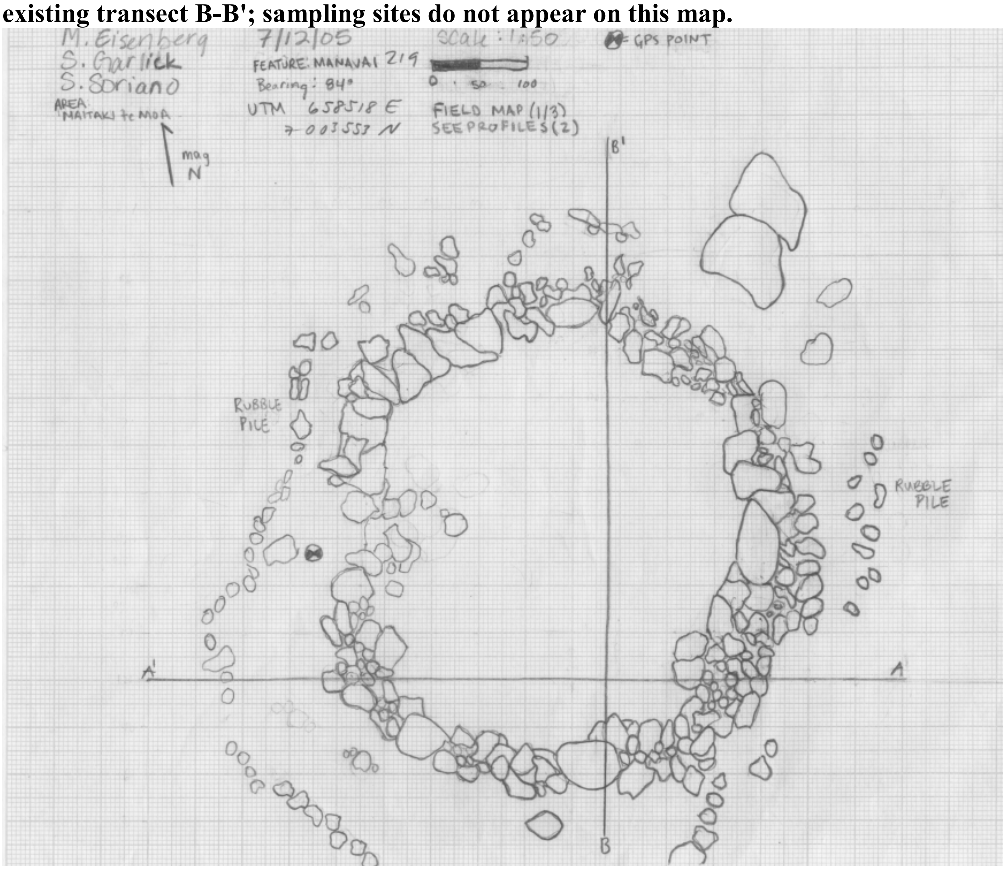



**Table 5: Mean values and t-test results comparing data inside and outside Feature 057 at Maitaki Te Moa. n=number of samples in each category. p-value ≤ 0.05 considered significant.**

| Soil Property | Mean In | Mean Out | n In | n Out | p-value |
|---|---|---|---|---|---|
| pH | 6.40 | 6.66 | 3.00 | 7.00 | 0.27 |
| %N | 0.11 | 0.12 | 3.00 | 7.00 | 0.67 |
| %OC | 1.87 | 2.07 | 3.00 | 7.00 | 0.58 |
| P (μg/g) | 178.67 | 314.43 | 3.00 | 7.00 | 0.18 |
| K (μg/g) | 556.67 | 746.00 | 3.00 | 7.00 | 0.07 |
| Ca (μg/g) | 1466.00 | 1856.57 | 3.00 | 7.00 | 0.19 |
| Mg (μg/g) | 880.00 | 1059.43 | 3.00 | 7.00 | 0.10 |

Feature 219 is a well-formed manavai surrounded by boulders and rubble (Fig. 10). The mean values and well as the raw data reveal no trends along the transect (see Appendix A). Nitrogen (p=0.14) and OC (p=0.14) both tested higher outside the feature, while pH (p=0.41), P (p=0.72), K (p=0.62), Ca (p=0.42), and Mg (p=0.36) all provided higher values inside. As with Feature 057, Feature 219 offers no significant evidence of alteration of soils inside the *manavai*.

