Maize and Biodiversity: The Effects of Transgenic Maize in Mexico

Chapter 5
Assessment of Biological Effects in Agriculture in Mexico

for the Article 13 Initative on
Maize and Biodiversity

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Abstract
Mexico has the most diverse maize germplasm of any country, and is characterized by many small producers and high maize consumption. The country has an intricate agrarian history and a strongly polarized society. Maize is grown in contrasting environmental, social and technological conditions in plots that range from garden size to fields of hundreds of hectares. The typical *campesino* subsidizes maize with revenues from offspring working in cities or abroad and uses family labor to subsist. Until the 1960s, Mexico was more than self sufficient in maize, and could quickly be so again with minimal investment in local maize improvement and sustainable maize production strategies. NAFTA accelerated US maize imports, but Mexico produces 78 percent of the maize it uses; half of this is grown by smallholders who comprise two-thirds of all producers. Social forces impel *campesinos* to produce maize as insurance; economic forces invite them to quit. The situation is fragile; the breaking point uncertain. Finding alternative crops or jobs and housing for more millions in cities will not be easy.

Mexican *campesinos* depend on maize landraces, tuned to local conditions. Landraces are exchanged, mixed, re-selected and re-adapted. Varied ecology in Mexico has discouraged universal hybrid use. The proportion of maize production planted with landraces (80 percent) is high, compared to the rest of Latin America. Hybrids have existed since the 1950s, but often cannot compete with open-pollinated varieties; companies are unlikely to cater to specialized ecologies; public programs are too underfunded to develop such hybrids. Locally adapted, open-pollinated maize is often a "safer" crop under marginal farming conditions, and much maize is grown on marginal lands. Preservation of biodiversity in maize has been a service of Mexican *campesinos* for millennia. Germplasm banks preserve this material, but national funding has failed and continuous international funding is not available. Clearly, if widespread use of GMOs or wholesale maize imports were to become the future for Mexico, then first priority must be strengthening germplasm programs to preserve maize biodiversity. This chapter focuses on potential impacts on landrace diversity and on small-plot farmers because they are the key to Mexico's current maize biodiversity and what makes transgenic maize in Mexico unique. Impacts on agroecosystems as a whole (e.g., pest resistance and non-target populations) are not discussed in detail here, nor are they conclusive, as the topics remain controversial, but they are addressed in Chapters 2 and 4.

While GMOs are the headlines, the immediate threats to Mexican maize landrace biodiversity are economic, headed by subsidies paid to US farmers. Landraces provide variability to cope with vagaries of weather patterns, pests and diseases, but they cannot overcome the 20 to 30 percent subsidies that bolster US exports. In this fragile situation of maize landraces it is necessary to analyze possible benefits and risks of transgenes and their introgression. The major detrimental effect on teosinte populations, maize's closely related wild/weedy relative, is presently human population expansion and consumption pressures, not GMOs.

Currently available transgenes (Bt, other herbicide resistances) are marginally attractive in the United States and less so in Mexico, but future advances (25+ years) in drought tolerance and resistance to pests of stored grain could be helpful to *campesinos* if other environmental and economic constraints can be resolved. There is consensus that transgenic traits (including current ones, reasonably-proven ones such as virus-resistance and male-sterility, and newer traits still under development) will introgress into landraces via US imports, seed introduced by migrants and the continuity of the Mexico-US border; the speed with which this happens will depend on the

degree to which the sources are adapted to Mexico and the usefulness of the transgenes. Most transgenes are unlikely to pose more threat to landraces than a new, successful cultivar, but each transgene needs assessment of its long-term cost/benefit to Mexico, and costs may only become apparent long term. Opportunities lost by not using or developing useful transgenes need consideration; this is very long-term planning, as time from gene isolation to farmer-deployment is about 15 years and the cost is enormous (about US$50 million per transgene). It is conceded that widespread employment of single genes is unwise, and today's transgenes share several common traits: common background from tissue culture, usually the same promotor, similar selective agents and terminal constructs. The remedy for crop uniformity is a dynamic local seed industry developing new varieties and persistence of *campesino* production for local self-sufficiency, both using Mexico's diversity of maize germplasm. This appears to have been discouraged by past governmental policies. Certainly, the recent budget proposal to discontinue funding to INIFAP and *Colegio de Postgraduados* would discourage private investment in that arena.

Private development of transgenic crops may slow as investments are directed to more lucrative medical markets. There is a limit to surcharges for transgenic seeds. One transgene is valued at about $20 per hectare, the next is unlikely to be economically viable at $20 more. Transgenes specifically useful to Mexico probably need to be developed by Mexicans. Minimal-cost, community breeding projects with few inputs have shown 20 percent on-farm yield increases while preserving local landraces. No transgene currently meets the 20 percent standard and, while a few hybrids do, they are not widely-enough adapted to spread broadly.

Production of industrial/pharmaceutical chemicals in maize carries risks of pollen- and seed-borne contamination; there is consensus that such endeavors are inappropriate except in extreme isolation, far removed from any place maize is now grown. Even then, risk of escape and contamination is not zero. Thus far, contamination costs, mostly from routine-, rather than industrial-transgenes, and mostly for organic growers, have been borne solely by the farmers, rather than by distributors or licensors of transgenics.

If some or all transgenes are barred from Mexico, then maize imports need monitoring, and whole or cracked maize imports from any country permitting use of transgenic maize would need to be prohibited. Monitoring of all imported, unprocessed maize would be necessary as, once in commerce, tracing origins is difficult. Laboratories for quality control will need to be developed; these need unusual characteristics, if accurate monitoring of small amounts of gene flow (less than one percent) is to be done.

Some US maize transgenes are expected to flow into Mexico, despite regulations. A major question is whether transgene-owners will be due fees for use of transgenes by farmers growing native, open-pollinated landraces. This is very important to Mexican agriculture and of almost no consequence to industrialized farming or to transnational seed companies. The sensible answer is that no fees should be paid by Mexican farmers for use of Mexican open-pollinated maize. A minimal requirement for transgene suppliers would be provision for inexpensive, non-ambiguous testing of each experimental transgene construct.

An immediate roadblock facing the utilization of, say, Mexican-developed (and even royalty-free) transgenes aimed at characteristically Mexican *campesino* problems is that there are no seed distribution or agricultural extension programs in place to move such genes into local, open-pollinated landraces of maize adapted to the many ecological regions of Mexico. If transgenes are envisioned as eventually helping Mexican *campesinos*, then this roadblock would effectively prevent that from ever happening.

In the following sections, we sketch the background of maize farming in Mexico and address the following topics regarding Mexican maize:

1) The present status and future prospects of transgenic traits;
2) Their possible expansion across landrace germplasm;
3) Could they help with the most pressing problems faced by producers;
4) What risks are involved for Mexico (i.e., could these traits disrupt value, performance, diversity and integrity of landraces and their relatives, and could some impact ecological processes and have negative effects on the environment or on the economy);
5) Are the risks worthwhile or are there better alternatives; and
6) What preventive measures should be considered, what needs investigation, and what needs discussion with those at risk?

1. Current status and future prospects of conventional maize landrace production

The current status and future prospects of conventional maize landrace production and conservation form a baseline for discussing the potential impact of transgene introgression in Mexican maize.

Maize production and rural crisis in Mexico: A general overview

Mexico has the highest diversity of maize germplasm (Ortega, 2004), a large number and high percentage of *campesinos*, and the highest direct, per capita, maize consumption in the world (Warman, 2001; FIRA, 1998). The country has a complex landscape, an intricate and unique agrarian history (see Appendix 1) and a strongly polarized society. Maize production occurs in myriad combinations of environmental, social and technological conditions, all of which have contrasting extremes. Production occurs in the neotropical humid lowlands, midlands and highlands, in the cool, subhumid Central Plateau, and under irrigation in the northern semiarid lowlands. Land use intensity ranges from slash-and-burn, multispecies milpa to irrigated, monocrop maize fields with two harvests per year (Aguilar et al., 2003). Land tenure is either social (*ejido* and *comunidad indígena*), private or both, and maize plots per family range in size from home gardens to the order of hundreds of hectares. Agro-industrial inputs and mechanization can be totally absent or can be used heavily (Warman, 2001; García-Barrios and García Barrios, 1992). From the data presented in the 1991 Census (INEGI, 1994) and the analysis done by different authors (e.g. García-Barrios and García Barrios, 1994, Warman, 2001; Appendini et. al, 2003; Bartra, in press), we estimate that two-thirds of maize producers fall near the following description: The most commonly found Mexican maize producing family has a 50 year old family member who coordinates maize production (most commonly a man; occasionally a woman). The family plants 1 to 3 hectares of rainfed maize fields with some significant degree of erosion, yielding 2 to 3 tons per ha in the best years and producing modest, if any, marketable excess, usually sold at or below production costs. The family uses a mixture of hand and animal (or machine) power, limited amounts of herbicides and, occasionally, insecticides. It more commonly uses natural or synthetic fertilizers as maize requires much nitrogen (Jourdain et al., 2001). It plants two or more landraces commonly tuned to different local environments (e.g. García-Barrios et al., 1988) and/or for different consumption purposes. Although associated crops and edible weeds were commonplace in the past, they are now scarce or absent in his fields because they are incompatible with atrazine-type herbicides (McKnight Foundation, 1997). The family depends on its own labor and on wage labor for field activities, spends the minute PROCAMPO governmental aid on unproductive consumption and perhaps on a little fertilizer. In classical economic terms, it subsidies maize production with external revenues from sons and daughters working in Mexican cities or abroad and uses otherwise idle family labor, already trained for agricultural activities. The family's insistence on securing as much as possible of its direct-maize consumption, seems irrational to conventional economists, given the relatively low, nominal price of purchasable maize. Yet, this persistence makes sense to poor families in the face of ever increasing maize-flour prices, uncertain employment, market failures, and local, potential pressure over idle, productive land. Values such as habits, cultural identity, landrace-tortilla quality and food security are involved in the family's decision to continue to plant maize. Under the current maize price policies, a considerable number of these *campesinos* - with the potential for producing modest but significant maize surplus for the national market - prefer to self-limit their maize production to the amount necessary for supplying high-quality tortillas for their families (Appendini, et al, 2003).

The concern over ever-increasing prices for tortilla-flour with minimal prices for *campesino* maize, largely as a result of a shared monopoly over maize processing, may explain, in part, the widespread fear that international companies controlling seeds and transgenes are, in themselves, a threat to the independence and even to the existence of *campesino* farmers (Bartra, 2003). It is clear that there are many in Mexico who believe that the governmental policies favor agricultural oligarchies over the interests of *campesinos*. To some extent, that limits the role for science in the service of agriculture, as in the past science has been observed to simply favor business (Esteva, 2003).

Until the 1960s, Mexico was self sufficient in maize production and even exported modest amounts to other countries (Barkin and Suarez, 1981a). Partly as a result, rural conditions were more inviting, emigration pressures were less, the economy (and the peso) was reasonably stable and environmental pressures were less than today. Since then, the situation has greatly changed. NAFTA has exacerbated a long-term reduction in incentives for maize production in Mexico and opened the door to increasing United States' yellow-maize imports (the latter still mainly devoted to industry and animal feed; FIRA; 1998). NAFTA, as negotiated and signed, had a 15 year phase-in of liberalization of maize markets, but the Mexican government (in its goal to control inflation) allowed free importation, without invoking the tariff-rate quota. The increase of US imports has led to (or followed) an increase in domestic, industrial, livestock production utilizing these imports and an increase in meat and poultry consumption. Mexico could readily be self sufficient in maize (Esteva, 2003a, b), which would have direct positive effects on the maintenance of Mexican maize landrace biodiversity, but *campesinos* in remote, mountainous regions will rarely sell feed to feedlots and hog farms in other areas.

The rural population has never ceased to increase, but has fallen to 25% of the total Mexican population, due to the prevalent rural crisis and exodus. National maize production has continued to increase in absolute terms, but today it represents merely 1.1% of the GNP (Warman, 2001). An increasing number of urban and semi-rural families purchase industrially-produced tortillas and maize flour, in part because there is often no alternative, despite their generally poor quality. All this suggests to some that - because maize and maize producers are marginal from a macroeconomic perspective, and most are clearly uncompetitive in the global market with undifferentiated prices for Mexican maize - their fate as producers should be of little national concern, given the cheap and plentiful potential maize supply produced by the heavily-subsidized US agroindustry and sold in international markets well below real costs (Bartra, in press).

Yet, there is another way of looking at the situation. In spite of two decades of low incentives for maize, Mexico still produces 78% of the maize it uses. At least half of this maize is produced by *campesinos* who represent two-thirds of the total producers (Warman, 2001; Bartra, in press). Roughly, thirty-nine million people depend on the fate of these *campesinos*' production for their maize consumption (230 kgs per capita per year on average). Among the *campesinos*, one-third buy part of their maize, another third are self-sufficient, and the last third are maize providers for local and regional markets. In short, *campesino* maize production may be marginal under some standards, but still plays a significant social function in slowing down food insecurity, unemployment, migration, extreme poverty, urban criminality, and rural collapse (Bartra, in press). Nevertheless, problems keep accumulating. Pressure on land, pest problems and soil erosion continue to grow, while, at the same time, seasonal labor shortages are more common. In recent decades, opportunities for substituting land with fertilizers, and labor with herbicides and pesticides, have given *campesinos* a temporary break and have produced modest yield increments. But net benefits are stagnant, or continue to decrease, due to increasing input costs, loss of associated crops, development of some pest resistance, more use of marginal land and low maize prices. There is a tension between the social forces that impel *campesinos* to maintain maize production for food quality and as life insurance and the economic policies and ecological conditions that invite them to quit altogether. The situation is fragile, and the breaking point is uncertain. Mexican peasant organizations are becoming increasingly concerned and vocal about the matter (Bartra in press). If, in spite of increasing social unrest, nothing is done, we can expect these productive social systems to collapse in the short or medium term, one after another, depending upon their specific local conditions. It will not be easy to find alternative crops for the relatively harsh conditions of Mexican rainfed agriculture, nor to find accommodation for yet more scores of millions of people in the cities. Of direct consequence to this report, loss of *campesinos* and their *campesino*-grown maize translates directly into loss of maize landrace biodiversity in the field (Ortega, 2003b; Ortega et al., 2000).

