PERSPECTIVE

The diffusion of maize to the southwestern United States and its impact

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Our understanding of the initial period of agriculture in the southwestern United States has been transformed by recent discoveries that establish the presence of maize there by 2100 cal. B.C. (calibrated calendrical years before the Christian era) and document the processes by which it was integrated into local foraging economies. Here we review archaeological, paleoecological, linguistic, and genetic data to evaluate the hypothesis that Proto-Uto-Aztecan (PUA) farmers migrating from a homeland in Mesoamerica introduced maize agriculture to the region. We conclude that this hypothesis is untenable and that the available data indicate instead a Great Basin homeland for the PUA, the breakup of this speech community into northern and southern divisions ≈6900 cal. B.C. and the dispersal of maize agriculture from Mesoamerica to the US Southwest via group-to-group diffusion across a Southern Uto-Aztecan linguistic continuum.

early agriculture | migration | US Southwest | Mesoamerica | Uto-Aztecan

The dispersal of maize agriculture from Mesoamerica to the southwestern United States is a perennial topic of renewed interest as part of a broad, interdisciplinary effort to understand the development of maize agriculture in the New World (1–3). At present, there are two competing models of the mechanisms through which this dispersal took place. The first proposes that maize agriculture diffused northward as a complex comprised of the cultigen itself and the knowledge associated with its cultivation and use, transmitted from one foraging band to another without major population movements (4–6). The second argues that maize agriculture was introduced to the southwestern United States through the long-distance migration of Mesoamerican farmers (7–9).

Over the years, most scholars have considered group-to-group diffusion more likely, but since 2000 the long-distance migration model has gained adherents due primarily to perspectives developed by the archaeologist Peter Bellwood regarding the expansion of agriculture and language families in diverse regions of the world (8, 10–14). Bellwood suggested that maize agriculture expanded from its area of origin in Mesoamerica to the US Southwest as a consequence of the migration of farmers who were members of the Proto-Uto-Aztecan (PUA) speech community. He proposed that this migration began ≈3500 B.C. and involved the spread of PUA speakers across the region extending between Mesoamerica and the US Southwest. This population expansion led to the diversification of PUA into distinct dialects and eventually the distinct languages that comprise the Uto-Aztecan (UA) language family, distributed at the time of European contact from the Great Basin of western North America to Central America (see Table S1) (15–17).

The credibility of Bellwood's proposal was bolstered by the strong endorsement of the Uto-Aztecanist linguist Jane Hill, who in a series of publications presented linguistic, cultural, and human genetic data that she interpreted as supporting his perspective (9, 18–21). Largely as a result of her work, the Bellwood–Hill hypothesis is now regarded as offering a plausible scenario for the origins of maize agriculture in the US Southwest (22–24), but it has not yet received the critical evaluation that the evidence currently available allows. Here we review this evidence, concluding that it strongly supports the alternative view that maize agriculture spread from Mesoamerica to the Southwest via group-to-group diffusion. We propose that Uto-Aztecans played a crucial role in this diffusion but more than a millennium after the PUA speech community began dividing into subgroups and migrating out of the homeland that its members shared at that point in their history. We offer new data to argue that, at the time of the initial breakup of this speech community, its members were foragers located in the Great Basin rather than farmers in Mesoamerica and that this breakup began ≈6900 B.C., significantly earlier than previously proposed.

The Introduction of Maize Agriculture to the Southwestern United States. Multiple AMS radiocarbon dates firmly establish that maize (*Zea mays* spp. *mays*) was introduced to the southwestern United States no later than 2100 cal. B.C. (calibrated calendrical years before the Christian era) (Table 1 and Table S2) (25, 26). The arrival of maize in this region was preceded by a long period during which its wild ancestor, Balsas teosinte (*Zea mays* ssp. *parviglumis*), native to southwestern Mexico, was transformed through human intervention into a productive grain crop (3, 27–29). The oldest known maize macrofossils, recovered from Guilá Naquitz Cave in the southern Mexican state of Oaxaca, date to 4280 cal. B.C. (30, 31). For the purposes of this essay, we will assume that the initial dispersal of maize from Mesoamerica to the southwestern United States began ≈4300 cal. B.C.

The earliest evidence for maize in the southwestern United States comes from three open sites and two rockshelters in Arizona and western New Mexico (Table 1, Fig. 1) (32–37). Ranging in elevation from ≈700 to 2200 m, these sites are notable for the diversity of their settings. Clearwater and Las Capas are located along the middle Santa Cruz River in the

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Table 1. The earliest maize sites in the US Southwest

Site	Location	Latitude	Elevation	Type	Calibrated date (2 σ and median) (refs. 25, 26)
Old Corn	Colorado Plateau, western New Mexico	34°30′	1,910m	Open	2460–2060 B.C. (2260 B.C.)
McEuen Cave	Gila Mountains, eastern Arizona	33°14′	1,340m	Rockshelter	2270–1940 B.C. (2080 B.C.)
Clearwater	Tucson Basin, southern Arizona	32°13′	720m	Open	2200–1960 B.C. (2080 B.C.)
Las Capas	Tucson Basin, southern Arizona	32°20′	680m	Open	2200–1940 B.C. (2050 B.C.)
Three Fir Shelter	Colorado Plateau, northeastern Arizona	36°35′	2,240m	Rockshelter	2470–1540 B.C. (1990 B.C.)

The calendrical dates are calibrated to the maximum 2 σ range with the median (25, 26). Uncalibrated radiocarbon dates and references are in Table S2.

basin and range country of the upper Sonoran Desert. McEuen Cave is found in a deep canyon in the eastern Gila River valley, in the mountainous transition zone between the southern basin and range country and the Colorado Plateau. The Old Corn site is in an upland valley on the southeastern edge of the Colorado Plateau, and the Three Fir Shelter is situated on the central Colorado Plateau, near the north rim of Black Mesa. The fact that maize appears almost simultaneously in these upland and lowland sites suggests that the ancient landrace(s) were tolerant of a wide range of environmental settings.

Fifteen radiocarbon dates on maize macrofossils recovered from these five sites cluster ≈2100 cal. B.C. (Table S2). The earliest dates for maize at Old Corn, McEuen Cave, and Clearwater are consistent with dates derived from other associated materials at these sites, as well as those for the oldest maize recovered from Las Capas and Three Fir Shelter. Two other sites, Los Pozos in the Tucson Basin and Bat Cave in the Mogollon Highlands, also have yielded maize with very early dates, but the reliability of these dates has been questioned (4, 33). The presence of maize in about half of the features at the Old Corn site, including roasting and storage pits, and the existence of a few pre-2100 cal. B.C. maize dates from Old Corn and McEuen Cave (34, 35) raises the possibility that maize arrived in the southwestern United States before 2100 cal. B.C.

The paucity of archaeological data for the area between Mesoamerica and the US Southwest for the 4300–2100 cal. B.C. time period renders any scenario for the northward diffusion of maize agriculture highly speculative. The only early maize sites that have been excavated in these latitudes are the Ocampo Caves, located in the highlands of the northeastern Mexican state of Tamaulipas, where the oldest maize dates to ≈2400 cal. B.C. (38, 39).

The near contemporaneity of the appearance of maize in Tamaulipas and the US Southwest, as well as the genetic differences between the early maize recovered in the two areas, suggest that maize did not diffuse to the Southwest through northeastern Mexico (40). Mexico's Pacific coast, the Sierra Madre Occidental, and the eastern and western flanks of this cordillera have been proposed as likely routes (41, 42), but the absence of additional data precludes identifying both the point(s) of origin of the early southwestern maize and the route(s) of its dispersal.

Given the presumed adaptability of early maize, any or all of these routes are possibilities. Even if adaptations to the diverse ecological settings represented along these alternative routes were required, ample time would have been available for them. If we assume that maize diffused northward over the course of ≈2,200 years, between 4300 and 2100 cal B.C., its rate of diffusion would have averaged ≈1.3 km per year, using the ≈2,800-km highway distance between Oaxaca City and Tucson as a proxy for the actual distance covered. At this pace, it would have proceeded an average of one degree of latitude (120 km) every 92 years, allowing adaptations to local conditions to take place over numerous generations of maize.

