CHAPTER 7

EVOLVING THE THREE SISTERS: THE CHANGING HISTORIES OF MAIZE, BEAN, AND SQUASH IN NEW YORK AND THE GREATER NORTHEAST

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The "three sisters," maize (*Zea mays* ssp. *mays*), bean (*Phaseolus vulgaris*), and squash (*Cucurbita pepo*), were the dominant crops in many Northeast Native American agricultural systems during the late prehistoric and historic periods (Hurt 1987; Trigger 1978a). The histories of these crops have long been of interest to archaeologists because it is often thought that their adoption and the intensification of their production were important in the developments of cultural traits evident in the late prehistoric archaeological record and recorded by early European chroniclers. For example, the development of matrilineality, matrilocal residence, and longhouses, key traits of northern Iroquoian groups, has been thought by some to have developed with the increasing importance of female agricultural production (e.g., Trigger 1978b). Alternatively it has been suggested by others that Iroquoian migrants brought maize-based agriculture to New York and that this helped them to displace non-agricultural Algonquian groups (e.g., Snow 1995). New England archaeologists, on the other hand, have debated for years the significance of maize's adoption for regional subsistence-settlement systems and have often contrasted the New England archaeological record with that of New York (e.g., Bendremer 1999; Bernstein 1999; Ceci 1979-80; Chilton 1999, 2002, 2006, this volume; Demeritt 1991; Petersen and Cowie 2002; Snow 1980; Stein, this volume).

As can be seen in many of the chapters in this volume, as well as in Hart (1999a) and Hart and Rieth (2002), the adoption and intensification of maize-based agriculture are primary topics of interest among archaeologists and paleoethnobotanists working on late prehistoric times in the Northeast. The histories of maize, bean, and squash have been the subject of an on-going research program for the past decade by me and several colleagues (e.g., Hart 1999b, 1999c, 2000a, 2001, 2003, 2004, 2007; Hart and Asch Sidell 1996, 1997; Hart and Brumbach 2003; Hart and Scarry 1999; Hart et al. 2002, 2003, 2004, 2007a, 2007b,

2008; Thompson et al. 2004). In this chapter, I summarize the results of that research to date. I also provide brief overviews of three models that I believe can contribute to our understandings of the histories and evolution of maize-bean-squash agriculture in the Northeast and of the nature of the evidence we use to explore the histories and evolution of the triad.

SETTING THE STAGE

Polycropping maize, bean, and squash has a long history in the Western Hemisphere. Evidence for each of these crops extends back millennia in Central and South America (e.g., Dillehay et al. 2007; Kaplan and Lynch 1999; Piperno and Flannery 2001; Smith 1997) while there are much shorter histories in the North American Southwest, Plains, and East (e.g., Adair 2003; Asch and Hart 2004; Fish 2003; Schneider 2002). However, it does appear that whenever these three crops were available, they were in some manner grown and eaten together (Mt. Pleasant 2006). In fact soon after Europeans arrived in the Western Hemisphere, the three crops were transplanted to Europe and Africa, where they were also often grown and eaten together (e.g., McCann 2004; Paris 2000; Paris et al. 2006; Rebourg et al. 2004; Zevon 1997).

As noted by Mt. Pleasant (2006), there may be both agronomic and dietary benefits to the polycropping system of maize-bean-squash. Agronomically, each of the three crops may benefit the others when grown together (but see Park et al. 2002). Maize competes well against weeds and acts as climbing poles for bean vines. As legumes, bean plants fix nitrogen through symbiotic relationships with bacteria (Bernai et al. 2004). This nitrogen may be made available to the other plants (Giller et al. 1991; van Kessel and Hartley 2000), especially when remnants of bean plants are worked into the soil each year

(Mt. Pleasant 2006:536). Squash plants grow rapidly along the ground, and their large leaves act as mulch, preserving soil moisture and suppressing weeds. By mimicking natural plant communities, polycultures, such as maize-bean-squash, can be more stable than monocultures; they may withstand stochastic climatic events better than monocultures. By using nutrients, light, and water more efficiently than monoculture systems, agricultural productivity may be higher (per unit area) than monocultures (Mt. Pleasant 2006; Tsubo and Walker 2004; Willey 1990; Wooley and Davis 1991; but see Parker et al. 2002). The ability of farmers to take advantage of polycultures depends on their knowledge of each crop and each crop's interactions with the others within specific environments (Mt. Pleasant 2006; Wolley and Davis 1991).

Each of the crops also provides complementary value to diets (Mt. Pleasant 2006). Maize is high in calories but relatively low in protein and is deficient in two critical amino acids. Bean, on the other hand, is a rich source of protein, and has an amino acid profile that complements maize. Eating the two crops together provides a complete array of amino acids (Kaplan 1965). Squash is high in calories, vitamins, and minerals and its seeds are good sources of protein and oil (Robinson and Decker-Walters 1996).

