

Crop Diversity in Peasant and Industrialized Agriculture: Mexico and California

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The loss of biological diversity of crops in centers of crop origins and evolution (“Vavilov centers”) is recognized as a cost of agricultural modernization. Another effect is to alter processes of crop evolution by restructuring farmer seed management. This article uses two case studies of “traditional” and “developed” agriculture to examine crop diversity and the management of crop evolutionary processes. The Mexican milpa is regarded as a descendant of Mesoamerican agriculture within which crop evolution of maize, beans, squash, and numerous other species developed and acquired diversity. Here, farmer-based selection prevails. California peach orchards are far removed from the original region of peach domestication, evolution, and diversity. Here, breeder-based selection prevails. The contrast is intended to show three things. First, farmer-based selection versus breeder-based selection is not necessarily a contrast of diverse versus not diverse farming systems. Second, agricultural development, including a prominence of centralized crop improvement, commercial agriculture, and well-integrated markets, can actually lead to increased diversity. Third, conserving the elements of farmer-based crop evolution may be equally important as conserving crop genetic diversity.

Keywords California, crop diversity, maize, Mexico, peaches

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The loss of biological diversity in agriculture has been associated with agricultural development (Fowler and Mooney 1990), and this change is believed to be particularly problematic in “Vavilov centers,” areas where crops were originally domesticated and have evolved over several thousand years (FAO 1996). The loss of crop diversity that occurred with the diffusion of hybrid maize in the American corn belt and the diffusion of semidwarf varieties of wheat and rice in Asia’s Green Revolution suggest that the well-known dichotomy between “traditional” and “developed” agriculture pertains to biological contrasts as well as those between subsistence and commercial production. Nevertheless, divergence in crop diversity between Vavilov centers where diffusion of modern agricultural is limited and industrial agriculture far removed from Vavilov centers is more often assumed than demonstrated.

Interdisciplinary research on crop diversity in Vavilov centers has challenged the belief that modernization inevitably results in the disappearance of local crop varieties (landraces) that are biologically diverse (Brush 1995; Wood and Lenné 1997). Landraces contrast with the uniform and stable crop varieties, including certified seed stock, that are associated with modern farming systems. Landraces are now considered to be versatile assemblages of different genotypes, or populations, that farmers gloss under a single name (Zeven 1997). Moreover, landraces are open systems that receive regular infusion of new germ plasm through seed flows among farms and farming regions (Zimmerer 1998; Louette 1999). As a result, crop diversity in traditional agricultural systems is more often greater within populations than between them. Agro-ecological research suggests that traditional farmers tend to select a single landrace for a field or even their entire farm rather than plant a collection of different landraces (Perales et al. 1998). When it is found in traditional agriculture, diversity often is concentrated in particular fields or home gardens (Bellon and Brush 1994). Farmers who plant landraces easily accommodate modern, high-yielding varieties by planting different parcels with different seed stock (Brush 1995).

Despite these revisions in our views of crop diversity and the consequences of agricultural modernization in Vavilov centers, a singular focus on diversity may obscure the importance of the ecological and evolutionary processes that are affected by the transition from traditional to modern agriculture. If the simple dichotomy between traditional and modern agriculture as biologically diverse versus homogeneous cannot be maintained, what other contrasts might pertain that are relevant to social goals such as conserving biological diversity and creating a sustainable agriculture? One area to investigate is the evolutionary processes that have created crop diversity in Vavilov centers.

Crop Evolution and Agricultural Development

Agricultural development involves both the social and technological transformation of crop production. A number of social changes associated with agricultural development can be discerned from the vast and multifaceted literature and theory on the topic. These social changes include a shift to market allocation of land and labor and the integration into a spatially wide production system that involves the provision of agricultural inputs from off-farm sources and the sale of commodities (de Janvry and LeVeen 1986). Land and labor markets, the replacement of land and labor by capital, and spatial integration are expected to lead to a specialization of production. Technologically, agricultural development involves the intensification of

production through increased energy inputs and crop outputs (Turner and Brush 1987). Another way to define this technological transformation is as increased control over the biophysical components of agricultural production: soils, water, weeds, pest and diseases, and seed (Loomis and Connor 1992).

A predicted result of the social and technological changes involved in agricultural development is that biological diversity will be lost. Crop diversity is specific to each species and can be measured in different ways. Genetic measures include heterozygosity of alleles, crop species with different numbers of chromosomes (polyploidy), and variation in qualitative and quantitative traits that are linked to genetic variation. Ecological measures include population structure such as the number of distinct genotypes ("richness"), the distribution of different genotypes in a crop population ("evenness"), indices that involve both richness and evenness (e.g., the Shannon Weaver index), and the rate of turnover of genotypes in a population. Social measures include the number of farmer varieties (landraces) and the reliance on local versus purchased seed. Intuitively, these different measures are linked to one another, although very few studies of crop diversity show this linkage. Local seed of landraces is expected to show both greater heterozygosity and more complex population structure than certified seed purchased from a seed company.

The loss of crop diversity in developed agriculture is expected for two reasons relating to the nature of crop diversity: isolating mechanisms and function. Theoretically, diversity in crop species has increased after the genetic bottleneck of domestication through the diffusion of crops, adaptation to different environments, the natural emergence of variation, and geographic isolation (Harlan 1975). In Vavilov centers, diversity is associated with heterogeneous and often mountainous environments and isolation. Functionally, diversity is attributed to the agro-ecological services that it fulfills. These include adaptation to heterogeneous soils and other field conditions and environmental risks such as drought or disease (Bellon 1996; Frankel et al. 1995).