**Figure 10: Field map plan view of Feature 219 from 2005 field school. We took samples along the existing transect B-B'; sampling sites do not appear on this map.**




*Features by Region: Anakena*

Anakena is the location of the only white sand beach on Rapa Nui, located on the northern shore. The site of numerous excavations and archaeological projects, the landscape of the beach is ever-changing with consistent winds from the north and threatens to bury the reconstructed historical structures and any current projects. (Heyerdahl 1961, Hunt and Lipo 2006). To the west of Anakena Beach and the paved parking lot is a sloping hillside where the village once stood and the remains of several structures can be seen. Features 420 and 421 are found on this hillside approximately 130 m from the coast on a dry terrain of grass and rocks (Fig. 11). The combined data for the two features at Anakena reveal much clearer trends than those taken at Maitaki Te Moa (Table 6). Nitrogen (p=0.00) and OC (p=0.00) are significantly higher in soils outside the *manavai*. Soil pH (p=0.62), P (p=0.82), K (p=0.98), Ca (p=0.95), and Mg (p=0.76) all tested higher inside the *manavai* at Anakena, though the p-values indicate no significant differences.

**Figure 11: Satellite image of Anakena West survey region with sampled *manavai* denoted by white diamonds and labeled by University of Hawai'i Field School survey feature number. Anakena beach and a paved parking lot lie to the east of sampled features.**

