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## Achieving Mexico's Maize Potential

**Antonio Turrent Fernández, Timothy A. Wise, and Elise Garvey**

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**Antonio Turrent Fernández, Timothy A. Wise, and Elise Garvey**

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## Abstract[1]

Once the poster child for free trade, Mexico is now better known for its failures, among them the loss of the country's food sovereignty. Rising agricultural prices, combined with growing import dependence, have driven Mexico's food import bill over $20 billion per year and increased its agricultural trade deficit. Mexico imports one-third of its maize, overwhelmingly from the United States, but three million producers grow most of the country's white maize, which is used primarily for tortillas and many other pluricultural products for human consumption. Yield gaps are large among the country's small to medium-scale maize farmers, with productivity estimated at just 57% of potential on rain-fed lands. To what extent could Mexico close this yield gap, using proven technologies currently employed in the country, to regain its lost self-sufficiency in maize? A comprehensive review of the literature highlights the potential for achieving that goal. The authors examine policy options open to Mexico's new government, identifying those most likely to increase both maize productivity and sustainable resource use while reducing import dependence. With climate change likely to constrain input-intensive agricultural productivity growth, these involve an emphasis on farmer-led extension services, the promotion of sustainable agricultural practices, and improved water management, including expanded irrigation. They also involve a change in the Mexican government's approach to agricultural trade. Mexico's profound loss of its food sovereignty in recent decades offers rich lessons for developing country policy-makers.


## Executive Summary

Rising agricultural prices, combined with growing import dependence, have driven Mexico's food import bill over $20 billion per year and increased its agricultural trade deficit. The current drought in the United States is making this situation worse, with maize prices setting new record highs. Mexico now runs an annual production deficit of roughly 10 million tons and an import bill for maize of more than $2.5 billion/year. Mexico imports one-third of its maize, overwhelmingly from the United States, but three million producers grow most of the country's white maize, which is used primarily for tortillas, and more than 59 native maize landraces that are basic ingredients of nearly 600 food preparations. Yield gaps are estimated at 43% on rain-fed land, compared to just 10% on the country's larger irrigated farms. Most of the country's small to medium-scale maize farmers are operating at less than 50% of potential.

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[1] *An earlier version of this paper can be downloaded at:*
*English:* http://www.ase.tufts.edu/gdae/Pubs/wp/12---03TurrentMexMaize.pdf.
Spanish: http://www.wilsoncenter.org/desarrolloruralmexicano

To what extent could Mexico close this yield gap, using proven technologies widely employed in the country, to regain its lost self-sufficiency in maize? This comprehensive review of the literature highlights the potential for achieving that goal as well as the policies most likely to be effective. Based on a close examination of productivity gains and potential in Mexico's diverse maize-producing sectors – irrigated and rain-fed, industrial scale and small scale, using hybrid seeds and native varieties, with strong and weak access to natural resources – we find that Mexico has the potential to regain self-sufficiency in maize relatively quickly based on existing technologies and without relying on controversial transgenic maize varieties.

Evidence suggests that within 10-15 years Mexico could increase annual production on current lands from 23 to 33 million tons, meeting the current deficit of 10 million tons. Irrigation and infrastructure projects in the southern part of the country could add another 24 million mt/year. This would be more than enough to meet Mexico's growing demand for maize, estimated to reach 39 million mt/year by 2025.

With climate change likely to constrain input-intensive agricultural productivity growth, policies must build on the resilience offered by Mexico's rich diversity of native maize varieties while promoting more sustainable agricultural practices. Since reduced water availability is projected to be one of the primary agriculture-related effects of climate change in Mexico, improved water management will be essential In both irrigated and rain-fed farmland, as will expanded irrigation in the southern part of the country better endowed with water resources.

