Sunset Crater Archaeology: The History of a Volcanic Landscape

Environmental Analyses

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Submitted to

Arizona Department of Transportation
Environmental and Enhancement Group
Phoenix, Arizona
Contract No. 97-41

Anthropological Papers No. 33
Center for Desert Archaeology
303 West University Boulevard, Tucson, Arizona 85705 • December 2007

HOPI CORN AND VOLCANIC CINDERS: A TEST OF THE RELATIONSHIP BETWEEN TEPHRA AND AGRICULTURE IN NORTHERN ARIZONA

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For over 70 years, archaeologists have speculated that the eruption of Sunset Crater Volcano in northern Arizona may have been the primary factor in the migration of a large population of prehistoric, agricultural people to this region (Colton 1932, 1936; Duffield 1997; Sullivan and Downum 1991). Colton developed this concept, based on an understanding of the timing of the eruption, archaeological studies in the region, and observations of contemporary agricultural methods of the Hopi Indian Tribe. Colton (1932, 1936) noted the presence of large numbers of ruins in shallow cinder fields, which were constructed and occupied after the eruption of Sunset Crater. He proposed that the prehistoric inhabitants used volcanic cinders or ash as a mulch to retain soil moisture in this high desert region. He also observed that modern Hopi Indians successfully grow corn in unirrigated fields, using a dry-farming method. This method entails planting corn at a considerable depth in late spring to capitalize on residual moisture until the onset of summer monsoon rains, which contribute more than one-third of the region's annual precipitation (Colton 1932, 1960, 1965).

Colton further reported that the Hopi use a variety of corn that develops a longer mesocotyl than conventional corn, allowing it to successfully grow when planted at depths of up to 1 ft. With this information, he concluded that the prehistoric inhabitants of the Flagstaff region may have farmed in a similar manner, using cinders to retain moisture.

Colton (1965) conducted the first experiments to test the idea that volcanic ash or cinder might serve as a valuable mulching medium. In the early 1930s, he planted corn in plots in the vicinity of Wupatki Pueblo, NA 405, and Sunset Crater (see Figure P.1) at elevations ranging between about 5,000 ft and 6,800 ft (1,524-2,073 m). Some plots were covered with varying depths of cinder, while others remained uncovered. Although Colton's results were somewhat inconclusive, his findings did suggest a thin layer of cinder mulch, rather than either a thick layer or no layer, benefited corn plants.

Colton's work inspired further research. Maule (1963) conducted experiments at Wupatki Pueblo where he showed that a thin layer of cinders produced the greatest germination rates in Hopi corn. He covered corn plots with 0-, 1-, 2-, or 3-inch cinder layers. Plots that received supplemental water had a germination rate of 90 percent, regardless of cinder depth. Among plots that received only summer rain, the best germination rate (40 percent) occurred with an overlying 1-inch-thick cinder layer, while deeper layers of 2-3 inches resulted in lower germination rates (23 percent and 10 percent, respectively). Perhaps most significantly, there was no germination in plots without cinder cover. Maule (1963) concluded that the best agricultural efforts would be near the edges of cinder fall areas.

The field experiments conducted for the U.S. 89 Archaeological Project—and reported on here—represent the most systematic evaluation, to date, of the effect of varying depths of volcanic cinders on corn growth. This relationship was considered along an elevational gradient to understand its value to agricultural efforts made at a more mesic, higher elevation site near Sunset Crater, versus a drier, warmer, lower elevation site near Wupatki National Monument. The control site, on the grounds of the Museum of Northern Arizona (MNA), was at the highest elevation and received supplemental water, making its results a natural extension of the elevational gradient encompassing the other sites. A wider range of both planting depths and cinder depths was also considered in this experiment to better define the ideal interaction between these two variables.

As noted by Muenchrath and Salvador (1995), for successful fruit production, corn needs at least 10 inches (25 cm) of annual precipitation, 6 inches (15 cm) of which must fall during the growing season. Most varieties of corn also need 115-120 frost-free days, although some short-season varieties grown by pueblo groups in the northern Southwest mature in as few as 75-90 days (Bradfield 1971:6; Muenchrath and Salvador 1995:311). Frost damage depends on the length of time the plant is subject to below freezing temperatures. Most varieties of corn can tolerate brief periods below freezing (32.5°F), but even a short period below a hard freeze (28.5°F) can cause significant damage (Muenchrath and Salvador 1995:311).