The current status of landrace and hybrid maize in Mexico

Maize is both a very productive crop and a species that has responded extremely well to selection for the many local, and commonly harsh, conditions in which it is grown in Mexico. The range of environments and practices used in maize production in Mexico is extremely wide. Partly as a consequence, there is more diversity among Mexican maize than is found anywhere else in the world (Anderson, 1946; Sanchez and Goodman, 1992a, b; Sanchez et al., 2000; Wellhausen et al., 1951). Nearly all Mexican *campesinos* depend on one or more of the circa 60 maize races, all finely tuned to local conditions (Ortega et al., 1991). Their great-grandparents (and *their* great-grandparents) would have recognized most of them, and these Mexican varieties and races of maize are one of the legacies they left to mankind. Landraces are not static and perfectly distinct resources, but are continuously being exchanged, mixed, re-selected and re-adapted by farmers, through their social networks (Perales et al., 2003b).

In contrast to the situation in the United States, where hybrids were essentially introduced in the early 1930s and occupied virtually all maize farmland by 1945, the varied ecology in Mexico has greatly discouraged such universal adoption of hybrids (Frankel et al., 1995; Ortega, 2003a; Perales et al., 2003a). In Mexico, the proportion of maize land surface sown with landraces (80%) is far beyond both the average world value (48.5%) and the average for Latin America (55%; Morris, 2001), excluding Argentina, which now only plants hybrids.

Excellent hybrids were developed in the public sector in Mexico in the early 1950s. Private breeding programs started in the 1960s, and their products dominate certain ecological sectors (Matchett, 2002). However, in many environments, current hybrids are not competitive with open-pollinated varieties, there is little economic benefit to commercial companies to cater to small, specialized ecologies, and public programs are so underfunded and understaffed that hybrids are unlikely to be developed for such regions any time in the near future. The maize farmer growing maize for home consumption often has little reason to choose hybrid maize over locally-adapted open-pollinated maize. When maize is a main food source, texture, flavor and even appearance may be more highly valued than absolute productivity under rarely-achieved, optimal conditions (Anderson, 1952; Hernández, 1993; Ortega, 2003a). Local prices for local maize can be several times higher than for common, yellow imported maize (Barkin, 2003), but at the national level, with current governmental policies, there is pricing discrimination against native, open-pollinated maize (Ortega,2003a). Known, locally-adapted, open-pollinated maize with its more variable flowering times is often a "safer" crop under marginal farming conditions (Farr, 2001; Ortega, 2003a), and much of Mexico's maize growing is on marginal lands, especially in terms of water supplies.

To date there are no comprehensive national accounts of where and to what extent hybrids are planted in different parts of the country. General estimates show that some regions have contrasting proportions of land planted to hybrids. In 1990, 38% of maize cropland surface was planted to modern varieties in Chiapas and 55% in Jalisco. That contrasts greatly with Sinaloa and Sonora, which averaged 95% hybrids, and the states of Mexico, Oaxaca, and Yucatan, which were 10% or lower (calculated by Perales, 1998, with 1992 data from SARH-FIRA-BANRURAL). Half of the very poor rural families live in the southern states of Veracruz, Puebla, Guerrero, Oaxaca and Chiapas (Warman, 2001). These are areas with high diversity of local maize landraces (Ortega, 2003a,b). Within these regions, environmental and social differences are of consequence. Some studies suggest that hybrids have been more successful in the lowlands than in the temperate and tropical highlands (Perales et al., 2003a), and that they are more common in relatively large commercial fields with irrigation or good rainfall (Perales, pers. comm.); they are not absent, however, in medium-size commercial holdings. In Jalisco, one of the three or four most important maize production regions in Mexico, two field studies (Orozco et al., 1990) report high input, commercial maize producers having only an average of 10 to 13 hectares of maize. The situation for the state of Chiapas illustrates contrasts within states. Chiapas is representative of the southern *campesino*-dominated mountainous region of Mexico, but also has a commercial sector of medium-size producers in the inner lowlands of the Fraylesca region. Figure 1 shows the proportion of land planted with maize; that proportion is high throughout, but is very high in higher elevation areas. Figure 2 presents the average size of a cultivated plot, which is generally very small and smaller still in the higher elevations. Figure 3 shows the average plot size for maize farmers, again very small, and smaller still at higher elevations. At high elevations only landraces are sown; in the Fraylesca valleys both hybrids and landraces are planted, the latter in higher proportion (Perales, pers. comm.)

To the best of our knowledge, there are few formal studies regarding the swamping of local landraces of maize in Mexico by gene flow from hybrids or improved varieties (e.g., Ortega et al., 2000; Bellón and Risopoulos, 2001), and findings of introgression of local landraces by transgenics are still being formally confirmed. In areas where landraces are strongly preferred, the use of hybrids is usually minimal and fleeting. However, the consequences of even a small amount (less than 5%, for example) of *constant* gene flow can have substantial impact over time.

Threats to landrace conservation in Mexico, before transgene introgression

Basically, the symbiotic relationship between Mexico's maize landraces and Mexican *campesinos*, where each nurtures the other, is a delicate one. While GMOs may be the headline threat, the more immediate threats to both are largely economic, and, while GMOs do have potential economic risks, such risks are probably minor relative to the risks of Mexico's *campesinos* and their maize landraces being displaced by US imports. These economic risks include, but are certainly not limited to, subsidies paid to US and European farmers that Mexicans don't receive, large imports of U.S. maize, immigration of some of the best and brightest young people to the major metropolitan regions and to the US, lack of investment in applied agricultural research by the Mexican government, difficulties in finding loans for agricultural improvements, lack of infrastructure (roads, potable water, electricity, telephone) in many rural areas, etc. The landraces provide the variability to cope with the vagaries of changing weather patterns, pests and diseases, but they cannot overcome the huge subsidies that bolster U.S. maize exports to Mexico (US $22 to $30 per metric ton, roughly a 20% to 30% subsidy that comes to about $400 per hectare; Nadal, 1999, 2000, 2002). According to a recent report (Otte, 2004), the "average" US farm receives about $50,000 per year in governmental subsidies.

If imported maize prices remain near or below cost of production in Mexico, it is likely that Mexico's own maize growing will decrease substantially and rapidly. *Campesino* maize farming, especially, will change status from an occupation to a luxury; maize will be grown in smaller populations (with adverse effects on vigor and diversity), mostly for household use. Maize will basically become a vegetable or horticultural crop, rather than a field crop, for many Mexican farmers. The effects are likely to be immense for those farmers, for maize is a cross-pollinated crop, and its vigor is highly dependent on population size. With small population sizes, inbreeding, drift, and loss of vigor soon occur. Loss of vigor, drift and minimal pricing are apt to jointly interact to further decrease farmers' interests in growing local-community maize varieties. The traditional, labor-intensive milpa growing system, where edible weeds were tolerated and inter-planting rather than monoculture was followed, a tradition based on millennia of farming experience (Hernández X., 1985a; García-Barrios and García Barrios, 1992; Farr, 2001; Aguilar et al., 2003), has largely been displaced because of widespread herbicide use that compensates somewhat for labor scarcity. The result is less overall biodiversity, more soil erosion on steep slopes, patchwork planting patterns and fewer companion crops grown. The milpa system probably also helped control pests that thrive best on monocultures (Altieri, 1994; Morales, 2000); it certainly served to insure that some crops reached harvest successfully (Thurston, 1990). The loss of the milpa system, followed rapidly by widespread abandonment of local maize landraces by *campesinos* would be a global catastrophe, given the precarious status of even the best of the world's maize germplasm banks (Goodman, 1984). Some of the political aspects of the situation have been summarized by Dyer and Dyer (2003) and Bartra (2003).

Campesinos and their maize landraces are on the line, and the socioeconomic conditions described above currently constitute the most important threat to their persistence. For those who consider that the rule of comparative advantages should prevail at any cost, there is no point in continuing to support globally-non-competitive maize producers (e.g. Levy and Wijnberger, 1992; Tellez, 2004). Mexican government programs during the 1990s, such as PROCAMPO, were designed, among other things, to discourage non-competitive maize producers from continuing to grow maize (Dyer-Leal and Yunez-Naude, 2003). The governmental attitude, as early as 1991, was succinctly summarized by Barkin (2003, p. 171), "Es la política de este régimen remover del México rural la mitad de su población en los siguientes cinco años." Esteva (2003a, p. 205) quoted the then

Secretary of Agriculture directly, "Mi obligación como Secretario de Agricultura es sacar del campo a diez milliones de campesinos." A recent Secretario de Agricultura was quoted as replying "atiendan a las señales del mercado, muchachos," dismissing requests for rural assistance (Bartra, 2003, p.227).

Current Mexican landrace germplasm conservation for future maize improvement programs in Mexico or elsewhere should then be a matter of having appropriate germplasm banks and reproduction facilities, either in Mexico or abroad, if necessary. For those who value national maize sufficiency, consider it technically feasible (Turrent, 1993) and expect *campesino* maize production to continue to play an important social role, national support is imperative (García Barrios and García-Barrios, 1994; Appendini, et al., 2003; Bartra, in press). From an agronomic perspective, *in situ* landrace conservation and improvement (Brush, 1995), reduced tillage (Erenstein and Cadena Iñiguez, 1997), intercropping (García-Barrios, 2003), cover crops and green manuring (Bunch, 1994; Velázquez-Hernández et al., 1999), efficient fertilizer use (Pool-Novelo, 1999), agroforestry (García-Barrios and Ong, in press), integrated pest management (Morales, 2000) and other low input techniques are being developed further in order to meet the environmental challenges and economic constraints faced by *campesinos*. These efforts are not necessarily in conflict with supporting the medium and large, commercial Mexican producers who constitute the other third of Mexican producers, and who deliver the other half of the Mexican maize crop. Under this view, germplasm banks are considered as part of the effort to support *in situ* landrace conservation, as well as insurance policies against unknown and unpredictable future ecological threats.

The preservation of the enormous biodiversity in maize in Mexico has really been the service to mankind of Mexican *campesinos*, who have cultivated the maize inherited from their ancestors for millennia. Basically, the world's future maize breeding depends upon access to adequate genetic diversity. Germplasm banks are useful for preserving existing diversity, they serve as essential insurance against loss of diversity, but it is the *campesino* that continues the development of *in situ* diversity. As diseases and insects continue to evolve, with several generations per season, simply locking up germplasm in freezers or housing a part of it in active breeding programs is an inadequate (although clearly a needed) response to pest evolution. Any functioning maize improvement programs for *campesino* regions will need to be locally-focused for the foreseeable future. Germplasm banks have tried to collect, study and preserve this material (Zavala et al., 1999), but the Mexican government has largely failed in recent decades to fund national germplasm banks (Rincón and Hernández, 2000), and international sources are not focused on such never-ending-funding missions. Even in the U.S., Duvick (1984), then vice-president for research at Pioneer, commented

"I reserve my most severe condemnation for those government agencies ultimately responsible for funding of our germplasm collections. Our national stinginess in collecting, storing, renewing and describing the collections is inexcusable, not only in regard to our national obligations, but also in regard to our responsibility to the entire world."

Clearly, if GMOs are any sort of threat to Mexican maize biodiversity, and that seems to be the most important question here to the world-at-large, first priority should go to strengthening the germplasm system responsible for preserving maize biodiversity. The question is not *increasing* its budget, but *establishing* a realistic one. Mexico's germplasm resources program is currently very precarious and in need of major equipment and programmatic support (Rincón and Hernández, 2000). The second need is the encouragement of *in-situ* germplasm improvement and conservation programs on a local level. Recognition by the government of the economic premium that local maize merits over U.S. number 2 yellow corn in Mexican markets (Appendini et al., 2003) would be a reasonable first step.

This is the general context in which maize imports from the US (much of them transgenic) have grown from 396 thousand tons in 1993 to five million tons in 2001 (Meng and Ekboir, 2001), and in which the possibility of eliminating the *de facto* moratorium on growing transgenic maize in Mexico is being discussed. This is the complex and fragile situation of maize landraces in which it is necessary to analyze the possible biological and ecological benefits and risks of transgene introgression, and of developing purposeful, and possibly useful, transgene constructs in Mexican maize. Such constructs could add to the elimination of *campesino* maize farming if they contribute to US and large-scale farming dominance in Mexico. They might contribute to *campesino* farming and preservation of landrace biodiversity if they added traits that *campesinos* could use to their advantage and if adequate means of distribution existed.

In the next sections, we address the following controversial topics: 1) What are the present status and future prospects of traits induced in maize varieties through transgenes; 2) How feasible would be their intended or unintended expansion across Mexican maize germplasm in the short and long run; 3) Could they solve or mitigate some of the most pressing ecological problems faced by Mexican maize producers; 4) What are the risks involved for Mexican maize production: a) under what circumstances could some of these traits further disrupt the commodity value, biological performance, diversity and integrity of landraces and their relatives; b) under what circumstances could some of these traits impact ecological processes within the maize fields that would have negative effects on the environment and on the economy of producers; 5) Are the inevitable risks worthwhile or are there more innocuous alternatives; 6) Given the uncertain responses to these questions, what preventive measures should be seriously considered, what needs to be investigated, and what needs to be discussed with the population directly at risk?

2. Maize Transgenes: Current Status - Future Prospects

In the US and Canada, the first generation of plant transgenes is now nearing its teenage years. The obvious candidates ("low hanging fruit" in the words of Bruce Walsh in Thro et al., in press) for transgenic deployment have largely all been tried. Four types clearly work, work reasonably well in the sense of doing what they were expected to do, have reasonably few deleterious traits on the crop itself, and have demonstrated that one more new technology works. For maize, they have thus far demonstrated little economic return to farmers or to their developers, even in the U.S. (Ferber, 1999; Duffy, 2001; Obrycki, 2001). To claim that the traits thus far harnessed are of utmost importance to mankind, or that they represent the most revolutionary achievement in plant breeding, or that they have or soon will have made a positive contribution towards relieving world hunger is patent nonsense, but some of the new traits fill gaps that breeders couldn't previously address effectively. And more useful traits, some of which may appeal to Mexican farmers and consumers, will follow, although far more slowly than the more ardent biotechnology promoters suggest (Goodman and Carson, 2000; Gepts, 2002) and at a very high cost of investment (Goodman, 2002).