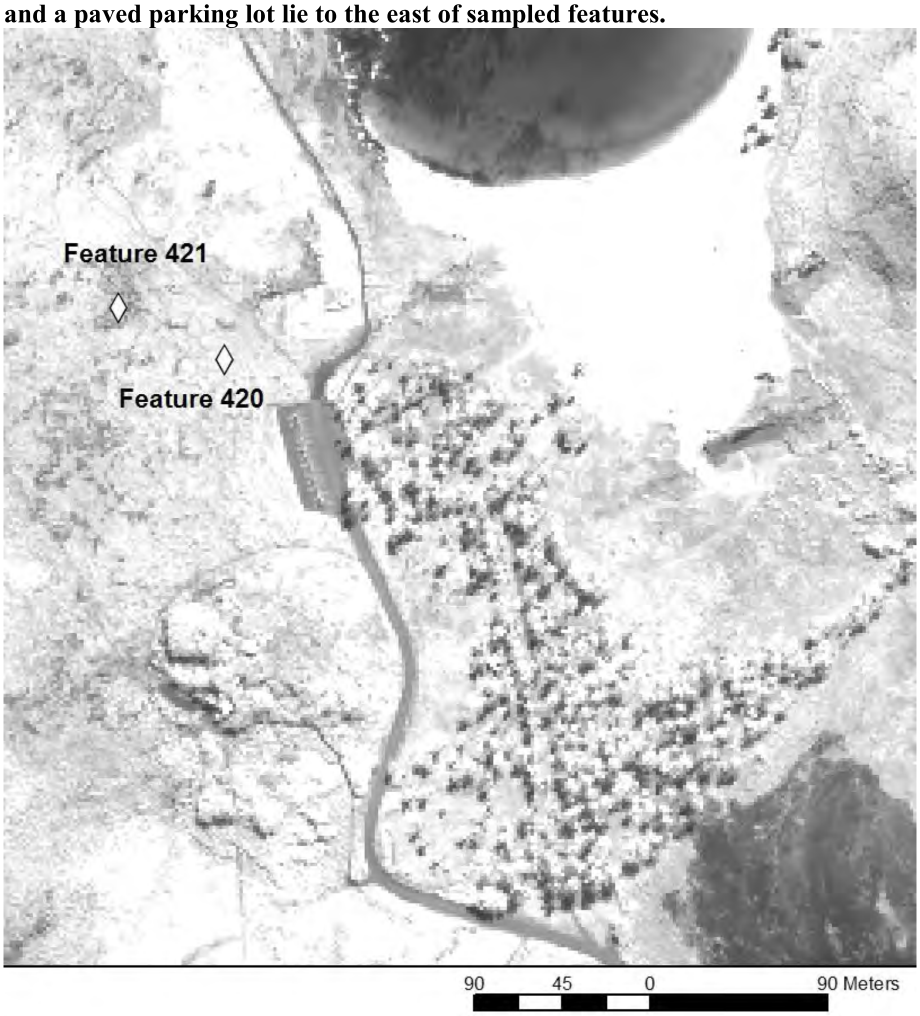
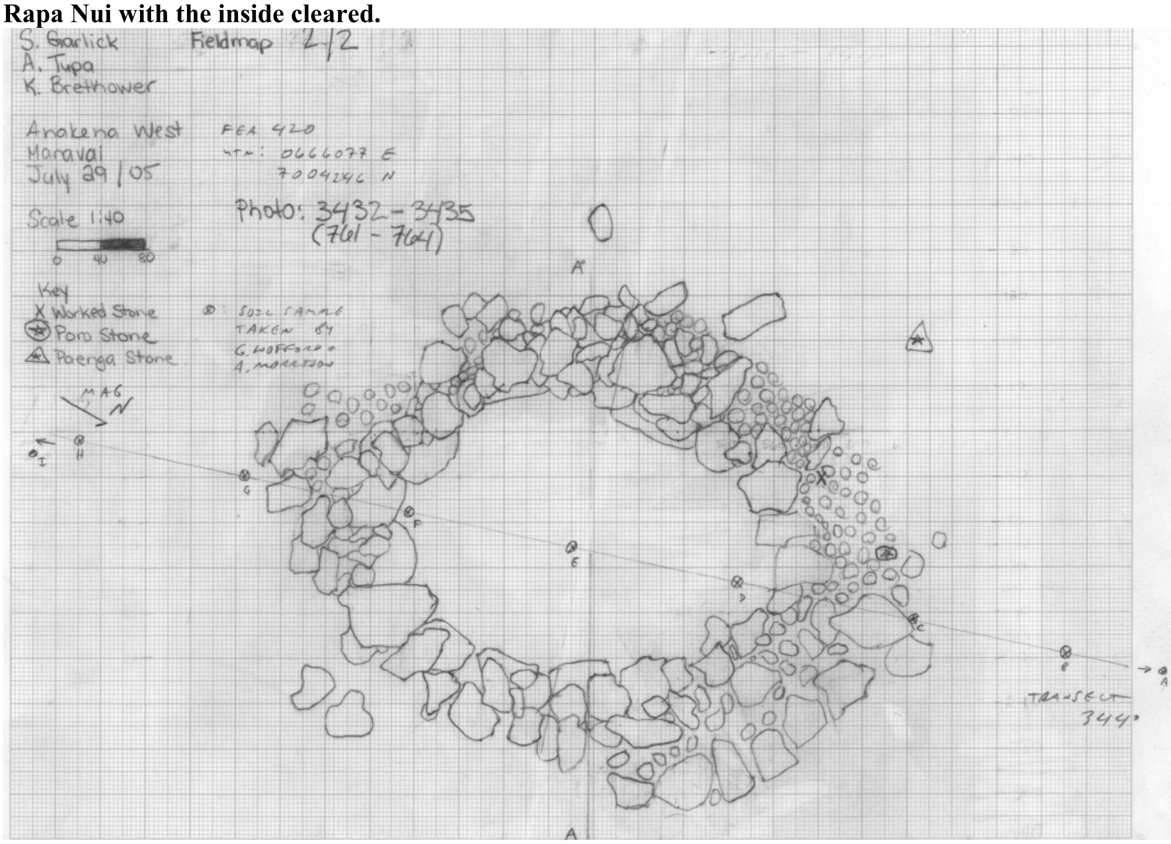


**Table 6: Mean values and t-test results comparing data inside and outside *manavai* at Anakena. n=number of samples in each category. p-value ≤ 0.05 considered significant.**

| Soil Property | Mean In ( $\bar{x}$ ) | Mean Out ( $\bar{x}$ ) | n In | n Out | p-value |
|---|---|---|---|---|---|
| pH | 6.19 | 6.05 | 7.00 | 14.00 | 0.20 |
| %N | 0.30 | 0.43 | 7.00 | 14.00 | 0.00 |
| %OC | 4.13 | 5.93 | 7.00 | 14.00 | 0.00 |
| P (μg/g) | 473.14 | 449.86 | 7.00 | 14.00 | 0.83 |
| K (μg/g) | 207.43 | 201.43 | 7.00 | 14.00 | 0.91 |
| Ca (μg/g) | 1778.29 | 1631.86 | 7.00 | 14.00 | 0.66 |
| Mg (μg/g) | 626.29 | 605.29 | 7.00 | 14.00 | 0.79 |