We review four current government programs that have the goal of increasing maize productivity. We find that:

- Mexico's current push to expand the use of transgenic maize is unnecessary and ill-considered. Its yield potential is limited, particularly for smaller scale producers, and its risks are high for a country with Mexico's rich diversity of native maize varieties and wild relatives.
- The state aims of Mexico's recently introduced MasAgro Program, with its focus on smallholders and resource conservation, are laudable. But the program is unlikely to meet its goals with its small budget and its overreliance on improved seeds and the promotion of conservation practices poorly suited to small-scale farms and marginal lands. "Conservation" and "no-till" practices should, however, be encouraged where appropriate, particularly on Mexico's larger farms, where such methods have shown excellent environmental impacts.

- A pilot program in farmer-led extension services, the Strategic Project for High-Yield Maize (PROEMAR, by its Spanish acronym), has proven the most promising, raising yields 55-70% in one project carried out in several states by a farmer organization. The project provided basic soil analysis and improved input use and other sustainable management practices among small and medium-scale farmers on rain-fed land. The project did not rely on the introduction of new hybrid seeds nor transgenic seeds. Positive results were achieved within one year with producers on both high-quality and more marginal lands and with those using hybrid seeds and those using native maize varieties.
- An innovative program to introduce fruit trees into traditional intercropped farms has shown promise for increasing family income, decreasing runoff water, reducing soil erosion in hillside farming, and increasing fixation of atmospheric carbon.

Such findings are consistent with the prevailing international consensus around the "sustainable intensification" of small-scale production. Public investment should go where the yield gaps are the greatest, among small-to-medium-scale farmers. This is also where private investment is scarce and where market failures are prevalent.

Public investment is also desperately needed in water systems, since climate change is expected to reduce water availability. Existing irrigation systems, mostly in the semi-arid northern part of Mexico, are poorly maintained and inefficient. Mexico would also benefit greatly from investment in new irrigation in southern Mexico. This would represent a wise long-term investment in both maize productivity and resource management in the region of the country that most needs economic development and sustainable livelihoods.

Mexico's current transition to a new government offers an opportunity to address the country's maize dependence. High international prices provide a strong incentive. The import savings are substantial and the market is providing strong incentives for farmers to adopt productivity-enhancing improvements. Ambition is needed, backed by public investment.

*The earlier versions of this paper can be downloaded at:*
*English:* http://www.ase.tufts.edu/gdae/Pubs/wp/12---03TurrentMexMaize.pdf.
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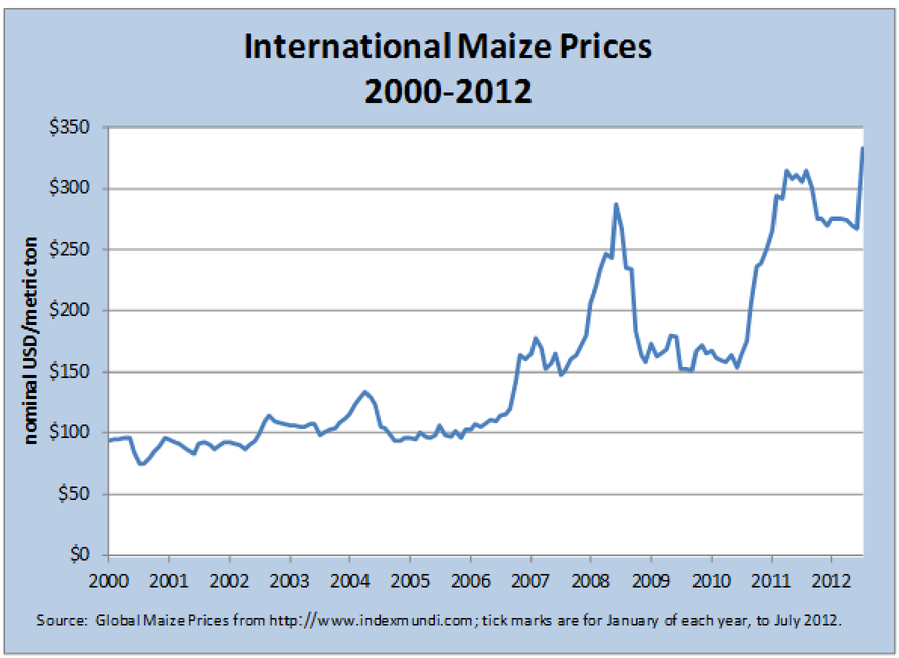
## Introduction