The new traits include several herbicide resistances (glyphosate and glufosinate types have been commercialized), Bt (*Bacillus thuringiensis*) toxins for certain insect resistances, a type of pseudo-cytoplasmic male sterility, and virus resistance. The latter two have yet to be commercialized in maize, but their general efficacy across several genera suggests that, if economic conditions become favorable, they could quickly be deployed (in plant breeding terms that means in about 15 years). Almost any single-gene trait that exists in maize can probably be altered transgenically, so a wide array of starch, protein, oil, wax and sugar variants will eventually be tested for potential use. Similarly, many single-gene traits from other organisms, with appropriate genetic modifications, should function in maize. Clearly, their potential utility depends greatly on their modes of gene action (complete dominance is usually helpful), stability across environments, interactions with other genes of consequence and pleiotropic effects on traits other than the trait the transgene itself was designed to create or modify. Pleiotropic risks are fairly minimal, but they can occur, even years after deployment, as happened in 1970 with southern leaf blight (Committee on Genetic Vulnerability of Major Crops, 1972). Risks are likely to be minor from alleles isolated directly from maize (and these will generally be incorporated by marker-assisted backcrossing rather than classical molecular engineering). Risks from modifying such alleles and using them as transgenes should also be minor, roughly equivalent to risks encountered with mutation breeding. Risks involving transgenes from other species are likely to be transgene-specific and require assessment in Mexico on an individual transgene basis (Ervin et al., in press; Wilkinson et al., in press). Before assuming that multiple transgenes will revolutionize maize breeding, it might be wise to realize that the greatest advances in plant breeding were accomplished many thousands of years ago in the fertile river valleys of Mexico and other centers of plant domestication. The next revolutionary event was the birth of hybrid maize. Both these events involved the simultaneous harnessing of multiple genes, alleles and modifiers. Today's era of modern molecular genetics can really only deal with a gene or two at a time, and we may be several generations of molecular biologists away from understanding and manipulating whole genomes (Bernardo, 2001), even within the same crop. Our current understanding of the simultaneous manipulation of numerous transgenes, their possible rewards and risks is very limited.

Evaluating the direct effects of transgenes is sufficiently controversial that private companies, governmental agencies and concerned NGOs invest much effort to reach reasonable, if not always unanimous, conclusions. Efforts to monitor all of the many potential indirect effects of transgenes via pleiotropy, interactions with other genes, interactions with other organisms in the environment, or with the environment itself have generally had lower priority for transgenic developers and governmental regulatory agencies (as the list is virtually endless, funding is finite, and effort is concentrated on what are thought to be the more obvious potential problems), and some of these can only be studied *in situ*, once the transgene is actively deployed across a reasonably widespread area. In some ways for Mexico, the US Corn Belt is serving as a large-scale experiment for newly introduced transgenes, but the U.S./Mexican border is porous, and results in the US may not always be directly applicable to Mexico. Some results may be known only well-after widespread use of the transgene, despite widespread experimental trials (see Pline et al., 2001, and Johnson, 2003, for examples).

There, of course, is the possibility of the production of industrial chemicals and pharmaceuticals in maize (Fitzgerald, 2003). "Pharming" is potentially a significant threat to Mexican maize; although, if employed, it would involve a few contract-farmers and little hectarage (hopefully very well isolated). The advantage that maize genetics has over self-pollinated crops with less detailed genetic knowledge is relatively minor relative to the risks of pollen or seed contamination of seed and food supplies (Nature Biotechnology, 2004; Thro et al., in press). Industrial-chemical production is of more general interest to farmers, because more farmers would be needed, but with a cross-pollinated crop like maize, the result is apt to turn into synthetic-rubber-infested maize flakes or solvent-contaminated maize sweeteners or some other headline-grabbing innovation that no one really wants to see. Such products would have to be restricted to 100%-male-sterile maize or its equivalent to be safe, and, as of today, no one can produce such an all-male-sterile maize (National Academy of Sciences, 2004). In the best of steriles, there are a few escapes or reversions to fertility. Whether pharma/industrial crops should use maize as a platform needs to be resolved at the US level as well. It may not be acceptable for pharmaceutical or industrial applications to use maize in the U.S., if there is any risk of gene flow into Mexico. At present, pharma/chemical production in maize is not generally prohibited, despite the risks involved.

A concept that has just begun to become apparent to industry is that biotechnology is very expensive, the financial returns are distant, and the financial returns are apt to be much higher in medicine, human and veterinary, than in plant breeding or plant molecular biology. Perhaps the best example of this to date is the Pharmacia spin-off of Monsanto, freeing the pharmaceutical company from agricultural plant molecular biology (Clark, 2001). The relatively low and slow return on investment will certainly not stop the application of biotechnology to plant breeding and the deployment of transgenics, but is apt to shift some focus from private investment to public and philanthropic investment. If Mexico or Argentina were to engage in transgenic-virus resistance in maize, public financing may be required to achieve it, as the potential cost/benefit ratio to a private company is probably not as rewarding as developing a lymphoma or breast-cancer vaccine or treatment.

2.1 Transgenic Bt

Several different Bt-toxin constructs have been commercialized, initially for use against European corn borer, secondarily against some other stalk borers; more recently, resistance to maize rootworm has been successful. There has been some effectiveness against earworm, but much more is needed. There is little doubt that Bt-resistance will develop over time in insect populations, so management strategies have been developed to delay the development of Bt-resistance (Andow and Hutchison, 1998; Gould, 1998; Storer et al., 2003a, b). It is not yet clear how effective these management strategies will be in the US, but they would probably be quite effective in much of Mexico, largely because the maize crop there is so much more diverse than in the US. Bt was an obvious transgenic target, and relatively little novelty has been employed in the development of transgenic Bt maize. Perhaps most disconcerting was the fact that the one Bt engineered to be tissue-specific (to avoid having the Bt protein in the kernels) was a failure in the market. It was simply much less effective than more generally expressed Bt.

While relatively little insecticide was ever used for European corn borer in the U.S., maize rootworm receives copious, soil-applied insecticide under large-scale farming operations. Thus, root-worm-resistant Bt hybrids may dramatically lower environmental hazards in the United States, if secondary insect pests (now largely controlled by insecticides for rootworm) don't become serious problems. In the absence of insecticides, several genera of insects (now largely controlled by insecticides used for rootworms) can attack the growing points of maize seedlings, effectively lowering stands and yields dramatically. In Mexico, other pests (in addition to rootworms) feed on maize roots, and the newer Bts do not control these. Use of Bt corn has not produced a concomitant reduction in the volume of insecticides applied in all cases (Obrycki et al., 2001), largely because it was rarely economically sensible to spray $80 per ton maize (see also Duffy, 2001; Ferber, 1999).

While evolution of insect resistance to the various Bts is a significant problem, there is potential to develop new types of Bts to circumvent the problem. The potential also exists, however, to have the same sort of treadmill-effect encountered with single-gene resistances in crops such as wheat.

However, breeding for insect resistance in maize had always been a very slow and generally unrewarding endeavor until the advent of transgenic Bt. A secondary effect of most Bt transgenes in maize is later maturity in many hybrids and, for some Bt transgenes, occasional dramatic, detrimental effects on parental inbred seedling growth. The latter effect would certainly serve to decrease any selective advantages that such transgenes might have in landrace populations. Reports exist of higher lignin content of Bt maize and soil persistence of Bt (Tapp and Stotzky, 1998), but it is not clear that the former is a general feature of all Bts and, if so, whether it is an advantage or disadvantage, and it is not clear how general or how important Bt soil residues might be. It is hard to believe that they would be more detrimental than Furadan, Lorsban or Counter, all widely used soil insecticides used for maize (Ackerman, et al., 2003). In many *campesino* maize plots where such insecticides are seldom needed or used (Morales and Perfecto, 2000) any negative effects, should they actually exist, might be of consequence.

Snow et al., 2004 have recently reviewed indirect effects on nontarget insect populations: negative tri-trophic level effects of transgenic Bt corn pollen and Bt sprays have been reported for the green lacewing (*Chrysoperla carnea*) in the laboratory (reviewed by Hilbeck 2001; Dutton et al. 2002, 2003). Plot-level studies in the US detected no significant effects of Bt corn on the abundance of green lacewings, although the authors point out the need for studies on larger fields because of high between-year variability and small plot sizes (Pilcher, 1997). Prey insects vary in how much Bt toxin they assimilate (Head et al. 2001); therefore, the abundance and diversity of prey insects as well as an insect predator´s foraging preferences affect results of Bt studies carried out under field conditions.

2.2 Transgenic herbicide resistance

There are two types of herbicide-resistances currently commercialized in maize: transgenic and mutagenic. For practical purposes, the effects are the same, plants with the appropriate gene are resistant to the corresponding herbicide. Long-run, however, weed-resistance will develop to both, but the route to mutagenic-resistance is well-known, frequent and effective. Glyphosate-resistant and glufosinate-resistant transgenic maize hybrids perform well, but carry a heavy price premium (on the order of 30% of seed cost). As long as cheap, effective herbicides, such as atrazine and 2,4-D, are readily available, transgenic or mutagenic maize herbicide resistance is likely to be limited to problem fields or to farmers who wish to use only one herbicide for an entire farm. Since maize grows quickly and provides rapid shade, control of weeds is quite effective if done well during seedling growth. This contrasts greatly with crops such as cotton and soybean, where pre-transgenic herbicide combinations were less than ideal. On the other hand, there are serious health risks with many herbicides, including atrazine and 2,4-D, while both glyphosate and glufosinate are relatively innocuous pesticides (Ackerman et al., 2003). Thus, on the whole, transgenic herbicide resistance in maize seems to date favorable to non-target organisms in maize monocrop fields, as long as it does not promote indiscriminate or excessive spraying, even though it has little economic advantage (Duffy, 2001). On the other hand, as any other herbicide-based technology, it promotes land use and land management changes, loss of associated crops, edible and medicinal weeds, and possibly-beneficial micro- and meso-fauna associated with such plants in the maize field. For more detail, see Appendix 2. In addition, the reduced tillage (usually considered a favorable trait due to lower erosion rates) often associated with herbicide-resistant cultivars can sometimes lead to new disease and pest problems (such as gray leaf spot and root and stalk feeding insects).

2.3 Transgenic virus resistance

Transgenic virus control has thus far not been employed in maize, but should be quite feasible for certain viruses, given extensive results for other cultigens. There may be little economic incentive for this, however. In the US, good farmers have little problem with viruses. Johnson grass is the main alternate host there, and Johnson grass can be spot- or field-controlled by several herbicides. In recent years, popular herbicides such as Beacon and Accent have greatly reduced its importance as a weed in and around U.S. maize fields. In the tropics, many maize viruses are endemic, alternate hosts are often common, but resistance can often be found and deployed (see Kim et al., 1987, as an example). This might be a case where the public sector should take some action, however. Many viruses are transmitted by region-specific leafhoppers and aphids, both quite small, easily transported insects that are probably not immune to adapting to new environments. There are several regionally-specific viruses that can be quite devastating, and for which there is little resistance among elite breeding materials in other areas. For example, even in the Homestead, Florida, winter nursery area, fields and fencerows must be sprayed at regular intervals to prevent leafhopper transmission of a half-dozen tropical viruses and virus-like diseases, which together can literally eliminate entire nurseries of elite US germplasm. Conventional or transgenic breeding, if done at routine rates would take perhaps 15 years to develop resistant, proven cultivars. Perhaps in an emergency, with testing safeguards waived and 3 to 4 nursery-generations grown per year, this might be cut to 5 to 8 years. This delay would not be an inviting prospect to a prosperous Iowa or Jalisco farmer, it would mean devastation and a cardboard hut in the nearest shanty town to a marginal farmer in Oaxaca or Chiapas. Two obvious such viruses are streak virus from Africa and Rio Quarto virus from Argentina. In each case, combinations of host-plant resistance, effective seed treatment, and timely insecticide application now keep the problems in check. However, materials with resistance from those areas would be unlikely to be well-adapted to many of the maize-growing areas of Mexico and would undoubtedly face phytosanitary restrictions as well. Not all viruses are currently good candidates for transgenic control; classical transgenic virus-control was developed for viruses not restricted to the vascular system, and control of strictly vascular viruses may require marker assisted selection (Kyetere et al., 1999). Transgenic virus-control is a very active field at present, and new methodology is constantly being developed (Nikki Robertson, personal communication).

Transgenic virus resistance in maize would eliminate some use of preventative insecticidal spraying just before or immediately after planting, but would probably have minimal impact on herbicide use, as the weed targets are often fairly strong competitors with juvenile maize and need control with or without the threat of virus. While some have expressed concern that there might be genetic exchange between viruses and virus-resistance transgenes, the probability of that happening seems small, and the possibility that such an exchange would result in an increase in virulence seems even smaller (see Halls, 2002, and Ervin et al., in press, for more discussion and a less optimistic view), but genetic exchange between viruses themselves has been in the news recently ("bird flu"; Ginsburg, 2004), and over time some strange genetic phenomena have occurred (Palmer, 2003).

2.4 Transgenic male sterility

Plant Genetic Systems of Belgium (whose rights now - after many detours - belong to Bayer) developed a type of male sterility that acts very much like the various cytoplasmic male sterility types that have been used off and on (sometimes infamously, as in 1970) since the mid 1950s in maize. Their system is widely used in canola, but apparently needs some refinement before it will work well in maize (too many reversions - Surinder Seghal, personal comm.). One of the few clever, deployed uses of plant biotechnology for plant improvement, it uses an anti-RNA narrowly targeted at pollen-producing tissue to produce the male steriles. To produce the fertile restorers, an enzyme is engineered to destroy the pollen-specific RNAse enzyme. This invention is mostly aimed at lowering labor costs in seed production fields of hybrid maize (in some other crops, such as canola, it has made hybrid crops feasible). Although clever, it probably has little third-world appeal in maize, as labor is often plentiful and cheap. In contrast, in the US Midwest, farm labor is dear and scarce. Conceivably, it could be harnessed by Mexico's hybrid seed industry, mostly concentrated in Jalisco, possibly even for seed export sales to tropical areas (or even for winter production for the U.S.).

2.5 Transgenic drought resistance

Drought resistance might potentially be greatly effected by a single gene, but the evidence for this is slim, and the single gene certainly has not been publicly identified. The obvious "answer" is that cactus and maize differ by more than a few genes, and probably no one of them would enable widespread maize cultivation across the Sahara or Atacama. That said, it might be possible to develop more drought tolerance in maize transgenically; both additional drought and salt tolerance seem likely transgenic targets. Until that day arrives - and under the most optimistic projections it won't be soon - the most drought-resistant hybrids are likely to remain grain-sorghum hybrids. The main risks here appear to be environmental; drought tolerance transgenes *per se* would be unlikely to threaten maize biodiversity, but they might lead to increased use of marginal lands, creating erosion problems and possibly encroaching further on teosinte habitats.

