PREHISTORIC SOLAR INNOVATION AND WATER MANAGEMENT ON RAPA NUI

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ABSTRACT

The prehistoric Rapa Nui (Easter Island, East Polynesia) population radically transformed the island environment as it was changed to accommodate an agricultural system based primarily on taro, yam and sweet potato production. These changes included the extinction of several bird species, the heavy exploitation of coastal and near-shore marine resources, and the near total deforestation of the island's palm forest by AD 1350. The removal of the forest exposed the agricultural fields to increased wind velocities, promoted evapo-transpiration, moisture loss in the soils, and led to erosion in some sloping areas.

Archaeological survey and excavation of the Rapa Nui landscape has documented that prehistoric agriculturalists reduced the possibility of crop failure by careful management of the soil moisture regime. This was accomplished by the development of gardens covered with a dense layer of stone, or lithic mulch, where rocks were accumulated from the open landscape, removed from outcrops, and placed over growing areas. What appeared to be random strewn volcanic rocks have recently been discovered to be a solar innovation. It is hypothesized that a rock layer captures the intense solar radiation on a cool soil to manufacture dew, retain soil moisture, facilitate moisture percolation, reduce wind velocities and maintain higher soil temperatures. We evaluate this hypothesis with some preliminary data gathered from monitoring the soil temperature and moisture in the near surface region.

1. INTRODUCTION

The prehistoric people of Rapa Nui relied primarily on the agricultural production of sweet potato (*Ipomoea batatas*), dry land taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), and ti (*Cordyline*). All of these crops arrived with the first Polynesian immigrant population to Rapa Nui around A.D. 900 and for the next 900 years the tubers served as the staple foods. These starchy tubers were planted in small gardens, open fields, and intensively cultivated plantations in both the coastal and elevated regions of Rapa Nui (Stevenson 1997; Stevenson and Haoa 1998; Stevenson et al. 1999, 2002). The population was dispersed among the agricultural fields in single family or multiple family hamlets and produced food for household needs. In remote field systems located away from domestic sites, surplus foods were likely produced to support communal ceremonies and temple building projects. In this paper, we will provide an overview of how the prehistoric Rapa Nui coped with the difficulties of agricultural production in a risky environment that was in the process of continuous degradation over a span of about 700 years. Specifically, we will describe how the landscape was physically transformed to provide better growing conditions for agricultural plants.

2. THE RAPANUI ENVIRONMENT

When the first Polynesians arrived on Rapa Nui the island around A.D. 900 (Figure 1) it was forested with palm and multiple under story species of small trees and bushes (Flenley 1998; Flenley et al. 1991; Orliac 2000;

Orliac and Orliac 1998). This vegetation covered the three volcanoes and intervening lowlands. In some locations, where preserved root systems have been identified in the subsoil, the spacing of trees is estimated to be a mere 2.6m (Bork and Mieth 2003). Smaller indigenous plants would have covered the spaces underneath and between the larger trees. This native cover would have buffered the on-shore winds and maintained an adequate level of soil moisture.

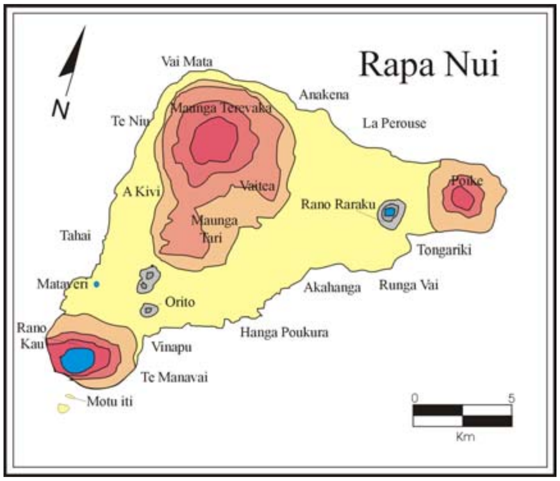

Fig. 1: Map of Rapa Nui showing the location of the Mataveri meteorological station and the Vaitea study area.

As documented on other Polynesian islands (Kirch 2000), the clearance of the native forest for living space and agricultural fields was one of the earliest activities. Pollen analysis of cores from the crater lake of Rano Kau (Figure 1) indicates that the process of deforestation was initiated around AD 950 and was probably completed in the 13th century (Flenley 1998). Archaeological excavations on Poike Peninsula (Figure 1) have dated the cutting of the forest in this region to the early AD 1400s (Mieth and Bork 2003). Early swidden fields within a forested environment would have been partly protected from strong winds and sun. However, with extensive removal of trees and surface ground cover, higher evapo-transpiration and reduced soil moisture retention became more significant impediments to successful farming.