Agricultural development, which involves spatial integration, specialization, and increasing control over production environments, is logically assumed to decrease diversity. Isolation gives way to participation in input and commodity changes. Specialization diminishes or eliminates production that does not involve a comparative advantage. Off-farm inputs of fertilizers, herbicides, pesticides, and scientifically produced seed satisfy the agro-ecological services once performed by crop diversity.

In terms of crop evolution, agricultural development represents a change in the traditional pattern of decentralized selection by farmers. While farmers continue to select seed in developed agriculture, they are joined by crop breeders who follow different protocols and work with different crop material than is available to farmers. A result observed in many developed agricultural systems is that the role of human selection in crop evolution has shifted from being farmer based to breeder based (Donald and Hamblin 1984; Fischbeck 1991).

Under farmer-based management of crop evolution, crops have become more productive, they have been widely diffused, and they have developed tremendous amounts of genetic diversity. This period is, of course, several thousand years, from the time of domestication to the rise of modern crop breeding less than 100 years ago. Farmers are purposeful in both producing variation, for instance by inter-planting different varieties of open-pollinated crops and by directional selection for specific traits. Farmer-based selection is decentralized, relatively slow, and confined to selecting material from a relatively limited geographic range. Farmer-based

selection often results in narrowly adapted crop types, although it also results in broadly adapted types. Farmer-based selection is open ended in terms of extralocal access to seed lots and because of the relatively frequent replacement of seed (Louette 1999; Zeven 1999). The crop populations that form the biological foundation of farmer-based crop evolution are assemblages of heterogeneous genotypes, with flows of genotypes and genes between distinct subpopulations. Therefore they can be considered as meta-populations, where no single farmer or farm region contains the entire population. Rather, farms and farm regions contain fragments of the meta-population, and they experience recurring cycles of local extinction and reestablishment of the landrace population. The heterogeneity that is found within populations of landraces and the fact that they are selected under farm conditions mean that crop evolution under farmer management can have a very high genotype by environment interaction as part of the selection process.

Breeder-based management of crop evolution contrasts with farmer-based management in several ways. Its population effects are both more rapid and more far-reaching in a short period than farmer-based selection. Breeder-based selection is centralized, but its raw material is derived from a wider geographic range than farmer-based selection. It is likewise purposeful, but the strength of directional selection is increased by fuller and more consistent information about crop traits and pedigrees and by specific techniques to control hybridization among different crop types. Breeder-based selection aims to produce new crop material that is widely adapted, in contrast with farmer methods that may incidentally result in widely adapted material. Breeder-based selection can be understood as an island biogeographic system rather than the meta-population system that characterizes farmer-based crop evolution. The island biogeographic system is one in which the centralized seed system ("mainland") supplies crop types ("colonizing species") to dispersed farms ("islands"). Natural and artificial selection occur at the farm level, but the source of new material is reduced and centralized to breeding stations.

Another difference is that breeders manage crop selection under conditions designed to minimize environmental heterogeneity and use statistical techniques to screen for genotype by environment ($G \times E$) interaction. In a breeder-based system, environmental heterogeneity and $G \times E$ interaction is introduced fairly late in the selection process in multilocation trials. In farmer-based selection the constant influx of genetic material combines with environmental heterogeneity (e.g., climate conditions or pest pressures that cannot be controlled from year to year), resulting in a greater importance of $G \times E$ interactions. The genetic characteristics of a given farmer's landrace become a constantly evolving target, as the farmer uses visible traits to manage the crop population while unseen genetic characteristics may vary.

In places where farmer-based selection and breeder-based selection are in direct competition, the former is often but not always the loser (Brush 1995). When farmers are a small fraction of the labor force and when markets for information, inputs, and produce are well developed, breeder-based selection and formal seed supply are likely to replace farmer-based selection and seed supply. In many farming systems, however, lack of breeders, environmental and cultural heterogeneity, agricultural marginality, poverty, and missing markets for information, inputs, and commodities pose effective obstacles to the replacement of farmer-based selection (Perales 1998). In other systems, equilibrium between farmer-based and breeder-based selection appears to prevail, with different sources of seed occupying different niches within an agro-ecosystem (Bellon and Brush 1994).

Methods

In order to further investigate the implications of agricultural development on crop diversity and on crop evolution, this article will compare two farming systems that lie at opposite ends of the hypothetical continuum between traditional agriculture in a Vavilov center of crop diversity and industrial agriculture in a non-Vavilov region. The first case is in the Sierra Norte de Puebla of Mexico within the center of domestication and diversity for numerous Mesoamerican crops, including maize. The second case is Fresno County, California, where agriculture developed only after the European conquest of the New World. Research consisted of household surveys in the study regions in both Mexico and California.

We examine the diversity and selection of native Mexican crops, maize, beans, and squash and compare this to peach production in Fresno. While the crops that are compared are different, they can be compared in terms of the relative diversity in each system as well as the association between agricultural development and diversity. Our purpose in comparing these two cases is to go beyond comparing crop diversity and to look at cultural practices behind crop diversity that reflect crop evolutionary processes. In the case of Mexico, we discuss diversity of landraces, but it should be understood that a single landrace is actually a heterogeneous population of different genotypes that satisfy farmers' criteria as being a single type (Zeven 1997). In the case of California, we discuss the diversity of commercial peach cultivars that satisfy the criteria of seed certification systems, distinctiveness, uniformity, and stability (Trehane et al. 1995). Each peach cultivar is a distinct genotype, in contrast to a maize landrace that is a composite of many genotypes.