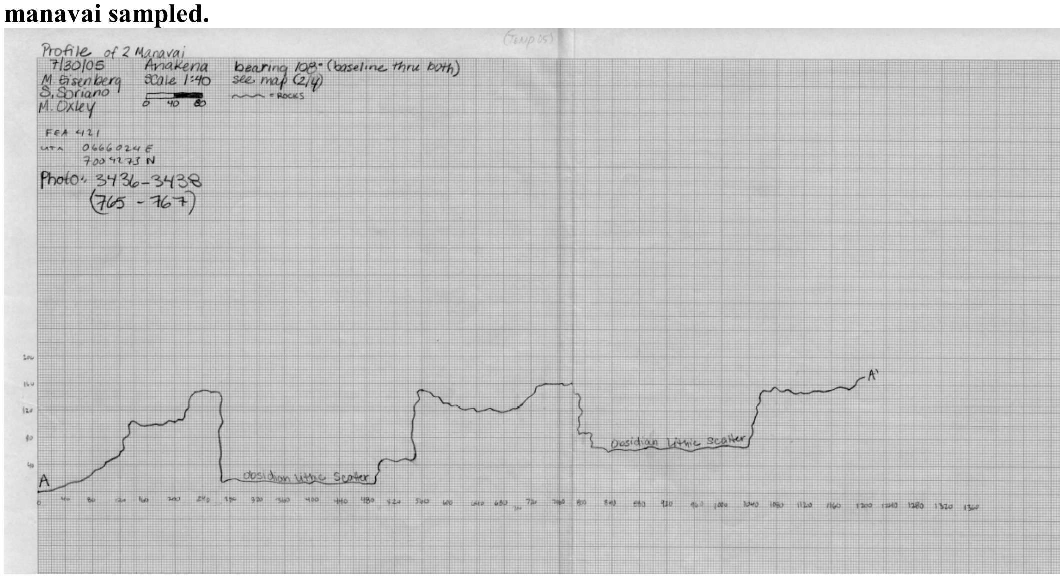
Feature 420 is a complete manavai with a bare interior of sediment and rock (Figs. 12). The trend of high %N (p=0.03) and %OC (p=0.02) outside of the *manavai* at Anakena was maintained (Table 9). With identical pH values (p=1.00) and inconsistent values for other concentrations, there is a great deal of variability among the soils. P (p=0.25) and Mg (p=0.15) also had higher mean concentrations outside the *manavai*, while K (p=0.70) and Ca (0.92) were present at higher concentrations inside, although the difference was statistically negligible. This *manavi* had apparently been reconstructed for historical, as opposed to agricultural, purposes. This alteration likely influenced the soils in the immediate area, especially with the clearing of the inside of the *manavai*.

**Figure 12: Field map plan view of Feature 420 from 2005 field school with sampling transect added. Though many *manavai* exhibit pre-contact construction, this feature was reconstructed by modern Rapa Nui with the inside cleared.**




Feature 421 is the only double manavai structure where both enclosures were sampled for this study. The structure is situated with a north-south orientation and the northern manavai is slightly higher than the southern (Figs 13 & 14). Obsidian and lithics found both in and around the manavai point to other human activity in the vicinity, and the structure has not received the modern attention that may have affected Feature 420. Again, mean concentrations of N (p=0.04) and OC (p=0.03) were significantly higher outside the structure. K (p=0.87) concentrations were also higher in the outside samples for this feature, though almost identical in the immediate vicinity (p=0.99 without inclusion of the distant sample). The remaining soil properties: pH (p=0.07), P (p=0.22), Ca (p=0.09), and Mg (p=0.29) all gave higher values inside the *manavai*. The lack of indices for anthropogenic influence is in keeping with patterns for Anakena. However, Feature 421 has not been disturbed or reconstructed, and more consistent values for nutrient concentrations inside the structure indicate possible human influence.

**Figure 13: map profile of Feature 421 from 2005 field school, looking west; both north and south manavai sampled.**




*Summary of Individual Manavai*

Features 001 and 003 both displayed higher values inside the *manavai* for every property. The highest measurements for Feature 001 were at the central point inside the *manavai*, while two extremely high samples were found inside Feature 003. Feature 057 had no consistent trends along the transect, but all soil parameters gave higher average values outside the *manavai*. For Features 219, 420, and 421, %N and %OC were found to have higher values outside the *manavai*, with higher P, Ca, and Mg values inside for all three features as well. Measurements of pH were higher inside Features 219 and 421, but provided the same average for values inside and outside Feature 420. Feature 421 was unique with concentrations of K higher outside, while this parameter was higher inside Features 219 and 420.