This study provides an opportunity to evaluate the importance of cinder mulch to prehistoric agriculture along an environmental gradient of both water and temperature availability. Physical factors, including soil moisture, soil temperature, and nutrient levels, were measured throughout the study. Soil nutrients were measured to observe changes in levels before and after one season's growth, providing initial data on how agricultural efforts may lead to measurable deficiencies in soil nutrients.

METHODS

Two field sites and a control site along an elevational gradient were selected for this study. The field sites encompassed high desert and pine forest conditions, which are most representative of regional conditions in which the prehistoric inhabitants lived. The Hulls Wash field site was located on Coconino National Forest land at an elevation of 5,660 ft (1,725 m), within a pinyon pine, juniper, and grassland habitat. It was approximately 0.7 km northeast of the North End site, NA 25,767 (see Figure P.2).[1] The substrate consisted of soil overlain with an extensive, shallow layer of volcanic cinder. The site was exposed to full sunlight throughout the day. Dominant vegetation included one-seed juniper species (*Juniperus monosperma*) and grasses, including Indian ricegrass (*Oryzopsis hymenoides*), galleta (*Hilaria jamesii*), threeawn (*Aristida purpurea*), and feathergrass (*Stipa neomexicana*).

The Lenox Park field site was also located on Coconino National Forest land at an elevation of 6,900 ft (2,103 m), within a ponderosa pine woodland-parkland habitat in the area between Lenox Park and Black Bill Park. It was approximately 0.2 km southwest of the Ant Hill site, NA 19,007 (see Figure P.2). At this site, patches of fine-grained cinders occurred sporadically. The site was exposed to full sunlight throughout the day. Dominant vegetation included ponderosa pine (*Pinus ponderosa*), rabbitbrush (*Chrysothamnus nauseosus*), and grasses, including blue grama grass (*Bouteloua gracilis*).

The third site, which was the control site, was located in an open, disturbed field at MNA northwest of Flagstaff. The MNA site was at an elevation of approximately 7,100 ft (2,164 m). The eruption of Sunset Crater did not affect this area, and no ambient cinder is present. The site was exposed to full sunlight throughout the day. Dominant native vegetation here included ponderosa pine (*Pinus ponderosa*) and blue gramma grass (*Bouteloua gracilis*).

Elson et al. (2006:20-26) examined temperature and precipitation variables along the U.S. 89 project area elevational gradient, extrapolating data from seven weather stations in the general Flagstaff, Sunset Crater, and Wupatki areas. The Hulls Wash site falls in Elevation Zone 1 (5,700-6,199 ft [1,736-1,899 m]), which is characterized as having a mean yearly precipitation between 12.5-15.1 inches (31.6-38.4 cm), mean growing season precipitation between 5.0-5.9 inches (12.7-15.0 cm), and a yearly mean temperature of 50.4°F (mean maximum of 66.8°F; mean minimum of 34.3°F). In this elevation zone, the mean minimum falls below the freezing point (32.5°F) an average of 5.4 months of the year, but below freezing temperatures have been recorded in 11 of the 12 months. At 70 percent probability (or, in 7 out of 10 years), there are an average of 115 consecutive frost-free days (above 32.5°F) and 141 consecutive days without a hard-freeze (above 28.5°F).

The Lenox Park and MNA sites fall in Elevation Zone 3 (6,700-7,199 ft [2,042-1,294 m]), with the higher elevation MNA site being colder and wetter than the Lenox Park site. This zone is characterized by a mean yearly precipitation between 17.8-20.5 inches (45.2-52.1 cm), a mean growing season precipitation between 6.8-7.6 inches (17.3-19.3 cm), and a yearly mean temperature of 46.0°F (mean maximum of 62.7°F; mean minimum of 29.6°F). The mean minimum falls below the freezing point an average of 6.9 months of the year, and below freezing temperatures have been recorded in every month. At 70 percent probability, there are an average of 83 consecutive frost-free days and 106 consecutive days without a hard freeze.

As these data indicate, sites within the U.S. 89 project area were at the margins of where corn agriculture could have been successful (Elson et al. 2006:17). The Hulls Wash site, while having a sufficient number of frost-free days, receives, on average, too little rainfall during the growing season for reliable corn propagation. The Lenox Park and MNA

[1]Note that the Hulls Wash agricultural field site, while within 350 m of Wupatki National Monument, is approximately 800 ft (244 m) higher than Wupatki Pueblo and about 300 ft (91 m) higher than the Citadel, NA 355, the two largest sites in the Monument area (Downum and Sullivan 1990:5.39). Precipitation lapse rates based on elevational differences calculated for the U.S. 89 project area (see Elson et al. 2006) suggest the experimental field site would have received roughly 4.3 inches more rain than Wupatki Pueblo and 1.6 inches more than Citadel.

sites have sufficient precipitation, but barely a long enough growing season. Clearly, environmental variables must have been a major factor in prehistoric decision-making—particularly in the selection of agricultural field locations.