The Mexican research was part of a larger interregional project on crop diversity (maize, beans, squash, and quelites—wild greens) and crop improvement. The Sierra Norte de Puebla (SNP) was chosen as being representative of subsistence oriented production by indigenous people in a relatively marginal environment for crop production. The geographical area of the Sierra Norte de Puebla consists of roughly 3500 square kilometers of steep canyons situated between the Central Mexican Plateau and the coastal plain of the Gulf of Mexico. The climate ranges from temperate at high elevations (1400–1850 masl) to tropical at lower elevations (250–1000 masl), and the climate is moist (250–400 cm/yr) with 12 months of rain per year. The population is largely indigenous (36%) from the Nahuatl and Totonaco ethnic groups. The region is a net importer of maize and other basic staples, and while a majority of the households surveyed continue to plant maize, half of the households produce less than half of their annual maize consumption. While the SNP may not be typical of the fertile highland valleys of Mexico, it conserves characteristics such as isolation from major markets, marginal agricultural conditions, and overlapping ethnic populations that are typical of areas of traditional agriculture in Central and Southern Mexico and into Central America.

An in-depth socioeconomic survey (281 households in 24 villages) was undertaken in the SNP in 1999, in order to apply a similar methodology to that proposed by Bellon, Louette, and Perales to the questions of the *milpa* cropping system (Van Dusen 2000). The survey sample was structured to cover a representative sample of villages in the study area (e.g., high and low altitude). The villages were chosen to incorporate a wide range of geographic, agro-ecological, agronomic, market, and cultural diversity. The survey sample was intended to contain enough cross-section variation in the key characteristics affecting crop diversity among different farms to test the significance of environmental, risk, and market factors.

Our unit of analysis for diversity was the seed lot, defined as the set of seeds selected by a farmer, planted, and used for selection in the next generation and maintained as distinct from other seed lots (Louette 1999). A landrace here is defined as being a single morphological type as recognized and named by local farmers. The maize landraces that are maintained by SNP farmers are open-pollinated populations that are continually mixed by seed exchange and cross pollination. An individual landrace shows considerable variation but is comprised for the most part of a single race, defined by similar phenotypic, morphological, and genetic characteristics (Wellhausen et al. 1952; Sanchez and Goodman 1992). Mexican farmers commonly identify landraces by color, but this characteristic alone does not signal the presence of a different maize race. Indeed, a race in a single environment may have several color variants that mask underlying genetic similarity. Following the farmers' system of classification, we treat different colored types as separate landraces. Interracial mixtures of maize occur, but farmer seed selection tends to separate races (Bellon and Brush 1994). For beans, squash, and quelites, we followed the classification for maize, a seed lot being the basic unit that a farmer uses and maintains as distinct from another, and a landrace being a grouping commonly referred to and recognized by many farmers. In contrast to maize, differentiation between types of these secondary crops usually corresponds to species rather than intraspecies differences.

While farm-level research on the loss and maintenance of crop diversity has been carried out in several Vavilov centers located in less developed countries, research on crop diversity in industrialized countries has largely been done with aggregate data. In order to overcome this lacuna our research combined farm-level research, including a random survey of 70 peach-producing households, and analysis of historical data on peach diversity in California. The survey was carried out in 1999 on orchard diversity in Fresno County in California's San Joaquin Valley. An advantage to research in California is the existence of historical records for some crops of the extent of cultivation of different crop varieties over time. Peaches are a case in point, with records maintained by the California Fruit and Nut Acreage statistical report published by the USDA Statistical Reporting Service and the California Agricultural Statistic Service between 1914 and 1992. In addition, the California Tree Fruit Agreement keeps annual reports with peach diversity data.

The Mexican *Milpa*

Mesoamerica is one of the primary hearths of crop domestication and agricultural evolution. The agriculture practiced by the pre-European people of North America was derived from the domestication of maize and other crops in Mexico. Contemporary farmers in parts of Mexico manage fields in ways that are similar to their pre-Colombian ancestors. Field patterns, native soil taxonomies, agricultural implements, grain storage methods, preparation and use of harvested foodstuffs, and agricultural rituals observed today are also evident in the archeological and ethno-historical record. While we have no basis for determining the genetic composition of Mesoamerican crops at the time of European conquest, the same complex of crops is dominant in peasant farms in central and southern Mexico as 500 years ago. Contemporary Mexican farmers are known to be relatively conservative in terms of adopting modern types of maize, their most important crop. In 1997/1998, 80% of Mexico's maize crop was planted with local landraces (CIMMYT 1999).

The "classic" Mesoamerican farming system is referred to as *milpa*—defined as a field that is intercropped with three principal species (*Zea mays*, *Phaseolus* spp., and

Cucurbita spp.), often with minor species (e.g., *Capsicum* spp., *Lycopersicon esculentum*), and in which edible leafy weeds—*quelites* (e.g., *Amaranthus* spp.)—are tolerated and harvested. As Nigh (1976, 3–4) observed, the *milpa* is more than a field of crops; rather, it “forms the core institution of Indian society in Mesoamerica and its religious and social importance often appears to exceed its nutritional and economic importance.” Maize is the primary crop. In some locations, maize’s closest and interfertile relative, *teosinte* (*Zea mexicana*), is present as a weed in the *milpa*. Numerous social and biological elements of maize’s crop evolutionary system are still present in the contemporary *milpa*. Social elements include farmer selection and exchange of seed, postharvest selection, intercropping of various species, the movement of seed lots among fields according to field rotation and fallow cycles, production for home consumption, and the use of local inputs such as energy and soil amendments. Biological elements include gene flow from crop relatives such as *teosinte* and wild bean and squash relatives, agro-climatic heterogeneity, and co-evolved pests and pathogens. Crop evolution in the *milpa* farming system has produced high amounts of genetic diversity in Mesoamerican crops. Mexican maize, for instance, has both the world’s greatest amount of racial diversity and allelic diversity among races (Smith 1986).