2.6 Pharming and food supplementation

Small-scale trial, pharmaceutical production has been tried in maize (sometimes with embarrassing evidence left behind, as in the case of Prodigene's volunteer transgenic maize seed contaminating a subsequent crop of soybeans; Brasher, 2002). It seems likely to be restricted to recalcitrant drugs that can't more readily be produced in dicots such as tobacco or in inedible plant tissue, preferably of obligate-selfing plants or sterile triploids (National Academy of Sciences, 2004). Even with cytoplasmicly transmitted transgenes, which are not yet available but which are under development/research and which are not transmitted by pollen, there is the possibility of seed-admixture contaminating food products. Even in cases where maize is the "pharming" plant of choice, it would need to be grown under great isolation, essentially under quarantine, on a contract basis. Such complete isolation is not currently required, so that risks do exist. On the other hand, it may eventually be possible to use transgenes to "enrich" maize, much the way milk, bread, salt and even water are routinely "improved" to benefit overall human health in many areas of the world. Still, the general failure of high protein maize in the marketplace, despite its scientific successes, should not be forgotten. And perfect foods for people often become excellent growth media for undesirable, toxin-producing fungi (Goodman and Carson, 2000).

Error! Bookmark not defined. 2.7 Industrial chemical bioproduction

Industrial chemical production in maize might be feasible, but only under extreme isolation (a remote ocean isle where no other maize is ever grown?), with all the problems of "pharming." Isolation distances of even 1 km can be inadequate to completely isolate maize pollen. There is no problem with the concept, just with the potential consequences. Note that there were no health problems or unusual allergenic risks with Star-Link maize (Sutton et al., 2003), simply decision-making errors, yet it became a poster-child for the evils of industry, the evils of science, the evils of government. (It was only, really, evidence of the evils of naivety of governmental regulators and transgenic suppliers). Imagine the furor over baby-food (or even pet-food) contaminated with some industrial chemical (say, asbestos-like or PCB-like, perhaps even a non-utilized by-product of the target chemical) as a result of pollen flow from a transgenic, industrial-chemical-producing maize field. The contamination risks here seem high, the clean-up costs seem even higher; it does not seem a sensible path to follow wherever maize is currently a consequential crop. High risks persist even if planted in areas where maize is not now grown. Seeds can accidentally or intentionally be taken to maize areas; preventing this seems very costly, perhaps almost impossible.

2.8 Other potential transgenes and transgenic combinations

Many other potential transgenic targets exist. The most likely of these to be deployed soon are those dealing with modifications of kernel composition. Seed proteins, oils and starches are obvious choices, as genes controlling these traits have already been isolated, many more soon will be, and these traits have obvious economic potential. It seems likely that genes for early seedling vigor, heat and cold tolerance and ozone-resistance should soon be available from the numerous genomics projects now underway. Genes for higher photosynthesis rates will probably be available, but maize may not benefit much there, as maize photosynthesis rates are rarely limiting. Evidence is still out on the existence and utility of major genes for aluminum and salt tolerance, but these seem possible. A major disappointment thus far has been almost total failure of transgenic fungal-resistance. Most obvious single-gene candidates failed, followed quickly by a fair number of two-gene combinations. Will three-gene combinations be the charm? Fungal resistance would be a genuine service for human and animal health and potentially far more important to rural (and urban) Mexico than currently deployed transgenes.

Finally, there is the problem, economic and biological, of "stacking" multiple transgenes. We are really still in the early years of plant molecular biology, and the potential problems of inserting 10 to 20 or more genes, together in one "cassette" or separately, into maize is not well known. Multiple copies of the same gene often lead to inactivation or "gene silencing" (Hammond et al., 2001). While this has been well-studied empirically, and generally simply leads to loss of function for the transgene, soundly-based concepts applicable to multigene groups are not currently available (National Academy of Sciences, 2004). In addition, it is not clear what might happen as farmers themselves accidently stack transgenes by accumulating multiple ones in their landraces, intentionally or not. Transgene inactivation would probably not be consequential under current circumstances, but might not be inconsequential with hundreds of new transgenes. Secondly, there is a clear economic limit to what a seed company can charge for seeds of a crop that sells for $80 a metric ton. If one transgene is valued at $20 per hectare, it is highly unlikely that the next three will also bring in $20 each. In the U.S., Bt maize is sold at the equivalent of about $20 per hectare, and this is roughly the break-even point for farmers. In a year with heavy insect infestation, it makes a profit (or, more likely, lowers the loss margin); in years with mild insect damage, the farmer loses the investment in biotech seeds (Duffy, 2001). In this respect, it is somewhat like life insurance; one hopes that the insurance won't be needed.

3. Potential Impacts of Transgenic Maize in Mexican Agroecosystems

The approached used here is to examine the two possible extreme cases (1) transgenic maize will be legally banned in Mexico or (2) it will be have no legal barriers. There, of course, are many intermediate routes that could be followed, including mixtures of these two boundary positions over time, and such cases will be addressed after examining the two boundary positions. One of these, a ban on planting, but essentially unrestricted importation for food, feed, and processing, is currently in place.

Error! Bookmark not defined. 3.1 Maximum use and impact

To examine the "no barriers" situation first, consider the traits that would be of most interest to Mexican, *campesino* farmers. Perhaps, the most important traits to them would be (Qualset, 2003):

a) Protection of stored grain from attack by insects/vermin
b) Drought/heat resistance
c) Cold tolerance of seedlings and maturing plants.

While nothing is close to commercialization for any of these, all, except attack by vermin, appear to have some ultimate feasibility. Unfortunately, the metabolism of humans doesn't differ much from that of mice, so there's not much opportunity to use a transgenic rodenticide in maize. Weevils are not very susceptible to current Bts, but some alternative form of Bt might control them, or an alternative, weevil-specific toxin might be discovered. Deployment of transgenic improvements in drought, heat and cold tolerance look to be at least 25 years away, if all goes well.

A transgene conferring drought tolerance or weevil resistance would have positive impact on household and livestock farming operations throughout much of Mexico, both in hybrids and in landraces. Such a gene would likely have a very positive selection response in local populations and might spread fairly rapidly throughout Mexico (since its effects would be obvious most years in most locations). This contrasts dramatically with the transgenes that are currently available. Despite favorable pictures painted by James (2003a, b), by ICSU (2003) and by transgenic suppliers, most current maize transgenes are of marginal value except in rather special circumstances (Ferber, 1999; Duffy, 1991). Cold tolerance would be highly beneficial to maize farming at high elevations, where hybrid maize has generally had little impact. There, planting often starts only with seasonal rains in June, and harvest can be badly affected by early frost in the fall. Conversely, some irrigated maize is planted early in the highlands, and that can be damaged by late frosts in the spring. Again, such a transgene would have a very positive selection coefficient, and might spread widely, although probably rather slowly (since its effects would not be obvious in most years), even with minimal distribution of hybrid maize. In general, it is difficult to conceive of a situation where a transgene meeting any one of these *campesino* needs would be detrimental to landrace biodiversity maintenance. Perhaps the introduction of a single transgenic cultivar (hybrid or open-pollinated) that would sweep across the genetic landscape of central and southern Mexico might fill the bill, but experiences of maize breeders, public and private, over the past 75 years in Mexico (Matchett, 2002) suggest that such a variety has never been developed, and Mexico's varied ecology suggests that it probably never will be.

Of the transgenes that are essentially available for deployment now, herbicide resistance offers improvements in pesticide safety and some potential for reduced tillage, hence lower rates of soil erosion. But it can also promote the use by farmers of excessive quantities of herbicides. On the whole, transgenic herbicide resistance in maize seems favorable to non-target organisms, relative to conventional herbicide regimes, as long as it does not promote indiscriminate spraying. It is obviously not a candidate for use in milpa agriculture, and then neither are herbicides. Bt offers some current potential for lowering pesticide rates and much future potential. Secondarily, Bt should eventually greatly reduce the levels of aflatoxins and fumonisins, two types of toxins produced by kernel-fungal infections that are negatively associated with human and animal health, even at very low doses, especially in diets where maize predominates and sporadic drought occurs (James, 2003a, b; White et al., 2003). A reasonable argument can probably be made that earworm-targeted Bts should be introduced into most food maize, but mechanisms for doing this seem very unlikely to be implemented for landraces. Special care would be needed to employ new forms of Bt in Mexico, as Mexico is the center of diversity for many crop plants and their related wild species. Some of these wild relatives are at risk of extinction, and secondary, non-target effects of Bt could adversely affect their pollinators. In addition, there may be other butterfly/moth species, endemic to Mexico and not intended Bt targets, that could be adversely affected by new Bt constructs (the Bts vary greatly in their effectiveness, both in timing and in targeting lepidoptera and coleoptera species [Andow and Hutchinson, 1998]). Insects will eventually overcome Bt, but in the several decades that it and its modified successors persist, human and animal health might be notably improved. Virus resistance, especially to certain currently non-indigenous viruses, are another potential use of transgenes, although Marker Assisted Selection, using conventional breeding, may ultimately prove adequate, more economic and probably faster. Most of the other, currently very experimental, transgenic projects (kernel composition modification, maturity changes, DNA/RNA modifications) seem remotely of interest to Mexican farmers and maize breeders, although a new surprise could be just over the horizon.

Assuming that someday, somehow, somewhere, there will be a transgene that will be widely employed in Mexico, there are really two quite separate issues about how it would be used and distributed. The hybrid seed industry could quickly supply large, industrial-type farmers with seeds, presumably at a cost that would be mutually beneficial to farmers and to seedsmen. However, there has never been a very satisfactory distribution system available for open-pollinated varieties of maize of any type in Mexico (Matchett, 2002). Thus, it is unclear how such a transgene could be popularized throughout the large segment of Mexican agriculture relying on open-pollinated maize. It would appear to be necessary to rely on farmer sources, recycling of seed and informal exchange. For any widespread success, the transgenic trait would have to be one that farmers could select for and that would survive the levels of pollen flow that occur. Despite efforts in both private and public sector breeding, landraces dominate. Can any single-gene solution be useful to Mexican farmers who rely on open-pollinated populations? Before investing heavily in transgenic plant breeding, the distribution problems, many of which are ecological in nature, need to be resolved if such research is aimed at improving the lot of the common farmer. Basically, it is unclear how an "ideal" transgene, one that was specifically helpful to *campesinos*, but not to industrial producers, that was developed in Mexico, and that carried no patent costs or restrictions, would ever be readily incorporated into the wide range of ecologically-differentiated, open-pollinated Mexican maize landraces.

At the other extreme, with transgenics barred from Mexico, export markets would be available to those areas of the world where transgenics are unacceptable, but Mexico now imports much maize (see Table 5.3.1 which indicates that imports are increasing rapidly, presumably a direct result of NAFTA), even with constantly increasing domestic production. In addition, Mexico would need to monitor maize imports and bar whole or cracked maize imports from any country permitting use of transgenic maize. It might be possible to install mills at the border and import processed grain only. Monitoring of all imported, unprocessed maize would be necessary, as, once maize is in commerce, tracing country or region of origin can become obscure.

If transgenic maize seed is prohibited for sale or planting, but importation for food or feed is permitted, as is current practice, then some small amount of transgenic maize would actually get planted. This would be the general scenario for almost any situation chosen in the wide range possible between a complete ban and open acceptance of transgenics. Most that did get planted would not be adapted (as it would presumably come from the US Corn Belt) and would rarely survive, but some very small amount of gene flow through pollen would, almost certainly, eventually occur. The amount of gene flow would likely be proportional to the amount of transgenic imports from latitudes and climates similar to Mexico. Thus, transgenic imports from Texas flowing into northern Mexico might result in measurable gene flow, while similar imports from Iowa to Chiapas would result in minuscule or non-existent gene flow, unless the transgene had a favorable selective value, despite its unlikely genetic background.

Whether imports are barred or not, one can almost be certain that the flow (legal and clandestine) of people and goods between Mexico and the U.S. will guarantee that some amount of transgenic maize seed will be planted in Mexico. Most will not be adapted, and gene flow will not occur; most of the gene flow that will occur will be linked to genes conveying susceptibility to Mexican climates, diseases and insects, and will be rapidly eliminated from populations following well-known principles of population genetics. (Note that until the early-1980s, U.S. maize was regarded as being impossible to use, even for breeding, in the tropics and sub-tropics). However, transgenic maize from Texas can be well adapted to northern Mexico, so that gene flow into landraces in that area is almost guaranteed, despite any patent or importation restrictions. As early as the mid-1980s, hybrid seed from Texas was being imported into Mexico in quantities sufficient that it caused concern to some Mexican corn breeders (Glenn Robison and Ramon Godoy C., personal communication, 1985). Thus, it is likely that some commercial hybrid maize seed, some of which likely contains transgenes, is probably being planted in northern Mexico, even today.

Error! Bookmark not defined. 3.2 Possible negative effects

The potential negative effects of transgenic maize for landrace preservation under the unrestricted transgene use model are mostly the same sorts of negative effects associated with hybrid maize or indeed with any improved, newly introduced, widely adapted, cultivars. The fact that these cultivars carry one or two current transgenes is, for the most part, of secondary or lower consequence. They might eliminate the possibility of marketing to a premium-priced, non-transgenic, organic market, should one develop, but maize is not a major food commodity in Europe or Japan, where most such non-GMO markets are found. Clearly, each transgene would need testing for potentially deleterious effects (in Mexico, as well as abroad), but the effects on landrace biodiversity would generally be the same for acceptable transgenic and non-transgenic hybrids. Plant breeding and the adoption of new, better varieties is the major cause of the loss of crop biodiversity. In the past (and this is not a new phenomenon or we would all still be hunting and gathering), this has not been of great concern because plant breeding was a local or regional endeavor. Different farmers or different programs constantly developed unique varieties; many independent programs, public and private, were active; and the products of these programs were freely available for others to use as initial breeding materials. Few varieties crossed regional borders, and coordinated international programs were impractical due to inherent problems of adaptation, especially to latitudinal changes.

