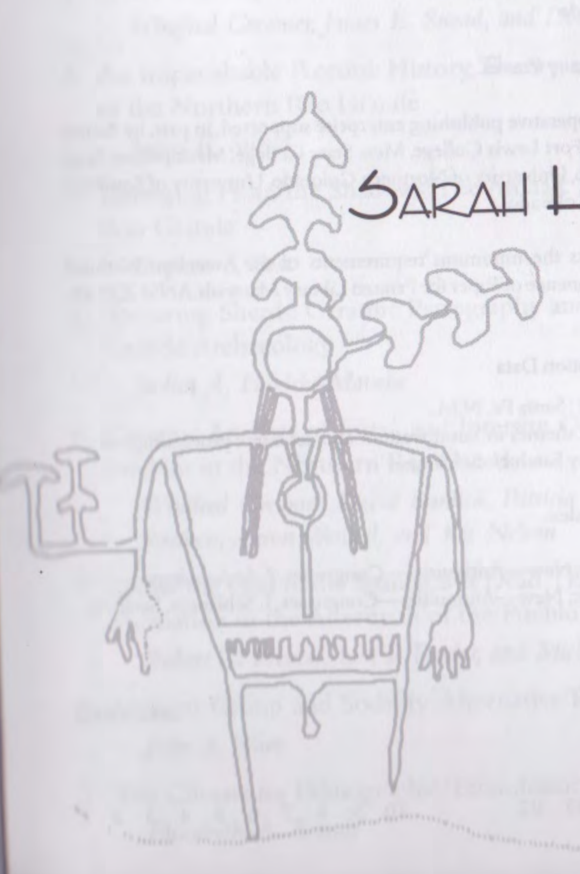
Traditions, Transitions, and Technologies

Themes in Southwestern Archaeology

Proceedings of the 2000 Southwest Symposium

Sarah H. Schlanger, editor



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11

Maize Agriculture and the Rise of Mixed Farming-Foraging Economies in Southeastern Arizona During the Second Millennium B.C.

Bruce B. Huckell, Lisa W. Huckell, and Karl K. Benedict

For nearly fifty years, archaeologists interested in the arrival and incorporation of agriculture into the economies of prehistoric Southwestern societies have attempted to understand the impact of farming on preceramic foragers. The last half of the twentieth century saw tremendous advances in the theoretical, methodological, and analytical tools available to students of this transition, as well as a wealth of new data from the field (for reviews see Huckell 1996a; Matson 1991; Smiley 1994; Wills 1988, 1995; Wills and Huckell 1994). Despite these leaps in knowledge, however, in many ways the dawn of the twenty-first century finds us no closer to resolving a key question confronted by Emil Haury, Herb Dick, and Paul Martin in the 1950s: How important was agriculture—particularly maize farming—in the economies of late preceramic Southwestern populations?

We do not propose that this question has a single answer; the importance of agriculture, at least in absolute terms, must have varied with environmental settings and cultural decision making with regard to subsistence options. Archaeological opinion on this matter seems to have resolved into two camps: one group views agriculture as critical to subsistence from the time of its arrival around

1000–1500 B.C. or very shortly thereafter, and the other group sees agriculture as undergoing a long settling-in process with minimal dietary reliance on cultigens until after about A.D. 500. The foundations for these differing positions on the contribution of agriculture to late preceramic economies tend to center—depending on the source—on whether and how inferences are derived from the archaeological record, the botanical record, and the ethnographic record, in addition to the theoretical orientation employed.

The suggestion that late preceramic agriculture was a minor element in the subsistence economy has a long history, beginning with Haury (1962) and Dick (1965). Evaluating the evidence acquired from sites in the highland portions of the Southwest—Bat Cave (Dick 1965), Tularosa and Cordova Caves (Martin et al. 1952), 0 Block Cave (Martin, Rinaldo, and Bluhm 1954), Jemez Cave (Alexander and Reiter 1935; Ford 1975), and the open Cienega Creek site (Haury 1957)—from the late 1940s through about 1960, both men were persuaded that the lack of obvious changes in seed milling technology and settlement types for around 2,000 years after the apparent arrival of agriculture must reflect limited impact of maize and other cultigens. Early maize cultivars, it was thought, were not drought tolerant and therefore must have been grown only in the higher-elevation, more mesic part of the Southwest. The apparent absence of maize in San Pedro sites in the arid basins of southeastern Arizona (Sayles 1945; Sayles and Antevs 1941) was seen as supporting evidence.

Studies of the maize from preceramic levels of Bat Cave by Paul Mangelsdorf and his collaborators (Mangelsdorf 1974; Mangelsdorf, Dick, and Cámara-Hernández 1967; Mangelsdorf and Smith 1949) characterized it as primitive and capable of producing only small ears. Hugh Cutler's (1952) evaluation of the Tularosa Cave maize provided additional support for this position. Richard Ford (1981) updated and restated this point of view, suggesting that early maize from these sites was a low-productivity cultivar. For this reason, as well as the mobility demands placed on late preceramic Southwestern foragers to exploit wild plant and animal resources, agriculture played only a minor role. Wirt Wills's (1988) reinvestigation of Bat Cave and examination of other rock-shelter sites led him to propose that early maize in the highland Southwest functioned more to support continued reliance on a wild resource foraging economy. Both Ford and Wills used foraging theory to infer that the principal contribution of maize was as a resource highly predictable in time and space but not one on which much dietary reliance could be placed. Paul Minnis (1985a, 1992) employed a similar view of Archaic foragers to argue that historic Western Apache groups provided an excellent ethnographic analog to the late preceramic situation in that their agriculture was at best casual and clearly secondary to wild resource procurement.

A contrary position—that maize was an integral component of many late preceramic Southwestern groups—developed in the 1980s, primarily from work in southeastern Arizona (Fish et al. 1986; Huckell 1988, 1990; Huckell and Huckell 1984; Mabry 1998). Haury's (1962) synthesis posited that for at least 500 years following its arrival in the higher-elevation, more mesic parts of the Southwest, maize cultivation had no economic impact on groups in lower, more arid areas of the region.