The dynamics and persistence of diversity in maize has received more attention than they have for beans and squashes. Bellon’s work in Chiapas (Bellon 1996; Bellon and Brush 1994) and more recently in Oaxaca emphasizes the agronomic performance of landrace and improved maize under different soil conditions and household resources of labor and agricultural inputs. Bellon (1996) has also emphasized farmers’ concerns with maize qualities other than yield in their continued selection of local material. Working in the central highlands in the states of Mexico and Morelos, Perales (1998; Perales et al. 1998) found that at high altitude (>1800 masl), local maize landraces had no improved maize competitors. At lower elevations in Morelos, Perales found local maize to be more diverse and dynamic and faced improved competitors. One of Perales’s findings was that all types of maize are “uneconomic” in terms of financial returns to farmers. In the north/central state of Jalisco and at midelevation, Louette (1999) found a similar level of dominance of unimproved maize types. She also demonstrated that the maize populations of farmers’ fields were “open systems” with a high percent of seed coming from outside of the farm’s location and a high exchange of pollen across different farmers’ plots.

The research of Bellon, Perales, and Louette reveals several patterns of contemporary Mexican *milpa* agriculture:

1. Persistence of local landraces, especially maize.
2. Persistence of farmer selection.
3. High levels of seed flow within and between communities, especially for more commercial areas.
4. A shift toward monocropping of maize, with a decrease first in squash and then beans.

However, the previous studies by Louette, Bellon, and Perales covered communities that were not indigenous and were integrated or adjacent to commercial maize-growing regions. These studies concentrated on the persistence of local landraces, but they did not cover the changes in the whole cropping system or the consequences for genetic erosion of changes in intercropping. Furthermore there are reasons to believe that the simplification of the *milpa* cropping system may have

TABLE 1 Number of Farmers in Each Cropping System, Sierra Norte de Puebla, Mexico

Crop	Maize	Maize only	Maize and squash	Maize and beans	Maize, beans, squash; and quelites
Number of households	225	42	35	50	98
Percent		19%	16%	22%	44%

implications for the crop evolutionary potential because of genotype by cropping system interactions (Davis et al. 1986).

In Table 1 we see the persistence of the multiple cropping system in the Sierra Norte de Puebla, where almost half of the households continue to plant all of the classic *milpa* crops: maize, beans, squash, and *quelites*. Only 19% of households plant maize alone, indicating that this is a useful study site to look at the process of conservation and loss of minor landraces.

The farmer populations of the principal *milpa* crop, maize, are made up of different racial mixtures that are adapted to microclimates and ecological niches in an area characterized by a high degree of agro-ecological heterogeneity. Most farmers only plant a single major landrace of white maize. Across farmers within a village, and to a greater degree across villages in the region, there is diversity within the population of the major landrace due to the differing relative contributions of three major races, *arrocillo*, *conico/chalqueño*, and *tuxpeño*. Each farmer may only plant a single white landrace, but through both farmer selection and environmental fitness, the various contributing races and climate and altitude adaptations can lead to the evolution of segregating populations. A minority of farmers maintain separate seed lots of a small number of minor colored landraces, usually planted on a smaller area. The number of households growing minor, colored landraces is presented in Table 2. Almost all farmers plant a white landrace, while only 22% plant yellow, and only 8% plant blue maize. While the color does not necessarily indicate a major genetic difference between landraces, the classification is useful because it is the one used by farmers in maintaining separate seed lots for planting in the next season, and in their eyes determines whether they have one or two crop populations.

The most important secondary crop is beans, grown either as a bush between maize rows or as a vine climbing onto the maize stalks. The most common bean species (*Phaseolus vulgaris*) has both bush and vine types. Table 3 reports the number of households and uses for different bean species. The bush type dominates in the

TABLE 2 Maize Types Grown by Household (HH)

	White	Yellow	Blue	Red
Number of HH growing	220	44	18	3
Percent of HH's	98%	22%	8%	1%
Average plot size (ha)	1.23	0.57	0.29	0.2

TABLE 3 Number of Households Growing Beans (*Phaseolus*) by Type

	<i>P. polyanthus</i>	<i>P. coccineus</i>	<i>P. vulgaris</i> (Bush)	<i>P. vulgaris</i> (Vine)	<i>P. vulgaris</i> (Other)	Any bean (% all HH)
Local name	Frijol Gordo/ Xoyema	Frijol Pinto/ Tacahuacet	Negro de Mata	Negro Enredadero	Michigan/ Nayarit	
Households	113	7	44	21	10	151 (53%)
Cut green beans	74	6	20	14	8	112 (39%)
Eat flower/ stalks	51	4	6	3	2	59 (21%)

lowlands, but imported seed purchased as food in the market is starting to replace local seed sources. This is indicated by the column for *P. vulgaris*, “other,” which are basically improved bush types adapted by farmers. The vine type is a traditional *milpa* intercrop, but appears to be disappearing, and farmers report difficulties in finding seed. In the highlands the most popular bean species is *P. polyanthus*, a vine type that is favored because there is a market premium for both the green and dried beans. A third species, *P. coccineus*, exists in an intermediate state where it is a weed for some farmers, tolerated by most, but only actually sown by a few. Wild *P. vulgaris* also exists and there appears to be gene flow and pollination visits across the three species (MILPA Project 1998).