The same experimental design was used at all three sites to assess the effects of different planting depths and overlying cinder depths on the growth of Hopi corn across the elevational gradient. Hopi corn was purchased from the Hopi Indian Reservation. This large kernel corn is noted for its long mesocotyl (distance between root and first leaf), which enables it to be planted deeply to take advantage of soil moisture.

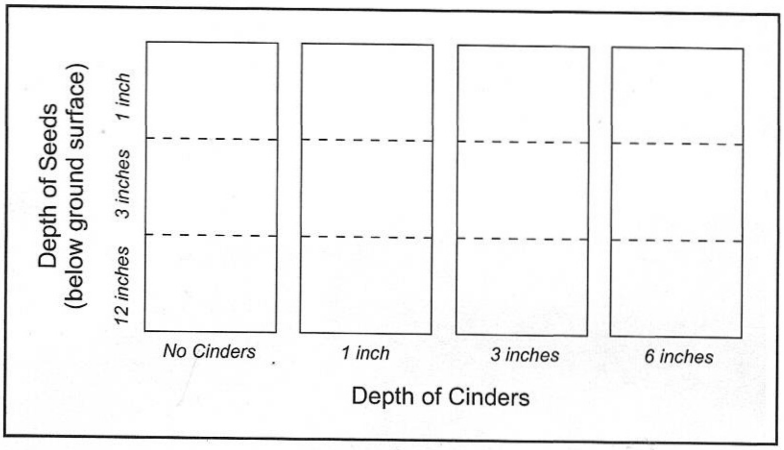

Figure 4.1. Design for experimental plots.

At each site, four 7-ft by 15-ft plots were established and covered with: (1) no cinders; (2) 1-inch-deep cinders; (3) 3-inch-deep cinders; and (4) 6-inch-deep cinders (Figure 4.1). Each plot was further subdivided into three 5-ft by 7-ft sections. Within each section, 20 sets of eight corn seeds each were planted beneath the original ground surface at progressively deeper depths of 1 inch, 3 inches, and 12 inches. Sections were delineated with pin flags.

There were a total of 240 plantings at each site, divided among the 12 treatment combinations (see Figure 4.1). The number of corn seeds planted and the planting depths were based on conversations with Hopi corn farmers and on the previous experiments described above. Plot design and dimensions, planting depths, and cinder depths are presented in English measurements (inches and feet), while experimental results are presented in metric measurements. This is to facilitate comparison with earlier studies that used English measures.

Black cinders from the vicinity of Strawberry Crater were imported to all sites and used to create cinder layers of varying depths across the planted plots. These cinders were less than 1 cm in diameter and macroscopically resemble cinders from Sunset Crater. Within each site, Plot 1 received no cinders, Plot 2 received 1 inch of cinders, Plot 3 received 3 inches of cinders, and Plot 4 received 6 inches of cinders. Because the plots could not be continuously monitored, they were fenced to prevent damage from deer, rabbits, and other animals (Figures 4.2 and 4.3).

Corn seed was planted in the plots at the Hulls Wash site on 30 May 2000, at the Lenox Park site on 1 June 2000, and at the MNA site on 5 June 2000. Plots were monitored until early October of 2000. This time period spanned the summer monsoon rainy season characteristic in northern Arizona. Plots at the Hulls Wash and Lenox Park sites received no supplemental water during the experiment. Plots at the MNA site were watered daily at 5:00 a.m. for 30 minutes. Water was carried among the plots with a soaker hose, and this provided enough water to saturate the soil (see "Results" section). The intent of watering the MNA site was to ensure measurable corn growth for at least one site in the event the rainy season failed to produce adequate precipitation to support corn growth at the other sites. It was valuable to conduct the same experiment in both water-limited and water-unlimited environments.

All sites were monitored between 8:00 a.m. and 10:00 a.m. at monthly intervals, with the following measurements recorded: (1) number of corn stems per planting (eight seeds were planted per planting); (2) maximum plant height (the tallest leaf in the planting cluster was measured); (3) soil temperature; and (4) soil moisture. At the MNA site, corn reproduction (number of plantings per section with flowers) and cob production (number of plantings with cobs present) were also measured. Plant data were gathered in September and October at both the Lenox Park and Hulls Wash sites, once plants germinated in August. Plant data were collected at the MNA site in June, August, September, and October.