In conjunction with the rise of accelerator mass spectrometer radiocarbon dating technology in the early 1980s and new fieldwork, however, it became clear that maize from the arid Santa Cruz and San Pedro River Basins had an antiquity (ca. 1000–1200 B.C.) comparable to that in the highlands. Moreover, this maize was recovered from open sites—either deeply buried along stream channels or situated atop Pleistocene terraces adjacent to the streams—that contained pit structures, probable storage pits, and thick, artifact-rich cultural deposits. Maize was recovered in high ubiquities from flotation samples at several such sites, along with remains of several species of wild plants that represented multiple seasons. This led to the proposition that these communities represented greatly reduced residential mobility and that farming likely took place on the adjacent floodplains. Multiseasonal residence in settings similar to those utilized by ceramic period agriculturalists, reliance on storage for overwintering, and indications that mobility organization had shifted toward greater use of logistical strategies all pointed to the likelihood that a mixed farming-foraging economy was in place in southeastern Arizona by the second millennium B.C. Indications that the Colorado Plateau had witnessed the coeval rise of a similar economic system were soon forthcoming from studies of stable carbon isotopes in human bones (Matson and Chisholm 1991), as well as the discovery of sites similar to those in southeastern Arizona (Gilpin 1994; Matson 1991).

It is difficult to resolve these two conflicting positions, and it is clear that broad generalizations are difficult to support across the Southwest as a whole. Maize was almost certainly adopted earlier and with a much more economically significant role in those areas where it could be grown with greater assurance of success, based on local climatic, geomorphic, hydrologic, and biotic factors. Still, a lingering question is whether maize farming is a practical strategy at the low levels of investment posited by some investigators. It is also likely that continuing to debate material evidence that can be interpreted in multiple ways will not necessarily permit this question to be resolved.

Our goal in this chapter is to present the initial results of an assessment of the possibility of determining if there are lower limits to investment in maize agriculture as a viable economic strategy. That is, can we identify the minimum investment in farming necessary to promote sustainability of this agriculture? We attempt to do so within the framework of environmental risk and uncertainty, guided by the principles of evolutionary ecology. In particular, our focus is on southeastern Arizona and the San Pedro phase (ca. 1200 or 1500–800 B.C.) farmer-foragers occupying that region. We argue that the prominence of in-the-ground, bell-shaped storage pits represents a tactical response to subsistence risk and uncertainty and that some of those pits were filled with maize. By assessing the storage capacities of those pits, we have a point of departure for evaluating whether a threshold of investment in maize farming exists below which it ceases to be a sustainable solution for ameliorating subsistence risk in a mixed farming-foraging economy. Storage-pit capacities can serve as a proxy for a target level of maize production by San Pedro phase farmers and provide an empirical foundation for this chapter. To evaluate sustainability, we employ a simulation of maize farming productivity using historical climatic data for southeastern Arizona.

RISK AND UNCERTAINTY IN EVOLUTIONARY ECOLOGY

Through the use of foraging models, framed in terms of optimization, evolutionary ecologists attempt to understand how human foraging systems operate and change. Models that focus on diet breadth (resource choice) are particularly useful in that they approach questions of subsistence choice and change in terms of identifying which resources in a given environment are likely to make up a diet based on the ranking of available resources in terms of search, pursuit, and handling costs (Kaplan and Hill 1992; Stephens and Krebs 1986: 17–24).

In the early 1980s, models of diet breadth treated the environment as essentially static, leading to more or less fixed ranking of resources. Wild resources, however, are not static but change in response to both patterned and stochastic environmental processes; and more recently, models created by Eric Smith, Bruce Winterhalder, and others have emphasized variation in resource abundance (Smith 1991; Stephens 1990; Winterhalder 1986, 1990; Winterhalder and Goland 1997). One component of such variability is seasonality—that is, the annual cycle of seasons accompanied by predictable changes in plant resource availability—and to a lesser degree changes in the condition, location, and behavior of animals (Cashdan 1992). Against this background of predictable change is a second component of variability—unpredictable variations in resource abundance primarily dictated by variability in climatic conditions of a particular season. Variation in resource abundance leads to changes in resource rank within the diet, as costs change (Stephens and Krebs 1986: 151–169).

The predictable aspects of resource distribution and seasonality allow foragers to construct an annual round of subsistence, but unpredictable variability in resource availability creates both risk and uncertainty for human populations. Risk is defined here as the effects of stochastic variation on the outcome associated with a decision, whereas uncertainty refers to the lack of information that affects decision making (Smith 1991: 231). Both are particularly acute for humans occupying arid environments such as the southern Southwest. Here there are predictable rhythms of winter and summer precipitation, each with an associated pulse of resource production in the early spring and late summer, respectively. They are separated by late spring–early summer and fall droughts associated with periods of little or no wild resource productivity; this creates risk, although it

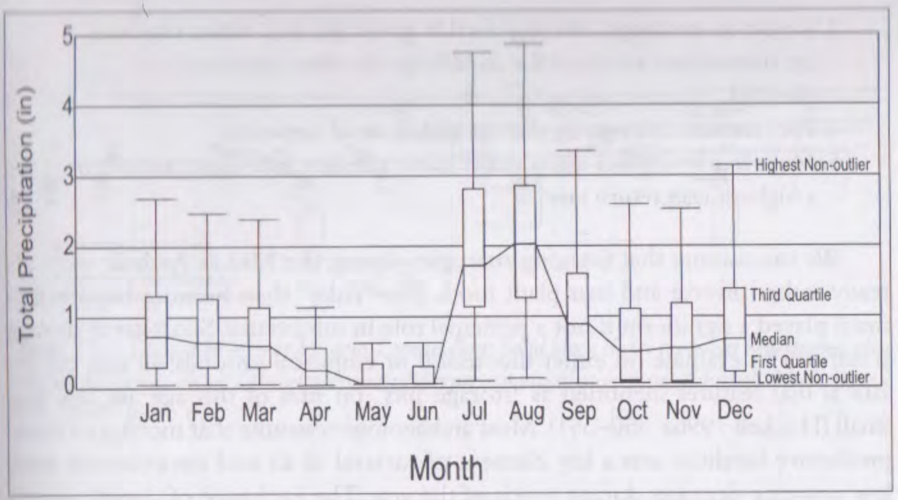

Figure 11.1. Mean monthly precipitation, Tucson, Arizona, 1884–1998

does not contribute greatly to uncertainty. In addition, as a typical arid-semiarid environment, the southern Southwest sees great variation in amounts of precipitation from season to season and year to year; such variation is unpredictable (Figure 11.1) and thus creates both risk and uncertainty. Recent work by climatologists has highlighted variation in the circulation of Pacific Ocean water as an important force in conditioning temperature and precipitation variability in the Southwest. El Niño, La Niña, and the Pacific bidecadal oscillation are examples (Bradley 1999).