There are, then, good proximal reasons why these three crops were frequently grown and eaten together. However, this does not explain their joint occurrences and uses. Each of the crops has separate evolutionary and dispersal histories. It is necessary to understand these histories in order to build explanations of the evolutions of the polycultural systems and the impacts of the crops on regional subsistence-settlement systems. I will briefly review the history of these crops in the Northeast generally and New York specifically, and follow this by a consideration of models that may help in building future explanations for the crops' histories in the various regions of the Northeast.

CROP HISTORIES

New macro- and microbotanical evidence and suites of accelerator mass spectrometry (AMS) dates directly on macrobotanical crop remains and charred cooking residues containing microbotanical remains are transforming our understandings of the histories of the three crops.

Cucurbita pepo

The earliest of the "three sisters" in the Northeast are cucurbits, commonly referred to as gourds and squashes. Gourd refers to a fruit that is generally small and extremely bitter and thus unpalatable, and squash refers to a palatable fruit that unlike a pumpkin is not round (Paris

2001:75). Current genetic evidence indicates that the squashes present in eastern North America prior to the European incursion had evolved in the East from *Cucurbita pepo* ssp. *ovifera* gourds native to the lower Mississippi drainage (Decker-Walters et al. 1993, 2002; Paris et al. 2003; Sanjur et al. 2002). These squashes included various summer squashes as well as acorn squash. The earliest published evidence for these gourds is at the Page-Ladson site in Florida. A direct AMS date of 12,570±100 B.P. (cal. 2σ 15,105–14,234 B.P.) was obtained on a gourd seed, but it is not clear that the gourds were related to human use (Newsom and Mihlbachler 2006:268; Newsom et al. 1993:77–79). Older seeds of *Cucurbita* have been recovered from the Latvis-Simpson also in Florida AMS dated to 31,900±400 B.P. and 31,610±240 B.P. (Mihlbachler et al. 2002:291; also see Newsom and Mihlbachler 2006:323), although detailed descriptions of these seeds have not been published to date. At both sites, the seeds were associated with mastodon remains.

The earliest evidence in the East for gourd use by humans comes from Illinois and Tennessee where charred rinds and seed fragments have been directly dated to a few centuries on either side of 7000 B.P. (Asch and Asch 1985; Smith 1992). The earliest evidence in the Northeast comes from the Sharrow Site in Maine, where a rind fragment was directly dated to 5695±100 B.P. (cal. 2σ 6717–6295 B.P.) (Petersen and Asch Sidell 1996). Rind fragments from the Memorial Park site in central Pennyslvania were directly dated to 5404±556 B.P. (cal. 2σ 7338–4875 B.P.). The large standard deviation of this date is offset by a wood charcoal and three bulk soil sample dates from the same deposit that have a mean pooled age of 5009±53 B.P. (cal. 2σ 5900–5644 B.P.) (Hart and Asch Sidell 1997). More recently, Monaghan et al. (2006) report the recovery of a gourd rind fragment from Marquette Viaduct in Michigan, which was directly dated to 3840±40 B.P. (cal. 2σ 4411–4103 B.P.). Thus, the evidence for early gourd use in the Northeast, although compelling, is nonetheless sparse. The wide geographic distribution of the remains, however, suggests that the finds are not isolated cases (Hart and Asch Sidell 1997), and that additional finds will be made in the coming years.

The evidence for early squash use in the Northeast is also sparse. Based on current evidence in the East, it appears that squashes had evolved by cal. 5000 to 3000 B.P. and spread fairly rapidly (Monaghan et al. 2006). In the Northeast, squash rind fragments were directly dated to 2625±45 B.P. (cal. 2σ 2852–2545 B.P.) at the Memorial Park site in Pennsylvania (Hart and Asch Sidell 1997). Monaghan et al. (2006; Lovis and Monaghan, this volume) report a direct date of 2820±40 B.P. (cal. 2σ 3064–2803 B.P.) on an uncarbonized squash seed from the Green Point site in Michigan. It is not clear if this seed represents *Cucurbita*

pepo ssp. *ovifera* or *Cucurbita pepo* ssp. *pepo*, the Mexican subspecies. Hart et al. (2003; 2007b) and Thompson et al. (2004) report the recovery of squash phytoliths from charred cooking residues adhering to the interior surfaces of a pottery sherds from several New York sites. A residue with squash phytoliths from the Scaccia site was directly dated to 2905±35 B.P. (cal. 2σ 3205–2947 B.P.). Adovasio and Johnson (1981:72–73) report the recovery of an uncarbonized seed fragment from the Meadowcroft Rockshelter in southwestern Pennsylvania in a stratum bracketed by radiocarbon dates on charcoal of 2820±75 B.P. (cal. 2σ 3157–2768 B.P.) and 2815±80 B.P. (cal. 2σ 3158–2762 B.P.). Another uncarbonized seed was recovered from a higher stratum at this site with wood charcoal dates between 2134±65 B.P. (cal. 2σ 2321–1951 B.P.) and 2075±125 B.P. (cal. 2σ 2343–1740 B.P.). It is not clear if these seeds are from gourds or squashes, but given the dates, squash seems likely. What is clear from this evidence is that edible squashes were present in the Northeast by the end of the third millennium B.P., while gourds were in use at least two millennia earlier.