Mexican maize production has increased 50% since the early NAFTA period, much to the surprise of many observers. Mexico produced an average of 22.7 million metric tons (mt) of maize in 2006-2010. The increases came despite a quadrupling of U.S. exports to Mexico and a 66% drop in real producer prices in Mexico through 2005 under the pressure of dumping-level prices estimated at 19% below U.S. production costs. Maize production grew even with a broad reduction in government support for small and medium-scale producers, who remain the overwhelming majority of maize producers and who still produce the majority of Mexico's maize (Wise 2010).

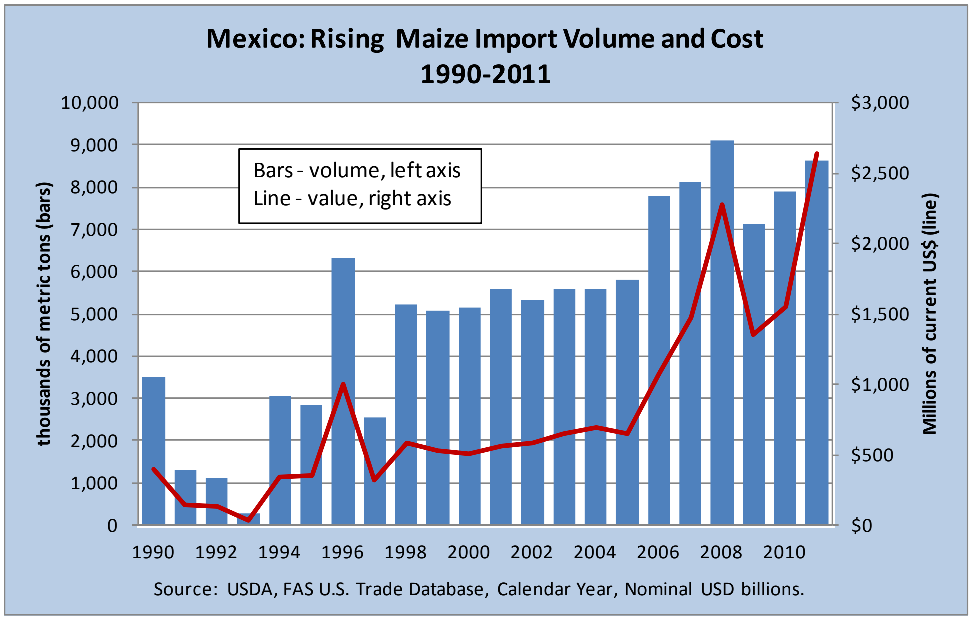
Still, even with the added production Mexico's import dependence for maize grew from 7% in the early 1990s to 34% in recent years (2006-8). This was part of a generalized rise in import dependence on the United States for key grains and meats. This shift now carries high costs, with the price spikes in 2007-8, 2010-11, and now with the drought in the United States. (See Figure 1.)