COPING WITH RISK AND UNCERTAINTY

Human populations in southeastern Arizona must have designed subsistence and settlement strategies to exploit an environment characterized by a generally patchy distribution of resources and predictable seasonal variability, complicated by unpredictable interseasonal and interannual variability. We argue that the ways in which these strategies were developed by preagricultural Archaic and Early Agricultural populations differed significantly but in ways that can be understood in terms of risk and uncertainty.

How might preagricultural foragers have coped with these environmental conditions? Smith (1991: 233) identified five strategies, none mutually exclusive, that could reduce risk:

1. Alter foraging practices by seeking less risky (i.e., less variable) prey.
2. Use short-term storage to even out variance between days of successful and unsuccessful foraging.

3. Resort to exchange, offering durable goods for food when resources are uncommon and food for durable goods when resources are plentiful.
4. Pool resource harvests by sharing within social networks.
5. Move to a locale that offers either lower variance in foraging returns or a higher mean return rate.

We can assume that foraging strategies during the Middle Archaic were already rather diverse and that plant foods (less "risky" than hunting large mammals) played a significant if not a principal role in subsistence. Short-term storage is difficult to evaluate on either theoretical or empirical grounds; all that can be said is that features identified as "storage pits" on sites of this age are few and small (Huckell 1996a: 350–351). Most archaeologists assume that moving to more productive localities was a key element of survival in an arid environment with low resource densities during much of the year. The exchange of durable goods for food has not been considered by archaeologists working with the Archaic period, but some evidence for the practice may exist. Pooling resource harvests has not been considered, nor have the social and spatial scales at which sharing may have occurred.

The arrival of agriculture in southeastern Arizona offered preceramic societies what would seem to be a new strategy to address subsistence risk and uncertainty: cultivation and long-term storage of maize. Smith (1991: 233, footnote 10) suggested that storage is another mechanism by which foragers can help to address problems of variation in foraging success; however, it does have associated costs of processing, facility construction and maintenance, defense, and lost opportunities for other subsistence activities created by extended residence time at the storage locale. Winterhalder and C. Goland (1997) observed that short- and long-term storage is an appropriate strategy when periods of resource scarcity and high yield alternate regularly over long time periods. This is typical for the predictable biseasonal peaks of wild biotic resource production in the Southwest, as well as for cultivated crops, and food storage may be an appropriate mitigating strategy for the risk these conditions create. We suggest, however, that when all of these costs are considered, some minimum threshold probably exists below which the costs of storage are too high for the acquired benefits.

Maize farming and storage may have served as a mechanism to reduce subsistence risk for late preceramic populations in southeastern Arizona (Huckell 1990). Maize in particular was a new resource for the region, has great productive potential, and is highly storable. Unlike hunting and gathering, agriculture is more under human control with regard to decisions about where to plant, how much to plant, how much care to invest in cultivation, and how to use the crop. Most of the streams in southeastern Arizona began to aggrade rapidly sometime after about 4000–3000 B.P., creating excellent floodplain soil and moisture condi-

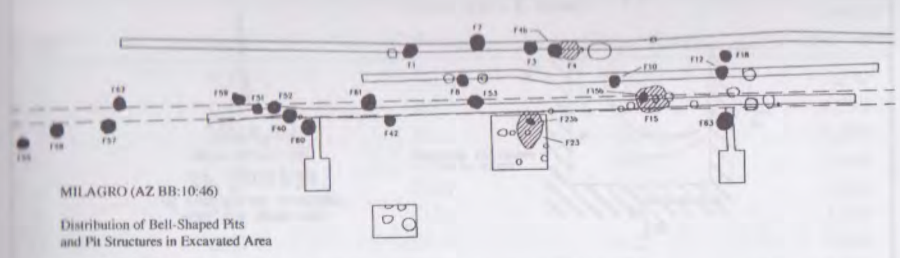

Figure 11.2. Excavated area at Milagro. Legend Text: Solid black circles represent bell-shaped pits, hatched oval areas are pit structures, open circles represent pits of other types (Huckell, Huckell, and Fish 1995: figure 6.1)

tions for farming (Huckell 1996b). Further, farming creates a resource that is predictable in both time and space and has a very high yield over a very short period of time. Also, unlike hunting and gathering, agriculture has great intensification potential (Earle 1980: figure 1.2).

The archaeological manifestation of long-term storage at San Pedro phase sites in southeastern Arizona is the bell-shaped pit, which occurs in both intramural and extramural settings and is often one of the most common features at such sites. After about 1200–1500 B.C. we see the rise of village settlements in southeastern Arizona; the San Pedro phase site of Milagro (Figure 11.2), a 2,900-year-old site in the northeastern Tucson Basin, is an example of such a settlement (Huckell, Huckell, and Fish 1995). An 8m-wide linear swath across Milagro was excavated in 1984 and 1993 within a water and sewer line right-of-way, and block excavations south of the right-of-way took place in 1988 and 1994. These investigations revealed four pit structures and over seventy extramural pits that included bell-shaped, straight-sided, rock-filled, and small basin-shaped forms. A cultural deposit rich in artifacts, ash, charcoal, and fire-cracked rocks covered the features. At a minimum, such settlements demonstrate greatly reduced residential mobility and probably greater use of logistic strategies for procuring at least some resources. In addition, the appearance of large numbers of bell-shaped storage pits of considerable capacity (Figure 11.3) testifies to a shift toward delayed consumption of resources. Reliance on storage would reduce the impact of predictable and unpredictable fluctuations in plant resources.