An important variable in the spread of gourds well into the Northeast, presumably through human mediation, is the fact that the flesh of these gourds is extremely bitter and inedible. The question then becomes, why would people have made use of these fruits over such a large region, extending well beyond their probable natural range? Two hypotheses are that the seeds were processed for consumption through the removal of seed coat bitterness (e.g., Cowan and Smith 1993) and that the dried fruits were used as floats for fishnets (e.g., Fritz 1999). Recently conducted experiments indicate that both uses are feasible (Hart 2004; Hart et al. 2004). Another possibility is that a non-bitter morph was discovered and isolated from gene flow with gourd populations with bitter flesh. Isolation from gene flow would have been necessary because bitterness is a dominant trait. If farmers relied on seed stock from the previous year's crop, cross pollination between gourds and squashes would result in ruined squash crops because the bitterness would be expressed in the F_1 generation (Robinson and Decker-Walters 1996:32–33). Asch (1994:41) identified a non-bitter gourd population in the Red River valley of Arkansas. "Either Red River farmers all formerly grew non-bitter gourds, which escaped, or more likely there is a pronounced founder effect and the present population has descended from a single lineage" (Asch 1994:41). In the terminology used here, this population would be classified as squash. This population must have been genetically isolated from the more common bitter gourd populations. Interestingly, there is ethnohistoric documentation of a small sweet squash referred to as vine apple because of its size (Trumbull 1876). Perhaps this is analogous to the first cucurbits with edible flesh in eastern

North America.

The fruits of *Cucurbita pepo* squash are highly polymorphic with a lengthy list of current cultivars (Paris 2001; Robinson and Decker-Walters 1996). This phenotypic variation reflects genetic variation that has arisen over millennia of crop population interactions with human populations. Important in the evolution of squashes was selection for non-bitter flesh, delay in lignification of the rind, and consequently increased fruit size.

Zea mays ssp. mays

Current evidence indicates a lengthy history for maize in the Northeast as well. Adovasio and Johnson (1981) reported the recovery of a maize cob fragment from Meadowcroft Rockshelter in Pennsylvania in deposits bracketed by radiocarbon dates on charcoal of 2325±75 B.P. (cal. 2σ 2700–2147 B.P.) and 2290±75 B.P. (cal. 2σ 2683–2069 B.P.). No direct dates on maize macrobotanical remains have approached these early ^{14}C ages, and the Meadowcroft evidence is generally discounted in discussions of maize history in eastern North America (see MacConaughy, this volume; Smith 1992). However, the calibrated 2σ ranges of two early dates from Ohio overlap those of the Meadowcroft dates. Maize macrobotanical remains from the Edwin Harness site in Ohio (Ford 1987), have direct AMS dates of 2077±70 B.P. (cal. 2σ 2304–1881 B.P.) and 2017±50 B.P. (cal. 2σ 2115–1875 B.P.). Somewhat later, the Grand Banks site in southern Ontario yielded maize remains that were directly AMS dated to 1730±85 B.P. (cal. 2σ 1861–1416 B.P.) and 1720±105 B.P. (cal. 2σ 1872–1403 B.P.) (Crawford et al. 1997). The earliest published directly dated maize macrobotanical remain in New York is 1050±50 B.P. (cal. 2σ 1166–833 B.P.) (Cassedy and Webb 1999). In New England, the earliest direct date is from Massachusetts at 960±30 B.P. (cal. 2σ 929–795 B.P.) (Chilton 2006). There are a number of additional pre-1000 B.P. [14]C ages on wood charcoal spatially associated with maize remains in northeastern North America that may provide further evidence of early maize in the region (see Crawford and Smith 1997:114). However, because of the vagaries of site formation, these early ages must be substantiated through direct AMS dating (see Conard et al. 1984; Hart 1999c).

In a series of articles, my colleagues and I have reported on results of analysis of phytoliths extracted from directly AMS dated charred cooking residues removed from the interior surfaces of pottery sherds (Hart et al. 2003, 2007b; Thompson et al. 2004). The majority of sherds are from sites in the northern Finger Lakes region of New York. Our analyses suggest that maize was being cooked in pots by 2270±35 B.P. (cal. 2σ 2348–2157 B.P.) at the Vinette site and was certainly commonly used by 1500 B.P. in this region. The phytolith record indicates a more-or-less continuous presence for maize in the region, with

all dates but the earliest from Vinette falling within the range of direct dates for maize macrobotanical remains from the riverine interior (Hart et al. 2007b). The early date from Vinette suggests that the macrobotanical remains from Meadowcroft need to be seriously reconsidered as positive evidence for maize use in the Northeast at this time pending direct AMS dating. Interestingly, Brown's (2006a:656) glottochronological analysis indicates only that maize became a staple sometime after 3500 B.P.