**Figure 1.**



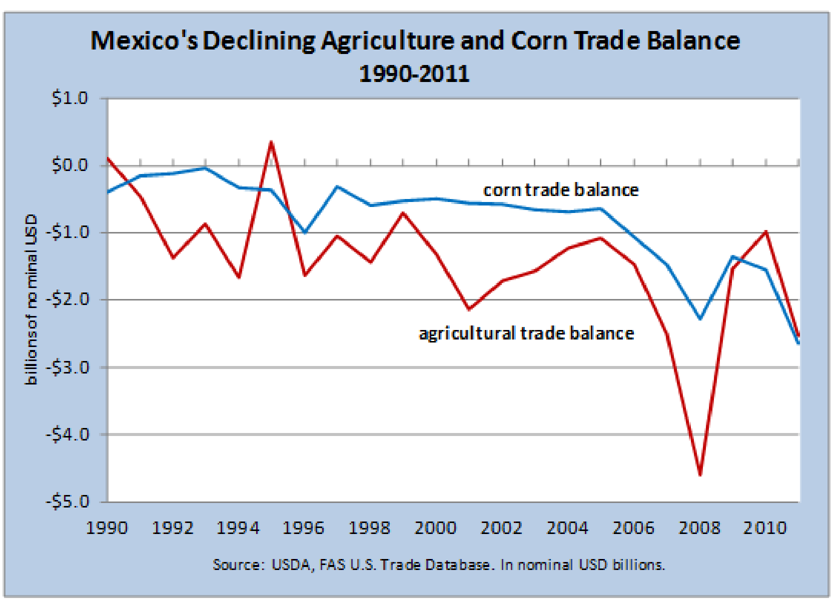

In 1990, Mexico's food import bill just from the United States was $2.6 billion. It grew to $6.4 billion in 2000, and by 2011 had jumped to a record $18.4 billion. It is now on pace to exceed $20 billion. Mexico currently imports 8-10 million tons of maize each year at a cost that reached $2.6 billion in 2011. (See Figure 2.)

**Figure 2.**




Even with the rapid increases in Mexico's agricultural exports to the United States, the country's agricultural trade balance worsened, going from a small surplus in 1990 to a deficit of $1.3 billion in 2000, to a disastrous $4.6 billion in the price-spike year of 2008. In 2011, the agricultural trade deficit was still at $2.5 billion. The costs of maize imports accounted for a rising share of Mexico's agricultural trade deficit. In the last two years, Mexico's maize import costs accounted for the entire agricultural trade deficit (Wise 2012). (See Figure 3.)

**Figure 3.**



Rising international maize prices caused tortilla price protests in 2007, and the high cost of Mexico's rising import dependence has become a matter of public policy debate. Some Mexican government officials have vowed to reduce, if not eliminate, import dependence in maize (SAGARPA, CIMMYT et al. 2011), though policies have yet to support such goals.

Indeed, the centerpiece is the Mexican government's recently unveiled $138 million ten-year program to increase the country's maize production by five-nine million metric tons per year by the end of the program. MasAgro, the Sustainable Modernization of Traditional Agriculture, focuses on improved seeds and extension services to promote better farm management and improved conservation practices among Mexico's small and medium-scale maize producers (SAGARPA, CIMMYT et al. 2011). The government is also promoting the adoption of genetically modified (GM) maize varieties, which are now approved for limited experimental planting despite substantial scientific evidence of the dangers this involves and widespread popular opposition in Mexico.

In Mexico's 2012 presidential campaign, agricultural policies were not a major focus of attention, but one candidate made the explicit commitment to cut the country's maize import dependence in half by 2018 based on 4% annual growth in food and agricultural production while banning transgenic maize (Suarez Carrera 2012, page 18).

Is such an ambitious goal really attainable? Many have argued that Mexico's small-scale maize farmers are not worth the investment because they cannot significantly raise their productivity. This argument, prevalent since NAFTA and now under scrutiny due to rising maize import costs, flows from the theory of comparative advantage that suggests Mexico, in an integrated global – and especially North American – market, should produce what it can most efficiently produce and import the rest. The failure of the NAFTA-based model to generate adequate employment and ensure food security, however, has caused many to question this approach (Zepeda, Wise et al. 2009). More recently, high and rising international prices have made such an approach very expensive. Mexico's soaring food import bill may well force the incoming administration of Enrique Peña Nieto to rethink Mexico's agricultural policies.

Climate change is also exerting pressure for more ambitious agricultural policies. Research on climate change in Mexico (Magaña, Conde et al. 1997; Jones and Thornton 2003) and on the vulnerability and required adaptation to mitigate its negative effects on food production (Conde, Ferrer et al. 2006; González-Chávez and Macías-Macías 2007; Tinoco-Rueda, Gómez-Díaz et al. 2011) identify availability of water to crops as the central impact on food production in Mexico. The impacts of global warming on Mexican maize farming are expected to be severe, mainly due to the increase in extreme weather events, such as the recent drought in the north and the rise in crop-damaging tropical storms in the south. Such impacts were not adequately considered in previous assessments, some of which predicted more favorable growing conditions in Mexico due to climate change (see Conde, Ferrer et al. 2006). A more recent estimate suggests that climate change will cause a 5% decline in Mexican maize production by 2030 (Hertel, Burke et al. 2010).