The investment in storage facilities at San Pedro phase villages is impressive in terms of numbers and capacities. Table 11.1 provides figures regarding storage capacities of these bell-shaped pits as manifested by excavated examples at Milagro. Pit capacities are expressed in terms of cubic meters, liters, bushels, and "maize ears." Storage capacity was calculated by subtracting 10 percent of the actual

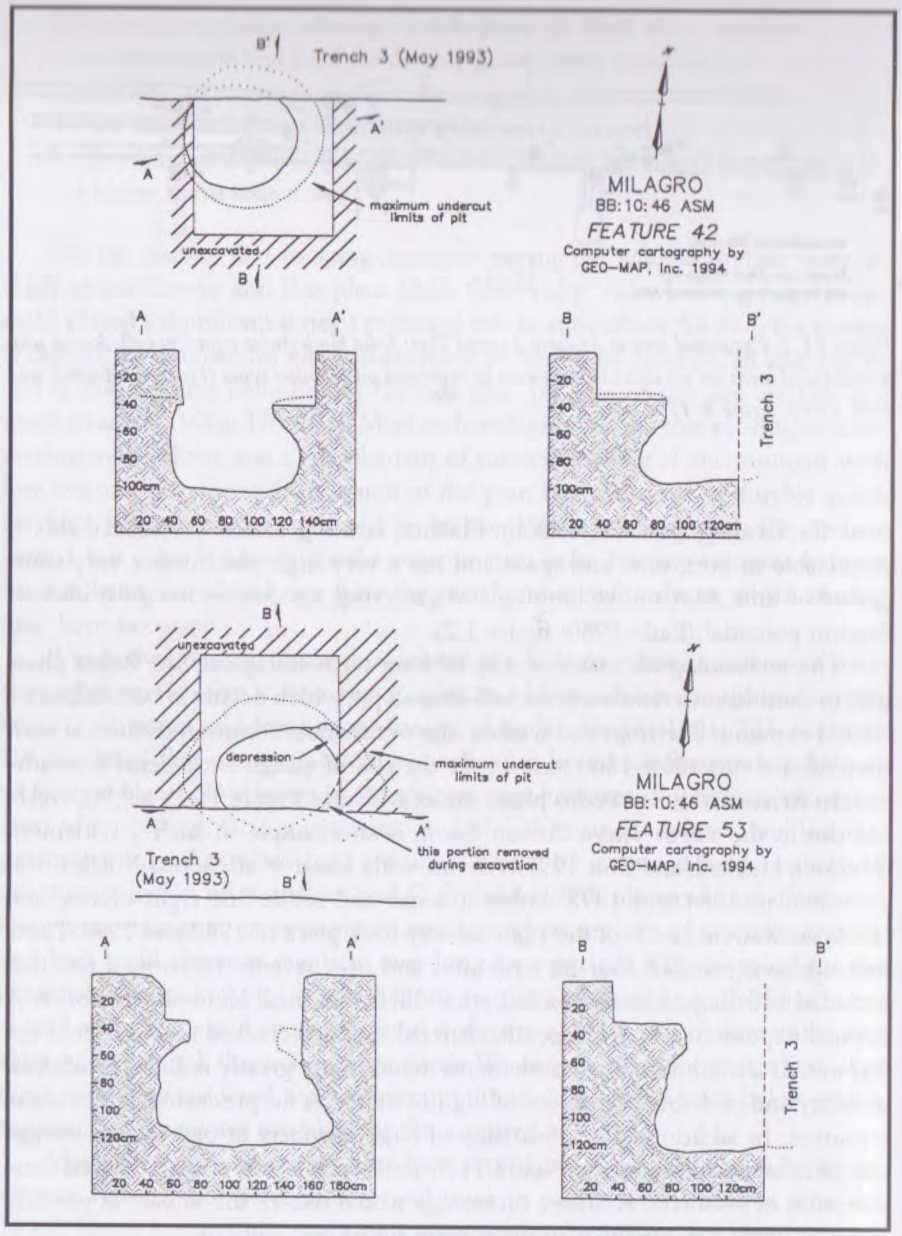

Figure 11.3. Examples of bell-shaped pits from Milagro

Table 11.1—Bell-shaped pit volumes and capacities at Milagro (AZ BB:10:46)

Feature	*Vol. (m^3)*	*Capacity (l)*	*Capacity (bu)*	*Capacity (maize ears)*
1	0.35	351.7	10.0	5,190
2	0.41	413.3	11.7	6,110
3	0.56	561.3	15.9	8,330
4b	0.37	374.2	10.6	5,560
8	0.15	156.1	4.4	2,220
10	0.13	132.5	3.8	1,850
12	0.57	570.9	16.2	8,520
15b	0.46	465.5	13.2	6,850
23b	0.06	63.8	1.8	930
40	0.37	370.0	10.5	5,560
42	0.33	327.0	9.3	4,810
53	0.66	660.0	18.7	9,810
55	0.34	343.0	9.7	5,000

Notes: 1. A "b" following the feature number denotes an intramural pit.
2. Calculated volumes in this table represent 90% of the actual excavated volume of the pit—10% has been subtracted to account for a pit lining.

excavated volume of the pit to allow for space taken up by a lining of grass or some other vegetal material. Further, the capacity of a pit in terms of maize ears includes allowance for the packing inefficiencies entailed in trying to fit such cylindrical objects together. Capacity in maize ears is based on calculations of the size and volume of a "typical" ear of late preceramic maize; expressing capacity in such terms seems warranted by the nearly ubiquitous occurrence of carbonized maize cob fragments in flotation samples from the site. The size of a typical ear was set at 8.43 cm long by 2.85 cm in diameter, which represents the average computed from two ears (one large and one small) from Tularosa Cave illustrated by Cutler (1952: figure 172, lower right pair). A pit of approximately 0.5 m^3 could have held nearly 7,500 ears of maize. Such a store of food might represent nearly one person year of caloric requirements, assuming no storage loss. Wild resources may also have been stored in some of these pits; for example, a pit of small capacity (Feature 8, 156 l) at Milagro yielded nearly 800 carbonized amaranth seeds, as well as more than 300 grass caryopses.

We lack important information on San Pedro phase storage with respect to exactly what was stored in pits, whether particular resources were stored separately in individual pits or together in the same pit, the use life or longevity of pits, social and spatial organizational aspects of storage, and how to interpret variation in the sizes of storage pits. There are indications, however, that maize was one of the key resources stored in bell-shaped pits. These indications include the demonstrated high ubiquity of maize cob macrofossils in San Pedro village sites; ethnographic data from ethnohistoric Southwestern societies such as the

Apache (Buskirk 1986), as well as the Missouri River tribes (Wilson 1987), regarding storage of maize in such features; and archaeological data from coeval Basketmaker II sites indicating that maize was stored on the cob in subterranean pits (Guernsey and Kidder 1921). For this exercise we assume that the sizes of these pits reflect production targets with respect to the growing of maize and that some of the pits held maize stored on the cob. These production targets, expressed in terms of the quantity of maize ears a pit could contain, form a baseline of data against which to measure the long-term sustainability of maize cultivation as a means of reducing risk and uncertainty. We opted to use a value—computed by averaging the capacities of two intramural bell-shaped pits in two pit structures (Features 4 and 15) at Milagro—of 6,205 ears. Our rationale for selecting the pits is that they are more likely to represent food stores owned by the occupants of the structures and thus to reflect the harvest obtained from one or more fields controlled by the occupants. In essence, then, we can view this as representing the harvest for a single consumptive social unit, probably a household.