Based on these results, it appears that maize and squash were being grown in the region much earlier than was thought previously. Phytoliths of both squash and maize have been found together in residues dating as early as 1525±35 B.P. (cal. 2σ 1518–1345 B.P.) at the Fortin 2 site in the Upper Susquehanna River valley (Thompson et al. 2004). Bean, on the other hand, appears to have a shorter history in the Northeast than previously thought.

Phaseolus vulgaris

The macrobotanical evidence for bean in northeastern North America has changed significantly since the mid-1990s. A direct AMS date of 658±48 B.P. (cal. 2σ 677–550 B.P.) on a bean cotyledon from Feature 35 at the Roundtop site in the Upper Susquehanna River valley in New York (Hart 1999b) contradicted the assertion by Ritchie (1969, Ritchie and Funk 1973) that bean was present at this site by the ninth century B.P. Ritchie's association of bean with a date on charcoal from another feature of 880±60 B.P. (cal. 2σ 918–694 B.P.) was widely accepted in the archaeological and paleoethnobotanical literature, and the bean was often cited as the earliest occurrence in eastern North America (e.g., Riley et al. 1990; Yarnell 1976). My colleagues and I subsequently obtained direct AMS dates on an additional 35 bean remains from purportedly cal. pre-650 B.P. contexts at 24 sites across northeastern North America (Hart et al. 2002; Hart and Scarry 1999). While not every bean remain from such contexts was accessible for the project, there is currently no credible macrobotanical evidence for bean in northeastern North America prior to cal. 700–650 B.P. Brown's (2006b) glottochronological analysis is consistent with these results. While some may question the sole reliance on direct AMS dates to establish this history, given that so many direct dates on bean from purportedly pre-700 B.P. contexts were shown to be late, any purported pre-700 B.P. bean must be questioned in the absence of a direct date.

None of the residues from pottery analyzed to date have yielded the distinctive hook-shaped hairs characteristic of bean pods (see Bozarth 1990). The recovery of a single hooked hair from residue encrusted on the interior of a steatite vessel sherd dating to the cal. fourth millennium B.P. (Hart et al. 2008) is undoubtedly from an indigenous legume given that there is no evidence for bean north of Mexico prior to 2500 B.P. (Kaplan and Lynch 1999).

Summary

It appears at this time that squash and maize have extended histories in the Northeast, while bean, and therefore, maize-bean-squash agriculture has a much shorter history. The maize-bean-squash remains from Feature 35 at Roundtop, with a pooled mean date of 667±30 B.P. (cal. 2σ 674–559 B.P.) on maize, bean, and a twig, are the earliest occurrence of the three crops together in the Northeast (Hart 1999b). The previous correlations of the development of Iroquoian cultural traits in New York and southern Ontario with the adoption of these crops is no longer tenable; each of the crops and the various Iroquoian traits have separate histories, only merging together later in prehistory, sometime after cal. 700 B.P. (see Hart 2000b, 2001; Hart and Brumbach 2003, 2005; Hart and Means 2002). The crops did not have immediate transformative impacts on settlement and subsistence patterns (compare to Chapdelaine 1993). Rather, there appears to have been over a millennium of time during which two of the crops were in use before the advent of nucleated villages and longhouses with the inferred matrilocal residence pattern (Hart 2000b, 2001; Hart and Brumbach 2005; Hart and Means 2002). How do we explain, then, the adoption of these crops and their long-term use prior to the advent of the settlement and subsistence traits to which they have been traditionally linked?

MODELING CROP ADOPTIONS AND AGRICULTURAL EVOLUTION

We are presently not in a good position to understand the implications of the new chronological evidence for maize, bean, and squash. There is need to think about new ways of understanding the processes of maize, bean, and squash adoptions in new areas and the manners in which archaeological recovery techniques and archaeological site formation processes bias the recovery of evidence for these adoptions (Hart 1999c, 2001, 2003). As often happens in science, the discovery of new, unexpected evidence requires a change in methods for linking evidence with theory. This perspective suggests that there is need to have a larger incorporation of biological theory and fact into our efforts to understand the adoption and histories of these crops in various regions (Hart 1999c, 2003).

Three simple models can inform our perceptions of crop adoptions and histories and the meaning of early archaeological evidence. These are the biological, shifting balance, and archaeological recovery models. Each model builds on the others and has implications for understand-

ing crop adoptions and intensifications of production. In the following sections I discuss how these models can provide important insights on the adoptions and intensifications of these crops in the Northeast, and the kinds of evidence needed to track the early histories of maize, bean, and squash in the region.