The Proto-Uto-Aztecans as Mesoamerican Maize Farmers. Bellwood proposed that migrating Mesoamerican farming populations could have diffused maize agriculture northward because the distribution of Uto-Aztecan languages between Mesoamerica and the US Southwest conformed to his assumption that the spread of language families over such great distances often was the result of the expansion of agriculture (8, 11). Hill developed this proposal into a more detailed scenario (9, 18–21). She argued that during the early period of maize agriculture, the PUA speech community most likely was

Fig. 1. Principal early maize sites and proposed Proto-Uto-Aztecan homeland before breakup.

located on the northwestern edge of Mesoamerica, in the region of the modern Mexican states of Jalisco, Nayarit, Durango, Zacatecas, and Aguascalientes, and that at least some segments of this community of maize farmers migrated northward to gain access to new arable lands. Following Bellwood, she identified the principal factor motivating this migration as population pressure resulting from rapid population growth that she assumed had followed their shift from foragers to farmers. She suggested that the presence of other early farming societies on the east and south of the PUA homeland blocked PUA expansion in these directions, so the PUA maize farmers migrated northward, displacing or assimilating the local populations of foragers they encountered. The vanguard of this northward migration was comprised of the ancestors of speakers of what would become the northern branch of the UA language family. In Hill's scenario, these Proto-Northern Uto-Aztecans were farmers when they departed Mesoamerica and arrived in the Southwest, but the majority later shifted back to foraging because the wealth of wild resources in the areas where they lived made foraging a more productive strategy than agriculture or because the environmental conditions in these areas precluded agriculture.

The viability of the Bellwood–Hill hypothesis hinges on establishing that the members of the PUA speech community cultivated maize before the breakup of this community and that they were located in Mesoamerica, where maize agriculture initially developed. Hill makes the case that the PUA were maize farmers primarily on the basis of her claim that terms related to maize cultivation can be reconstructed to the PUA period (9, 19–21). She identified twelve terms as comprising "the Uto-Aztecan maize complex", compiling in each case sets of terms from modern UA languages that she regarded as being related to one another and upon which a reconstructed PUA form could be proposed. She characterized these twelve sets as "cognate sets," that is, sets of terms that derive from the same protoform, but in her analysis she described many of these terms as potential, rather than confirmed, cognates or as phonologically similar forms, i.e., "resemblants," rather than cognates (9, 20).

In the final analysis, Hill presents no Northern Uto-Aztecan (NUA) terms that (*i*) are unquestionably cognate with maize-related terms in Southern Uto-Aztecan (SUA) languages and (*ii*) also share comparable maize-related meanings with them (43). Her proposed NUA cognates either show the phonologically expected form but lack the expected meaning or have the expected meaning but fail to attest to the phonologically expected form, raising in the latter case the prospect that they are loan words from SUA or other languages. Hill attributes the absence of a corpus of unequivocal NUA cognates in part to gaps in our knowledge of many NUA languages and SUA languages as well (9). However, in the case of Hopi, a well-documented NUA language associated with the NUA society traditionally most reliant on maize agriculture, not only would we expect a larger number of cognates but the meanings associated with these cognates should also resemble more closely those of the proposed SUA cognates.

With regard to the PUA homeland, neither Bellwood nor Hill offer data that would sustain a compelling argument for the location of the PUA speech community in Mesoamerica. Hill implied that such data exist, for example, in the form of "evidence for the presence of Uto-Aztecan cultural practices in Mesoamerica at an early date", but this evidence relates only to her claim that "Aztecan people were important in Mesoamerica through the Classic period", a position that refers to only one UA subdivision millennia after maize agriculture diffused out of Mesoamerica (9). She also proposed that certain genetic evidence supports a Mesoamerican homeland for the PUA, stating that "members of both northern and southern branches of Uto-Aztecan... seem to carry a clear Mesoamerican signature in the form of a rare mutation at the Albumin locus, 'Albumin Mexico'" (19). However, Albumin Mexico (AL*Mexico) is extremely rare among NUA populations while showing a high level of incidence among individuals affiliated with certain Yuman-speaking societies in or near the southwestern United States and also the SUA language group known as Tepiman, which includes the Tepehuan and Piman languages (22, 44). This pattern suggests that the AL*Mexico mutation occurred first among Yumans, who transferred it to Tepiman speakers during a period of interaction at some point during the first or early second millennium A.D. (45). The mutation would then have been diffused southward by Tepehuan speakers who, at the time of European contact, were distributed from northern Mexico to the northern margins of Mesoamerica (46) and from there to other Mesoamerican populations.

It should be noted that the available mitochondrial DNA (mtDNA) evidence is not consistent with the proposal of a Mesoamerican homeland for the PUA. Modern mtDNA data from individuals affiliated with NUA societies in the US Southwest, the Great Basin, and California indicate the absence of haplogroup A, which occurs with high frequency in Mesoamerican populations. Haplogroup A also is present in all SUA populations, which display a cline in frequency from low (5–7%) among the Upper Piman Akimel O'odham and Tohono O'odham in the US Southwest, to intermediate (30–34%) among the Tarahumara, Cora, and Huichol in northwestern and west central Mexico and to intermediate or high (38–63%) among different Nahua populations in east central Mexico (44, 47–49).

LeBlanc suggests that this cline could reflect the dilution of haplogroup A in northward-migrating UA farming populations as the result of intermarriage with "non-A-bearing forager women" (24). However, comparable results would be expected if SUA populations with a low incidence of haplogroup A had migrated southward from the western United States and intermarried with women from non-UA populations with higher haplogroup A frequencies. In addition, the frequency distributions of the other haplogroups (B, C, and D) determined for NUA populations are more similar to those of neighboring, non-UA populations in the western United States than they are to those of any SUA populations, just as the Nahua haplogroup frequency distributions most closely resemble those of other Mesoamerican populations (47, 48, 50). This pattern is best explained by millennia of gene flow across adjacent cultural and linguistic boundaries, a conclusion reinforced by the fact that detailed haplotype analyses have failed to detect evidence of a UA migration from Mesoamerica to the Southwest (44, 50).

The mtDNA data indicate marked differences in female lineages between the US Southwest and Mesoamerica, but, as Hill and others have argued (19, 44), they would not preclude a PUA homeland in Mesoamerica if only UA males had migrated northward. A 2008 study of the demographic impact of the introduction of maize agriculture to the US Southwest reports that recent research on Y-chromosome variation "provides no support for close genetic connections between southwestern and Mesoamerican Uto-Aztecan populations" (51), but the associated data are not presented. An evaluation of this male-only migration hypothesis requires data on the distribution of Y-chromosome haplotypes among both NUA and SUA populations as well as populations affiliated with the various non-UA language groups in both Mesoamerica and the US Southwest. In the absence of these data, we simply note that a 2,000-km migration of male farmers from Mesoamerica to the US Southwest seems improbable, as is the prospect that small groups of UA males would have not been absorbed into local, non-UA speech communities along the way.

A Great Basin Homeland for the Uto-Aztecans. The Bellwood–Hill proposal of a Mesoamerican homeland for the Uto-Aztecans challenges the longstanding view that the PUA speech community was based somewhere in the western United States or northern Mexico at the time of its initial breakup (9, 52). Fowler identified this broad area as the most likely PUA territory based on reconstructions of PUA terms for plants and animals and the assumption that the biological taxa labeled with related terms, or cognates, in different, and especially the more widely separated, UA languages would have been present in this ancestral homeland (52). She offered likely PUA forms for a variety of plants (long-needled pine, prickly pear, agave, cane, and a kind of grass) and animals (fly, bee, louse, flea, frog, turtle/tortoise, a kind of snake, small bird, screech owl, horned owl, eagle, hawk, heron, sandhill crane, vulture, and a kind of woodpecker), noting that these taxa would be found "in a mixed woodland/grassland setting, in proximity to montane forests", but not in hot desert or tropical settings. She concluded that the southwestern United States and northwestern Mexico corresponded to the area where this particular ensemble of taxa was most likely to be found ≈3000 B.C., the date she adopted for when the PUA speech community was intact but dispersed in a dialect chain across ≈1,500 km of this region (52).

In support of the alternative view of a Mesoamerican homeland for the Uto-Aztecans, Hill pointed out that Fowler's diagnostic taxa also are found in central Mexico, and she explained the inability to reconstruct PUA terms for tropical species by the loss of these terms in the languages of the Uto-Aztecans who migrated northward into temperate zones (9). However, our examination of the Uto-Aztecan biological lexicon leads us to conclude that the PUA homeland was located in the north rather than in Mesoamerica and also that the breakup of the PUA speech community began ≈6900 cal. B.C., much earlier than proposed by Fowler, Hill, or anyone else. Our perspective is based on a consideration of both the biological terms that can be reconstructed for PUA and those that cannot, including, in the latter case especially, the term for "pinyon" or "pine nut."

Both Fowler and Hill noted that the NUA languages share cognates for "pinyon", reconstructed for Proto-Northern Uto-Aztecan as **tɨpat*, whereas the few terms for "pinyon" that have been recorded in the SUA languages are not cognate either with the NUA terms or with one another (19, 21, 52, 53). In our view, the absence of a PUA term for "pinyon" reflects the absence of pinyon species (mainly *Pinus monophylla*, *P. edulis*, and *P. cembroides*) in the PUA homeland. Before expanding across the Great Basin during the middle Holocene, pinyon populations reached the northern limits of their distribution along the Basin's southern and southwestern edges, extending from there to southern Mexico, where pine nuts have been recovered from archaeological contexts before 7000 cal. B.C. (54–61). If the PUA homeland had been located within this area, a PUA term for "pinyon" would be expected.