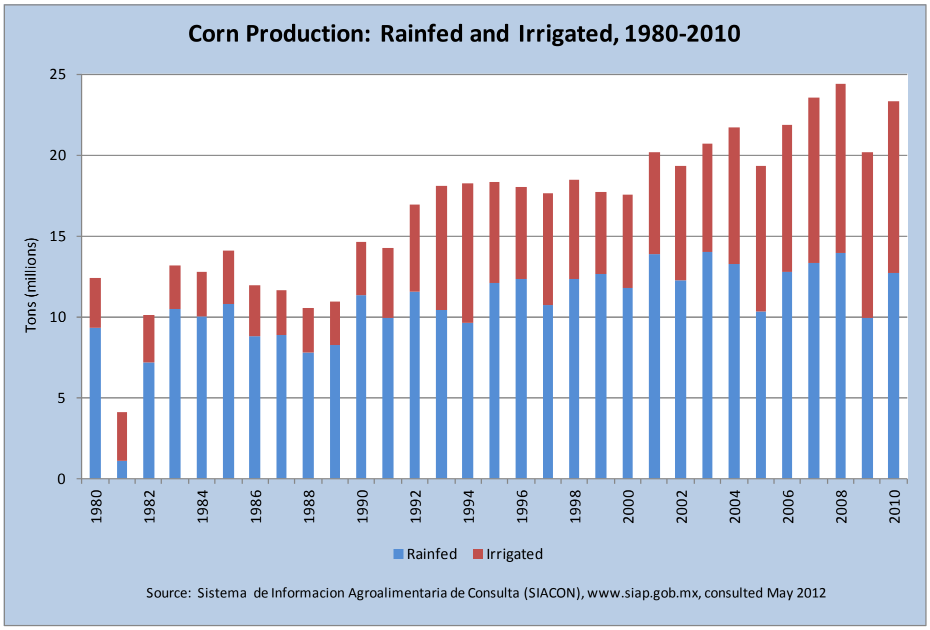
In fact, at a time when global leaders are calling for a significant increase in food production to meet rising demand, research suggests that global maize yields already lost about 5.5% of their expected gains since 1980 because of climate change (Lobell, Schlenker et al. 2011). Research confirms that developing country agriculture is expected to be particularly hard-hit (Parry, Canziani et al. 2007; Nelson, Rosegrant et al. 2009; Nelson, Rosegrant et al. 2010; Wassmann, Nelson et al. 2010; Müller, Cramer et al. 2011; FAO, OECD et al. 2012). The urgency of reducing emissions will also put limits on resource-intensive farming, making it a priority to develop more resilient and sustainable production methods (Royal Society 2009).

Here we review the available evidence to assess whether Mexico, using existing technologies but not expanding the use of genetically modified maize, could recover its self-sufficiency in maize and even become a net exporter. We also seek to assess the unrealized productivity potential among the country's two million small-scale maize farmers and those using more sustainable agricultural methods than the industrial farms. And we evaluate some recent Mexican government policies as well as proposals that would be more ambitious, in the event the incoming government makes it a priority to regain the country's self-reliance in maize.

## Background

Eight million hectares are planted with maize in Mexico yearly. Of these, 1.5 million hectares are irrigated while the majority – 6.5 million hectares – are rain-fed. The rain-fed land tends to be farmed by smaller scale producers using more traditional farming methods, though this is a heterogeneous group. Collectively, their production still accounts for the majority of Mexico's maize production. (See Figure 4.) The rain-fed land includes 1.5 million hectares of good quality land, 3.5 million hectares of medium quality land, and 1.5 million hectares of marginal land (Turrent Fernández, Aveldano Salazar et al. 1996).