Biological Model

The biological model (Cleveland et al. 2000; Falconer and Maekay 1996; Soleri and Cleveland 2004) is expressed by this very simple equation:

$$(1) \quad V_P = V_G + V_E + V_{GxE}$$

where:

V_P is population phenotypic variation,
V_G is population genotypic variation,
V_E is environmental variation, and
V_{GxE} is genotypic-environmental interaction.

Environmental variation can in turn be broken down into at least three components as expressed by this equation:

$$(2) \quad V_E = V_L + V_T + V_M$$

where:

V_L is variation in location including edaphic and climatic variation,
V_T is variation in time including season, and
V_M is variation in human crop management activities.

Each of these, of course, is affected by the interactions of human and crop populations. Variation in location results from the human-determined siting of agricultural fields, which includes the frequency of field movement to track that of human populations across the landscape (Hart 1999c, 2001). Because plants are sessile, they must be adapted to a specific location (Bradshaw 1972; Linhart and Grant 1996). For example, environmental conditions explain the diversity of maize varieties in non-industrial-agricultural areas of Mexico and Central America (Anderson 1947; Brush and Perales 2007). V_T is determined by human-mediated planting schedules. V_M is determined by human activities concerned with the manners in which crops are planted and tended. This latter is affected by V_L because management includes development of the agroecology in which crop plants are grown (Rindos 1984), thus necessitating the addition of an interaction term in the equation so that it becomes :

$$(3) \quad V_E = V_L + V_T + V_M + V_{MxL}$$

where:

V_{MxL} is the interaction between location and management (see e.g., Gómez et al. 2000; Pressoir and Berthaud 2004a, 2004b; Soleri and Cleveland 2001, 2004; Smale et al. 2001).

While the model is quite simple, it has important implications for how crops would have responded to adoption

in new areas. In present day industrial agriculture, large expenditures of energy and resources are made to customize agricultural fields to specific crop varieties (McCann 2004). This represents a major departure from the long history of small scale agriculture in which crops were adapted to specific locations via selection acting on intrapopulational variation resulting in the many varieties evident in the ethnohistorical record and maintained traditional crops (e.g., Parker 1910; Russell 1980; Waugh 1916). The relationships between environment, population structure, and management on crop diversity are well established in traditional farming communities, for example, in Mexico (e.g., Longmire and Moldashev 1999; Soleri and Cleveland 2001).

In order to understand crop adaptations, it is necessary to understand the sources of variation on which selection could act. Founder populations represented the introductions of crops into new areas (see Hart 1999c). Variation in the first generation of a founder population, V_{G1}, was dependent on the variation in the parent population, the sample of that variation captured in the seeds entering the new area, and any subsampling done thereto by the adopting human population (Hart 1999c; also see Taylor and Keller 2007). This can be expressed by the following equation :

$$(4) \quad V_{G1} = V_{GPar} - V_{GS1} - V_{GS2}$$

where:

V_{G1} is the variation in the first generation of the founder population,
V_{GPar} is the variation in the parent population,
V_{GS1} is the variation not in the sample of the parent population, and
V_{GS2} is the variation removed by any subsequent subsampling.

The genetic variation in the founder population would determine in part its ability to survive in and become adapted to its new environment through selection (Hart 1999c).

Subsequent variation in the founder population would be determined by environmental and genetic variation as expressed in the original equation:

$$(1) \quad V_P = V_G + V_E + V_{GxE}$$

in which V_E includes the term V_M, which in turn includes human activities that would have affected genetic variation, including sampling, selection biases, and inclusion of seed from other populations obtained by trade in subsequent plantings, among others.

Also important to include in our understandings of the processes involved in establishing new crop populations is the concept of heritability (Cleveland et al. 2000; Falconer and Mackay 1996). Broad-sense heritability is that portion of phenotypic variation resulting from genetic variation: V_G/V_P. Narrow-sense heritability is the actu-

al proportion of phenotypic variation resulting from genotypic variation directly transmittable to the subsequent generation, or additive variation: V_A/V_P. Important for our purposes here is that not all phenotypic variation is heritable and thus subject to human mediated selection. So, for example, mass selection for productivity by choosing kernels from the best maize cobs in a given field in a given year may not produce more productive subsequent generations in different years in different fields, or even the same field under different climatic conditions (e.g., more or less rain).