Today, however, we have coordinated "public" (CGIAR) and private plant breeding organizations using the same, or very similar, breeding materials worldwide. In the U.S., maize hybrids used to be very locally adapted, but, with today's widespread testing, there are occasional hybrids that are grown very widely. One recent example was Pioneer 3394, that, in its day (before gray leaf spot became common), was grown from Louisiana to Ontario (and winning yield trials all along the way). Today, there are basically just a handful of major companies, perhaps an equal number of public programs and CGIAR conducting serious maize breeding programs. The future problem is the high degree of coordination within organizations. This maximizes current achievements, but has the potential to erode future gains by effectively eliminating the local, independent breeding that formerly occurred, even within a single organization. This is one case where many small, independent efforts may be a far better long-term solution than a single, highly coordinated one.

In any case, new, improved varieties eventually replace older ones. Records of this in Mexico date back to at least the 1930s (Matchett, 2002), but it was clearly occurring in prehistoric times. Today, improved maize is responsible for about 20% of Mexico's maize plantings. One might expect that within fifteen years, as much as 25% of Mexico's improved maize (or 4 to 5% of its total) would be transgenic, based on adoptions of transgenics in the southern U.S., and assuming that there are few legal barriers to transgenic use.

Unless there is a ban on the use of atrazine, there seems little likelihood that profitless Mexican maize farmers will pay any great premium for transgenic herbicide resistance. In any case, the only plant likely to gain herbicide resistance from transgenic maize is teosinte. In places, teosinte is a weed in or alongside maize fields. Would glyphosate-resistant teosinte be a consequential weed problem, a specific case of a more general problem posed by Ellstrand (2001). Only, if a farmer were to rely on glyphosate-resistant maize. It would be no more of a maize-weed problem than it is now, as teosinte is, like maize, atrazine-resistant. On the whole, teosinte probably occupies less territory today than at any time in the past several thousand years. While not endangered as a whole, many populations are endangered and some are now extinct (Wilkes, 1985, 2004; Sanchez and Ordaz, 1987; Benz et al., 1990, Sanchez et al., 1998). Addition of glyphosate-resistance to teosinte probably won't change the situation, nor would Bt be of much consequence to teosinte; both might delay its extinction. Allelic transfer from maize to teosinte certainly does occur, despite the selective disadvantages of F1 and backcross hybrids (Wilkes, 1967), but it happens at very low frequencies (Kato, 1997). Given the near-neutrality of these two transgenes, combined with a strong selective disadvantage of maize (let alone midwestern US maize) germplasm in a teosinte background, effective gene flow into teosinte is likely to be of far less concern that, say, the population density of goats (a real enemy of plant diversity) and cattle. Indeed, Wilkes (2004, plus an unpublished manuscript) argues eloquently that immediate action is needed to save teosinte remnants from extinction. While a weedy, herbicide- and insect-resistant teosinte might conceivably emerge from crosses with transgenic maize, many populations of teosinte will become extinct long before that could possibly happen (Wilkes, 1985, 2004) and neither chromosomal (Kato, 1997), isozyme (Smith et al., 1984; Doebley et al., 1987; Doebley, 1990) or SSR (Matsuoka et al,. 2002a, b) studies suggest much genetic exchange between maize and teosinte. Currently, more detailed studies on this topic are underway at the University of Guadalajara by Jesus Sanchez.

Some forms of Bt maize are actually the most likely transgenics that would have, at least in the short-term, potential for use in Mexico. The known negative effects of Bt maize are few, as the Bt toxin is specific to the early larval stage of lepidopterous insects (specifically, some moth and butterfly larvae, i.e. caterpillars). Resistance to Bt can and will develop in these populations (although this resistance is likely to develop very slowly if Bt maize is only a small fraction of the maize being grown), so that there will have to be a constant flow of new Bt transgenes into maize to maintain resistance if Bt use is widespread. Those farmers who use Bt spores to control insects on nearby vegetable crops will then find its effectiveness diminished. But perhaps the biggest threat, over time, is the widespread use of any single gene. While a repeat of a situation like the 1970 southern corn leaf blight epidemic (Committee on Genetic Vulnerability of Major Crops, 1972) might not occur, the potential vulnerability is there. This vulnerability is increased considerably by today's transformation technology that relies upon basically two elderly inbred sources (and really mostly on the inbred line A188 and its derivatives) as the transformation target. Despite 25 years of intense effort, modern maize inbreds cannot readily be transformed due to unacceptable growth in tissue culture. As a result, the few widely-used transgenes all carry with them some unknown amounts of A188 (or its equivalent) as a result of their tissue-culture origins and backcross derivations. In addition, of course, there is always the possibility of some latent mutation conferring susceptibility to some currently unknown or unremarkable disease or pest. Such a mutation could be acquired directly with the transgene insertion or indirectly through tissue-culture mutagenesis. Most transgenes rely on the same promotor (usually CMV 35s), use either herbicide-resistance (usually to glyphosate or glusfosinate) or antibiotic-resistance as a tissue-culture-selection agent and NOS terminators in their constructions, thus providing additional potential regions of genetic uniformity.

The widespread use of single cultivars and single genes (which has actually rarely been practiced with maize, but is routine in soybean and wheat) increases the likelihood of novel disease or insect problems, but only their actual widespread deployment can really serve to detect these. Thus, each deployment is an experiment unto itself.

While there is potential landrace biodiversity loss from widespread use of transgenic maize, that loss will actually occur only if there is increased use of hybrids. Although adoption of hybrids has been relatively slow in Mexico, it continues to happen (Table 5.3.2) and is likely to do so indefinitely. In addition, farmer-sourced seed can include recycled hybrids - advanced generation hybrids, intentional or unintentional crosses of local landraces with hybrids, and introgression of a few genes from hybrids into local varieties by backcrossing (Bellón and Risopoulos, 2001). A farmer, or someone else in a community-exchange network, may have materials tracing to commercial or public elite varieties from decades earlier, and these may be maintained in local populations that are simply labeled as landraces. Estimation of the amount hybrid use is affected by re-use of open-pollinated seeds from fields planted to hybrids. Perales (personal comm., 2004) reports that many farmers buy hybrid seed only every several years, replanting hybrid progeny during intervening periods. However, relative to the current acute economic threat from cheap, imported maize, hybrid swamping of local maize by new hybrids, with or without transgenes, seems an almost insignificant threat today, given the history of maize breeding in Mexico (Matchett, 2002).

While it is possible that the accumulation of many transgenes (current rates of adoption suggest that we might have 50 or so deployed transgenes over the next 50 years, based on doubling the number every 15-year cycle) could somehow disrupt the maize genome, the fact that maize has accumulated huge numbers of retrotransposons (a type of chromosomal segment that is at least largely genetically inert) without negative impact suggests that a few transgenes probably won't have ill effects (Bennetzen, 2000, 2003; Kumar and Bennetzen, 1999). A more likely scenario would be the development of a new disease or new strain of an old disease associated indirectly with a transgene through unsuspected background susceptibility (Smith, 2003).

Error! Bookmark not defined. 3.3 Responsibilities

In the US currently (and probably in Mexico's future), the general trend in farming operations is to have the farmer serve as contracted labor, or, in favorable circumstances, as contracted manager. This began in the poultry industry in the U.S., is now routine in pork production and is standard practice for many commercially-marketed vegetables and most types of U.S. food maize. Transgenic seeds and the contracts that accompany them simply have carried this one step further. It is a trend that appears inevitable, with the farm regarded as just one more factory supplier. Most risks are shouldered by the farmer, while most profits flow to the suppliers, food distributors and middlemen (Johnson, 2003). The result is often far less concern about soil erosion, water quality and environmental pollution, because the farm is no longer a family operation, and there is little concern about the future status of the farm. The usual goal of farm-raised children is to escape impoverished rural life, so farmland maintenance and improvement have declined in importance.

The role of most current maize transgenes, themselves, in a non-industrial environment, where the appropriate herbicide may not even be available for a herbicide-resistant hybrid, is probably neutral, although the genetic background may be detrimental, if it involves a Midwestern U.S. hybrid. There is little doubt that over time, even with transgenes banned, some transgenes will escape into Mexican landraces. Some of the better Bt transgenes currently in use in the U.S. might have a selective advantage in a Mexican landrace, as they should have better lodging resistance and slightly better ear-worm resistance, assuming that they can persist until adequate recombination and segregation eliminate most of the other, background genetics. If breeding programs in Mexico develop transgenic versions of Mexican hybrids or if transgenic hybrids from Texas are widely used in Mexico, then transgenic transfer to Mexican landraces will occur without much restriction in areas where this occurs. There are at least five separate questions that need facing:

a) Is there any harm to landrace structure and landrace biodiversity from a transgenic source above and beyond the corresponding threats from a new successful hybrid?

b) If there is, who should pay the costs of the damages, the seed company or the licensor of the transgene, to whom and how much?

c) Is the transgene owner due fees for unintentional use of the transgene by farmers growing native landraces?

d) Who is responsible for unintentional use of transgenes by public or private seed producers or breeders when the source of the transgene is unwanted pollen contamination?

e) If so, who pays whom and how much?

The most sensible answers to these questions are "no", "no one" and "nothing", but emotions are high and, in at least one case, Monsanto has managed to collect fees from a canola farmer whose crop incorporated stray seed or pollen from transgenic canola (Schapiro, 2002). Point c) above is extremely important to Mexican agriculture, and it may be of essentially no consequence to industrialized farming operations. Clearly, Mexico should be able to negotiate free use of transgenes in open-pollinated maize cultivars, as (1) these cultivars pose no threat to the operations of hybrid seed producers and (2) Mexico is a very large market for transgenic maize exports from the US. If Mexico were to ban imports of U.S. transgenic maize for use in food and feed, there would be immediate, negative repercussions for the developers, distributors and users of transgenic maize seed in the U.S.

The genetic studies of Bennetzen (2000, 2003) and Palmer (2003) certainly demonstrate the enormous flexibility for genomic variation that occurs throughout the plant kingdom, especially in maize and loosely related grasses, such as rice, sorghum, barley and wheat. Their work suggests that incorporation of most transgenes should fall well within the realm of "natural" genetic variation, as insertions of various sorts appear to be far more common than previously expected, although clearly some transgenic products may not, themselves, appear to be "natural" to maize.

According to Earl Wernsman (personal communication, 2004), probably the public scientist with the widest experience with transgenes in a crop plant, the average successful (functional, genetically stable) transgenic insertion carries a selection disadvantage relative to its normal counterpart. This is relatively difficult to measure, as it is imposed on regenerated plants (usually grown from tissue-culture), which have additional (and often greater) disadvantages. Presumably, most selected and deployed transgenes are close to the non-transgenic mean, but all arise from mutational events and probably carry some slight biological disadvantage compared to their normal counterparts. Furthermore, it appears that there are no "silver bullets" in the growing biotech arsenal (Duvick, 2003).

4. Research Needs for Risk Assessment of Transgenic Maize in Mexico

There are basically five types of risk with transgenic maize in Mexico: a) Potential detrimental effects on Mexican landraces, b) Potential detrimental effects on teosinte populations, c) Potential detrimental ecological effects on associated organisms, cropland, and associated crops, d) Potential human health effects and e) Potential for being left behind as science advances. The last three of these are not unique to Mexico (National Academy of Sciences, 2000; Gallagher, 2004), although (c) is a more complex issue in Mexico due to its concentration of endemic species and its role in the origin of crop plants. The first two points will be considered in more detail; in Mexico, (c) requires more attention than is currently routinely given to transgenic constructs. Note that due to the porous border between the U.S. and Mexico, any decisions about use of transgenic maize in the U.S. has a direct effect on Mexico. Although such effects may be delayed by various import restrictions, given current migration rates between the two countries, absolute isolation of US maize from Mexico would appear to be nearly impossible. Thus, the regulatory framework discussed in the National Academy of Sciences (2000) is not only pertinent to Mexico, but would seem to be an important diplomatic issue to Mexico as U.S. decisions will have direct effects on Mexican maize agriculture.

If transgenics are to be strictly regulated, then serious sampling and very accurate and reliable testing procedures need to be developed. Zero tolerance, given the porosity of Mexico's borders, is unlikely to be possible, so models of deviations from zero tolerance will need to be developed.

The archetypical farmer with a yield of 2 to 3 tons/ha is operating far below the yield levels that correspond to the archetype of high production, especially that represented by field-trial data used for policy decisions on transgenes. In a practical sense, the minor differences in yield from current-(and perhaps many future-)generation transgenes may not be useful or perceptible to farmers at such low yields - due to all of the other agronomic constraints faced besides the one addressed by the single genetic trait. This is an important point where field-trial data should take into account *campesino* practices, conditions and yields, when and if transgenics are to be helpful to such farmers. Experiment station results may not always apply directly.

Error! Bookmark not defined. 4.1 Research and infrastructure needs

The environmental risks of transgenic maize in large-scale, mechanized farming in Mexico are very much like similar risks elsewhere in the world. In Mexico, there is the added risk that, if transgenic hybrids are more successful than normal hybrids, they may displace more local landraces. Over time, many, if not most, maize landraces and the farmers who grow them are likely to be displaced by hybrids, by conventionally improved varieties or by unrestricted, cheap, maize imports. The most pressing need to address this problem is a functioning national maize germplasm program, with a reasonable working budget in the vicinity of US $1 million per year and completely new cold room and seed processing facilities at a centrally located, high and dry location, probably at INIFAP's Texcoco location, so that activities could readily be coordinated with CIMMYT and the Colegio de Postgraduados. The added risk of transgenics is small, except for the possibility of genetic vulnerability accompanying the widespread use of one or a few transgenic sources. The best insurance against these sorts of problems is the maintenance or development of locally-strong plant breeding programs to make use of Mexico's diversity of maize germplasm. A first step would be revitalization of INIFAP's maize breeding programs, with real and continuous operating budgets; secondly, local private breeding projects could readily be encouraged. There have been spin-offs of academic breeding projects at both CP and Saltillo; there is good potential for more of the same at the University of Guadalajara. An intelligent third step would be the national implementation of local, in-situ breeding programs of the type pioneered by Castillo et al. (2000, 2002) at the Colegio de Postgraduados (also see Smale et al., 1999; Smith et al., 2001; and Marielle, 2003). In the past, there has been a long history of excellent breeding at INIFAP, but associated governmental seed production organizations have had a long history of incompetence, poor leadership and unacceptable quality control (for a summary see Matchett, 2002). This sort of record does not bode well for the type of quality control that will be necessary to monitor transgenic use.