We propose that the PUA speech community before its breakup was located north of the northern extent of the distribution of pinyon at the time and also east of the Sierra Nevada range, probably in the west central Great Basin (Fig. 1). The determination of these latter limits is based on the absence of a PUA term for "oak" and the presence of oaks to the west, northwest, east, and south of this portion of the Great Basin (52, 53, 62–64). There are no other areas that correspond to the ecological zone identified by Fowler and accepted by Hill for the PUA homeland in which the taxa for which PUA terms can be reconstructed were present and pinyons and oaks were absent.

This set of circumstances existed in the Great Basin during the early Holocene, between 9700–6900 cal. B.C. [10,000–8,000 radiocarbon years before the present (^{14}C yr b.p.)], a period during which the PUA speech community probably was intact. We attribute its breakup to a significant decrease in effective moisture that began in the Great Basin ≈6900 cal. B.C. (65). We propose that this climate change motivated the PUA bands to migrate to the south and west, into areas watered by runoff from the Sierra Nevada range. In our scenario, the ancestors of the NUA remained in this region at least until ≈5500 cal. B.C. (6600 ^{14}C yr b.p.), when pinyon populations began spreading northward (56, 60, 66). We suggest that, before this date, the bands ancestral to the SUA split off and moved southeastward toward the Colorado River, crossing into the Gila River drainage of Arizona, where the onset of the increasingly arid conditions may have been delayed until ≈6400 cal. B.C. (7500 ^{14}C yr b.p.) (67, 68).

Other Considerations Relevant to the Long-Distance Migration Hypothesis. The absence of convincing evidence that the PUA were Mesoamerican farmers renders the Bellwood–Hill hypothesis untenable, but it does not automatically preclude the possibility that maize agriculture was introduced to the US Southwest by in-migrating, proto-Mesoamerican farmers who were not Uto-Aztecans. The most compelling evidence for such a long-distance migration would be marked discontinuities in the archaeological record of the southwestern United States between the pre- and postmaize periods. A potential example of such a discontinuity is the appearance of ceramics in early maize sites in the Tucson Basin, in the form of low-fired fragments of human figurines and what appear to be small serving vessels. Dated to ≈2100 cal. B.C., they provide the earliest record of fired ceramics in the US Southwest (2), but a Mesoamerican origin is doubtful. The oldest known human figurine in Mesoamerica, recovered in the Valley of Mexico and assigned an earlier date of 2300 B.C. (69, 70), was fashioned from a single piece of clay whereas those of the Tucson Basin were created from multiple pieces of clay assembled in an appliqué approach (71). Ceramic vessels appear in far southwestern Mexico ≈2000 cal. B.C., about the same time as in the Tucson Basin, but they are quite distinct in form and size from the Tucson Basin examples and also were fired at higher temperatures (72, 73). In any case, ceramics are absent from all other known early farming sites in the US Southwest outside of the Tucson Basin, suggesting that their production was a highly localized, not imported, development.

It has been suggested that Gypsum-style, contracting stem points were introduced to the US Southwest from Mesoamerica, where similar points are found in association with maize during the Abejas phase (4200–2900 cal. B.C.) in the Tehuacán Valley (7, 31, 74, 75). Nonetheless, various contracting-stem point traditions existed in this region of western North America for millennia before the introduction of maize, as well as being widespread in areas lacking evidence of early maize agriculture, and Gypsum-style points themselves may predate the appearance of maize in the Southwest (4, 6, 37, 76). In fact, no items of material culture that would indicate the likely presence of Mesoamerican migrants, such as the distinctive stone bowls found in early farming settlements in central and southern Mexico (77), have been recovered from the early southwestern maize sites.

If in-migrating Mesoamerican farmers had introduced agriculture into the US Southwest, a more diverse suite of crops might be expected at the earliest maize sites there. By 3540 cal. B.C., maize, pepo squash (*Cucurbita pepo*), and bottle gourd (*Lagenaria siceraria*) were being cultivated together in central and southern Mexico (39), but they apparently entered the US Southwest as separate introductions over the course of nearly two millennia. Pepo squash is reported at McEuen Cave in southeastern Arizona by 2000 cal. B.C. (34, 37), but the data required to evaluate this report remain unpublished. This cucurbit is not documented elsewhere in the region for another 800 years, appearing *ca.* 1200 cal. B.C. in the Mogollon Highlands of New Mexico, where the earliest evidence for bottle gourd, dated *ca.* 300 B.C., also occurs (4, 78). Other Mesoamerican domesticates—including Mexican grain amaranth (*Amaranthus cruentus*), the common bean (*Phaseolus vulgaris*), and cotton (*Gossypium hirsutum*)—appear in the US Southwest between ≈800 B.C. and A.D. 300 (Table S3). Although future research may alter the dates for the introduction of these crops, the evidence currently available indicates not only that they arrived in the US Southwest at different times but that each became integrated into local economies in distinct ways in different parts of the region (79).

Bellwood and Hill (9, 11) proposed that the integration of maize cultivation into Mesoamerican subsistence systems led to population growth and the need to increase food production, which encouraged farming populations to expand into new agricultural areas. However, such demographic factors appear to have been of little significance in the northward dispersal of maize agriculture. Estimates of population size and densities offered for different areas of Mesoamerica are quite low throughout the terminal Late Archaic (2500–1600 B.C.) (72), during the same period that maize agriculture was already being adopted in the US Southwest. For example, even though maize had been cultivated in the 2,000 km^2 of the Valley of Oaxaca for at least 2,000 years, the total Late Archaic population at any given time is estimated at 75–150 people, representing a maximum density of 0.075 persons/km^2 (57). In addition, except in lowland areas where swidden cultivation may have been practiced and soils were nutrient-poor, there is no indication that early Mesoamerican farmers migrated over any great distances for lack of arable land (80, 81). Evidence of northward-migrating populations also is absent in the late Middle Archaic archaeological record of northwestern Mexico (6, 82).

The migration of Mesoamerica farmers would more likely have been motivated by climatological factors. During the 4300–2100 cal. B.C. period when maize agriculture would have been diffusing northward, the climate of highland central Mexico was characterized by decreased effective moisture, whereas after 3900 cal. B.C., the southwestern United States and northwestern Mexico experienced increased effective moisture (2, 68, 83–89). Farmers living in the transitional zone between these two regions at this time may have been drawn northward by the relatively greater effective moisture available there. Unfortunately, no archaeological data for this interval are available for this zone, but even if such migration took place, it is doubtful that, once the farmers reached the region of higher effective moisture, their populations would have increased so rapidly that they would have been forced to seek new arable lands much farther north. There is no reason to assume that the rate of population growth in this area would have differed significantly from that further south in Mesoamerica, where, despite the cultivation of maize and other domesticates, population densities remained low even during wetter periods (57, 72, 90). In addition, the area of greater effective moisture in the 3900–2100 cal. B.C. period extended at least 900 km south of the Tucson Basin, to near the northern borders of Mesoamerica (90). It is difficult to conceive that the more southerly portions of this vast area would not have included sufficient arable land to accommodate the needs of any farming populations that might have migrated there.

An Alternative Scenario. Our interpretation of the data currently available on early maize agriculture in the US Southwest provides the basis for the following scenario. We propose that soon after the beginning of the drier middle Holocene ≈6900 cal. B.C., the foraging bands that comprised the PUA speech community migrated from the west central Great Basin to the southwestern edge of the Great Basin, with the bands ancestral to the SUA then migrating to moister areas east of the Colorado River. Decreasing effective moisture in subsequent centuries probably motivated these SUA bands to abandon the lowlands of this region in favor of better-watered middle Holocene refuges, which may have included the Colorado Plateau and the northern Sierra Madre Occidental. Climatological factors may also have encouraged some SUA bands to continue migrating southward. The interval of decreased effective moisture in the southwestern United States and northwestern Mexico between 6400 and 3900 cal. B.C. (7500–5000 ^{14}C yr b.p.) corresponded to a period of increased effective moisture in some areas of central Mexico (68, 83–86, 88–92).

Linguistic evidence, mainly cognate densities among the various modern SUA languages, supports the view that the SUA speech community did not remain intact for a long period but rather began separating into distinct bands, with some remaining in the US Southwest and adjacent areas of northwestern Mexico while others moved south (15, 16). The latter probably included ancestors of the speakers of Cora, Huichol, and the Aztecan languages, the southernmost of the Uto-Aztecans at European contact. We suggest that the bands in this southern vanguard were the first Uto-Aztecans to acquire maize, which then diffused northward from one UA-speaking band to another.