Shifting Balance Theory Model

The second model is Sewall Wright's (1932, 1978a) shifting balance theory of evolution or SBT. An important component of which is the fitness landscape, represented here in its simplified two-dimensional form (Figure 7-1). Although a fitness landscape is actually n-dimensional, for conceptual purposes it can be simplified as a topographic map with the contour lines representing fitness values for the alleles of two genes or the expressions of two phenotypic traits on the X and Y axes. The peaks represent fitness optima and the valleys low fitness states. Given sufficient genetic variation, selection will always push a population up the nearest fitness peak regardless of whether there are higher peaks on the fitness landscape. Given that selection will then act to maintain a population on its peak, the primary issue in adaptive evolution is how a population can move to and ascend a higher fitness peak (Wright 1978a).

While SBT was designed and is still used as a general model of evolution (e.g., Nicklas 1997; Wade and Goodnight 1998), it was devised by Wright based on his

Figure 7-1 Simplified two-dimensional fitness landscape (after Sewall Wright 1932)

knowledge and experience with agriculture (Provine 1986; Wright 1978b). As a result, it should have general applicability in modeling prehistoric agricultural evolution (Hart 1999c). Under SBT, a population is split into numerous subpopulations, or demes, partially isolated from gene flow, and scattered across the fitness (and physical) landscape. Three forces interact in the adaptive evolution process: selection, drift (or chance), and gene flow as affected by population structure and migration. While each of these forces may hold sway at a given time, the three balance out in population adaptive evolution. SBT occurs in three phases. In Phase I, demes move across the fitness landscape as a result of genetic drift—the stochastic part of the process. In Phase II, one or more demes approach fitness peaks and ascend them as a result of selection working on genetic variation. In Phase III migrants from the more fit demes, those on higher fitness peaks, pass favorable gene complexes to less fit demes, allowing them to ascend higher fitness peaks, thus increasing the fitness of the whole population.

Maize, is a monoecious plant, producing both staminate (male) and pistillate (female) flowers. The male flower, the tassel, is located at the top of the plant, while the female flowers are located further down the stalk. This arrangement minimizes self-fertilization (selfing). Fertilization is anemophilous (achieved by the movement of pollen by wind). In theory, each kernel on a maize ear may have a different male parent. *Cucurbita pepo* is also a monoecious plant, but it is entomophilous (insect pollinated), most commonly by solitary bees of the genera *Peponapis* and *Xenoglossa* (Hurd et al. 1971). Each flower is open a single day, and insects are attracted to both male and female flowers by nectar. The production of male and female flowers is determined by levels of female hormones in the plant, and this in turn is affected by various factors including temperature, moisture availability, stress, age of plant, photoperiod, maturing fruits on the plant, and inbreeding depression (Avala-Shkar et al. 2001; Hayes et al. 2005a; Jóhannsson and Stepenson 1998; Robinson and Decker-Walters 1996). The production of flowers on any given plant is timed to minimize selfing (Robinson and Decker-Walters 1996). In the absence of pollination, fruits may develop parthenocarpically (without fertilization) late in the season when temperatures are lower and day lengths are shorter (Robinson and Decker-Walters 1996:19).

Both *Zea mays* and *Cucurbita pepo* are subject to inbreeding depression in small populations in the absence of gene flow through repeated mating in a population of close relatives. Inbreeding has a variety of deleterious effects that lower fitness in these species (e.g., Hallauer and Miranda 1988; Hayes et al. 2004a, 2004b, 2005a, 2005b; Jóhannsson et al. 1998; Jugenheimer 1976). As a result, prior to their becoming major crops, the popula-
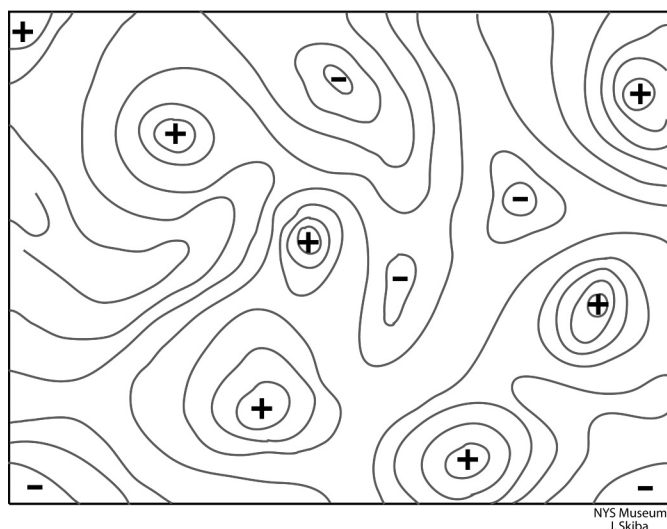
tion structure most feasible for a maize or cucurbit population's long-term survival was that envisioned by Wright in SBT (see details in Hart 1999c).