This landscape change brought on by vegetation removal occurred within the context of a naturally risky rainfall situation. Modern meteorological recordings since 1960 indicate that in lowland coastal areas the rainfall amounts to an annual average of 1091 mm (Mataveri Station, Figure 2). However, deviations from the mean value can be significant. Within the 20-year recording period, dispersions from the mean value can be as much as 200 mm and result in periods of very high humidity or greatly reduced moisture. In the latter case, this would result in significant crop declines for plants placed in open and unprotected settings. Hunt and Lipo (2001) note that moisture fluctuations do not appear to be predictable and therefore introduce a degree of uncertainty into agricultural production.

This difficulty is exacerbated by the presence of an additional factor. The high soil moisture permeability created by soils containing large amounts of volcanic ash (Louwagie 2003; Louwagie and Langhor 2002) made moisture retention problematic. It has been shown that the lack of moisture retention in the critical upper rooting zone for sweet potato and taro (0.15-0.50 m) can prevent a plant from reaching maturity.

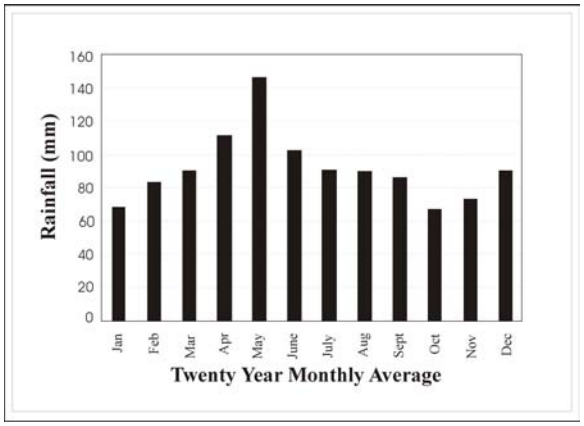

Fig. 2: Rapa Nui mean monthly rainfall

3. STRATEGIES FOR AGRICULTURAL PRODUCTION

The prehistoric Rapa Nui would have quickly recognized the impacts of deforestation and rainfall variability on the productive potential of the agricultural system. These limiting and unpredictable factors, would have introduced an uncertainty about the outcome of farming during each year. As a result, the Rapa Nui adopted a set of agricultural innovations to counteract the effects of moisture loss. These developments included the use of a surface lithic mulch to facilitate water permeability and reduce evaporation, rock placement within gardens as protection from wind, and garden placement within protected environments at the base of slopes that benefited from surface water runoff (Stevenson et al. 1998, 2002; Wozniak 1998, 1999, 2001) (Figure 3). Excavations conducted beneath these surface rock distributions have documented an anthropogenic soil horizon 20-80 cm deep with casts of humanly created planting pits preserved within the upper anthropogenic soil horizon and penetrating the underlying B-horizon.

Fig. 3: A Rapa Nui rock garden showing deep rock accumulations (pu) and boulder gardens.

Our landscape survey on the northeast coastal and inland areas of Rapa Nui have identified four basic types of rock gardens. The first type is termed *pu* and consists of deep accumulations of stone 10-25 cm in diameter that may reach up to a meter in depth. Planting wells are typically found within the rock cover, which is found almost exclusively at the base of hills and in the lower reaches of swales (Figure 3). The second type of garden contains extensive distributions of lithic mulch. Here, many small stones ranging in size from 5-15 cm have been incorporated into the upper 30 cm of the soil and cover a deeper planting region. This stone layer frequently caps planting pits that reach a depth of 50-75 cm. A third garden type consists of scree pavements, or a layer of 1-2 stones that cover the surface of the agricultural field. The agricultural horizon and planting pits lie beneath this surface cap. In the final type of garden configuration, boulders may be added to either scree pavements or lithic mulch gardens to form a boulder garden (Figure 3, foreground).