The arrival of maize in the southwestern United States ≈2100 cal. B.C. (3700 ^{14}C yr b.p.) occurred near the midpoint of the wettest interval of the late Holocene (3900 B.C.–A.D. 50) (5000–2000 ^{14}C yr b.p.) (2, 68, 83, 84, 86, 90, 91, 93). The subsistence and settlement strategies of the Archaic residents of the region at the time provided the cultural contexts into which maize was introduced, but the paucity of excavated premaize Archaic sites limits our ability to construct models of these strategies (4, 33, 79, 94–96). Floral and faunal remains recovered from a few of these sites suggest a general pattern of exploitation of a wide range of resources—agaves, cacti, wild grasses, a variety of other herbaceous plants, and diverse animal species—with an emphasis on a comparatively small subset of these (33). In keeping with behavioral ecological models of subsistence strategies in unpredictable environments like the southwestern United States, it is assumed that this pattern reflected a combination of considerations regarding resource availability, predictability, and productivity, with Archaic foragers focusing their subsistence activities on species with higher energetic return rates when these were available and shifting to resources with lower return rates when they were not (3, 34, 89, 97–99).

Although many of the same or similar wild plant and animal species were found throughout the area where the earliest maize sites are located, some high priority resources were more abundant in or restricted to certain areas, for example, pinyon pine in the Colorado Plateau uplands and saguaro cactus and mesquite in the Sonoran Desert lowlands. The lowland deserts and grasslands also were characterized by a greater species diversity and density than the uplands, and in some areas like southeastern Arizona, uplands and lowlands occurred in relative close proximity (97, 100, 101). Intraregional differences in the distribution, density, and seasonal availability of taxa of dietary significance obviously would have affected settlement strategies, with the result that a wide array of specific strategies emerged.

The range of settlement strategies usually is conceptualized in terms of differing degrees and forms of mobility. At one end of the continuum is residential mobility, in which hunter–gatherer bands moved from one resource zone to another, often in a seasonal round. At the other is logistical mobility, in which residential base camps were used for months at a time, with some members traveling for short periods to acquire more distant resources. Other strategies fall between these two extremes, combining seasonal residential mobility between resource zones with logistical mobility within these zones (37, 102).

The arrival of maize in the southwestern United States coincided with a period of increased effective moisture that presumably would have promoted abundance in local wild resources and provided a reliable subsistence base for the hunter–gatherers there (2, 83, 84, 89, 103). Berry has argued that successful hunter–gatherers in the region would not have been attracted to maize agriculture because its adoption would have disrupted their preexisting subsistence strategies (104). He concluded that maize more likely would have been introduced to the region by migrating farmers from the south because they were already committed to its cultivation. However, the damp alluvial locales most favorable for farming were already being used intensively by foragers, and those bands that followed a more logistical mobility strategy could have integrated maize agriculture into their economies with few adjustments, particularly if they focused during the summer rainfall season on wild resources available in areas suitable for growing maize (4, 5, 79, 105).

Such a preadaptation for maize agriculture has been proposed for early farmers in the Tucson Basin, where the exploitation of diverse, concentrated wild resources on the floodplain and adjacent areas of the middle Santa Cruz Valley may have been associated with reduced residential mobility during much of the year (37, 97, 101, 106, 107). Nonetheless, some of the earliest, directly dated maize in the entire southwestern United States was recovered from the Old Corn site on the Colorado Plateau, an area characterized by low species diversity and a short growing season (35). This fact suggests that certain features of maize—for example, its storability and potential for higher yields than many wild, small-seeded plants—made it attractive to Middle Archaic hunter-gatherers in diverse ecological settings, who adjusted their settlement and subsistence strategies to take advantage of the benefits that it offered (89, 108). Yet the apparently short duration of the Old Corn occupation (2150–2050 cal. B.C.) may indicate that the initial cultivation of maize in such upland areas was less successful than in the Tucson Basin, where a record of the continuous use of maize exists from the early third millennium B.C. onward. Alternatively, relatively short-term occupations similar to that indicated for Old Corn may have been one of a range of settlement strategies associated with successful maize agriculture, but the low visibility of many of these strategies in the archaeological record may have limited our appreciation of their diversity and distribution within the region.

The Tucson Basin sites clearly document the shift from a foraging to a mixed foraging–horticultural economy, followed by increasing reliance on maize and the emergence of agricultural intensification in the form of irrigation. Features interpreted as irrigation canals have been dated to the period between 1750 and 1500 cal. B.C., and networks of canals have been identified for the period beginning at ≈1250 cal. B.C. (2, 37, 109–111). This evidence predates that for Mesoamerica, where irrigation was established between 1200 and 800 B.C. (37, 79, 112, 113).

The construction and maintenance of irrigation systems implies the development of new forms of social organization in the Tucson Basin during the first millennium following the introduction of maize (37). The emergence of more complex labor organization at this time also is suggested by the complex terrace constructions at Cerro Juanaqueña, located in the Río Casas Grandes Valley of Chihuahua, Mexico (Fig. 1) (114–117). Occupied between 1300 and 1100 cal. B.C., this 10-hectare site includes ≈8 km of berm walls and 550 residential terraces on the top and sides of a 140 m-high hill. We estimate that the construction of these features entailed ≈30 person-years of labor, an investment comparable with that required to build a 550-room stone pueblo like those constructed in the southwestern United States during the first millennium A.D. (115). Although we do not regard Cerro Juanaqueña and the Tucson Basin sites as representative of all early agricultural sites, they do illustrate the dramatic impact that maize agriculture had in some areas of the region.

Cerro Juanaqueña forms part of one of three clusters totaling ten terraced hilltop sites located along 85 km of the Río Casas Grandes floodplain. We interpret these clusters as fortified, defensive sites because they display several attributes expected of such sites: evidence of planning and rapid, coordinated construction, perimeter berms, high frequencies of projectile points, 360-degree views, and intersite visibility, which would have facilitated line-of-sight signaling (118). Although identifying precisely who their enemies were is impossible, they may have been defending themselves and their food stores against the raids of hunter–gatherers in the area. We doubt that they were constructed because of competition among the farmers themselves as extensive tracts suitable for water-table and overbank flood agriculture were available but unused in other sections of the local river valleys.

LeBlanc suggests that these sites may have been constructed by Mesoamerican migrants who were entering northwestern Mexico at the time that they were occupied (119). However, similar constructions do not appear in Mesoamerica until centuries later (120), and if the builders had originated in Mesoamerica, ceramics, which were widespread in Mesoamerica by 1600–1400 B.C., should be present (72). We suspect that the residents of these sites migrated from relatively modest distances to exploit the agricultural potential of the local river valleys, possibly from the northwest, north, or east where Archaic sites are numerous (121–123). Many of the Late Archaic projectile points found at these sites are most similar in style to projectile points found to the northeast in southern New Mexico and far western Texas, and the identified obsidian sources for the stone tools recovered from the site are located to the northeast, east, and southeast (124).

Discussion

Our conclusion that maize agriculture spread from Mesoamerica to the US Southwest via group-to-group diffusion is based on two fundamental considerations. First, other than maize itself, the early agricultural sites in the Southwest have yielded no evidence of a Mesoamerican presence that would be expected if maize cultivation had been introduced by in-migrating Mesoamerican farmers. Second, the earliest agricultural components of these sites document continuity with longstanding foraging traditions and these and subsequent components are consistent with demographic and behavioral ecological models of what would be expected in this region when an introduced cultigen like maize was integrated into a broad-spectrum foraging subsistence strategy (51, 99, 111).

The scenario we propose here fits with archaeological evidence that the desert lowlands of the Arizona–Sonora borderlands, which appear to have been largely depopulated during the generally arid middle Holocene (6400–3900 cal. B.C.), were reoccupied from both north and south at the onset of wetter conditions at ≈3900 cal. B.C., creating what we suspect was a SUA linguistic–cultural continuum across which maize could have diffused into the US Southwest (2, 6). It also is consistent with other, mainly linguistic, data relevant to understanding the role of the Uto-Aztecans in the spread of maize agriculture. The NUA and SUA branches are rather distinct, suggesting an early separation, but patterns of cognate-sharing indicate that interaction among speakers of distinct UA dialects and languages continued to take place, especially within each of these two main branches (15, 16, 125). By envisioning the northward diffusion of maize as involving primarily interaction among SUA bands, our model offers a parsimonious accounting for the high level of cognate density for maize-related terms in these languages and the near-total absence of possible cognates for these terms in NUA languages (9, 43, 126–128).