The farmers in the sample here are not major producers of squash, but some farmers do maintain squash landraces on a small scale, a small number of plants intercropped within the *milpa*. The three main species are *Cucurbita moschata*, *Cucurbita ficifolia*, and *Sechium edule*, and the frequency of cultivation is reported in Table 4. The squashes are used as fresh and stored vegetables, fed to animals, and the seeds, blossoms, and/or tender shoots are eaten. Many other vegetative species are grown in the *milpa* on a minor scale. Among the most important are three species of amaranths, which are eaten as tender greens in the first months after maize is planted.

Econometric analysis of the survey data found that factors which contribute to the continued planting of the diverse *milpa* systems are environmental heterogeneity, cultural uses, and missing markets (Van Dusen 2000). Agro-ecological conditions require the matching of different local landraces to different elevations or soil types.

TABLE 4 Number of Households (HH) Growing Squash (Cucurbitaceae) by Species

	<i>Cucurbita moschata</i>	<i>Cucurbita ficifolia</i>	<i>Sechium edule</i>	Any squash (% all HHs)
Local name	Pipian	Chilacayote	Chayote	
Number of HH growing	95	41	71	137 (48%)
Eat stalks/flowers	69	25	70	119 (42%)
Average number of Plants/HH	9.9	7.4	6.2	

TABLE 5 Age and Source of Maize Seed (percent)

Parameter	White	Yellow	Blue
Age (yr)			
0–5	19	23	21
5 to 20	28	17	16
>20	53	60	63
Source of seed			
Father	45	56	68
Same village	52	40	32
Outside of village	3	4	0

Specific cultural uses or landrace attributes may mean that a minor landrace is cultivated because of its use for a specialty dish or relationship to cultural practices in planting or harvesting. Finally, households may maintain a diverse set of landraces because of missing markets, which means that if it demands a crop the household has to produce it, because the quality or trait demanded can not be found in the market.

Factors leading to a decrease in farmer-based selection and management of crop evolution are often tied to the process of economic development. Cultural change to a more commodity-based consumption is believed to lead to a decreased demand for agricultural diversity because of the ability to consume a diverse set of market and processed goods, such as manufactured tortillas. The development of labor markets and the increased participation by the household in off-farm work and migration also decrease diversity and farmer seed selection. First, the household income share from farming decreases, and thus the need to reduce risk through crop diversification decreases. Second, off-farm work and migration decrease the availability of family labor, competing with the labor intensive activities required by the diversity of minor landraces in the intercropping system.

However, conservation of diversity and farmer seed selection practices in centers of crop diversity does not solely rely on whether farmers continue to plant the crops and landraces. It is also dependent on characteristics of farmer seed systems and seed selection practices that contribute to the continued evolution of crop populations. The basic characteristics of farmer seed systems are reported in Tables 5 and 6.

TABLE 6 Age and Source of Bean Seed (percent)

Parameter	<i>P. polyanthus</i>	<i>P. vulgaris</i> (bush)	<i>P. vulgaris</i> (vine)	<i>P. coccineus</i>	Other
Age (yr)					
0–5	25	40	10	33	36
5 to 20	14	19	10	33	18
>20	61	40	81	33	45
Source of seed					
Father	40	33	43	33	27
Same village	47	45	48	50	36
Outside of village	13	21	10	17	36

Information on the dynamic nature of farmer seed systems can be seen in these tables. In the maize table for the age of seed, 20% of farmers' seed lots have been acquired in the last 5 years. However, a majority of farmers have had the same landrace for their entire lives. The source of maize seed is principally within the same village, but 3–4% of maize seed is imported into each community annually. While this may seem like a small percentage in any given year, the cumulative effect upon the overall crop population given a constant influx will be considerably larger. In the table for beans, the frequency of seed replacement and the imports from outside the community are higher than for maize. A unique pattern emerges for the vine form of *P. vulgaris*, which could be endangered because of the low renewal of seed lots. Across crops a bimodal distribution emerges for landrace seed management: Seed lots have either been recently acquired or have been maintained for a long time. The source of seed is principally within the family or within the village, with a small but steady flow from outside the community.

Thus the evolutionary context for local landraces is more complex than the idea of static conservation. Individual seed lots are maintained separately by each farmer, planted each year, selected from the harvest and used as seed the next year. Local landraces constitute meta-populations with genetic flows through farmer seed exchange across and within communities and pollen dispersal across the fragmented landscape (Louette 1999). The sources for new seed or the renewal of older landraces are highly decentralized, relying principally on informal social networks. The introduction of improved germ plasm is usually through a slow and indirect process of "creolization" where one farmer selects and adapts improved varieties for local conditions, and seeds are then disseminated through informal networks (Bellon and Risopoulos 2001).