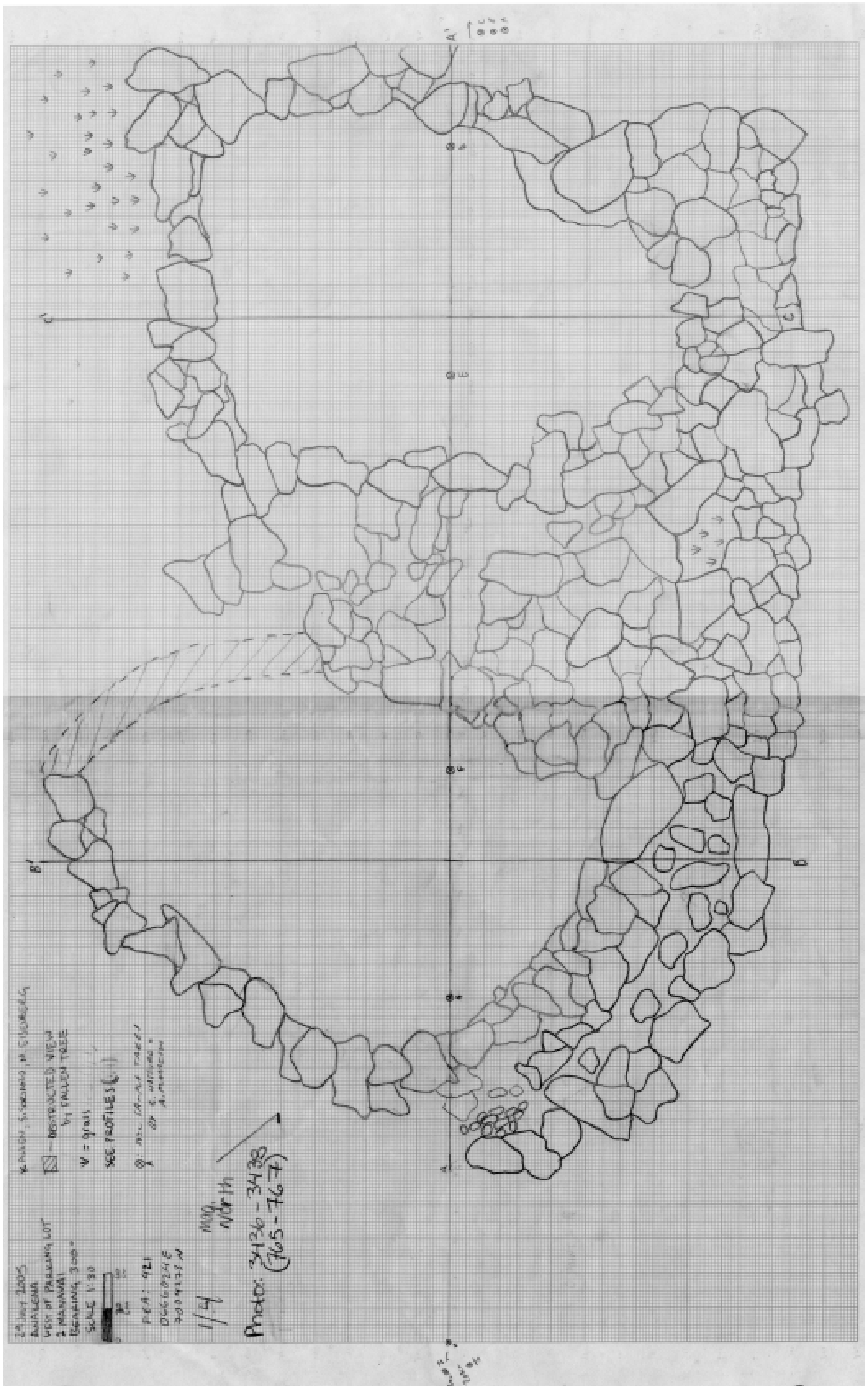
*C:N:P ratios*

The ratios of carbon to nitrogen and phosphorus (CNP) of soil reflect the original CNP of fresh organic material, the degree of degradation of that organic matter to form soil humus (which in turn can be related to age, lability of organic matter, microbial activity, and climate), and any alteration of the soil composition by human activities (growth of agricultural crops which would deplete N and P, or fertilization which would enrich N and P). Mackenzie et al. (2002) cite an average soil humus CNP ratio of 140:10:1. C:N and C:P ratios for the manavai samples are given in Appendix B.