A most basic question concerns when this technological innovation was introduced and how long it continued to be used. It is our hypothesis that the application of lithic mulch would have appeared as deforestation severely impacted the landscape. This is estimated from the Rano Kao pollen cores to have been critical in the 13th century (Flenley 1998) and to have occurred on Poike peninsula by A.D. 1400 (Mieth and Bork 2003). However, direct evidence about the appearance of stone gardens is limited. Mieth and Bork (2003) find no evidence for lithic mulch use in buried gardens on Poike peninsula dating to the 15th century but there is little stone in this part of the island. The only buried non-lithic mulch garden identified to date comes from the base of Mount Orito in the southwestern corner of the island (Figure 1). Here, a homogenized A-horizon is capped by 20 cm of sediment from the adjacent steep slope. Two AMS radiocarbon dates on carbon fragments within a planting pit place the use of the garden in the first quarter of the 15th century (Stevenson et al. n.d.). This suggests that the introduction of the lithic mulch is a late phenomenon introduced well after deforestation had occurred. However, it is likely that the implementation of lithic mulch did not occur instantaneously across the island. Several more such contexts will need to be identified before the time range for this introduction can be defined.

Similarly, there is equally sparse evidence for how long the practice of creating lithic mulch gardens continued. The 18th century contact literature taken from ship logs and exploration accounts mentions the presence of orderly agricultural fields along the northwest coast and extensive banana plantations in the region of Vaihu but there is no mention of a stone ground cover. Other portions of the Orito garden study (Stevenson et al. n.d.) indicate that the use of boulder gardens and scree pavements continued into the late AD 1700s. However, labor-intensive applications of deep lithic mulch are absent at this time and are likely to have been abandoned much earlier.

4. MANIPULATION OF THE GROWING ENVIRONMENT BY ROCK PLACEMENT

Agricultural production was a challenging task on Rapa Nui because of the harsh environmental conditions. The Rapanui farmers sought to improve the growing conditions through the use of readily available rock and the strategic location of gardens in protected areas. These strategies can be viewed as buffers against three detrimental conditions: wind, high temperature and low moisture.

4.1 Wind Deflection

Winds are a near constant occurrence on Rapa Nui and are present throughout the day. From September to June the southeasterly trade winds predominate and during July and August the northeasterly trade winds occur. Wind buffering innovations against strong winds have been documented in Hawai'i where thousands of artificial earthen enclosures about a meter in height enclosed large planting areas. The earthen embankments disrupted the winds (Ladefoged et al. 2003) that evaporated the surface moisture and likely reduced the soil temperature. The creation of a small microenvironment with reduced wind velocities would restrict plant damage and facilitate plant maturation. On Rapa Nui, large earthmoving undertakings were not completed. Rather, the numerous inflections in the topography such as the slopes of hills, hillside swales, and basalt outcrops were used as protection (Figure 3). In open areas small boulders under a meter in size were placed in the fields to protect individual plants.

4.2 Temperature Modulation

The application of mulch to a bare ground surface has many beneficial properties. Much of the current experience is with organic mulches that reduce evaporation, help maintain a constant soil temperature, facilitate percolation of rainwater, reduce runoff, minimize evaporation and inhibit erosion. Less is known about the effects of stone mulch because of its limited application. In cooler locations it has been reported that rock mulch can increase ground temperatures that may enhance crop growth and germination but if the region is too hot it can increase the moisture requirements of plants (Whiting et al. 2003). Rock mulch may also buffer the temperature extremes because heat slowly diffuses through a large mass before reaching the ground below. The Rapa Nui environment is subtropical with an average annual temperature of around 21^{o}C. The temperature is at the low range of temperatures preferred for the cultigens of taro, sweet potato and yam (Louwagie et al. n.d.). Thus, thermal additions to the rooting zone during cooler periods would be beneficial.

4.3 Moisture Conservation and Generation

Surface soil with limited vegetation that is exposed to the sun can become hard and resistant to water penetration during the early phases of rainfall. Such is the case on Rapa Nui. However, the addition of lithic mulch that can be up to 30 cm in thickness may facilitate water percolation into the rooting zone. The mulch provides many channels for drainage into a soil and the rainwater can accumulate within the mulch if the rate of percolation in the soil is slow. It is also stated that a surface stone cover will inhibit evaporation of the soil moisture because it is protected from direct exposure to the sun. As a result, rock mulched plants have an increased availability of water compared to plants in open gardens. It has also been proposed that in regions of higher temperatures that condensation may occur during the evening temperatures when the air temperature is less than the rock surface temperature. This would provide additional moisture to the rooting zone even during periods of limited rainfall or during drought conditions.

5. MONITORING SOIL TEMPERATURE AND WATER CONTENT

An experiment was initiated using soil temperature and moisture sensors to evaluate some of the proposed benefits of using a lithic mulch technology over open gardens exposed to direct sun and wind. Here, we report some very preliminary results that are to be augmented with data from a complete annual cycle near the end of 2005.