The initial Mexican budget proposal for 2004 also held out little hope for scientific advances in agriculture in Mexico; INIFAP and the Colegio de Postgraduados are both essential institutions. INIFAP has a long history of maize breeding excellence and holds almost all Mexican germplasm collections of consequence; CP has educated many agricultural researchers, is the leading agricultural university in all of Latin America, and it leads research on agricultural genetics and plant breeding in Mexico. Both were slated for elimination (Colegio de Postgraduados, 2003) before national and international outrage prevailed.

Measuring the effects of transgenics on local landraces grown by *campesinos* first requires a transgene that might be beneficial to them, as the fates of transgenes that are neutral or actively selected against are well-known from basic principles of population genetics. This would require the development, probably in Mexico, of a locally-useful transgene, experimental studies in several local-village situations, monitoring the fate of the transgene throughout the community and assessing the consequences in neighboring communities. While the gene itself need not be of Mexican origin, it would need to be in an appropriate Mexican genetic background. It is not apparent that there would be negative consequences either on landrace biodiversity or on agricultural ecology (or indeed *any* consequences of any sort, positive or negative) from this. However, until it is done several times, either in planned or in *a posteriori* (after commercial transgenic introduction) experiments, we simply will not know what might happen. Erwin et al. (2000, 2001) quite reasonably suggest that such experiments be conducted prior to general release of any transgene, and certainly for new transgenes that are atypical of variants encountered in conventional breeding.

The major detrimental effect on teosinte populations is human population expansion and increasing human consumption, and these seem unlikely to decrease any time soon (Wilkes, 1985, 2004). While a transgene might enter a teosinte population from a neighboring maize field, so might any number of other genes. Virtually all of these would, at least initially, be highly detrimental (maize-teosinte hybrids and backcrosses are not favored by man or nature), and most would be quickly eliminated. Experimental insertion of several transgenes into several teosinte populations might demonstrate any innate harm that the transgenes might carry, but would have little relevance for natural populations that would soon eliminate genes with negative selective value. Again, the major defense against invasive humans or crop varieties, is a functioning germplasm system with good collections and proper maintenance. Mexico has Jesus Sanchez, a world-authority on teosinte distribution and biodiversity, at the University of Guadalajara, an institution with a long history of work with teosinte, and that would seem to be the logical place to place emphasis on collection, study and maintenance of the teosintes.

Studies of the indirect effects of transgenes on subsequent and neighboring, non-maize crops, pollinators of such crops, and other non-target effects in Mexico require research beyond that routinely required in the United States. There, inter-cropping and relatives of crop plants are rare, populations of potentially endangered, endemic pollinators are less commonly encountered and field sizes and distributions differ greatly from what is commonly found in Mexico.

4.2 Risk assessment, monitoring and their costs

Basically each transgene needs separate assessment of potential risks (see Wilkinson et al., in press). Isolation of genes from maize (and probably other cereal crops, possibly from any other widely-grown annual crop) and subsequent transformation experiments probably carry little more risk than conventional or mutation breeding. Transgenes and groups of transgenes from more diverse sources require more scrutiny and testing. The transgenes currently in hand appear neither to carry much risk nor to offer many benefits to Mexican agriculture, although monitoring indirect, long-term ecological effects requires more attention. The risks seem small for several reasons: the biological effects are relatively minor, generally a difference in a single enzyme or protein out of tens of thousands involved in plant metabolism; half a dozen years of wide-scale testing has revealed only minor consequences in a neighboring country; despite widespread availability in a region with relatively uniform growing conditions, no available maize transgenic hybrid has managed to dominate the market in the US (indeed several maize transgenes have all but disappeared); and the transgenes involved are near-neutral in wide scale tests (National Academy of Sciences, 2000). However, the current benefits are correspondingly small for most Mexican farmers: the transgenic traits available do not solve major, Mexican problems. If benefits that are purely or mostly Mexican are to be discovered, they likely will need to be discovered in Mexico, by Mexicans, probably with Mexican grant monies. Examples of types of traits that would be most helpful to *campesinos* in Mexico would be resistance to grain-storage pests and tolerance to drought. Neither of these traits is likely to be conferred by conventional breeding, and both would have high demand in Mexico relative to interests elsewhere. For such work to be effectively implemented so as to assist *campesinos*, considerable attention would be needed to develop open-pollinated seed delivery and agricultural extension activities that are both essentially non-existent at present.

Assuming that Mexico wishes to carefully monitor the status of transgenics in Mexico, then laboratories for quality control will need to be developed. These will need unusual characteristics, if accurate monitoring of small amounts of gene flow (less than 1%) are to be monitored. Laboratory conclusions need to be tested using double-blind experiments to determine levels of accuracy. False positives can create serious economic problems, including rejection of entire boat loads of seeds, recall of entire manufacturing lots of food products, embargoes on germplasm for breeding use, etc. Failure to detect can lead to contamination of seed lots and, if non-approved transgenics are involved, can lead to later recall of food products and potentially adverse health effects. The conclusions of Quist and Chapela (2001) are still under investigation, hopefully with some double-blind testing, but consultation with a knowledgeable Mexican maize breeder about likely levels of gene flow from unadapted maize would quickly lead to the conclusion that estimates for central or southern Mexico that are much above a very few tenths of a percent certainly should viewed with great caution. None-the-less, there is no question that gene-flow from transgenic US maize will eventually occur almost everywhere, probably slowly and at very low rates in most places, despite patents, contracts, embargoes, restrictions and phytosanitary regulations.

Presumably, each transgenic construct would need to be separately monitored. Hence, much more detailed, public information about the molecular structure of released transgenes is needed. A knowledge of at least a portion of the sequence of each transgene is required, so that reliable molecular markers can be developed. This knowledge would either have to be supplied by the developer or inferred from patent applications. If a transgene is to be marketed (either as seed or as grain) in Mexico, it would be reasonable to require the developer of the transgene to provide adequate sequence data to make this possible. Indeed, it would not seem unreasonable for the developers to be required to supply a unique, cost-effective detection system for each transgenic event to be tested or deployed in Mexico or bordering areas.

Transgenes arriving in Mexico by unorthodox means would probably need to be detected using patent information, unless agreements can be reached with genetic suppliers to provide sequence data or detection mechanisms for all transgenes (perhaps as a condition for marketing or testing transgenic seed in Mexico or even for importation for use as food, feed or fabrication). Implementation of this would require multi-disciplinary policy action, but is perhaps the only way to satisfy intellectual property concerns and achieve transparent and accessible biosafety procedures.

However, the problems don't end at that point. To reliably detect crossing rates of less than 1%, one has to have excellent sampling methods, several independent samples from each seed-lot, highly accurate sample-handling, exceptional detection quality and great assurance against false-positive results. Some detection kits are available for specific transgene constructs (see http://www.genescan-europe.com, for example) that claim very high rates of accuracy, but accurate sampling is critical, processed products can be difficult, and double-blind test results are not publicly available, even for seeds or seedlings. False positives ("finding" transgenic presence when it is really absent) appear to be a major problem. Typical error rates from molecular marker labs are from 1 to 3% (Gethi et al., 2002, Smith, J.S.C., personal comm.). With three independent samples per determination, that overall error rate declines to less than 0.01%, but few operational labs run such independent samples, given the per sample expense, currently about US $1.50, but rates as low as 20% of that may soon be feasible.

Costs of real field-tests (Perry, 2001) for transgenes in centers of diversity are difficult to estimate. The problems that really need assessing are not the effectiveness or stability of the transgene or whether insect-pests will develop resistance or that weeds will mutate to resistant forms. The problems unique to Mexican maize are whether a specific transgene or some group of transgenes will have long-term detrimental effects on local maize or teosinte populations or to the ecological environments where they occur. In fact, only trial and error, over decades of implementation will provide that sort of evidence. There is no evidence that anything detrimental will happen, but not even 25 years of harmonious coexistence with transgenes would provide absolute proof that something might not eventually go wrong. Small-scale field trials may be able to identify gross problems with a transgene, but subtle problems may never be encountered in isolation from real-world farming.

The other risk is that by boycotting transgenes, scientific maize breeding might by-pass Mexico completely, with ultimately disastrous results. While there might not be short term (next 25 years) harm in that, the long-term investment in buggy whips was endangered by the horseless carriage, and the same analogy might apply to maize production in Mexico. That said, the studies of Castillo et al. (2000, 2002; Herrera, 1999; Romero et al., 2002) have shown that maize yields can be readily increased by 20% in *campesino* fields with community breeding efforts and essentially no new inputs, simply using local varieties of maize and modest testing and selection. Local hybrids would increase yields still further, without new technology. Clearly, Mexico could be self-sufficient in maize production, if there existed a national will to do so. That would directly assist the maintenance of maize landrace biodiversity. Certain transgenics might be helpful for this and other Mexican needs, but current ones certainly aren't essential.

Error! Bookmark not defined. 4.3 Investments, costs, options

There have really been no comprehensive studies comparing investments (public or private) in genetically engineered crops vs. conventionally bred crops. Clearly, the expense of the former greatly exceeds the latter (Goodman and Carson, 2000; Gepts, 2002; Goodman, 2002), but accurate estimation of the potential profits is elusive (Acumen, 2003). Clearly, investors in Dow, Dupont and Syngenta have seen very little, if any, return on their very substantial plant molecular biology investments. Companies as diverse as Pfizer, Occidental Petroleum, Stauffer Chemical, Shell, Standard Oil of Ohio and numerous plant molecular biology start-ups basically lost all of their investments in the field. It is generally conceded that university intellectual property offices have cost far more than they have earned from seeds and plant molecular biology products, such as patents and licenses (Press and Washburn, 2000). There have been real problems for organic farmers when their crops have been contaminated by transgenes (Aoki, 2003). Thus far, these costs have been borne solely by the farmers, rather than growers, distributors or licensors of transgenics. One problem faced by transgenic developers is that conventional breeding advances yields at a rate of 1% to 2% per year, and the development time for a new transgenic is in excess of 15 years. Thus, a new transgene must promise a gain of about 25% to be economically viable or must represent a trait essentially unattainable with conventional breeding (such as real drought tolerance) and have minimal adverse effects.

Questions Mexico must face is a) whether traditional plant breeding, private-, public-, or community-led, will be able to supply varieties and hybrids adequate to meet demand, b) should Mexico rely on imported maize and encourage farmers to adopt other crops, c) should Mexico rely on others for transgenic solutions to problems standard breeding practices can't address, d) is protection of maize biodiversity in Mexico of such high priority that Mexican *campesinos* must be protected against subsidized, cheap imported maize and e) will Mexico lose much by simply opting out of transgenic maize?

5. Extensions to other crops and regions

The same sorts of problems facing GM maize in Mexico would be faced with rice in India, soybean in China, cotton in Mexico, Brazil and Hawaii, wheat in Turkey, etc. The case for soybean in China (Carter et al., 2004) appears to very similar to maize in Mexico. In both cases, the wild relative appears to be non-aggressive and semi-weedy. Both teosinte and *Glycine soja* are widely dispersed, with most populations small. Neither is a likely candidate for becoming a noxious weed; indeed most populations are near extinction. Cotton falls in the same category, but weedy wheat and rice relatives could be problems, and Round-up Ready Johnson grass would not be a pleasant by-product of transgenic sorghum.

5.1 Wild relatives and other Mexican crops

While we worry about the loss of locally-adapted farmer-cultivars, in general, the worry over wild relatives of cultivated plants is whether they could become more weedy and invasive via transgenes. This tends to overlook the potential agronomic contributions that wild relatives might make in the future. Whitt et al. (2002) make the very valid point that domestication was a serious bottleneck for all crops, and, despite their current relic status, many ancestral species probably carry allelic variation that cannot be encountered among domesticated descendants. Furthermore, in this era of genomics, allelic variation is now much more readily mined with markers. Today, markers are not simply linked to genes, but now can often actually be within the gene of interest itself.

Furthermore, germplasm bank collections of wild relatives of cultivated plants are usually orders of magnitude worse than collections of cultivars. Wild relatives are usually more poorly collected, maintained and replenished than are landraces of crop plants. Certainly, the only reason that most collections of teosinte exist are the personal efforts of Kato, Sanchez, Wilkes and others, who have often had to beg germplasm banks to accept the seeds that they have collected. Similar situations have occurred in the past with cotton, peanut, squash and tomato (Personal communications with S.G. Stephens, T. Whitaker, W.C. Gregory, C. Rick).

At the beginning of NAFTA, the price of maize in the U.S. was roughly one-half that of maize in Mexico (Boyce, 1996). Freeing the Mexican market for U.S. imports effectively destroyed the incentive for Mexican farmers to continue growing local varieties, thus eliminating the vast, informal *in situ* conservation effort for maize germplasm in Mexico. Many other crops (beans, squash, peppers, etc.) will meet similar fates if Mexican *campesinos* abandon or age-out of farming. Local cotton varieties are perhaps less prone to extinction as many of these are now limited to perennial dooryard forms that grow as small trees or shrubs.

Error! Bookmark not defined. 5.2 Other crops and crop relatives in centers of origin

The extension to other crops in the regions of their origins is probably straightforward for cultivars, in cases where indigenous varieties are still widely grown. Where there has already been virtually complete displacement of local varieties, the situation is similar to that of the U.S. or Australia. For largely self-pollinated cultivars, migration effects are much slower than for cross-pollinators, but with a constant source (pressure) of transgenic cultivars, gene flow is very difficult to prevent.

The generalization to wild and weedy relatives is much less straightforward, as these vary tremendously in distribution, ecology and genetic structure. In most cases, environmental degradation, mostly from human population expansion and increased human consumption pressures, is a far more potent threat than gene flow from transgenics or other new cultivars. The threat of new weed forms also has to be considered on a case-by-case situation.

Error! Reference source not found.CONCLUSIONS

Preservation of biodiversity in maize in Mexico has been a service of Mexican *campesinos* for millennia. Germplasm banks collect and preserve this material. Clearly, if GMOs or wholesale maize imports were to be the future for Mexico, first priority must be strengthening germplasm preservation programs. While GMOs are the headlines, the immediate threats are economic. Landraces provide variability to cope with vagaries of changing weather patterns, pests and diseases, but cannot overcome subsidies that bolster U.S. exports. This is the fragile situation of maize landraces in which it is necessary to analyze benefits and risks of transgene introgression. The major detrimental effect on populations of teosinte, maize's closely related wild/weedy relative, is human-population expansion and ranching, not GMOs.