Although we reject the hypothesis that maize agriculture was introduced to the US Southwest through the long-distance migration of Mesoamerican farmers, Uto-Aztecans or otherwise, population movements form a crucial component of our scenario for the diffusion of maize from Mesoamerica to the Southwest. We are convinced that the southward migration of SUA bands facilitated the diffusion of maize agriculture from Mesoamerica to the US Southwest, and that maize agriculture was spread across much of the southwestern United States and adjacent areas of northwestern Mexico through both group-to-group diffusion and relatively short-distance migrations of local farming populations, which frequently repositioned themselves over the landscape to take advantage of damp floodplains and other conditions propitious for cultivating maize. We also would not argue that the dispersal of maize agriculture and language families never cooccurred in Mesoamerica. An example of this cooccurrence perhaps can be seen in the case of the Mayan language family and, more relevant to the issues at hand, in the northward migration of proto-Huastecan Mayan speakers from the postulated Proto-Mayan homeland in highland Guatemala to northeastern Mexico, a distance of ≈1,100 km (17, 129). That this migration took place after the Proto-Mayans received maize is indicated by the fact that reflexes of the postulated Proto-Mayan term for "maize" are found in 29 of the 30 modern Mayan languages (128). The near ubiquity of shared cognates for "maize" in these languages contrasts sharply with the lack of shared cognates for "maize" throughout the Uto-Aztecan language family.

Research conducted over the last decade has transformed our understanding of early maize agriculture in Mesoamerica and the US Southwest. We anticipate that research currently under way will soon produce new insights and more refined chronologies and that additional excavations, AMS dating, and genetic comparisons of archaeological samples of early maize will provide the empirical foundation upon which increasingly sophisticated models can be constructed. However, extensive archaeological and paleoecological research in the area between Mesoamerica and the US Southwest, especially for the Archaic period, is required to evaluate many components of these models. Although noting this need has become a cliché, the importance of filling this gap in our knowledge cannot be overemphasized.

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1. Staller JE, Tykot RH, Benz BF, eds (2006) *Histories of Maize* (Elsevier, Amsterdam).
2. Mabry JB (2005) in *The Late Archaic across the Borderlands*, ed Vierra BJ (Univ Texas Press, Austin, TX), pp 41–83.
3. Piperno DR (2006) in *Behavioral Ecology and the Transition to Agriculture*, eds Kennett DJ, Winterhalder B (Univ California Press, Berkeley, CA), pp 137–166.
4. Wills WH (1988) *Early Prehistoric Agriculture in the American Southwest* (School of American Research Press, Santa Fe, NM).
5. Minnis PE (1992) in *The Origins of Agriculture*, eds Cowan CW, Watson PJ (Smithsonian Institution Press, Washington, DC), pp 121–141.
6. Mabry JB, Carpenter JB, Sanchez G (2008) . In *Archaeology Without Borders*, eds Webster LD, McBrinn ME (Univ Press of Colorado, Boulder, CO), pp 155–183.
7. Berry CF, Berry MS (1986) in *Anthropology of the Desert West*, eds Condie CJ, Fowler DD, University of Utah Anthropological Papers (Univ Utah Press, Salt Lake City, UT) Vol 110, pp 253–327.
8. Bellwood P (1997) in *Archaeology and Linguistics*, eds McConvell P, Evans N (Oxford Univ Press, Melbourne), pp 123–134.
9. Hill JH (2001) Proto-Uto-Aztecan: A community of cultivators in central Mexico? *Am Anthropol* 103:913–934.
10. Bellwood P (1993) An archaeologist's view of language macrofamily relationships. *Bull Indo-Pacific Prehistory Assoc* 13:46–60.
11. Bellwood P (2001) Early agricultural population diasporas? Farming, languages, and genes. *Annu Rev Anthropol* 30:181–207.
12. Bellwood P (2003) in *Areal Diffusion and Genetic Inheritance*, eds Aikhenvald AY, Dixon RMW (Oxford Univ Press, Oxford), pp 27–43.
13. Diamond J, Bellwood P (2003) Farmers and their languages: The first expansions. *Science* 300:597–603.
14. Bellwood P (2005) *First Farmers* (Blackwell, Oxford).
15. Miller WR (1984) The classification of the Uto-Aztecan languages based on lexical evidence. *Int J Am Linguist* 50:1–24.
16. Cortina–Borjas M, Valiñas Coalla L (1989) Some remarks on Uto-Aztecan classification. *Int J Am Linguist* 55:214–239.
17. Campbell L (1997) *American Indian Languages* (Oxford Univ Press, Oxford).
18. Hill JH (2002) in *Examining the Farming/Language Dispersal Hypothesis*, eds Bellwood P, Renfrew C (McDonald Inst Archaeol Res, Cambridge, United Kingdom), pp 331–340.
19. Hill JH (2002) Toward a linguistic prehistory of the Southwest: "Azteco-Tanoan" and the arrival of maize cultivation. *J Anthropol Res* 58:457–475.
20. Hill JH (2004) in *Memoirs of the Seventh International Conference on Linguistics in the Northwest* (Translated from Spanish) eds Morúa Leyva MdC, Ortiz Ciscomani RM (Universidad de Sonora, Hermosillo), Vol 2, pp 59–81.
21. Hill JH (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 631–645.
22. Smith DG, et al. (2000) Implications of the distribution of Albumin Naskapi and Albumin Mexico for New World prehistory. *Am J Phys Anthropol* 111:557–572.
23. Matson RG (2002) in *Examining the Farming/Language Dispersal Hypothesis*, eds Bellwood P, Renfrew C (McDonald Inst for Archaeol Res, Cambridge, United Kingdom), pp 341–356.
24. LeBlanc SA (2008) in *Archaeology Without Borders*, eds Webster LD, McBrinn ME (Univ Press of Colorado, Boulder, CO), pp 107–142.
25. Bronk Ramsey C (2001) Development of the radiocarbon calibration program OxCal. *Radiocarbon* 43:355–363.
26. Reimer PJ, et al. (2004) IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr bp. *Radiocarbon* 46:1029–1058.
27. Benz BF, Long A (2000) Prehistoric maize evolution in the Tehuacan Valley. *Curr Anthropol* 41:459–465.
28. Blake M (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 55–72.
29. Piperno DR, Ranere AJ, Holst I, Iriarte J, Dickau R (2009) Starch grain and phytolith evidence for early ninth millennium b.p. maize from the central Balsas River Valley, Mexico. *Proc Natl Acad Sci USA* 106:5019–5024.
30. Piperno DR, Flannery KV (2001) The earliest archaeological maize (*Zea mays* L.) from highland Mexico: New accelerator mass spectometry dates and the implications. *Proc Natl Acad Sci USA* 98:2101–2103.
31. Smith BD (2005) Reassessing Coxcatlan Cave and the early history of domesticated plants in Mesoamerica. *Proc Natl Acad Sci USA* 102:9438–9445.
32. Smiley FE (1994) The agricultural transition in the northern Southwest: Patterns in the current chronometric data. *Kiva* 60:165–189.
33. Gregory DA, ed (1999) *Excavations in the Santa Cruz River Floodplain* (Center for Desert Archaeol, Tucson, AZ).
34. Mabry JB (2005) in *Subsistence and Resource Use Strategies of Early Agricultural Communities in Southern Arizona*, ed Diehl MW (Center for Desert Archaeol, Tucson, AZ), pp 113–152.
35. Huber EK, Van West CR, eds (2005) *Fence Lake Project* (Statistical Research, Tempe, AZ).
36. Whittlesey SM, Hesse SJ, Foster MS eds (2009) *Recurrent Sedentism and the Making of Place* (SWCA Environmental Consultants, Tucson, AZ).
37. Mabry JB, ed (2008) *Las Capas* (Center for Desert Archaeol, Tucson, AZ).
38. Smith BD (1997) Reconsidering the Ocampo Caves and the era of incipient cultivation in Mesoamerica. *Lat Am Antiq* 8:342–383.
39. Smith BD (2001) Documenting plant domestication: The consilience of biological and archaeological approaches. *Proc Natl Acad Sci USA* 98:1324–1326.
40. Jaenicke–Després VR, Smith BD (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 83–95.
41. Haury E (1962) in *Courses Toward Urban Life*, eds Braidwood RJ, Willey GR (Wenner–Gren Foundation for Anthropol Res, New York), pp 106–131.
42. Benz BF (1999) in *Pacific Latin America in Prehistory*, ed Blake M (Washington State Univ Press, Pullman), pp 25–38.
43. Campbell L (2002) in *Examining the Farming/Language Dispersal Hypothesis*, eds Bellwood P, Renfrew C (McDonald Inst Archaeol Res, Cambridge, United Kingdom), pp 49–63.
44. Malhi RS, et al. (2003) Native American mtDNA prehistory in the American Southwest. *Am J Phys Anthropol* 120:108–124.
45. Shaul DL, Hill JH (1998) Tepimans, Yumans, and other Hohokam. *Am Antiq* 63:375–396.