In general, the soil C:N and C:P ratios show little variability across individual features, but there are some differences between manavai. This would suggest that CNP ratios may largely reflect factors other than those related to human construction and use of the manavai. An exception is feature 421 which shows relative enrichment in both N and P (lower C:N and C:P ratios) inside the manavai compared to outside. Feature 003 also shows some indication of P (and slight N) enrichment inside the manavai. These enriched values may reflect human addition of nutrients to manavai soils.

Average values of C:N from all manavai range between about 12 and 17. These values are probably within the normal range (close to the average soil humus value of 14). Some manavai ( features 003 and 057) are slightly enriched in P relative to average soil humus (C:P = 140:1), while the others (features 219 and 421) appear to be depleted in P relative to average soil humus. Again, slight enrichment or depletion may be within the margins of uncertainty. The highly depleted values for 219 (average C:P = 624:1), however, are an indication of soil alteration. At 219, the most depleted sample was the control, although all samples show depletion in P relative to average soil humus. At 421, again, the most depleted sample was the control. The samples from inside 421 actually have relatively normal, or slightly enriched, values of C:P. The lack of correlation of the highly depleted samples with location inside the structures suggests that natural weathering processes, not agricultural nutrient depletion, are probably responsible for leaching of P from the soils.

**Figure 14: Field map plan view of Feature 421 from 2005 field school. Sampling used existing A-A' transect with extension for outside samples.**



## CHAPTER IV: CONCLUSION

Though little of the data demonstrated significant differences between soils inside the *manavai* and samples from the surrounding landscape, trends and extreme values indicate definite improvement of the soils due to anthropogenic influence. The features at Maitaki Te Moa showed many more signs of human influence, most notably in those *manavai* with modern vegetation growth. Similarly, the features at Anakena, lacking modern growth, showed little or no differences, but consistently higher %N and %OC values point to better soils outside. However, the trend of higher nutrients (P, K, Ca, and Mg) inside the *manavai* is maintained throughout. Feature 421 at Anakena, with no modern plant growth and without the modern disruption of reconstruction, may offer a viable baseline for the natural evolution of soils in a *manavai* following agricultural practice. Organic C and N levels would be decreased by cultivation practices in the event that nothing was added to the soils to replenish those nutrients. We know that modern use of the *manavai* at Maitaki Te Moa does not include active cultivation or the addition of fertilizer. At most, the possibility exists that organic refuse could be deposited in the structures, but otherwise it appears the plants are allowed to naturally take their course. Excavations in *manavai* by previous field schools indicated such input of organic waste in ancient times, and thus such modern practices would not disrupt this study. The natural cycle of heavy vegetation growing and dying in the features may be the improving factor in *manavai* soils, compared to the poor, deforested soils of the surrounding landscape. The plants provide additional humus, organic matter, to replenish the soils where no such reinforcement is provided outside of the *manavai*. However, the construction and planting of the features is still an indication of human practices which appears to have resulted in improvement of soils compared to the surrounding landscape.

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APPENDIX A: ANALYSIS RESULTS

| Feature No. UTM Coordinates | | pH | % N | %OC | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | | <------------------ | µg/g----- | | ------ > |
| 001 | A | 6.1 | 0.35 | 4.9 | 237 | 158 | 1436 | 1018 |
| 0658850 E | B | 6.2 | 0.29 | 4.4 | 253 | 368 | 1370 | 990 |
| 7004736 N | C | 6.5 | 0.27 | 3.6 | 294 | 390 | 1908 | 1198 |
| | D | 6.5 | 0.24 | 3.2 | 428 | 882 | 1648 | 1358 |
| | E | 7.1 | 0.43 | 6.1 | 696 | 2374 | 2754 | 2364 |
| | F | 6.9 | 0.19 | 2.8 | 384 | 1840 | 1676 | 1408 |
| | G | 6.6 | 0.22 | 3.0 | 232 | 988 | 1504 | 1090 |
| | H | 6.4 | 0.28 | 4.2 | 304 | 526 | 1516 | 1166 |
| | I | 6.1 | 0.18 | 2.9 | 253 | 444 | 1338 | 970 |
| | J | 6.3 | 0.16 | 2.3 | 302 | 304 | 1150 | 1116 |
| 003 | A | 6.5 | 0.12 | 2.2 | 312 | 534 | 1832 | 1276 |
| 0658805 E | B | 6.5 | 0.15 | 2.7 | 392 | 1074 | 1666 | 1190 |
| 7004603 N | C | 6.5 | 0.15 | 2.4 | 366 | 568 | 1726 | 1432 |
| | D | 7.2 | 0.61 | 7.8 | 6985 | 1972 | 5672 | 2314 |
| | E | 7.2 | 0.46 | 5.8 | 6495 | 1406 | 5248 | 1616 |
| | F | 7.0 | 0.22 | 3.3 | 428 | 1160 | 3222 | 1508 |
| | G | 6.3 | 0.22 | 3.4 | 356 | 478 | 1736 | 1248 |
| | H | 6.1 | 0.26 | 3.8 | 237 | 510 | 1524 | 1260 |
| | I | 6.4 | 0.17 | 2.4 | 180 | 338 | 1264 | 984 |
| | J | 6.3 | 0.19 | 2.6 | 309 | 160 | 1294 | 874 |