Milpa diversity and management is the result of factors affecting whether a farmer continues to plant a *milpa* crop as well as factors affecting population dynamics through seed systems. There are a variety of factors that affect diversity outcomes—environmental conditions, cultural practices affecting demand, and the level of market integration, which affects the crop directly as a commodity and indirectly through critical inputs such as family labor. A key question addressed by this research was whether the same social and economic pressures are affecting the diversity within the principal crop as the diversity within other minor crops within the cropping system. Another question was whether and how we need to consider farmer practices in managing crop evolution differently from considerations of diversity. To date, most emphasis has been on diversity and not on evolution. In the Sierra Norte, maize cultivation and diversity appears to be relatively conservative and impervious to modernization, although beans and squash are clearly and negatively affected.

Peach Diversity in California

In almost any dimension relating to agriculture, genetic diversity, and crop evolution, California presents a striking contrast to the Sierra Norte de Puebla. Historically, farms in the United States have been getting larger and fewer in number. According to the Census of Agriculture, in California there were almost 135,676 farms in 1930 with an average size of 224 acres. By 1997 there were only 84,000 farms with an average size of 357 acres, almost 1.5 times as large. Tenure in the southern San Joaquin Valley was dominated at the turn of the century by absentee owners who controlled vast holdings of undeveloped land (Goldschmidt 1978). At the same

time, in irrigated areas, small farmers predominated until large-scale land development was initiated with the construction of federal- and state-sponsored irrigation projects (Friedberger 1988). Although California has a reputation for corporate controlled agriculture, small family run businesses continue to be important in this part of the Central Valley (Friedberger 1988).

The peach, *Prunus persica*, is one of the most popular fruits grown throughout the world and is native to China. From China it was carried to Persia and then quickly spread to Europe. The Spanish introduced peaches to Mexico in the 16th century (Moore and Ballington 1990). Spanish, French, and English settlers also planted peaches soon after the founding of colonies on the east coast of the United States. Spanish missionaries introduced the peach to California in the 18th century, and in the early 1800s the Russians reportedly brought peach seeds or trees by ships to San Francisco and planted them near Fort Ross (Faust and Timon 1995; Hedrick 1917).

Like other fruit and nut industries, the peach industry developed in tandem with the agricultural infrastructure in California. The completion of railroads, refrigerated trucking, and the canning industry stimulated extensive commercial planting of fruits and nuts including peaches. Through the 1930s the average annual growth in production was over 5% (University of California 1946). Peach production has undergone many changes in California. At first trees were grown wherever there were ranches or settlements. As the industry became more commercialized it was concentrated in specific fruit-growing areas, such as the Placer County foothills and the Vaca and Santa Clara Valleys. With better control of floods, availability of irrigation water, and large demand, the industry spread to the fertile areas of the Sacramento and San Joaquin Valleys (University of California 1946).

Although peaches in the United States have been subjected to natural and artificial selection for many decades, peaches throughout the country share similar pedigrees. Werner and Okie (1998) point out that peach cultivars in the United States are from the same parentage and genetically closely related, and tracing their origin to Elberta and J. H. Hale cultivars and ultimately to cling peaches. Arulsekar et al. (1986) and Byrne (1990) using isozymes, and Warburton and Bliss (1996) using molecular studies, have documented the limited genetic diversity of peaches in the United States. However, the number of cultivars produced through breeding activity is large. The same criteria used to define a cultivar in the 1930s Plant Patent Act are still applied: "A cultivar is a group of plants with characteristics that are distinct, uniform and stable" (Trehane et al. 1995). A cultivar is distinct in that it differs by one or more morpho-physiological characteristics from all other cultivars. The degree of distinctiveness may range from subtle differences detectable only by extensive comparisons in a few environments to extreme differences that are immediately evident in many situations. Uniformity refers to the fact that a cultivar produces a fruit that is true to type. Stability implies that when the cultivar is reproduced, it will remain true to its essential and distinctive features. For asexually reproduced crops such as peaches, the cultivar must remain stable through any means of asexual propagation such as grafting, budding, cutting, or tissue culture. Cultivars from U.S. breeding programs have gained considerable acceptance throughout many of the world's peach growing regions, particularly Eastern and Western Europe (Moore and Ballington 1990).

Both private breeders and public institutions such as USDA and universities are active in producing varieties. However, the private breeders, namely, Zaiger Genetics of Modesto, CA, and Bradford Nurseries of Le Grand, CA, appeared to be

TABLE 7 Source of Peach Cultivars in Fresno County, CA (1999)

Source of cultivars	Number of cultivars	Percent of all cultivars
Nurseries	151	92.6
University	9	5.5
Friend	3	1.8
Total	163	

dominant in producing varieties. For instance; 8 of the top 10 producing white flesh peaches and 6 of the top 10 producing white flesh nectarine come from Zaiger Genetics (Hansen 1999). Table 7 shows the dominance of nurseries in providing new peach cultivars to California producers.

The top 4 peach varieties packed in 1998 were Elegant Lady, with 2.5 million boxes; O'Henry, at 2.1 million; Summer Lady, at 1.05 million; and Flavorcrest, at 903,000 boxes. Of these, only Flavorcrest was from the USDA and the rest originated from private breeders. The production acreage of peaches is dominated by cultivars originating from private sources—nurseries and private breeders. As seen in Table 8, only 9% of the area of the major cultivars was planted by a cultivar originating from the USDA.

A striking feature of peach production in California is a dramatic and sustained increase in the cultivar diversity peach orchards, especially since 1950. The level of cultivar diversity has increased whether measured by the increase in the number of cultivars found in orchards, the distribution of cultivars, or the turnover in peach cultivars. Indices that measure richness, evenness, and temporal cultivar diversity were calculated, and all show increases during the period of agricultural development in California.