46. Wilcox DR (1986) in *Ripples in the Chichimec Sea*, eds Mathien FJ, McGuire RH (Southern Illinois Univ Press, Carbondale, IL), pp 135–153.
47. Lorenz JG, Smith DG (1996) Distribution of four founding mtDNA haplogroups among Native North Americans. *Am J Phys Anthropol* 101:307–323.
48. Eshleman JA, et al. (2004) Mitochondrial DNA and prehistoric settlements: Native migrations on the western edge of North America. *Hum Biol* 76:55–75.
49. Kaestle FA, Smith DG (2001) Ancient mitochondrial DNA evidence for prehistoric population movement: The Numic expansion. *Am J Phys Anthropol* 115:1–12.
50. Kemp BM (2006) Mesoamerica and Southwest prehistory, and the entrance of humans into the Americas: Mitochondrial DNA evidence. PhD dissertation (Univ California, Davis, CA).
51. Kohler TA, Pier Glaude M, Bocquet-Appel J-P, Kemp BM (2008) The Neolithic demographic transition in the US Southwest. *Am Antiq* 73:645–669.
52. Fowler CS (1983) Some lexical clues to Uto-Aztecan prehistory. *Int J Am Linguist* 49:224–257.
53. Hill JH (2008) Northern Uto-Aztecan and Kiowa-Tanoan: Evidence of contact between the proto-languages? *Int J Am Linguist* 74:155–188.
54. Van Devender TR, Spaulding WG (1979) Development of vegetation and climate in the southwestern United States. *Science* 204:701–710.
55. Wells PV (1983) Paleobiogeography of montane islands in the Great Basin since the last glaciopluvial. *Ecol Monogr* 53:341–382.
56. Madsen DB (1986) in *Anthropology of the Desert West*, eds Condie CJ, Fowler DD, University of Utah Anthropological Papers (Univ Utah, Salt Lake City, UT) Vol 110, pp 21–41.
57. Flannery KV (1986) *Guilá Naquitz* (Academic, New York).
58. Malusa J (1992) Phylogeny and biogeography of the pinyon pines (*Pinus* subsect. *Cembroides*). *Syst Bot* 17:42–66.
59. Beck C, Jones GT (1997) The terminal Pleistocene/early Holocene archaeology of the Great Basin. *J World Prehist* 11:161–236.
60. Lanner RM, Van Devender TR (1998) in *Ecology and Biogeography of Pinus*, ed Richardson DM (Cambridge Univ Press, Cambridge, United Kingdom), pp 171–182.
61. Koehler PA, Anderson RS, Spaulding WG (2005) Development of vegetation in the central Mojave Desert of California during the Late Quaternary. *Palaeogeogr Palaeocl Palaeoecol* 215:297–311.
62. Byrne R, Edlund E, Mensing S (1991) in *Proceedings of the Symposium on Oak Woodlands and Hardwood Range Management, October 31-November 2, 1990, Davis, California*, ed Standiford RB (US Dept Agriculture, Pacific Southwest Research Station, Berkeley, CA) General Technical Report PSW-126, pp 182–188.
63. Van Devender TR (1977) Holocene woodlands in the southwestern deserts. *Science* 198:189–192.
64. Munroe JS (2003) Holocene timberline and palaeoclimate of the northern Uinta Mountains, northeastern Utah, USA. *The Holocene* 13:175–185.
65. Wigand PE, Rhode D (2002) in *Great Basin Aquatic Systems History*, eds Hershler R, Madsen DB, Currey DR, Smithsonian Contributions to the Earth Sciences (Smithsonian Inst Press, Washington, DC) Vol. 33, pp 309–367.
66. Grayson DK (1993) *The Desert's Past* (Smithsonian Inst Press, Washington, DC).
67. Menking KM, Anderson RY (2003) Contributions of La Niña and El Niño to middle Holocene drought and late Holocene moisture in the American Southwest. *Geology* 31:937–940.
68. Mabry JB (1998) in *Paleoindian and Archaic Sites in Arizona*, ed Mabry JB (Arizona State Historic Preservation Office, Phoenix, AZ), pp 19–31.
69. Niederberger C (1979) Early sedentary economy in the Basin of Mexico. *Science* 203:131–142.
70. Scott S (2001) in *Archaeology of Ancient Mexico and Central America*, eds Evans ST, Webster DL (Garland, New York), pp 266–270.
71. Heidke JM (2006) in *Rio Nuevo Archaeology Program, 2000–2003*, eds Thiel JH, Mabry JB (Center for Desert Archaeol, Tucson, AZ), pp 7.1–7.93.
72. Clark JE, Cheetham D (2002) in *The Archaeology of Tribal Societies*, ed Parkinson WA (Int Monogr in Prehistory, Ann Arbor, MI), pp 278–339.
73. Clark JE, Gosser D (1995) in *The Emergence of Pottery*, eds Barnett WK, Hoopes JW (Smithsonian Inst Press, Washington, DC), pp 209–222.
74. Carpenter JP, Sánchez G, Villalpando C ME (2005) in *The Late Archaic Across the Borderlands*, ed Vierra BJ (Univ Texas Press, Austin, TX), pp 13–40.
75. MacNeish RS, Nelken–Terner A, Weitlaner-Johnson I (1967) *The Prehistory of the Tehuacán Valley* (Univ Texas Press, Austin, TX), Vol. 2.
76. Justice ND (2002) *Stone Age Spear and Arrow Points of the Southwestern United States* (Indiana Univ Press, Bloomington, IN).
77. Adams REW (2005) *Prehistoric Mesoamerica* (Univ Oklahoma Press, Norman, OK), 3rd ed.
78. Cutler HC, Whitaker TW (1961) History and distribution of the cultivated cucurbits in the Americas. *Am Antiq* 26:469–485.
79. Doolittle WE, Mabry JB (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 109–121.
80. Neff H, et al. (2006) Early Maya adaptive patterns: Mid–late Holocene paleoenvironmental evidence from Pacific Guatemala. *Lat Am Antiq* 17:287–315.
81. Pohl MD, et al. (1996) Early agriculture in the Maya lowlands. *Lat Am Antiq* 7:355–372.
82. MacWilliams AC, Hard RJ, Roney JR, Adams KR, Merrill WL (2008) in *Archaeology Without Borders*, eds Webster LD, McBrinn ME (Univ Press of Colorado, Boulder, CO), pp 35–54.
83. Ely LL, Enzel Y, Baker VR, Cayan DR (1993) A 5000-year record of extreme floods and climate change in the southwestern United States. *Science* 262:410–412.
84. Metcalfe SE, Bimpson A, Courtice AJ, O'Hara SL, Taylor DM (1997) Climate change at the monsoon/westerly boundary in northern Mexico. *J Paleolimnol* 17:155–171.
85. Buckler ES, IV, Pearsall DM, Holtsford TP (1998) Climate, plant ecology, and central Mexican Archaic subsistence. *Curr Anthropol* 39:152–164.
86. Ortega–Ramírez JR, Valiente–Banuet A, Urrutia–Fucugauchi J, Mortera–Gutiérrez CA, Alvarado–Valdez G (1998) Paleoclimatic changes during the Late Pleistocene—Holocene in Laguna Babícora, near the Chihuahuan Desert, México. *Can J Earth Sci* 35:1168–1179.
87. Polyak VJ, Asmerom Y (2001) Late Holocene climate and cultural changes in the southwestern United States. *Science* 294:148–151.
88. Nordt L (2003) Late Quaternary fluvial landscape evolution in desert grasslands of northern Chihuahua, Mexico. *Geol Soc Am Bull* 115:596–606.
89. Hard RJ, Roney JR (2005) in *The Late Archaic across the Borderlands*, ed Vierra BJ (Univ Texas Press, Austin, TX), pp 141–186.
90. Metcalfe SE, O'Hara SL, Caballero M, Davies SJ (2000) Records of Late Pleistocene–Holocene climatic change in Mexico—A review. *Quaternary Sci Rev* 19:699–721.
91. Waters MR (1989) Late Quaternary lacustrine history and paloeclimatic signficance of pluvial Lake Cochise, southeastern Arizona. *Quaternary Res* 32:1–11.
92. Metcalfe SE, Street–Perrott FA, Perrott RA, Harkness DD (1991) Palaeolimnology of the Upper Lerma Basin, Mexico: A record of climatic change and anthropogenic disturbance since 11600 yr BP. *J Paleolimnol* 5:197–218.
93. Krider PR (1998) Paleoclimatic significance of late Quaternary lacutrine and alluvial stratigraphy, Animas Valley, New Mexico. *Quaternary Res* 50:283–289.
94. Huckell BB (1996) The Archaic prehistory of the North American Southwest. *J World Prehist* 10:305–373.
95. Mabry JB, Doolittle WE (2008) in *Archaeology Without Borders*, eds Webster LD, McBrinn ME (Univ Press of Colorado, Boulder, CO), pp 55–70.
96. Roth BJ, Freeman A (2008) The Middle Archaic Period and the transition to agriculture in the Sonoran Desert of southern Arizona. *Kiva* 73:321–353.
97. Diehl MW (1997) in *Rediscovering Darwin*, eds Barton CM, Clark GA, Am Anthropol Assoc Archaeol Papers (Am Anthropol Assoc, Arlington, VA) Vol. 7, pp 251–266.
98. Piperno DR, Pearsall DM (1998) *The Origins of Agriculture in the Lowland Neotropics* (Academic, San Diego).
99. Kennett DJ, Winterhalder B eds (2006) *Behavioral Ecology and the Transition to Agriculture* (Univ California Press, Berkeley, CA).
100. Huckell BB (1995) *Of Marshes and Maize*. Univ Arizona Anthropol Papers (Univ Arizona Press, Tucson, AZ) Vol. 59.
101. Fish SK, Fish PR, Madsen J (1990) in *Perspectives on Southwestern Prehistory*, eds Minnis PE, Redman CL (Westview Press, Boulder, CO), pp 76–91.
102. Doleman WH (2005) in *The Late Archaic across the Borderlands*, ed Vierra BJ (Univ Texas Press, Austin, TX), pp 113–140.
103. Castiglia PJ, Fawcett PJ (2006) Large Holocene lakes and climate change in the Chihuahuan Desert. *Geology* 34:113–116.
104. Berry MS (1982) *Time, Space, and Transition in Anasazi Prehistory* (Univ Utah Press, Salt Lake City, UT).
105. Ogilvie MD (2005) in *The Late Archaic across the Borderlands*, ed Vierra BJ (Univ Texas Press, Austin, TX), pp 84–112.
106. Matson RG (1991) *The Origins of Southwestern Agriculture* (Univ Arizona Press, Tucson, AZ).
107. Roth BJ (1995) Late Archaic occupation of the Upper Bajada: Excavations at AZ AA:12:84 (ASM). *Kiva* 61:189–207.
108. Diehl MW, Waters JA (2006) in *Behavioral Ecology and the Transition to Agriculture*, eds Kennett DJ, Winterhalder B (Univ California Press, Berkeley, CA), pp 63–86.
109. Craig DB, Hopkins M, Carpenter T (2009) *Summary of Archaeological Data Recovery for Pima County Regional Wastewater Reclamation Department Plant Interconnect Project, Pima County, Arizona* (Northland Research, Tempe, AZ).
110. Herr SA (2009) Las Capas. *Archaeol Southwest* 23:9–11.
111. Thiel JH, Mabry JB eds (2006) *Rio Nuevo Archaeology Program, 2000–2003* (Center for Desert Archaeol, Tucson, AZ).
112. Doolittle WE (1990) *Canal Irrigation in Prehistoric Mexico* (Univ Texas Press, Austin, TX).
113. Caran SC, Neely JA (2006) Hydraulic engineering in prehistoric Mexico. *Sci Am* 295:78–85.
114. Hard RJ, Roney JR (1998) A massive terraced village complex in Chihuahua, Mexico, 3000 years before present. *Science* 279:1661–1664.
115. Hard RJ, Zapata JE, Moses BK, Roney JR (1999) Terrace construction in northern Chihuahua, Mexico: 1150 B.C. and modern experiments. *J Field Archaeol* 26:129–146.
116. Roney JR, Hard RJ (2002) in *Traditions, Transitions, and Technologies*, ed Schlanger S (Univ Colorado Press, Boulder, CO), pp 163–180.
117. Hard RJ, Adams KR, Roney JR, Schmidt KM, Fritz GJ (2008) in *Case Studies in Environmental Archaeology*, eds Reitz E, Scarry CM, Scudder SJ (Springer, New York), pp 315–333.
118. Hard RJ, Roney JR (2007) in *Trincheras Sites in Time, Space, and Society*, eds Fish PR, Fish SK, Villalpando ME (Univ Arizona Press, Tucson, AZ), pp 11–52.
119. LeBlanc SA (2002) in *Examining the Farming/Language Dispersal Hypothesis*, eds Bellwood P, Renfrew C (McDonald Inst Archaeol Res, Cambridge, United Kingdom), pp 357–365.
120. Flannery KV, Marcus J (2003) The origin of war: New ^{14}C dates from ancient Mexico. *Proc Natl Acad Sci USA* 100:11801–11805.
121. Formby DE (1986) Pinto–Gypsum Complex projectile points from Arizona and New Mexico. *Kiva* 51:99–127.
122. Phelps AL (1998) An inventory of prehistoric Native American sites in northwestern Chihuahua. *The Artifact* 36:1–176.
123. Miller MR, Kenmotsu NA (2004) in *The Prehistory of Texas*, ed Perttula TK (Texas A&M Univ Press, College Station, TX), pp 205–265.
124. Vierra BJ (2005) in *The Late Archaic across the Borderlands*, ed Vierra BJ (University of Texas Press, Austin, TX), pp 187–218.
125. Heath J (1977) Uto-Aztecan morphophonemics. *Int J Am Linguist* 43:27–36.
126. Fowler CS (1994) in *Corn and Culture in the Prehistoric New World*, eds Johannessen S, Hastorf CA (Westview Press, Boulder, CO), pp 445–467.
127. Valiñas Coalla L (2000) in *Nomadic and Sedentary Peoples in Northern Mexico* (Translated from Spanish) eds Hers M-A, Mirafuentes JL, Soto MdlD, Vallebueno M (Universidad Nacional Autónoma de México, Mexico City), pp 175–205.
128. Brown CH (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 647–663.
129. Kaufman T (1976) Archaeological and linguistic correlations in Mayaland and associated areas of Meso-America. *World Archaeol* 8:101–118.