By returning to the biological model we can see how a population structure as in SBT, created through cucurbit and maize dispersal within dispersed human populations, would affect genetic variation. Drift and sampling would increase the amount of genetic variation (V_G) within the population as a whole even while limiting it within a given deme. Environmental variation (V_E) would increase for the population as a whole through dispersal across the physical landscape (V_L) as well as through varied management (V_M) practices by components of the dispersed human population and the interaction between location and management (V_{MxL}). These would both serve to locate crop demes on the fitness landscape and, if fields remained in place for long enough, would allow a deme or demes to ascend fitness peaks given enough genetic variation. Changes in the physical environment such as in field locations or management practices, and changes in genetic structure caused by samplings of seed for subsequent years' crops, gene flow between populations, and random climatic events, among other variables could relocate a deme onto another fitness peak, either higher or lower. Such variables could also result in an entirely new fitness landscape.

Exchange of seed stock among components of the dispersed human population (seed flow; e.g., Pressoir and Berthaud 2004a; Rice et al. 1997) would affect gene flow within the crop population, potentially increasing genetic variation (V_G) within demes and populations. Cross pollination between demes and even populations in cucurbits is very feasible because insects can and do travel relatively long distances. Cross pollination between maize demes is less likely and probably extremely rare between populations because maize pollen does not generally disperse more than a few hundred meters beyond the edges of maize fields (e.g., Bannert and Stamp 2007; Goggi et al. 2006; Luna et al. 2001). Different timing of anthesis in maize populations will also isolate those varieties from gene flow with one another (Pressoir and Berthaud 2004b). We would also expect a large amount of phenotypic variation in the population resulting from genetic and environmental interaction (V_{GxE}), only a small portion of it being heritable in the narrow sense. However, because of frequent settlement and, therefore, agricultural field movement, some crop demes may never have ascended fitness peaks, but, rather, were kept in constant motion on the fitness landscape as in the Red Queen hypothesis (Van Valen 1973).

Phaseolus vulgaris has hermaphroditic flowers, containing both stamens and pistelles, and is largely selfing; any cross pollination is entomophilous. The outcrossing rate for this species is 5% or less (e.g., Ferreira et al. 2000, 2007;

Ibarra-Pérez et al. 1996, 1997). Because it is selfing and does not suffer inbreeding depression in the absence of gene flow, once it had become adapted to broad environmental conditions, such as photoperiod and temperature (Massaya and White 1991) it could have spread fairly rapidly. The need for a population structure to ensure genetic variation as in SBT was not important for early adoption and dispersal of this crop as it was for maize and cucurbits. However, its dispersal across varying environments would result in the evolution of varieties.

We can see, then, that the adaptive evolution of maize and squash adopted into a new region was affected to a large degree by the structure of the adopting human population, including its internal dispersal and frequency of movement across the physical landscape, as well as the interaction between components of dispersed populations (Hart 1999c, 2001). As a result, we should not expect any simple linear trend in the evolution of agricultural systems in any given region. Rather we should envision a series of fits and starts, some leading to dead ends and extinctions of founder populations, and others to short- or relatively long-lived peaks in crop reliance prior to the widespread phenomenon of agricultural dependency throughout those regions (cf. Hart 1999c; Rindos 1984).

Archaeological Recovery Model

The third model is the archaeological recovery model, which connects the biological and shifting balance models to what we find in the archaeological record (e.g., Lopinot 1992:55-59; Miksicek 1987). I will use macrobotanical remains as an example because they have been used most frequently to address issues of crop adoptions, at least in eastern North America.

The probability of identification (P_I) of crop remains at a site can be represented by this equation:

$$(5) \quad P_I = P_A \times P_R$$

where:
> P_A is the probability of a crop entering the archaeological record, and
> P_R is the probability of probability of crop remains being recovered at a site on which it is preserved.

P_A is captured in this equation:

$$(6) \quad P_A = P_S \times P_C \times P_{SxC} \times P_D$$

where:
> P_S is the effect of site use, which is expressed in this equation:

$$(7) \quad P_S = S_I + S_L + S_F$$

where:
> S_I is the intensity of site use,
> S_L is the length of site use, and
> S_F is the frequency of site use.

Each of these reflects the amount of time spent on a particular location and the number of cooking events that occur at that location. The greater the number of cooking episodes, the greater the probability that crops will be lost and deposited in a context that ensures their preservation. For example a site that is occupied on a seasonal basis (S_L) repeatedly over a period of many years (S_F) by a relatively large number of people (S_I) provides a greater probability of crop remains entering the archaeological record than does a site occupied only a few times (S_F) during the same season (S_L) by a smaller number of people (S_I).

P_C is the effect of a crop's use, which is expressed in the equation:

(8) $P_C = C_C + C_I + C_L + C_S$

Where

  C_C is manner(s) in which the crop was cooked at a site,

  C_I is the intensity of the crop's use at the site during any given occupation,

  C_L is the length of the crop's use in any given occupation, and

  C_S is the kind of facilities in which maize was stored between harvesting and consumption.

The interaction of site use and crop use, P_{SXC} determine the probability that the crop will be lost and charred and/or charred and purposefully discarded.