**Figure 4.**




Yields vary widely. Irrigated farms are mostly industrial operations using commercial hybrids and achieving yields of about 10 mt/ha, comparable to their U.S. counterparts. On the best rain-fed lands, such as in parts of Jalisco state, farmers mostly plant commercial hybrid varieties, use relatively high levels of technology, and produce yields of 7-8 mt/ha. Those on medium-to-poor quality land tend to farm smaller plots, often rely on native seed varieties, and produce yields of 2-3 mt/ha; some produce a significant surplus for the market. Those farming marginal lands tend to be subsistence or sub-subsistence, with yields of 1 mt/ha or even much less. They still contribute to food security, of course, by sustaining some of Mexico's poorest households.[2]

In fact, three types of farming units have been described in the literature: (a) traditional, (b) subsistence, and (c) entrepreneurial. (Ethno-farming in the Sierras is a fourth type that has not been formally recognized as such, and is normally included within the subsistence type.) Traditional and subsistence farming account for nearly 75% of all farming units. Traditional farming typically produces grain surpluses in moderate amounts that go to local markets; subsistence farming would normally not produce enough food for the family and the difference has to be acquired in the local market (Turrent Fernández and Serratos Hernandez 2004).

[2] Estimates are based on observations in the 2006-10 period in Sinaloa (irrigated), Jalisco (high-quality rainfed), Toatlan, Jalisco (medium-poor rainfed), and District Ojo Calinte, Zacatecas (marginal lands) SIAP (2012a). Cierre de la producción agrícola por cultivo, Servicio de Informacion Agroalimentaria y Pequera (SIAP), Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA)..

This leaves Mexico with a labor-intensive maize sector. Mexican farmers use 14 man-days to produce one ton of maize while their U.S. and Canadian counterparts – and their countrymen in Sinaloa – require 0.14 or less man-days, or one hundred times the productivity per worker/farmer (Turrent Fernández and Serratos Hernandez 2004).

One of the striking features of Mexico's maize-producing sector is its resilience. According to the 2007 Agricultural Census, the number of farms actually increased over 1991 totals despite import competition and falling prices. The sector has remained largely resistant to government-led modernization efforts. The adoption of high-yielding hybrid seeds, for example, rose through the 1970s with strong government programs and an impressive domestic seed research effort. But that percentage has remained low, never surpassing 30% of land planted to maize, despite strong government incentives to adopt improved seeds.

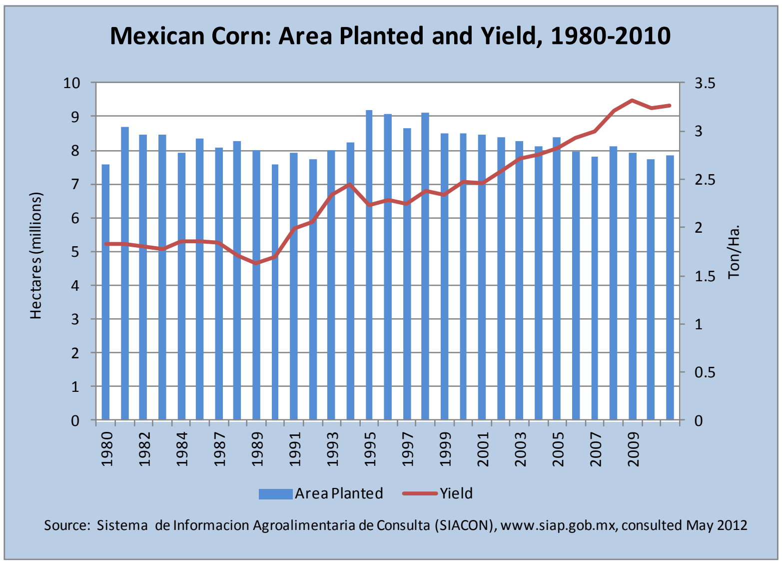
Most experts attribute this resistance to careful risk management among traditional farmers, who see limited gains from commercial seeds poorly adapted to their agro-ecological conditions and who cannot easily afford the cost of added inputs (seeds, fertilizers, pesticides, water) needed to maintain them. Unreliable access to credit has also hampered the adoption of technology packages(Turrent Fernandez 2012). According to the 2007 census, only 4% of Mexican farmers reported access to formal commercial credit (Robles Berlanga 2010). The conditions for hybrid adoption have worsened with market reforms, as transnational seed companies now dominate the market, displacing public sector programs that sought to develop improved varieties suited to local conditions.