Supporting Information

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SI Text

1. Bronk Ramsey C (2001) Development of the radiocarbon calibration program OxCal. *Radiocarbon* 43:355–363.
2. Reimer PJ, et al. (2004) IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr bp. *Radiocarbon* 46:1029–1058.
3. Huber EK, Van West CR, eds (2005) *Fence Lake Project* (Statistical Research, Tempe, AZ).
4. Huckell BB, Shackley MS, Huckell LW (2001) *The 1997 Test Excavations at McEuen Cave (AZ W:13:6 ASM), Fishhook Wilderness, Gila Mountains, South-Central Arizona.* Field report submitted to the USDI Bureau of Land Management, Safford, Arizona.
5. Mabry JB (2005) in *Subsistence and Resource Use Strategies of Early Agricultural Communities in Southern Arizona*, ed Diehl MW (Center for Desert Archaeol, Tucson, AZ), pp 113–152.
6. Mabry JB (2006) in *Rio Nuevo Archaeology Program, 2000–2003*, eds Thiel JH, Mabry JB (Center for Desert Archaeol, Tucson, AZ), pp 19.11–19.14.
7. Whittlesey SM, Hesse SJ, Foster MS, eds (2009) *Recurrent Sedentism and the Making of Place* (SWCA Environmental Consultants, Tucson, AZ).
8. Smiley FE (1994) The agricultural transition in the northern Southwest: Patterns in the current chronometric data. *Kiva* 60:165–189.
9. Mabry JB, et al. (1997) *Archaeological Investigations of Early Village Sites in the Middle Santa Cruz Valley* (Center for Desert Archaeol, Tucson, AZ).
10. Gilpin D (1994) Lukachukai and Salinas Springs: Late Archaic/Early Basketmaker habitation sites in the Chinle Valley, northeastern Arizona. *Kiva* 60:203–218.
11. Gregory DA ed (1999) *Excavations in the Santa Cruz River Floodplain* (Center for Desert Archaeol, Tucson, AZ).
12. Upham S, MacNeish RS, Galinat WC, Stevenson CM (1987) Evidence concerning the origin of maize de ocho. *Am Anthropol* 89:410–419.
13. Freeman AKL (2000) in *Farming Through the Ages*, ed Wellman KD (SWCA Environmental Consultants, Tucson, AZ), pp 84–106.
14. Hard RJ, Roney JR (2004) in *Society and Politics in the Greater Southwest*, ed Mills B (Univ Press of Colorado, Boulder, CO), pp 276–294.
15. Vierra BJ, Ford RI (2006) in *Histories of Maize*, eds Staller JE, Tykot RH, Benz BF (Elsevier, Amsterdam), pp 497–510.
16. Wills WH (1988) *Early Prehistoric Agriculture in the American Southwest* (School of American Research Press, Santa Fe, NM).
17. Simmons AH (1986) New evidence for the early use of cultigens in the American Southwest. *Am Antiq* 51:73–89.
18. Bohrer VL (2007) *Preceramic Subsistence in Two Rock Shelters in Fresnal Canyon, South Central New Mexico.* Arizona State Museum Archaeological Series (Univ Arizona Press, Tucson, AZ) Vol. 199.
19. Tagg MD (1996) Early cultigens from Fresnal Shelter, southeastern New Mexico. *Am Antiq* 61:311–324.
20. Cutler HC, Whitaker TW (1961) History and distribution of the cultivated cucurbits in the Americas. *Am Antiq* 26:469–485.
21. Elson MD, Clark JJ eds (1995) *The Roosevelt Community Development Study. Vol. 3 Paleobotanical and Osteological Analyses* (Center for Desert Archaeol, Tucson, AZ).