To measure soil temperature, a portable temperature probe was inserted in each plot at representative planting depths (without disturbing planted seeds). The probe was allowed to equalize prior to a temperature reading. Soil moisture was determined by collecting soil samples in doubled, sealable plastic bags in each plot at representative planting depths. Each sample was weighed within approximately one hour of collection and again after a combination of air and oven drying. Dry weight was divided by wet weight to calculate percent moisture.

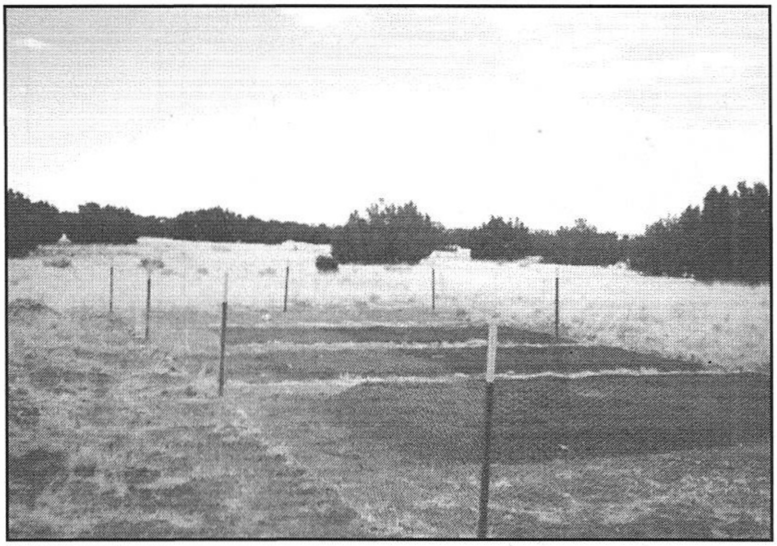

Figure 4.2. Experimental plot near Hulls Wash.

Figure 4.3. Experimental plot near Lenox Park.

Soil samples were collected at the beginning and the end of this experiment, and nitrogen, phosphorus, and potassium levels (NPK) (in mg/g) were determined by the Soil Sciences Laboratory at Northern Arizona University in Flagstaff. This analysis was conducted to determine if one season of crop production could produce a measurable reduction in available soil nutrients. All data were compiled in an Excel spreadsheet, and analyses were conducted with Statistica's ANOVA and non-parametric tests (StatSoft, Inc. 1999).

The effects of three treatments (cinder depth, planting depth, and cinder by planting depth interaction) were assessed using a 2-way ANOVA on the experimental data from Lenox Park and MNA. Separate ANOVA tests were conducted on each of the five response variables: number of stems, maximum plant height, growth rate, number of stems flowering, and cob production. Significance was evaluated using Rice's (1989) serial Bonferroni test to avoid Type II error. Too few plants germinated in the experimental plots at the Hulls Wash site for statistical analysis.

RESULTS

The results of this study are clear and quite robust with respect to the effects of cinder mulch on corn plant growth. Intermediate-depth cinder layers result in more plant establishment, increased growth, and ultimately, significantly more cob or fruit production (Figure 4.4.). Elevation also strongly affects this relationship and illustrates the importance of water.

Hulls Wash Plot

Seeds were planted at the end of May at the Hulls Wash site, but none germinated until late August, after the onset of summer rains. Corn germinated only when covered with a layer of cinders (Figure 4.5; see also Figure 4.4), strongly indicating the importance of cinders to agricultural production at this low elevation site. No seeds germinated in the plot without cinders, which is similar to the results of the previous Wupatki area studies (Colton 1965; Maule 1963). Overall, there was relatively little plant establishment at this site, even in plots with cinder layers. The numbers of established plants were so limited, it was impossible to analyze the results statistically.

There was plant germination in 4.6 percent, or 11 of the 240 plantings, at Hulls Wash. Most germination and stem production occurred among seeds planted in 1 inch of soil, covered by 3 inches of cinder (Figure 4.6; see also Figure 4.5). A mean of 0.95 plants/8 seeds/20 plantings occurred in this treatment. Only one plant germinated from seeds that were buried 1 inch deep and covered with 6 inches of cinder. No plants emerged when planted at a depth of 12 inches.