Currently available transgenes are only marginally attractive to Mexico, but future advances in drought tolerance and resistance to pests of stored grain could be helpful to *campesinos*, if risks prove to be small, and especially if other major restrictions were overcome simultaneously. There is consensus that transgenic traits will introgress into landraces; the speed will depend on the degree source genetics are adapted to Mexico and apparent usefulness of the transgenes. Most transgenes are less likely to be a threat to landraces than a new, highly-successful cultivar, but each transgene needs careful assessment of its long term cost/benefit ratio in Mexico; the long term costs may only become apparent long term. Costs of opportunities lost by not using or not developing useful transgenes need to be considered; this is very long-term planning, as the time from gene isolation to farmer-deployment is at least 15 years, and the cost is enormous. Widespread employment of single genes is unwise, and transgenes share several common traits. The remedy for crop plant uniformity is a dynamic local seed industry, constantly developing new varieties for market, and *in situ* conservation, both making use of Mexico's diversity of maize germplasm. Private development of transgenic crops is apt to slow somewhat as investments are directed towards more lucrative medical and veterinary markets. There is a limit to surcharges for transgenic seeds. One transgene is valued at about $20 per hectare, the next several cannot cost $20 each and be economically viable. Transgenes of use to Mexico would probably need to be developed by Mexicans. Minimal-cost, community breeding projects with essentially no new inputs have shown 20% on-farm increases in yield while simultaneously preserving local landraces. No transgene in current testing meets that standard. The production of industrial and pharmaceutical chemicals in maize carries many risks of pollen and seed-borne contamination, and there is general consensus that such endeavors are inappropriate except in extreme isolation. This, linked to the fact that transgene flow is almost inevitable, suggests that maize should not be used for such purposes.

Given the risks involved with pharma/chemical transgenes, simply not accepting transgenes that don't promise real value - and being cautious of those that do - would seem a safe course of action. Real value would mean contributing, however modestly, to solve crucial problems of agriculture, such as rural exodus, environmental degradation, and local food self-sufficiency, and not aggravating such problems. In practical terms, this could, but not necessarily would, translate into a private company making a buck with a successful development; governmental agencies and the public interest should be strongly involved. Currently-deployed maize transgenes do not meet these criteria.

If transgenes accepted elsewhere are to be barred from Mexico, then maize imports need monitoring and, if introgression is to be slowed, whole or cracked maize imports prohibited. Monitoring of all imported, unprocessed maize would be necessary. Laboratories for quality control will need to be developed; these will need unusual characteristics, if accurate monitoring of small amounts of gene flow (less than 1%) is to be done.

A major question for Mexico is whether transgene-owners will be due fees for intentional or unintentional use of the transgene by farmers growing native, open-pollinated landraces. This is very important to Mexican agriculture and may be of no consequence to industrialized farming operations or to transnational seed companies. The sensible answer is that no fees should be paid by Mexican farmers for use of Mexican open-pollinated maize. A minimal requirement for transgene suppliers would be provision for inexpensive, non-ambiguous testing of each experimental transgene construct.

If Mexico were to develop its own, patent-free transgenes, then a system for distributing them to campesinos and incorporating them into the many locally-adapted landraces would need to be developed and an extension network revived/created.

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Land Tenure (some useful figures from Warman, 2001)

Mexico's land "ownership" is rather complex. Between 1930 and 1970 land was continuously redistributed through the Secretaria de Reforma Agraria. Land tenure can be private, *ejido* or *comunidad indígena*. Land tenure in Mexico has a quite intricate structure, given its cultural, political and agrarian history. The *ejido* was conceived originally, after the Mexican revolution, as a strategy for giving land to farmers while precluding the possibility of a new process of land concentration. The *ejido* is formed by a group of families which have the right to hold a piece of land individually. The *ejido* also has territory for collective use (*e.g.* extensive cattle rearing, woodlots, etc.) and for further distribution among descendants. The *ejido* has juridical personality and specific authorities: the *asamblea*, the *comisariado ejidal* and the *consejo de vigilancia*. In the past, land could not be sold, transferred or embargoed. After the changes to Article 27 in the 1990s, this has been less rigid to allow for some land concentration. Indigenous communities are technically those in which 30% of people speak an indigenous language, and which were deprived of their land during the 19th century and were restituted during the 20th century. Land tenure and authorities are very similar to *ejidos*, although families have a right to a certain proportion of land considered as private property (which is a cause of many disputes among families). The constitutional form of organization is very similar to the *ejido*, but is commonly intermingled with religious and traditional forms of government. Legally, the *ejidatario* had the right to 10 hectares of irrigated land or 20 of reasonably well-rainfed land for agriculture (or its equivalent in more arid conditions and/or for cattle rearing and forestry). According to the law, private properties should have a limit of 100 hectares of irrigated land, or 200 of rainfed cultivated land, or 400 of pastures or 800 of forest. Indigenous communities used to have large areas of land. Today, indigenous agricultural land (or land with valuable natural resources) is *de facto* private, and, effectively, land per family is generally very small. Some communities still have marginal commons.

In 1990, the average private farming property had 51 hectares, while the average social property had 30 hectares (averaged over all land qualities). Social property covered 53% of the agricultural land, ranging from 95% in some states to 35% in others. Private property holdings were strongly skewed: 7% averaged 130 hectares each; 1.4% had more than 1000 hectares (most in semiarid cattle ranches). Sixty-two percent of private agricultural properties averaged 1.6 hectares. There were 3.5 M *pater familias* with rights over social property. The average individual plot assigned to each family was 9 hectares; of course, not all was agricultural land. This figure doesn't consider marginal and remote land that constitute the commons of the *ejido* or *comunidad*. Eighty percent of *ejidatarios* had less than 5 hectares (average was 2.8 hectares). In the important central highlands of Mexico (the states of Mexico, Tlaxcala, Puebla, Hidalgo and Morelos), the average ranged between 2.3 and 3.7 hectares. Sixty percent of the land owners of all types in Mexico had less than 5 hectares of cultivated plus non-cultivated land. In Mexico, 25% of families are extremely poor (by poor country standards). Of these, 53% live in rural areas.

Changes in land use and maize production and consumption (some useful figures from Warman, 2001 and other authors)

Agricultural land-use, and intensity of use, increased in Mexico between 1940 and 1990. Rainfed, cultivated land increased from 5.4 to 15.3 million hectares. At the same time, irrigated-land use increased from 0.6 to 5 million hectares. In 1990, irrigated land represented 30% of the cultivated land and produced 50% of the farm crop. In 1930, there was one hectare of fallow farmland for each hectare cultivated; by 1990 that had decreased to 0.6 hectare. From 1900 to 1990, the crop and animal (CAA) national product increased eight-fold. Yet, in 1900, CAA production represented 35% of GNP, while in 1990 it was only 5% of the GNP. In 1990, the active population engaged in CAA was around 5.3 million in periods of low demand and 12.5 million during demand peaks. Eighteen percent of the cultivated land was in perennials (fruits, coffee, agave, perennial forages, etc.) in 1990; 78% was planted to annuals (cereals, grain legumes, oil crops and forages); 3% was in fresh vegetables.

While 25% of the land used for annuals is irrigated, most maize is not irrigated. In 1900, 69% of cultivated land was planted to maize; in 1950, the percentage had decreased to 50%; and by 1990 to 40%. The rate of change was still down, but appeared to be decreasing prior to NAFTA, suggesting social limits to changes in cultivated-land use. In the 1960 to 1990 period, absolute maize cultivation increased by 900,000 hectares, but other crops increased even more, such that the relative contribution of maize to cultivated land decreased from 52% in 1960 to 30% in 1991 (INEGI, 1997). Chiapas, Veracruz, Jalisco, Puebla, Oaxaca, Michoacan, Guanajuato and Estado de México account for 51% of the land used for maize. Some semiarid states of the northwest increased maize production during the 1980s and beginnings of the 1990s (mostly on irrigated land). In 1990, 2.8 million families produced maize. Two-thirds were "*minifundistas*" (owning less than 5 hectares of land each). Thirty-five percent of Mexican maize production was for the growers' own families' consumption. Forty-two percent of the maize growers produced less than their own annual need and had to buy maize in the market. A second study by CEPAL (1995) indicated that during 1994, 28% of maize producers regularly sold maize, 13% sold small amounts sporadically; 31% didn't sell or buy and 28% had to buy maize for family consumption. In 1990, 10% of the total national economically-active Mexican population grew maize, in spite of the fact that maize only contributed 1.1% of the GNP and 19% of the CAA. In 2001, *ejidatarios* averaged 51 years old, and 76% were older than 40. Only five states have a majority of *ejidatarios* under 50. Difficulty in acquiring land and migration are major causes for the young not farming. In 1995, the average Mexican consumed 230 kgs of maize either directly or indirectly. Almost half of Mexico's maize production is consumed in the form of tortillas (Luna et al., 1993) and 68% is consumed as human food (Ackerman et al., 2003).

Chapter 5 APPENDIX 2

Herbicide use in Mexican *campesino* maize agroecosystems. Some elements for risk assessment, at the field and landscape level, of possible introgression of glyphosate resistance transgenes into maize landraces.

Weeds as maize agroecosystem resources

Maize landraces are sown by Mexican *campesinos* at relatively low densities (30 to 40 thousand plants per ha) in hills allowing significant intercrop and weed growth before maize canopy closure. Weed species richness is high but variable (in some cases, more than 200 spp; Villegas, 1970). Many of these species, though competitive with maize, are not seen strictly as noxious plants by *campesinos*, but are fostered or tolerated, as they serve for diet enrichment, fodder, honey production, medicine and as occasional cash sources in local markets (Hernández Xolocotzi, 1985b). For details on these topics, see Wolfenbarger and González-Espinosa, Chap. 4, in this volume. Properly controlled weeds can promote soil protection in early crop growth stages and host a rich associated beneficial biota, and weeding can provide important amounts of green manure.

Weeds as maize agroecosystem problems

Development of weed populations in Mexican maize fields is directly related to land-use intensification and to weed-management practices. At the lowest end of intensification (slash and burn), weed populations are low, diverse and quite manageable with little effort, as seed banks are small, pre-emergent control with fire is effective, and rapid field cover and weed shading by intercrops occurs (Pool-Novelo, 1997, García-Barrios, 2003). At the other extreme, weeds become abundant in permanent maize fields with little crop rotation. In the Mexican tropics, harvestable weeds tend to be displaced or dominated by very competitive grasses, due to better tolerance to control mechanisms and to proliferation of very aggressive, introduced grasses, often grown for pasture, adjacent to or rotated with corn fields (e.g., Velázquez et al., 1999).

Weed control strategies in Mexican maize

Because of rapid crop growth and canopy closure in maize fields, weeds can be a relatively smaller problem than in other crops, when they are controlled in a timely fashion. Late-maturing weeds that emerge abundantly above Mexican maize canopies near harvest time, seldom affect maize production, and some, like the Mexican sunflowers (*Tithonia diversifolia.), even offer additional resources (e.g., soil phosphorus mobilization, fungicide effects, nectar for honey production, fodder) (*Phiri et al. 2003; *Tongma et al. 1998).

Weeds have been controlled in Mexican maize fields in the past by using fire, flooding, hoe, plough, rotations and intercropping, all together comprising an integrated, multipurpose strategy (García Barrios and García Barrios, 1992). More recently, weeds are increasingly being controlled with herbicides and - still marginally - with introduced leguminous cover crops.

Herbicide use by *campesinos* in Mexico

In Mexico, there are no readily available trend statistics on herbicide use in maize fields. The Asociación Mexicana de la Industria de Plaguicidas y Fertilizantes reported that in 1995 Mexico used 41 thousand tons of insecticides and herbicides, of which the latter represented 38%. Of the 13 thousand tons applied to maize, 40% were herbicides. Those reported 5.2 thousand tons of herbicides correspond roughly to 0.75 kg of product per maize hectare.

For the time being, estimates must rely on the review of a few case studies. For example: 1) In a 1998 survey in a community of La Fraylesca, Chiapas, Velázquez-Hernández et al. (1999) found that small commercial and semicommercial farmers producing hybrid maize practiced pre-emergence, pre-sowing and pre-canopy-closure herbicide treatments. They applied as much as 1 kg ha^{-1} of Atrazine; 1.5 L ha^{-1} of glyphosate; 1 L ha^{-1} of 2,4-D and 4 L ha^{-1} of Paraquat.

2) According to a survey in the Sierra de Santa Martha, Veracruz (a typical *campesino* region), Buckles and Erenstien (1996) found that 92% of maize-producing families applied Paraquat, a herbicide prohibited in many countries. Weed control has become a problem, as short term fallows are dominated by grasses, both native and introduced, found in adjacent pastures for cattle production.

3) Hugo Perales-Rivera has provided us with current herbicide use data in Chiapas, derived form a geo-referenced database he has developed based on his research team´s 2002 field work (The Landscapes of Maize Project; see unpublished table and figures included at the end of this document). Out of 1528 interviews, 76% of families used herbicides in maize fields. A rough 75% frequency is common to all altitudes below 2000 m.a.s.l, but shifts to only 57% in the higher elevations of the Sierra Madre de Chiapas. In the Central Highlands of Chiapas, included in a second, more detailed survey, the frequency of families that use herbicides is as low as 30%. Herbicide is much more frequent in the lowlands, where hybrids are more common. Cheap Paraquat and 2,4-D formulations are more commonly used than glyphosate, and the latter is seldom used at the higher elevations.

Potential Effects of current HRTM on biodiversity at the field level

Current HRTM are resistant to glyphosate or glufosinate. These herbicides are classified as type IV-low toxicity products for humans, and are more expensive in Mexico than many of the readily available, more toxic herbicides. There are scientific reports which document resistance in important Mexican weeds to most common herbicides in maize fields, including glyphosate (Cotero-García, 1997)

Weeds support a wide range of invertebrate species at low densities through the provision of a variety of food resources and an heterogeneous habitat structure; many of the latter provide important ecological services as detritus recycling, pollination and herbivore control (Root 1973; Andow 1991; Haddad et al., 2001). It is to be expected and well established that herbicides reduce intercropping (García Barrios, 2003) and invertebrate animal diversity normally associated with secondary crop and weed communities (Robinson and Sutherland, 2002).