Is this number of maize ears in a single pit outrageously high? How much food does it represent? If the ears yielded an average of 22 g of kernels each—a figure obtained from experimental cultivation of maize (Human Systems Research 1973: 455–457)—the 6,205 ears would produce 136.5 kg of kernels. Maize typically has about 3,600 calories per kilogram (Minnis 1985b: 110), so 136.5 kg would represent 491,400 calories. W. Wetterstrom (1986: 161–164) stated that 2,000 calories per day can be used to estimate the average daily energy requirements of an adult. Thus if this daily caloric requirement were met solely using the contents of this particular pit, 245.7 person days of food are represented by the maize (Huckell, Huckell, and Fish 1995). Clearly, no one can eat only maize, and it is a certainty that more than one person had access to the food in these pits. So although this is a significant amount of food, it does not seem unlikely that so much maize could be stored in a pit of this size. Further, the contents of this "average" intramural pit may not have been the only store of resources available to the household; extramural storage pits are also present at Milagro and other San Pedro sites and in fact outnumber the intramural pits by a considerable margin.

THE SIMULATION

The goal of the simulation presented here is to provide an estimate for the probability of a shortfall in the contribution of maize to the mixed diet of prehistoric populations in southeastern Arizona given historically documented climatic variation and yield estimates for a variety of field sizes. The difference between this approach and previous agricultural productivity simulation efforts is that most simulations have emphasized retrodiction of crop yields and food availability for specific years from a combination of data sets including paleoclimate (Burns 1983; Kohler and Van West 1996; Sebastian 1991; Van West 1994), maize growth stages

and impacts of climate (Sebastian 1991), storage capacity (Burns 1983; Sebastian 1991), and food sharing (Kohler and Van West 1996). This simulation emphasizes a quantification of risk for any given year given a specific range of climatic variability and labor expenditure; it is similar to that of M. Hegmon (1989, 1996). She employed a general set of climatic conditions, planting strategies, and general yield reduction values to assess the risk of a subsistence shortfall for sets of simulated households exercising a variety of risk-reduction strategies including storage and food sharing. The simulation presented here is similar in that it also estimates risk for simulated households but differs in its emphasis. Hegmon concentrated on postproduction risk-reduction strategies, whereas we focus on variability in production resulting from climatic variation and an empirical maize yield reduction curve.

The simulation employs monte carlo methods in generating a large number of simulated harvests through the selection (with replacement) of random annual collections of monthly total precipitation and number of rain days, an empirical yield reduction curve, variable planting dates, and variable length of time to harvest. These input parameters are used in the application of a daily growth model for maize development that estimates yield reduction from the number of water stress days. The output of the simulation includes a distribution of yield percentages, estimated actual yields (given different field dimensions and plant productivity values), and ratios of actual production to a predefined target production value based on mean intramural pit volumes from Milagro.

Because the effects of water stress on yield are dependent upon the timing of that stress, a daily model for plant development and yield reduction has been employed. Specifically, the yield reduction curve generated by R. H. Shaw (1988) and adapted by D. A. Muenchrath and R. J. Salvador (1995: figure 20.5) for late vegetative and postsilking yield reductions was combined with an interpolated curve segment for germination through early vegetative growth stages (Figure 11.4). Each day in the growth of a maize plant corresponds to a point on the yield reduction curve. Since the exact dates of water stress are unknown, the daily yield reduction percentages represented by the yield reduction curve are multiplied by a weighting factor (w) calculated from the number of stress days (n_s) and the total number of days in the month (n_m).

$$w = n_s / n_m \quad (1)$$

The total yield reduction for the entire growing season is summed, providing an estimate of the total reduction in yield from a baseline of 100 percent.

The climatic data set employed in this simulation consists of daily precipitation measurements (summarized into monthly totals to facilitate analysis and provide a degree of "smoothing" in the resulting simulation) for the University of Arizona in Tucson for the period 1895–1998 (Office of the Arizona State Climatologist 2000, from which the record from 1895 to 1985 was used). For each

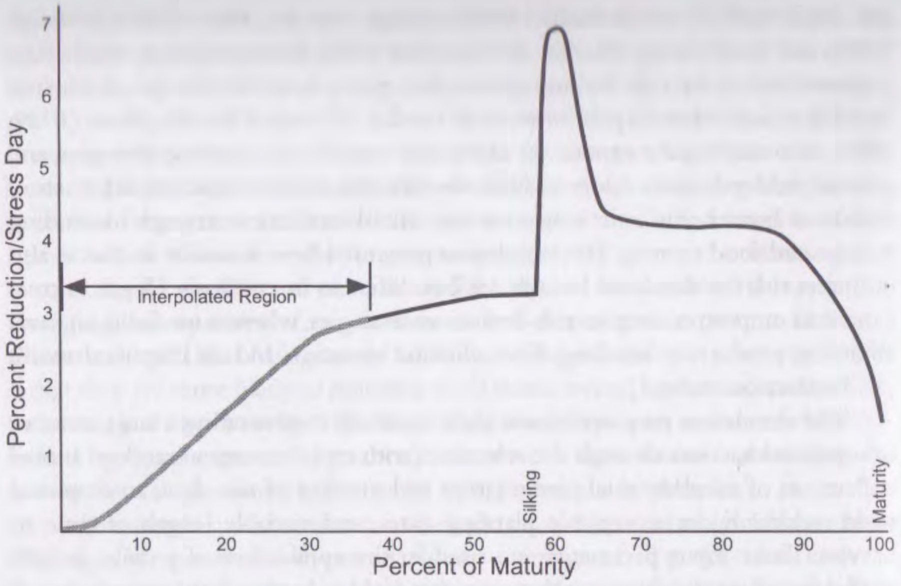

Figure 11.4. Empirical maize yield reduction curve

simulated harvest a year was randomly selected from which monthly precipitation data would be used to estimate the number of water stress days for each month (n_s), with the estimate derived from the number of nonrain days in the month (n_{nr}) divided by a sum of the total monthly precipitation (p) and a constant base divisor value (k).

$$n_s = n_{nr}/(k + p) \quad (2)$$

The resulting monthly water stress day estimates are divided equally over the entire month to provide a weighting factor (equation 1) for estimates of yield reduction for different stages in maize plant development.