In October 2004 two sets of HOBO temperature and water sensors were prepared to evaluate the difference between mulched and non-mulched gardens. The first set of sensors was placed under a 20 cm thick lithic mulch in the central part of Rapa Nui known as Vaitea (Figure 1). An excavation was made into an ancient garden and the mulch was repositioned close to its original form. At a distance of four meters away from the first plot a second set of sensors was placed in a stone free area at a depth of 20 cm below the surface. At the end of 5 weeks (5 October-11 November) the temperature and moisture readings made at hourly intervals over the 5-week period were downloaded.

The record of daily temperatures shows two interesting trends (Figure 4). First, the ground temperature located below the lithic mulch is always lower than the ground without stones. There is virtually no overlap between the daily minimum of the open bare ground plot and the daily maximum of the lithic mulch plot. Second, the amplitude of the daily temperatures for the stone free plot is approximately twice that of the lithic mulch plot.

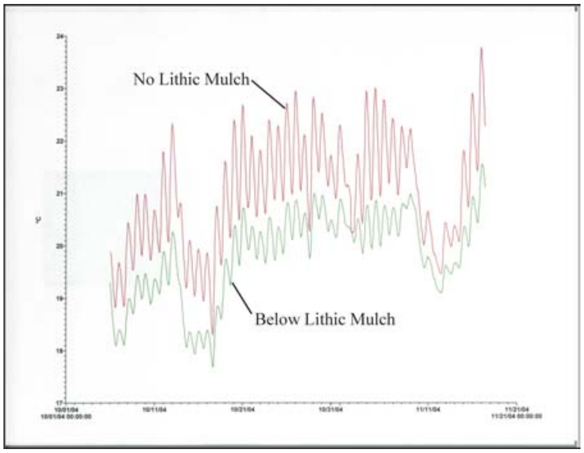

Fig. 4: Soil temperatures under lithic mulch and bare ground.

These data indicate that the lithic much acts as a buffer against temperature extremes and provides a more uniform growing environment. Much of the surface solar radiation does not reach deeper depths and is either reflected by the basalt rock surface and/or does not diffuse through the thick rock mass to lower depths. During periods of relatively stable weather the diurnal variation is about one degree centigrade. In contrast to other statements, the lithic mulch does not appreciably warm the underlying soil to bring the two data sets closer together. In the cooler evening there is a reversal in the thermal gradient and the heat begins to diffuse to the surface as the rocks cool.

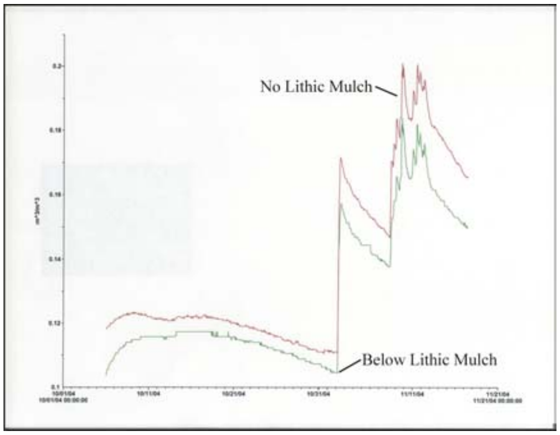

Fig. 5: Soil water content beneath lithic mulch and bare ground.

The water content profiles for the same test areas revealed some unexpected results. Contrary to our expectations, the soil located under the lithic mulch cap contained less water than the unprotected soil at the same depth (Figure 5). This difference existed during dry periods as well as during rainfall periods represented by the peaked areas. The pattern of the two plots varies in an equivalent manner and suggests that the lithic mulch inhibits the penetration of water to some degree. We do not expect this trend to continue through out the year. During the dryer summer period we anticipate a reversal in ground moisture levels where the lithic-mulched soil will have an overall higher level.

6. CONCLUSIONS

We have hypothesized that lithic mulch technology was an innovation developed to buffer agricultural crops against the detrimental effects of wind and reduced moisture conditions. A protected growing environment with sufficient moisture would improve plant health and lead to higher production levels needed by the prehistoric population. Our short term monitoring has revealed that lithic mulch technology reduces the extreme near surface temperatures that may impact the plant root system to provide a more uniform environment of limited thermal stress. However, the lithic mulch cap also slightly reduces water percolation contrary to the previous logic expressed in other studies. The lithic mulch cap may serve as a protective layer during the dryer periods of the year and raise the amount of available water for the plant root systems. Longer term monitoring is needed to determine if it is indeed a water management tool.

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