In relatively-homogeneous, industrial, maize-production systems such as those of the US or Canada, herbicide management regimes recommended for GMHT crops can differ from those used for conventional varieties. This can be of consequence for the abundance of weeds and associated biota (Squire et al., 2003). Effects of using herbicide-tolerant crops were examined experimentally in the Farm Scale Evaluations Project (FSEs) conducted in the United Kingdom (Freckleton et al., 2003). Within the FSEs maize trials, atrazine herbicides were applied before, at or near sowing in most conventional experimental half-fields (as is usual). In GMHT half-fields, pre-emergent

herbicides were not used, and glyphosate was sprayed later, when both crop plants and weeds were larger (Champion et al., 2003). *Weed biomass, weed detritus and associated invertebrates were higher in the GMHT half-fields than in the conventional half-fields. This can be explained simply by the earlier application, higher persistence and greater efficacy of the atrazine-based herbicides used in the conventional treatment (Hawes et al. 2003). The UK Secretary of the Environment, Margaret Beckett, has very recently told the Parliament that, based on these results, the ministers agree in principle (for the first time) to the growing of Chardon LL, a herbicide-tolerant, GM maize in England. Although the issue is still unsettled, it is interesting to note that among the many conditions established by Beckett, Chardon LL should only be grown and managed with herbicides as in the trials, or with the same effects on biodiversity.
<http://www.agbiotechnet.com/news/database/guestnews.asp; 25/03-2004>

The question is: Are the FSE findings relevant for the Mexican case? Can the Mexican government enforce herbicide management strategies such as the ones established as conditions for HRTM use by Beckett in the UK? In Mexico, pre-emergent herbicides such as atrazine are commonly used by big and medium size maize producers on flat-clean fields where the product is easily incorporated into the soil, but are seldom used by *campesinos* in the rough terrains of mountainous areas which lack sufficient residual soil moisture (needed to achieve good atrazine effectiveness) or where fields free of weeds at sowing time (Dr. Hugo Perales, Chiapas Highlands; Ing. Agron. Alejandro Ventura Maza, Fraylesca, Chiapas; personal communications; Velásquez-Hernández et al., 1999). In the former environments, an atrazine by glyphosate substitution policy could be hard to enforce in Mexico. In the latter environments, it would be of no consequence for increasing field biodiversity, as no atrazine is used and as weed control can start very early (before maize emergence), either manually or with broad spectrum herbicides (including glyphosate), thus mimicking to a certain extent the atrazine effect.

When considering herbicide spraying in intensively-cultivated maize fields, *campesinos* in mountainous areas have to strike a balance between the perceived benefits of less soil tillage and reduced labor, and the cost of the herbicide relative to their monetary income. For glyphosate resistance (GR) genes to be selected in *campesino* maize fields, at least five conditions seem necessary : (1) A significant flow of GR genes should reach these environments. (2) Producers would have to prefer herbicides over other weed management strategies. (3) Producers would have to develop an initial glyphosate preference over cheaper herbicides, motivated perhaps by hearing about GR seeds in the locality. (4) GR landrace individuals would have to dominate maize field populations before weeds themselves develop significant GR. (5) Practical management of "transition phase" conditions would have to be developed (i.e., GR maize fields peppered with non-resistant maize plants and with GR weeds!) and (6) the perceived benefits of a swifter and more thorough spraying process should override - in the eyes of the *campesino* - the extra cost of glyphosate, and the negative consequences of "squeaky clean" monocultures deprived of intercrops, useful weeds and associated beneficial organisms.

Should all these conditions be met (an improbable but not impossible scenario), a number of ecological consequences could result at the *campesino* field-level. Three obvious ones are: (1) Tillage as a weed control strategy could be reduced, with some of the positive and negative effects on agricultural soils (Bravo-Espinosa et al., 1992) associated with this practice; (2) Currently, experienced *campesinos* who practice ground-level herbicide spraying before maize canopy closure prefer to use broad-spectrum products cheaper (and less systemic) than glyphosate. As they have to avoid spraying maize plants, nearby associated crops and weeds escape spraying also, thus maintaining a precarious level of functional biodiversity. GR and subsequent transgene herbicide resistances could further promote "quick and dirty" spraying and eliminate this last redoubt of biodiversity. (3) Chemical-residue soil and water contamination would be lower than by using more toxic products, but higher than by using low external-input strategies. (4) development of weed resistance to glyphosate (and sequentially introgressed and locally selected HR transgenes) could render weed populations increasingly difficult to control with herbicides.

Herbicide impact at the landscape level.

Contamination of aquifers and lowland aquatic ecosystems are perhaps the most obvious direct impact of significant herbicide use at the landscape level. Glyphosate and glufosinate could be less noxious than more toxic herbicides, but as explained in chapter 4, their environmental effects are context dependant.

More subtle and indirect impacts can also develop at this scale. Where and when socioeconomic conditions increase pressure on land for maize production, herbicides have recently played a significant role in increasing milpa plot-size and cultivation/fallow ratio, thus promoting higher rates of deforestation and erosion in mountainous areas. (See for example Collier 1994 for an account of changes in milpa production in Apas, Zinacantán, Chiapas. We have prepared a Box with an analysis if this case. See below)

This syndrome has become more acute with PROCAMPO subsidies given out to *campesinos* by the government. Because it is a per-hectare-based subsidy, *campesinos* have been tempted to clear more fallow and forested land. This has been documented for the milpa system in Santa Martha, Veracruz (Buckles and Erenstien, 1996) and is observed in other parts of the country. Again, herbicides become an unfortunate tool for extending the agricultural frontier over forested land in rough terrain with fragile soils.

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BOX 1. (Appendix 2)

We have elaborated an example of the complexities of herbicide-related changes at the landscape level, based on a very well-documented anthropological case study (Collier, 1994) in the paraje of Apas, municipio of Zinacantán, Highlands of Chiapas :

George Collier is a well-known Stanford University anthropologist who has been doing field work in Apas, Zinancantán, since the 1960s. Apas, Zinacantán is in the highlands of Chiapas at the border of very steep slopes which fall into the Grijalva river valley. Before agrarian reform, a handful of wealthy Apas Indian families held tracts of communal land, and others had to work for them to produce maize. In the 1940s, agrarian reform reached Chiapas, and the Apas Ejido was created within densely forested communal lands; consequently, almost all families engaged in labor-intensive, swidden-agriculture in their own plots of land.

In the 1960s, the population had grown but fallow periods were not significantly reduced because the most prosperous families began to rent and clear marginal lands for maize production in the Grijalva valley, from cattle ranchers eager to convert scrub forests to grazing lands. Hybrids and herbicides were used to maximize yields and surfaces in this lowland deforestation/production endeavor. Older people acquired hand labor for this purpose from the young and from the landless.

In short, during this fist period, relatively favorable maize and cattle prices + complementary interests between Zinacantecans and cattle ranchers + labor-saving technology became a tremendous force, capable of changing the landscape of a considerable part of the Grijalva valley in several decades.

During the 1970s the lowland rental-option was exhausted, but wage labor in huge hydroelectric dams, oil exploration and city construction became an important option for thousands of people from the Highlands, most notably the people of Zinacantán. Corn-sale profits from the 1960s and wage savings from the 1970s were invested in transportation and commerce by a sector of neo-rich Apas families. During the 1970s, maize production in the highlands continued to be fallow-based and hardly expanded because of available, non-agricultural-livelihood income sources. A considerable portion of remote pine-oak forests in Apas were still barely touched.

During the 1980s, the massive wage-labor options were exhausted, and people returned to the community. Maize production changed in many ways: the wealthiest Zinacantecans welcomed loggers, who would clear pine forests, but also open roads in previously inaccessible areas. Maize production was now concentrated in the highlands (it was only 20% of their maize surface in the 60s and became 52% by 1987). Maize-production technology changed significantly: fertilizers and herbicides could be transported to far-away fields; fertilizers allowed for shorter or no fallow periods, while herbicides allowed for bigger plots, because more weeds could be quickly cleared per ha, in days instead of weeks. Maize production became less labor-intensive and more capital-intensive. Poorer farmers without enough capital turned part of their land over for rental to richer farmers.

Inshort, during this second period, development of neo-rich Zinacantecan families + lack of wage opportunities abroad + alliances with loggers + fertilizers and herbicides + land rental , shifted the Apas landscape balance from a forest punctuated by scattered milpas into a virtual sea of maize.

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<u>Do safer technologies exist ?</u>

Given increasing weed management problems with limited human labor and potential risks associated with HRTM, are there safer alternatives for *campesino* maize producers than long-term introgression of HRTM into landraces? What would be the necessary production conditions for such strategies to work?

Weed management has always been a critical aspect of agriculture because of its significant effects on yield. Given the rapid growth and canopy closure of maize, weeds can be a relatively minor problem if correctly managed at early growth stages. For centuries, Mexican *campesinos* controlled and even benefitted from weeds through a number of clever management practices, where the most important inputs were intense human labor and farming experience, transmitted and enriched by successive generations (García-Barrios and García-Barrios, 1992). These inputs are becoming scarce resources in the current rural crisis, and *campesinos* are seeking alternatives. To date, the most common weed control alternatives offered to *campesinos* by outsiders are either herbicides or intercrops, most notably leguminous cover crops.

Herbicides are attractive to *campesinos* who can afford them because of the ease with which they can be transported and used, but are currently inaccessible to the poorest farmers. They are promoted by private companies and public agencies, either as such or as part of a conservation-tillage-technological package. The most commonly used products (some already banned in rich-industrialized countries) are frequently misused or abused due to lack of proper information and law enforcement (Tinoco and Halperin, 1993), and their toxicity for the environment and for humans and domestic animals is well established. In the short term, glyphosate and glufosinate herbicide-use associated with HRTM might seem less risky in these circumstances. But the medium-term weed resistance treadmill could become costly, and there is no procedure in place to incorporate these traits into the many locally-important landraces.

Cover crops are meant to reduce weeds, prevent soil erosion, provide fodder and enrich soils (García Barrios, 2003). When sown simultaneously with maize, cover crops need to be properly selected and managed to reap their benefits as weed suppressors and biofertilizers. Some species can be too competitive with maize, can irritate the skin and/or can attract rats and snakes, while others work well. Most require additional labor by farmers (Velázquez-Hernández et al., 1999). Although most cover-crop systems have been developed for the lowlands, there is ongoing research for selecting appropriate legume species for the tropical highlands (e.g., Bernardino-Hernández, 2003). Important cover-crop, participatory-research projects in maize agroecosystems have recently been developed in the southeast states of Chiapas, Oaxaca, Veracruz and Yucatán. This has lead to successful production results and adoption in some cases, but to rather limited results in others (Narvaez-Carvajal, 1994; Buckles and Erenstein, 1996; Soule, 1997; Guerrero-Jiménez et al., 2001; Veláquez-Hernández, 2001; Vargas-Nicasio, 2002; Bernardino Hernández, 2003). The most important current drawback for maize cover-crop associations is not eco-technical, but rather the reluctance of new generations of *campesinos* to invest money in initial stages, and extra work all along, in a production system that is so little valued socially through low maize prices (Buckles and Erenstein, 1996).

Technically and ecologically, there is potential and need for further research and development of cover-crop technology for small and medium-sized *campesino* plots (Soule, 1997). There, use would need to be part of an integrated weed management strategy (where in extreme circumstances herbicides could be used), based on a "many little hammers" approach (sensu Leibman and Gallandt, 1997). In any circumstance, a multiple/integrated weed-management procedure seems the wisest course of action, given the capacity of weeds to rapidly overcome single and systematic control strategies (Leibman and Gallandt, 1997). To date, institutional research and development efforts in this area are still marginal, and adoption limited (Soule, 1997). Traditional Mexican integrated weed-management, with new technological elements added, could have a second chance, simply if better prices were established for Mexican maize in general and for some high-quality landraces in particular. Such pricing could be accomplished if North American governments clearly recognized that Mexican maize is quite distinct in physical and organoleptic properties from US yellow corn and is a critical input for high-quality tortillas and for a number of maize-based dishes, valued both in Mexico and around the world. The obvious consequence should be Mexican maize differentiation both in national and international markets (Robles and García-Barrios, 1994; Appendini, De-la-Tejera and García-Barrios, 2003).

<u>A list for an intuitive risk-analysis of transgene maize with resistance to glyphosate and future herbicides</u>

1) Hazards:

a. Increased economic dependence on a captive herbicide market.
b. Reduced agroecosystem diversity. Could be the last nail in the intercrop coffin.
c. If glyphosate is properly managed, it can reduce health problems relative to more toxic

herbicides. It can bring its own problems if it promotes a "quick and dirty" profuse spraying.
d. Greater difficulties to develop differentiated markets and organic markets for Mexican landraces at the national and international level.
e. Landscape changes, deforestation, water and aquatic ecosystem contamination if it further promotes herbicide use in mountainous areas.
f. Possibility of unwanted genotype and phenotype effects produced by long term stacking of treadmill HR genes and other transgenes.

2) Probability of an epidemic of introgression events across Mexico:

Given the current massive and increasing imports, probably proportional to such US maize flow. Would still occur, although at a much lower level, via ant-like introduction by Mexican migrants. Once in the country, it would flow through *campesino* seed exchange networks.

3) Probability of persistence in the TG in landrace genomes:

Usefulness and selection in favor would be a function of glyphosate-use among farmers. Currently, it is more probable among large, commercial farmers in the lowlands; less probable among *campesinos* in the highlands.

4) Probability of occurrence of each hazard once the GR transgene were fixed in the landrace population:
Context dependant; some are almost certain (e.g., d), others difficult to predict (e.g., f)

5) Knowledge and consent by stakeholders affected by such risks: practically no information for all producers and consumers, especially *campesinos*.

6) Are there less risky alternatives? Yes: integrated weed management offers limited possibilities in the current circumstances, but could be developed with better prices for Mexican maize in differentiated national and international markets.

Table and Figures for Appendix 2 were produced by Dr. Hugo Perales Rivera (ECOSUR) in march 2004. They are based on his unpublished field data from year 2000 survey. Project: The Landscape of Maize in Chiapas. (ECOSUR-UC DAVIS). Please do not cite or distribute without Dr. Perales' permission.

Figure 1. Percentage of families in each locality studied that use herbicides (circles = locality)

Figure 2. Percentage of herbicide using families in each locality that use glyphosate (circles = locality)

Figures can be found in another file: Chap5App2figs.doc

Table 1. Appendix 2. Percentage of families that use Herbicides

	altitude	no	yes

< 500 msnm	27.48	72.52
501-1000 msnm	15.08	84.92
1001-1500 msnm	27.43	72.57
1501-2000 msnm	26.84	73.16
> 2000 msnm	42.47	57.53
Total	364	1164

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