An additional requirement for utilizing a daily growth model is the need for specifying the planting date and days to maturity for the maize cultivar under consideration. For this simulation the planting date was set to July 10 + 7 days, meaning the planting date for a single iteration of the simulation would be July 10 + a random number of days derived from a normal distribution with a mean of 0 and a standard deviation of 7. This date was selected based on the fact that floodwater fields in this region were generally planted within several days after the onset of the summer monsoon (Castetter and Bell 1942), with that date and range yielding planting dates within the range provided by E. F. Castetter and W. H. Bell (1942). For the purposes of this simulation a value of 100 + 2 days to maturity was used. This value is based on ethnographic (Castetter and Bell 1942:

148) and experimental data (Shuster and Bye 1983) and yields a very tight range of values surrounding 100 days for each simulation. The introduction of variation in planting date and growing season length produces additional variation in the simulation results.

Once the percentage yield values are available from the simulation, actual yields and a ratio of yield to target can be calculated from these parameters: field size, planting interval, ears per stalk, stalks per hill, and a target value for a minimum necessary production level. For this simulation a range of field sizes was used, ranging from 0.25 acres through 100 acres. This range of values effectively brackets the household field sizes recorded for Piman farmers (Castetter and Bell 1942: 53–54; Russell 1975). Planting interval was set at 30 in., again as provided by Castetter and Bell (1942). Ears per stalk and stalks per hill were both set to 2, allowing for partial success in the growth of 4 seeds planted per hill (Underhill 1979: 53) and a relatively conservative 2 ears per stalk. Finally, the target yield was set to 6,205 ears, with this value representing the mean capacity of the two intramural bell-shaped pits excavated at Milagro (see Table 11.1). With these parameters having been defined, 2,000 simulated harvests were generated for each field size, yielding percentage yields, actual yields, and ratios of actual yield (y) to target (t) (an index value [y_i] that facilitates identification of years where yield fell below the target).

$$y_i = y/t \quad (3)$$

The final results of each simulation can be summarized in terms of the probability of a shortfall, a value easily calculated by counting the number of yield index values (y_i yield/target) that are less than 1 and dividing that number by the total number of simulated harvests.

An examination of the frequency distribution of yield percentages for any of the simulations (the different field sizes have no effect on the yield percentages) suggests a roughly 10–12 percent probability that the yield percentage will be less than 5 percent. The remaining yield percentages (those above 5 percent) are distributed symmetrically around 50 percent, with the tails of the distribution covering nearly the entire range of possible yield percentages (Figure 11.5).

Conversion of the yield percentages from each simulation (for each field size) to absolute yields (y, in terms of maize ears) through multiplication of field area (a_f), hills per acre (h_a), stalks per hill (s_h), ears per stalk (e_s), and percentage yield (y_{pct}) provides an estimate for the number of maize ears produced in a single harvest.

$$y = a_f \cdot h_a \cdot s_h \cdot e_s \cdot y_{pct} \quad (4)$$

The resulting yield value, when divided by the target of 6,205 ears, provides an index of production failure, with an index value of 1 indicating a perfect correspondence between yield and target, values less than 1 indicating an insufficiency in production, and values greater than 1 indicating production exceeding the

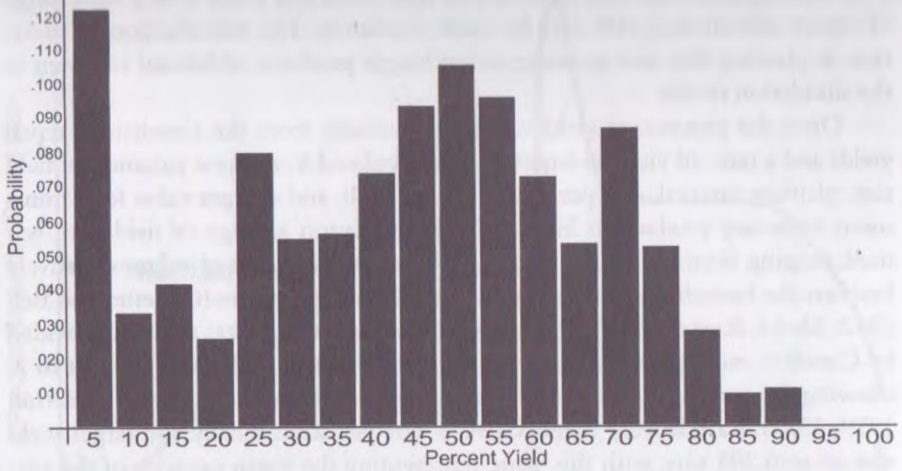

Figure 11.5. Percentage yield histogram

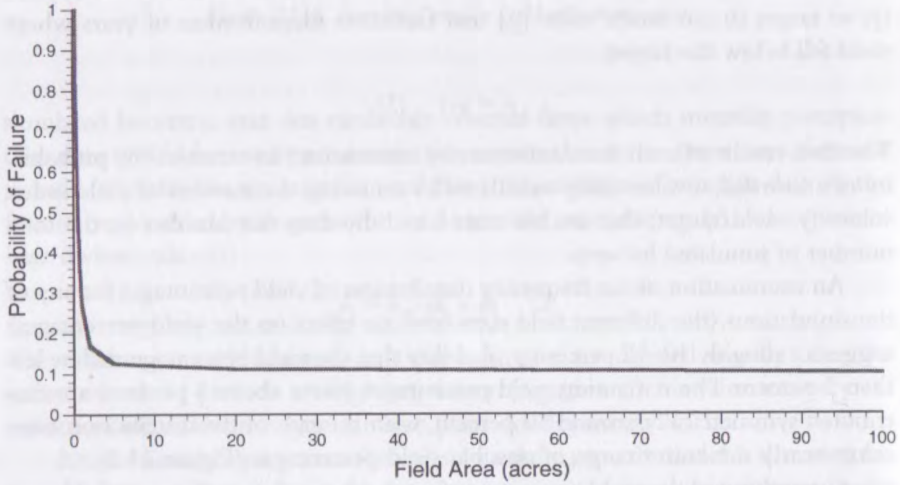

Figure 11.6. Probability of failure by field size

target. The probability of failure for a given simulation (field size) can then be calculated by dividing the number of index values that are less than 1 by the total number of harvests simulated. An examination of the resulting probabilities of failure for different field sizes suggests that very small field sizes have large probabilities of failure, whereas increasing field size only reduces the probability of failure to a minimum amount below which increasing field area has no significant effect on the probability of failure (Figure 11.6). In these simulation results it appears field sizes in the range of 2–5 acres yield the optimal combination of minimal probability of failure while minimizing labor investment.