| Feature No. UTM Coordinates | | pH | % N | %OC | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | | <------------------- | µg/g----- | | ------ > |
| 57 | A | 6.4 | 0.12 | 1.8 | 111 | 508 | 1462 | 912 |
| 0658754 E | B | 6.5 | 0.10 | 1.7 | 193 | 530 | 1534 | 1032 |
| 7004504 N | C | 6.6 | 0.10 | 1.7 | 180 | 866 | 1824 | 962 |
| | D | 6.7 | 0.07 | 1.4 | 155 | 568 | 1364 | 868 |
| | E | 6.3 | 0.12 | 1.9 | 180 | 500 | 1396 | 922 |
| | F | 6.2 | 0.14 | 2.3 | 201 | 602 | 1638 | 850 |
| | G | 7.4 | 0.17 | 3.3 | 781 | 976 | 3280 | 1594 |
| | H | 6.8 | 0.12 | 2.1 | 436 | 948 | 1962 | 1038 |
| | I | 6.7 | 0.12 | 2.1 | 312 | 896 | 1756 | 930 |
| | J | 6.2 | 0.11 | 1.7 | 188 | 498 | 1178 | 948 |
| 219 | A | 5.9 | 0.54 | 6.3 | 129 | 64 | 2248 | 768 |
| 0658519 E | B | 6.0 | 0.47 | 5.6 | 129 | 296 | 2308 | 756 |
| 7003555 N | C | 6.4 | 0.22 | 2.8 | 46 | 636 | 2194 | 870 |
| | D | 6.4 | 0.34 | 3.9 | 88 | 152 | 2588 | 676 |
| | E | 6.3 | 0.34 | 4.3 | 150 | 1538 | 1912 | 762 |
| | F | 6.2 | 0.35 | 4.0 | 72 | 186 | 2630 | 714 |
| | G | 6.6 | 0.31 | 3.5 | 54 | 338 | 2738 | 760 |
| | H | 6.1 | 0.48 | 5.8 | 144 | 422 | 1776 | 642 |
| | I | 6.4 | 0.44 | 5.4 | 88 | 530 | 2228 | 712 |
| | J | 6.0 | 0.84 | 10 | 57 | 238 | 1378 | 762 |
| 420 | A | 6.4 | 0.48 | 6.9 | 881 | 78 | 3142 | 834 |
| 0666077 E | B | 6.4 | 0.36 | 5.3 | 1077 | 60 | 2824 | 688 |
| 7004246 N | C | 6.3 | 0.33 | 4.7 | 675 | 280 | 2160 | 690 |
| | D | 6.2 | 0.36 | 5.0 | 472 | 256 | 2336 | 590 |
| | E | 6.2 | 0.27 | 4.0 | 536 | 142 | 2714 | 586 |
| | F | 6.2 | 0.32 | 4.7 | 343 | 256 | 1934 | 510 |
| | G | 6.3 | 0.43 | 6.2 | 317 | 418 | 2432 | 804 |
| | H | 6.4 | 0.42 | 6.0 | 642 | 354 | 2416 | 744 |
| | I | 6.2 | 0.45 | 6.5 | 418 | 94 | 2360 | 722 |
| | J | 5.4 | 0.67 | 8.9 | 255 | 42 | 694 | 284 |