Table S1. The Uto-Aztecan language family

Uto-Aztecan
Northern Uto-Aztecan
1. Numic
1.1. Western Numic
1.1.1. Mono
1.1.2. Northern Paiute
1.2. Central Numic
1.2.1. Panamint
1.2.2. Shoshoni
1.2.3. Comanche
1.3. Southern Numic
1.3.1. Ute
1.3.2. Kawaiisu
2. Tubatulabal
3. Hopi
4. Takic
4.1. Serrano
4.1.1. Serrano
4.1.2. Kitanemuk
4.2. Gabrielino-Fernandeño
4.3. Cupan
4.3.1. Cahuilla
4.3.2. Luiseño
4.3.3. Cupeño
Southern Uto-Aztecan
5. Tepiman
5.1. Upper Pima
5.2. Lower Pima
5.3. Northern Tepehuan
5.4. Southern Tepehuan
6. Ópatan
6.1. Ópata
6.2. Eudeve
7. Tarahumaran
7.1. Tarahumara
7.2. Guarijio
8. Cahitan (Yaqui–Mayo)
9. Tubar
10. Corachol
10.1. Cora
10.2. Huichol
11. Aztecan
11.1. Pochutec
11.2. General Aztecan
11.2.1. Nahuatl
11.2.2 Pipil

Table S2. Directly dated maize older than ≈1400 cal. B.C. (3100 ^{14}C yr b.p.)

^{14}C Lab number	Site	Location	^{14}C yrs B.P.	$\delta^{13}C$ ‰	Calibrated date (2 σ and median) (refs. 1, 2)	Ref.
Beta-185023	Old Corn	Colorado Plateau, NM	3,810 ± 50	−10.9	2460–2060 B.C. (2260 B.C.)	(3)
Beta-185022	Old Corn	Colorado Plateau, NM	3,760 ± 50	−10.6	2350–2030 B.C. (2180 B.C.)	(3)
Beta-185026	Old Corn	Colorado Plateau, NM	3,730 ± 40	−8.9	2280–1990 B.C. (2130 B.C.)	(3)
Beta-185024	Old Corn	Colorado Plateau, NM	3,710 ± 50	−9.1	2280–1960 B.C. (2100 B.C.)	(3)
Beta-179558	Old Corn	Colorado Plateau, NM	3,680 ± 40	−11.1	2200–1950 B.C. (2070 B.C.)	(3)
Beta-185025	Old Corn	Colorado Plateau, NM	3,700 ± 50	−9.7	2270–1950 B.C. (2090 B.C.)	(3)
Beta-185027	Old Corn	Colorado Plateau, NM	3,660 ± 50	−10.5	2200–1900 B.C. (2040 B.C.)	(3)
Beta-179557	Old Corn	Colorado Plateau, NM	3,660 ± 40	−10.9	2190–1930 B.C. (2040 B.C.)	(3)
Beta-179496	Old Corn	Colorado Plateau, NM	3,640 ± 40	−10.2	2140–1900 B.C. (2010 B.C.)	(3)
Beta-178616	Old Corn	Colorado Plateau, NM	3,620 ± 40	−10.2	2140–1880 B.C. (1980 B.C.)	(3)
CAMS-43177	McEuen Cave	East Central AZ	3,690 ± 50		2270–1940 B.C. (2080 B.C.)	(3–5)
Beta-175842	Clearwater, Congress St. Locus	Tucson Basin, AZ	3,690 ± 40	−10.9	2200–1960 B.C. (2080 B.C.)	(6)
Beta-160381	Clearwater, Congress St. Locus	Tucson Basin, AZ	3,650 ± 40	−10.4	2140–1910 B.C. (2020 B.C.)	(6)
Beta-148409	Las Capas	Tucson Basin, AZ	3,670 ± 40	−10.6	2200–1940 B.C. (2050 B.C.)	(7)
Beta-26275	Three Fir Shelter	Colorado Plateau, AZ	3,610 ± 170		2470–1540 B.C. (1990 B.C.)	(8)
AA-13257	Square Hearth	Tucson Basin, AZ	3,505 ± 65	−10.0*	2020–1680 B.C. (1830)	(9)
AA-9317	Lukachukai	Colorado Plateau, AZ	3,455 ± 45		1890–1640 B.C. (1780 B.C.)	(10)
AA-9319	Lukachukai	Colorado Plateau, AZ	3,135 ± 45		1500–1300 B.C. (1410 B.C.)	(10)
CAMS-34923	Los Pozos, East Locus	Tucson Basin, AZ	4,050 ± 50†	−10.0*	2860–2470 B.C. (2590 B.C.)	(11)
Beta-124111	Los Pozos, Sweetwater Locus	Tucson Basin, AZ	3,340 ± 60	−10.7	1770–1460 B.C. (1630 B.C.)	(11)
Beta-124114	Los Pozos, Sweetwater Locus	Tucson Basin, AZ	3,300 ± 80	−10.4	1770–1420 B.C. (1590 B.C.)	(11)
Beta-124113	Los Pozos, Sweetwater Locus	Tucson Basin, AZ	3,230 ± 50	−10.3	1620–1420 B.C. (1500 B.C.)	(11)
Beta-124112	Los Pozos, Sweetwater Locus	Tucson Basin, AZ	3,140 ± 50	−10.7	1520–1300 B.C. (1420 B.C.)	(11)
GX-12720	Tornillo Shelter‡	San Andres Mtns, NM	3,175 ± 240		2140–910 B.C. (1510 B.C.)	(12)
AA-28496	Valley Farms	Tucson Basin, AZ	3,145 ± 50		1520–1300 B.C. (1420 B.C.)	(13)
NSRL-12484	Cerro Juanaqueña	NW Chihuahua	3,130 ± 55	−10.7	1510–1270 B.C. (1405 B.C.)	(14)
AA-34173	San Luis de Cabezon	Northern Rio Grande, NM	3,125 ± 45	−9.4	1500–1300 B.C. (1400 B.C.)	(15)
A-4187	Bat Cave	Mogollon Highlands, NM	3,740 ± 70§		2430–1950 B.C. (2150 B.C.)	(16)
A-4188	Bat Cave	Mogollon Highlands, NM	3,120 ± 70		1600–1130 B.C. (1390 B.C.)	(16)

*Assumed.
†Ref. 11 questioned this date.
‡Combined sample.
§Ref. 16 questioned this date.

Table S3. Directly dated macrofossils of other cultigens: pepo squash, grain amaranth, common bean, bottle gourd, and cotton

Cultigen	Number	Site	Location	^{14}C Yrs B.P.	Calibrated Date (2 σ and median) (refs. 1, 2)	Ref.
Cucurbita pepo	A-4186	Bat Cave	Mogollon Highlands, NM	2,980 ± 120	1490–910 B.C. (1200 B.C.)	(16)
Cucurbita pepo	A-4182	Bat Cave	Mogollon Highlands, NM	2,630 ± 90	1000–420 B.C. (790 B.C.)	(16)
Cucurbita pepo	A-3388	Sheep Camp Shelter	Colorado Plateau, NM	2,900 ± 230	1680–540 B.C. (1120 B.C.)	(17)
Cucurbita pepo	A-3159	Sheep Camp Shelter	Colorado Plateau, NM	2,220 ± 290	980 B.C.–A.D. 400 (300 B.C.)	(17)
Cucurbita pepo	A-4178	Tularosa Cave	Mogollon Highlands, NM	1,900 ± 70	50 B.C.–A.D. 320 (A.D. 110)	(16)
Amaranthus cruentus	Beta-172104	High Rolls	Sacramento Mtns, NM	2,640 ± 40	900–770 B.C. (810 B.C.)	(18)
Phaseolus vulgaris	A-4179	Tularosa Cave	Mogollon Highlands, NM	2,470 ± 250	1260 B.C.–A.D. 20 (590 B.C.)	(16)
Phaseolus vulgaris	A-4184	Bat Cave	Mogollon Highlands, NM	2,140 ± 110	400 BC.–AD 80 (180 B.C.)	(16)
Phaseolus vulgaris	AA-6407	Fresnal Shelter	Sacramento Mtns, NM	2,085 ± 60	350 B.C.–A.D. 50 (110 B.C.)	(19)
Phaseolus vulgaris	AA-6405	Fresnal Shelter	Sacramento Mtns, NM	2,015 ± 65	190 B.C.–A.D. 120 (30 B.C.)	(19)
Phaseolus vulgaris	AA-6404	Fresnal Shelter	Sacramento Mtns, NM	1,955 ± 55	90 B.C.–A.D. 210 (A.D. 40)	(19)
Lagenaria siceraria	None	Cordova & Tularosa Caves	Mogollon Highlands, NM	Dated by association	est. 300 B.C.	(20)
Gossypium hirsutum	AA-13690	Eagle Ridge	Tonto Basin, AZ	1,725 ± 65	A.D. 130–510 (A.D. 310)	(21)