In an effort to further characterize the dynamics of field productivity and climatic variation, additional simulations were run in which the absence of direct precipitation could be mitigated through irrigation. This modification was accomplished through a reduction in the number of nonrain days by combining the daily precipitation record with mean daily river gauging station measurements. To do this we first needed data on stream flow from southeastern Arizona to match the historical climatic data. Because the reach of the Santa Cruz River passing through Tucson has been ephemeral for a century or so, we turned to the San Pedro River for the necessary data. That river, although entrenched like the Santa Cruz, maintained perennial (or nearly so) surface flow in its upper reaches throughout the twentieth century and has been measured consistently at gauging stations. We chose to use the stream-flow records from Charleston (United States Geological Survey 1999) for our simulation. Further justification for use of the Upper San Pedro is that San Pedro phase village sites have long been known in the area of Charleston and immediately downstream at Fairbank (Huckell 1990; Sayles 1945; Sayles and Antevs 1941). Further, Jonathan Mabry (2000) has reported one clear example of a San Pedro phase canal irrigation system along the Santa Cruz River in the Tucson area. We thus determined that it would be important to ascertain what impact irrigation would have on our maize dry-farming simulation. Although no traces of irrigation systems have yet been found in the San Pedro Valley, their existence does not seem unlikely.

The availability of irrigation water was modeled by determining the position of each daily flow value relative to a series of percentiles for stream flow for each month calculated from the entire historical record of measurements for the station. If the daily flow value was above the specified percentile (2.5%, 5%, 10%, 20%) for the month, the day was scored as a rain day, even if no direct precipitation occurred on that day. The specified cutoff percentiles were defined in an effort to simulate different water extraction efficiencies for the head gates of irrigation systems, with lower thresholds (i.e., 2.5%, 5%) representing systems with more effective water extraction systems and higher thresholds (10% and 20%) representing less effective systems. Although the values selected for the simulation are arbitrary, they represent a reasonable range of values that is within the realm of possibility when considering the efficiencies of irrigation head gate systems. With this modification, the summary monthly data were provided to the simulation in the same manner as was done for the nonirrigation simulation that is the major focus of this chapter.

The introduction of irrigation potential into the simulation had a significant impact on the resulting probability of failure curves, particularly at the lowest threshold levels (2.5% and 5%) for which the probability of failure, regardless of

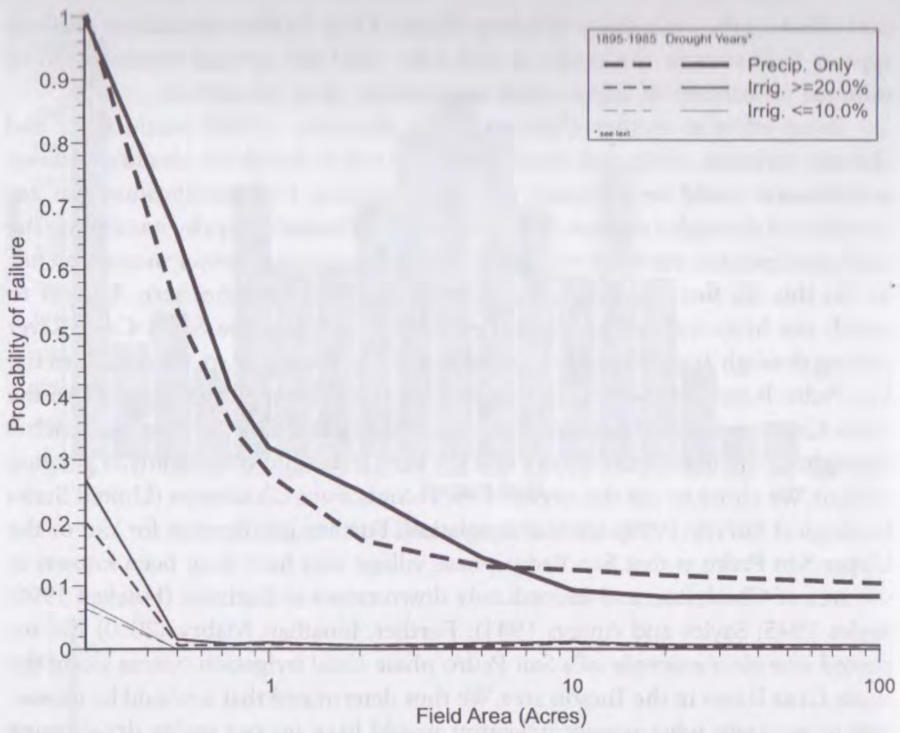

Figure 11.7. Probability of failure for direct precipitation and variable irrigation water capture efficiencies for all years and for drought years

field size, approached zero. Figure 11.7 illustrates a reduction in the probability of failure, particularly for small field sizes that otherwise had substantial probabilities of failure. In considering the potential of irrigation to offset the effects of drought conditions, the simulation was rerun with a subset of the full historical record of combined precipitation and stream-flow data. Specifically, the simulation was limited to the available data from the years 1906, 1915, 1918, 1924, 1942, 1947, 1950, 1953, 1960, 1978, and 1979—all of which had significant summer droughts (Huckell 1990). These simulations yielded similar results (see Figure 11.7), with the probability of failure for small and medium fields much reduced in comparison to fields for which irrigation was assumed to be unavailable.

DISCUSSION OF RESULTS

Simulation of success in farming yielded some interesting results. Figure 11.5 shows the probability distribution of obtaining a harvest of a particular size, expressed as a percentage of perfect production, from a field of 0.25 acre. Most striking is that the probability of obtaining 5 percent or less of the possible yield

from this field is about 0.13; once in every 13 years, on average, maize crop failure is the result. Note, however, that the median harvest from this field is at 50 percent or slightly better. Returning to the production target of 6,205 ears, a simple doubling of the field size to 0.50 acres would thus ensure a yield of this quantity of maize or more at least 1 year in every 2. Bear in mind that this simulation does not allow for irrigation and is in essence treating maize growing as dry farming. Investment in irrigation of the field would lessen the loss of production caused by water stress and aridity.