| Feature No. UTM Coordinates | | pH | % N | %OC | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | | <------------------ | | μg/g----- | ------> |
| 421 | A | 5.8 | 0.36 | 5.0 | 278 | 202 | 654 | 396 |
| 0666024 E | B | 6.1 | 0.30 | 4.0 | 361 | 54 | 1364 | 570 |
| 7004273 N | C | 5.9 | 0.64 | 8.7 | 482 | 226 | 1320 | 694 |
| | D | 5.9 | 0.25 | 3.3 | 356 | 24 | 960 | 398 |
| | E | 6.2 | 0.30 | 4.0 | 876 | 296 | 1522 | 654 |
| | F | 6.4 | 0.33 | 4.0 | 394 | 304 | 1678 | 948 |
| | G | 6.2 | 0.31 | 3.9 | 335 | 174 | 1304 | 698 |
| | H | 6.2 | 0.28 | 4.0 | 412 | 426 | 924 | 588 |
| | I | 5.8 | 0.47 | 5.9 | 240 | 126 | 978 | 520 |
| | J | 5.9 | 0.43 | 5.7 | 183 | 158 | 990 | 542 |
| | K | 5.6 | 0.45 | 5.2 | 77 | 302 | 588 | 398 |

# APPENDIX B: C:N:P RATIOS

| Feature No. UTM Coordinates | | C:N | C:P |
|---|---|---|---|
| 001 | A | 14.00 | 206.75 |
| 0658850 E | B | 15.17 | 173.91 |
| 7004736 N | C | 13.33 | 122.45 |
| | D | 13.33 | 74.77 |
| | E | 14.19 | 87.64 |
| | F | 14.74 | 72.92 |
| | G | 13.64 | 129.31 |
| | H | 15.00 | 138.16 |
| | I | 16.11 | 114.62 |
| | J | 14.38 | 76.16 |
| | Average | 14.39 | 119.67 |
| 003 | A | 18.33 | 70.51 |
| 0658805 E | B | 18.00 | 68.88 |
| 7004603 N | C | 16.00 | 65.57 |
| | D | 12.79 | 11.17 |
| | E | 12.61 | 8.93 |
| | F | 15.00 | 77.10 |
| | G | 15.45 | 95.51 |
| | H | 14.62 | 160.34 |
| | I | 14.12 | 133.33 |
| | J | 13.68 | 84.14 |
| | Average | 15.06 | 77.55 |
| 57 | A | 15.00 | 162.16 |
| 0658754 E | B | 17.00 | 88.08 |
| 7004504 N | C | 17.00 | 94.44 |
| | D | 20.00 | 90.32 |
| | E | 15.83 | 105.56 |
| | F | 16.43 | 114.43 |
| | G | 19.41 | 42.25 |
| | H | 17.50 | 48.17 |
| | I | 17.50 | 67.31 |
| | J | 15.45 | 90.43 |
| | Average | 17.11 | 90.31 |

| Feature No. UTM Coordinates | | C:N | C:P |
|---|---|---|---|
| 219 | A | 11.67 | 488.37 |
| 0658519 E | B | 11.91 | 434.11 |
| 7003555 N | C | 12.73 | 608.70 |
| | D | 11.47 | 443.18 |
| | E | 12.65 | 286.67 |
| | F | 11.43 | 555.56 |
| | G | 11.29 | 648.15 |
| | H | 12.08 | 402.78 |
| | I | 12.27 | 613.64 |
| | J | 11.90 | 1754.39 |
| | Average | 11.94 | 623.55 |
| 420 | A | 14.38 | 78.32 |
| 0666077 E | B | 14.72 | 49.21 |
| 7004246 N | C | 14.24 | 69.63 |
| | D | 13.89 | 105.93 |
| | E | 14.81 | 74.63 |
| | F | 14.69 | 137.03 |
| | G | 14.42 | 195.58 |
| | H | 14.29 | 93.46 |
| | I | 14.44 | 155.50 |
| | J | 13.28 | 349.02 |
| | Average | 14.32 | 130.83 |
| 421 | A | 12.95 | 179.86 |
| 0666024 E | B | 8.31 | 110.80 |
| 7004273 N | C | 13.28 | 180.50 |
| | D | 7.02 | 92.70 |
| | E | 3.42 | 45.66 |
| | F | 8.38 | 101.52 |
| | G | 9.25 | 116.42 |
| | H | 6.80 | 97.09 |
| | I | 19.58 | 245.83 |
| | J | 23.50 | 311.48 |
| | K | 58.44 | 675.32 |
| | Average | 15.80 | 196.11 |