  P_D is the probability of the deposition of charred crop parts in a context favorable for preservation.

This depends on the crop parts being processed and their exposure to heat for charring or conditions that facilitate desiccation or deposition in moist anaerobic conditions (e.g., Goette et al. 1994; King 1987; van der Veen 2007; Wright 2003).

King (1987:146–149) found that dried, flint maize kernels were more likely to preserve during charring than were fresh, moist kernels, which tend to pop and distort (also see Wright 2003). In fact, King (1987:147) suggests that many of the kernels found in the archaeological record were flint kernels processed as hominy, resulting in the crescent shape typical of especially later archaeological sites. "Given the difficulty of carbonizing maize kernels without distortion, it appears likely that many of the whole, well-preserved, maize kernels that occur in archaeological sites represent maize that had been boiled or made into hominy. More fragmentary remains may represent that carbonized during parching or roasting." Goette et al. (1994:8) reported similar results, "*the mote* [hominy] kernels were the quickest to char and were the most durable after charring, thereby making them the strongest candidates for preservation. In addition, they show the closest resemblance to much archaeological maize in lacking their pericaps, often their points of

attachment, and occasionally their embryos." Myers (2006) suggests that hominy technology was adopted relatively late across eastern North America. Wright (2003:582) found that preservation is more likely at lower temperatures and shorter exposure times in reducing atmospheres and when specimens are moist (also see Goette et al. 1994:12).

Cucurbit use was a major determining factor in its entering the archaeological record. For example, if Mid-Holocene gourds were use primarily as fish net floats, it seems unlikely that they would be exposed to fire frequently enough to enter and preserve in the archaeological record. A higher probability for entering the archaeological record would obtain if heat was used to process gourd seeds and/or flesh for consumption (Hart 2004; Hart et al. 2004). However, even in some cases where squash use was documented on ethnohistorically recorded sites, macrobotanical remains are very rare (Hart and Asch Sidell 1997:530).

To my knowledge, experiments similar to those done with maize kernels have not been performed for bean seeds. However, it has been my experience that bean cotyledons do preserve well, including seemingly fragile diagnostic structures such as the plumule and hilum (Hart et al. 2002). It seems likely that short exposure time in a reducing atmosphere would increase the probability of bean being charred and entering the archaeological record.

At late prehistoric village sites where it can be reasonably inferred that crops were used year-round by large numbers of people only fragmentary remains are typically found, except where subterranean storage facilities were burned or maize cobs were used as fuel in smudge pits. However, with maize, the remains tend to be more ubiquitous than at earlier, seasonally occupied, sites. If Myers (2006) is correct that hominy technology was a relatively late development in eastern North America, it might in part explain this pattern (C_C).

The probability of crop remains being recovered at a site, on which it is preserved, P_R, is captured in this equation:

(9) $P_R = E_S + T + L_S + I$

where:

  E_S is excavation sampling relative to the frequency and distribution of maize on the site,

  T is the recovery technique used (such as flotation),

  L_S is the sampling intensity in the lab, and

  I is the identification effort in the lab.

As should be evident, the greater the effort expended on each of these variables, the greater the probability that rare macrobotanical remains will be found. For example, the earliest, directly dated maize macrobotanical remains in eastern North America are from the Holding site (Riley

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et al. 1994), with a pooled mean of 2037±41 B.P. (cal. 2σ 2115–1898 B.P.) on directly AMS-dates maize remains. A total of 5,340 liters of soil were processed at this site yielding only 19 pieces of charred maize. A less intensive sampling and identification effort may very well have missed these early remains. However, at a site where S_I, S_L, and S_F were all high and cooking methods favored preservation, less intensive sampling and identification efforts will probably result in maize recovery and identification. This model can be modified to reflect any physical line of evidence for crops such as phytolith assemblages in charred cooking residues. The major categories do not change, but the specific elements will.

CONCLUSION

The adoption and perpetuation of agricultural crops in new locations is not always a simple proposition, nor is the recovery and identification of crop remains. What should be clear from the preceding discussion is that numerous interacting biological and cultural variables influence the success of a crop's adoption and perpetuation as well as its preservation and discovery in the archaeological record. In essence, the recovery and identification of crop remains from the archaeological record is the terminal point of a long probability tree. Each such probability tree encompasses numerous nodes including: (1) the actions of prehistoric individuals and their decisions regarding the management of those crops, (2) the nature of prehistoric settlement patterns, (3) the nature of prehistoric storage and cooking processes, and (4) the decisions of archaeologists and paleoethnobotanists regarding sampling and processing both in the field and laboratory. Each probability tree connects the actions of modern archaeologists and paleoethnobotanists with those of ancient farmers. Each of the various steps on a probability tree must be carefully considered and modeled. Doing so will allow us to better understand the meanings of the crop remains we find on archaeological sites.

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