Table 9 shows three indices of peach cultivar diversity—for evenness (equitability in distribution), richness (number of cultivars), and Shannon–Weaver (a combination of richness and evenness)—and the percentage change in each index by decade between 1910 and 1990. All show increases but at different rates; the Shannon–Weaver, evenness, and richness indices increased by 94, 5, and 312%, respectively. The high increase in the richness index reflects the addition of cultivars

TABLE 8 Major Peach Cultivars, Sources and Percentage Share of Land in Survey

Cultivar	Source	Acres	Percentage total area	Cultivar age
O'Henry ^a	Private	268	22	22
Elegant Lady ^a	Private	334	28	28
Flavorcrest ^a	Public (USDA)	109	9	9
Springcrest	Private	193	16	16
June Lady	Private	86	7	7
May Crest	Private	46	4	4
Summer Lady ^a	Private	166	14	14
Total		1202		

^aAmong top 10 packed cultivars in California in 1998.

TABLE 9 Diversity Indices and Percent Change by Decade for California Peach Cultivars, 1910–1990

Year	Shannon–Weaver ^a	Evenness ^b	Richness ^c
1910	1.59	0.82	0.68
1920	1.63 (2.5)	0.84 (2.4)	0.65 (–4.4)
1930	1.61 (–1.2)	0.83 (–1.2)	0.75 (15)
1940	1.56 (–3.1)	0.71 (–14)	0.76 (1.3)
1950	1.43 (–8.3)	0.59 (–17)	1.00 (32)
1960	1.75 (22)	0.63 (6.8)	1.47 (47)
1970	2.02 (15)	0.67 (6.3)	2.34 (59)
1980	3.29 (63)	0.79 (18)	6.06 (159)
1990	3.43 (4.2)	0.84 (4)	6.22 (2.6)
Total	(94.1)	(5.3)	(311.5)

Note. Numbers outside parentheses are actual diversity values, while those in parentheses are change in diversity in percent from the previous decade.

^a $H' = -\sum_{i=1}^n P_i \ln P_i$ where P_i is the proportion of the total area share planted by the i th peach cultivar.

^b $J = H'_{\max}(\ln S)$ where S is the total number of peach cultivars and H' is the Shannon–Weaver diversity index.

^c $d = (S - 1)/(\ln N)$ where S is the total number of peach cultivars and N the total area occupied by all peach cultivars.

in peach orchards. As peach cultivars have been added at an increasing rate, the average age of cultivars has decreased. In the 1950s, the mean weighted age of peach cultivars was 22.5 years, while in the 1990s, it was 3.1 years. The equitability index, showing evenness, has had a modest increase over 90 years, suggesting that the addition of cultivars has not merely been confined to a few trees. The Shannon–Weaver index is sensitive to changes in rare species, and in this case it indicates the addition of new cultivars in the farming systems.

Conclusion

The contrast between the diversity of agriculture in central and southern Mexico and in the United States formed a template to view the loss of diversity related to agricultural development and the replacement of farmer-based breeding by breeder-based breeding (Marglin 1996). The case of maize was archetypical in this contrast, but research on crop ecology and genetic diversity suggests we reevaluate the template. Several millennia before present, maize diffused out of its Mesoamerican hearth and became established as far north as the Great Lakes. Although we know little about the diversity of maize before the European arrival in North America, it was likely to be patterned in a similar fashion to the modern crop in Mexico: biogeographic pools of races and varieties that were distinguished by adaptation to macro-environmental zones (e.g., latitude, coastal v. interior) and perhaps by use (e.g., tortilla, hominy). Troyer (1990) defines a taxonomic race as “an interbreeding population within a species that has enough transmissible traits to characterize it as being distinct from other such populations.” Goodman and Brown (1988) identify 10 broad racial complexes in U.S. maize, but they note that there have been no attempts to identify all of the major races existing before hybrid corn. Race has been

a cardinal measure of diversity in studying Mexican maize (e.g., Wellhausen et al. 1952), and the current estimate is that Mexico has around 50 races of maize (Sanchez and Goodman 1992). Reduction in maize races and varieties occurred in the United States relatively rapidly in three distinct stages after the mid-nineteenth century, eventually eliminating overt racial diversity in the crop.

The first stage began in the 1840s when farmers in the Ohio Valley crossed two distinct races, northern flints and southern dents, and produced a hybrid race, the corn-belt dent (Wallace and Brown 1988). This vigorous race diffused rapidly and was crossed with local populations east of the Rocky Mountains. Between 1850 and 1900, a handful of names emerged that were associated with farmers who had produced superior open-pollinated lines and commercial seed through intervarietal crosses and mass selection: Reid, Krug, Hershey, Holden (Wallace and Brown 1988). Sturtevant (1899, cited in Smith et al. 1999) recorded 69 varieties of flint maize and 323 varieties of dent maize in the United States, although 25 of these were more common and 1, Reid Yellow Dent, was dominant (Smith et al. 1999). The second stage lasted between 1900 and 1930 and was defined by increasing pressure to improve maize production through mass selection. Corn shows with experts and competitions to pick the best ears (Wallace and Brown 1988) and ear-to-row breeding aimed at improving selection (Mangelsdorf 1974) epitomized this period. The third stage begins with the development and evolution of hybrid maize as a seed industry through double cross to single cross methods (Kloppenburg 1988; Troyer 1990). Between 1840 and 1920, variety crossing, selection, and competition in commercial seed may well have increased the number of distinct open pollinated maize varieties in the United States. By 1950, open pollinated races had been almost completely replaced by commercial hybrid varieties in the American corn belt (Griliches 1957). As shown in the example of the Sierra Norte de Puebla, a comparable change has not occurred in most of Mexico, and maize there remains a diverse patchwork of land-races maintained by farmer-based breeding and informal seed flow.