Successive simulation experiments were conducted for fields of 0.5, 0.75, 1.0, 2.0, 5.0, 10.0, 20.0, and 100.0 acres. All yielded similar histograms because we are simply expanding the field size and retaining the same experimental parameters. Slight differences can be attributed to patterns of resampling of the climatic record. If we take all of these simulations together and plot the probability of failure against field size, however, an interesting pattern emerges. With fields of less than about 2–3 acres, the probability of failure rises rapidly. Conversely, the probability of failure becomes virtually asymptotic with field sizes of 10 acres and larger.

This result is intriguing. It suggests that the sustainability of maize agriculture under these simulated growing parameters is indeed likely to become increasingly risky with smaller field sizes. This probability of failure rises to nearly 45 percent for fields of around 1 acre, ultimately peaking at approximately 80 percent with fields less than 1 acre. Theoretically, this could identify a lower level of effort investment for maize farming, below which the addition of maize to the diet might be ineffective in reducing subsistence risk as well as uncertainty. Therefore field acreages above 2 or 3 acres allow delineation of the point of maximum subsistence benefit for minimum acreage (i.e., cost). How well does this accord with the ethnohistoric record of southern Arizona cultivators? Castetter and Bell (1942) documented that Pima families typically cultivated between 1 or 2–5 acres with irrigation, whereas the Papago range for floodwater fields (Bryan 1929) was 0.25 to 2.0 acres per family.

Further, despite the fact that the probability of failure hardly lessens with the planting of increasingly larger fields, the amount of maize that can be harvested continues to increase. Thus intensification of maize farming by bringing larger field areas into cultivation is economically beneficial so long as labor is available. This result is in accord with Timothy Earle's (1980: figure 1.2) diagrammatic representation of the relative potential for intensification of hunting, gathering, and agriculture; of the three strategies, agriculture alone is continually responsive to increased labor investment by concomitantly producing more food.

Dry farming is a risky proposition in southeastern Arizona, as the simulation suggests and as reported by O. E. Meinzer and colleagues (1913: 216–223) for early-twentieth-century dry-farming efforts in the Sulphur Spring Valley of extreme southeastern Arizona. It is likely that, as was the case for historic period farmers in southern Arizona, San Pedro phase field location was chosen to increase the probability that additional water could be made available to crops. Almost invariably with maize, field location was along the floodplains of perennial or ephemeral streams, which could provide supplementary moisture to crops from localized high water tables, overbank flood flow, or possibly the construction of irrigation canal systems to deliver water from the stream channel to the fields.

It should come as no surprise that farming with irrigation greatly reduces the probability of crop failure. Note that the probability of failure never rises above 0.2 (see Figure 11.7), even if low stream flow conditions or relatively inefficient withdrawal of water from the stream limit the availability of irrigation water. Also, with irrigation, fields of 0.5 acre can achieve the target production value with a high degree of reliability. The relationship between field size and probability of failure becomes asymptotic above 0.5 acre. These data suggest that with irrigation, smaller field sizes can more reliably produce the target yield of maize. Even in drought years (see Figure 11.7), the probability of failure does not show marked increase so long as stream flow is not interrupted or so low that a canal system cannot efficiently extract it from the river.

We do not intend to argue that irrigation solves all the problems associated with maize cultivation. Clearly, crop reduction or failure can result from numerous causes, including catastrophic weather events (hailstorms, high-magnitude floods), fungal infestations, animal (birds, rodents, rabbits, deer) predation, declining soil fertility, irrigation system maintenance problems, and raiding by other human groups. In addition, we have treated irrigation as if there is only one field on the landscape, and during the San Pedro phase there were likely multiple village communities along major streams in southeastern Arizona. In years of low flow, the removal of water by upstream irrigation systems would clearly impact downstream systems. The simulation experiment, however, demonstrates the effect irrigation can have on the probability of success in maize farming in the San Pedro River Valley and presumably elsewhere in semiarid southeastern Arizona.

CONCLUSION

This cyber–San Pedro maize farming simulation is only a first step into a largely unexplored realm, but it shows considerable promise as a tool for investigating this subsistence tactic. The most fundamental conclusion we can draw is that maize cultivation, at levels of effort that do not seem excessive, is a sustainable and successful strategy for reducing subsistence risk and uncertainty. Clearly, more attention to the model parameters can hone the utility of the approach.

We also conclude that by employing simulation it is possible to establish something resembling a lower limit of investment in maize agriculture that will help to mitigate the potential risk in a stochastic environment. The implication of this result is that "casual agriculture," as envisioned for the late preceramic period by some investigators (Minnis 1985a, 1992), is liable to be a risky strategy in terms of sustainability. Instead, if maize is adopted to help reduce subsistence risk, it is unlikely to have been an unimportant component of the economy for several centuries before finally becoming sufficiently "productive" in the early ceramic period to merit serious effort. That is, the probability of crop yield reduction or outright failure is greatly increased if significant effort is not devoted to clearing and preparing a field of sufficient size for planting, if too small an area or number of seeds or hills is planted, or if no effort is made to provide additional water to the maize. Additionally, small or poor yields in times of hunger may make it difficult or impossible to conserve sufficient seed stock for next year's planting. At least in southeastern Arizona and probably in other parts of the Southwest, these relationships must have been evident to San Pedro phase farmers.

Another implication of these results is that depending on the desired target yield, the probability of reaching or exceeding that level is increased by planting more acreage with the expectation that a perfect (100%) yield is highly unlikely in most years because of the vagaries of summer precipitation. By the same token, increased investment in irrigation will reduce water stress and foster greater yields per field.

Finally, the fact that our simulation results are in accord with the range of field sizes documented for the historic Pima families suggests that the experiment is within the appropriate ballpark for the real world of arid southeastern Arizona. Future refinements to the model can be made by refining the yield reduction curve by using data from specific maize cultivars and adding stochastic events such as floods to the simulations. Increased archaeological knowledge of the attributes of San Pedro maize cultivars—such as how many ears each plant bore, tillering propensities, and sizes of ears—would also result in development of a more realistic model. Obviously, much more remains to be explored, but we believe this is an encouraging first step in assessing the importance of maize agriculture for Early Agricultural period farmers.

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