Diversity remains in the American corn belt, but in very different form than before the century of reduction encompassed by the three stages described above. Today, diversity in U.S. maize is not measured in numbers of races or distinct regional populations but in variability within and between breeding lines (Smith et al. 1985; Lu and Bernardo 2001). Smith (1986) found that the most prevalent race in the United States, corn-belt dent, was less diverse than a pool of Mexican races but more diverse than 80% of Mexican races on an individual basis. Duvick (1984) notes that diversity in modern American agriculture should not be measured as the sum of variation among farms but rather as the diversity comprised of material in conservation, improvement, and production activities that are spatially and temporally segmented. Lu and Bernardo (2001) report that a reduction in the number of elite maize inbreds used in breeding has reduced diversity at the gene level, but diversity at the population level, measured by genetic differentiation, has been maintained. Thus, modern agriculture may not eliminate diversity so much as reconfigure it.

The contrast pursued in this article between Mexican agriculture and California peach agriculture also illustrates the fact that the original template that views “traditional agriculture” and “modern agriculture” as contrasts in biological diversity needs to be refined. In the fruit tree system there is an interesting dynamic to look at in the use of diversity, the development over time, the single main source, and the relatively uniform ecology of different farms. In modern corn belt maize, diversity is obscured by the difficulty in distinguishing between commercial varieties and industrial competition. Diversity in American corn-belt maize exists across

numerous niches and heterogeneous firms. The comparison between the Sierra Norte de Puebla farmers and California peach farmers examines diversity between two systems that are internally uniform in terms of agro-ecological niche and farm type.

In many ways, the contrast between *milpa* agriculture in the Sierra Norte de Puebla in Mexico and peach ranching in Fresno California is typical of the differences between subsistence agriculture in underdeveloped farming systems and commercial agriculture in industrialized economies. The former employs largely local inputs and results in low levels of output. The latter employs industrial inputs and is highly productive. However, the contrast between these two farming systems also challenges some widely held beliefs about “traditional” and “modern” farming systems. The *milpa* fields of the Sierra Norte are biologically diverse in terms of interspecies diversity, but they are not particularly diverse in terms of intraspecies diversity. For instance, most households plant only one type of maize. The diversity of maize doesn't come from a practice of each farmer planting numerous types but from seed management practices—frequent acquisition from diverse sources. The result is a diverse and dynamic local maize population comprised of a dominant landrace with some admixture from several maize races, including highland and lowland types. Peach ranches in Fresno, in contrast, show little interspecies diversity but a surprising amount of intraspecies diversity, at least as measured by distinct cultivars. Moreover, the diversity of peach orchards has increased as California has become more developed and wealthier.

Milpa agriculture in the Sierra Norte and peach ranching in Fresno represent opposite ends on the continuum between farmer-based and breeder-based crop evolution. One point of the contrast is that a simple distinction based on diversity is inappropriate. Diversity must be conceived as more than a list of variants found on and among farms. The loss of diversity, per se, may be less relevant than the conversion of one pattern of crop evolution to another. As shown in the Fresno case, breeder-based agriculture in industrial societies is prone to the accumulation of diversity as commodity markets become segmented by consumer demand. Some analysts of genetic erosion have counted cultivar diversity as representing genetic diversity (e.g., Fowler and Mooney 1990; Hammer et al. 1996), but cultivar diversity and genetic diversity are best considered as separate measures. Nevertheless, the Fresno case demonstrates a value of crop diversity that has been neglected: its potential economic value to consumers. This value may be comparable to the value of potential agronomic traits that are known to be embedded in crop diversity and have been the primary rationale for conservation. The increase in California peach diversity is due in large part to the introduction of early and late maturing cultivars. This introduction is explained by both production and market factors—the smooth use of durable inputs like the packing shed, the need to avoid labor bottlenecks, the availability of new markets for early and late peaches, the opening of international markets after World War II. Consumer demand for diversity is not only evident in “dessert crops” such as peaches and among wealthy consumers such as those in California and where its peaches are marketed. The diversity of traditional crops in the Sierra Norte does not presently have an economic value as a consumer good, but as Mexico becomes more urban and wealthier, demand for different types of maize and other Mexican crops can be expected to increase. A reason to maintain diversity today is to meet this future demand.

Another lesson from the contrast between these two farming systems is that the object of conservation in centers of crop diversity and evolution should not be diversity alone. Arguments in favor of in situ conservation have noted its

complementarity with ex situ conservation (Wood and Lenné 1997). In particular, on-farm conservation aims to conserve elements of crop evolution that cannot be preserved in genebanks, elements that are abundantly evident in the Sierra Norte: farmer selection, decentralization of seed sources, relatively long periods of adaptation of crop populations. The result is meta-populations of crops whose diversity exists mostly among individual farms and villages. In contrast, the diversity of peaches in Fresno derives from the work of a small number of nurseries and private breeders, a narrow genetic base, centralization of the seed system, and the rapid turnover of material under conditions where the environmental impact of environmental interaction is dampened by abundant external inputs. The increase in diversity in peaches is a good sign that diversity in agriculture can be positively affected by market and industrial development. The challenge is to find ways to make similar progress in the Sierra Norte de Puebla without dismantling the crop evolutionary system embodied in the *milpa*.

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