Traditional farmers also maintain their native varieties because they are used in specific foods and cultural practices. More than 59 maize native races are grown in medium to marginal land as specialized ingredients of regional cuisines, including more than 600 preparations as food and beverages, including some 300 types of tamales. There are strict correlations among native maize landraces and food preparations, e.g., the special tortilla called "Tlayuda" of the Oaxacan cuisine can only be prepared with the "Bolita" race; the "totopo oaxaqueño" is only prepared with the "Zapalote chico" native landrace.

Annual production of maize averaged 22.7 million tons in the period 2006-2010. Production fell short of national apparent demand by an annual average of 10 million tons. Still, Mexico has doubled its maize production since 1990 (Robles Berlanga 2010), a considerable accomplishment given economic shocks to the sector following adoption in 1994 of NAFTA (Wise 2010). Rising demand for maize, especially yellow maize for livestock feed, kept demand high. Domestic producers largely satisfied Mexico's demand for white maize, used mainly to make tortillas, and for many native varieties. The markets for yellow maize, largely imported, and white maize, largely grown domestically, are distinct but closely related. Since the implementation of NAFTA, prices have tended to be closely correlated, with international prices transmitting to local and regional markets, if imperfectly. There is often a price premium for white maize in Mexico. The markets are related because white maize is an adequate substitute for yellow maize in feed and most other industrial uses. Yellow maize is less often a substitute for white in tortillas and other food preparations.

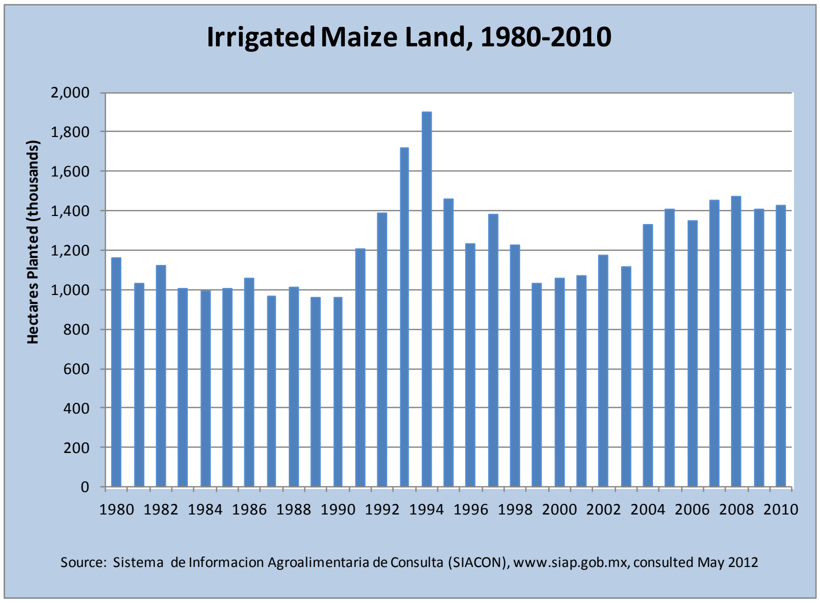
The rise in domestic production was driven primarily by sustained increases in maize productivity, since the area planted in maize held relatively steady, or even declined slightly (see Figure 5) (Fox and Haight 2010). Average maize yields more than doubled from 1990 to 2007 to 2.82 tons/hectare (Robles Berlanga 2010).

**Figure 5.**




Some of this is attributed to a rise in irrigated land, mainly in the late 1980s and early 1990s and overwhelmingly on large farms in northern Mexico (see Figure 5). Irrigated maize lands rose from 1.06 million ha in 1980-84 with average yields of 2.94 mt/ha, to 1.422 million ha in 2006-10, with average yields of 7.42 mt/ha. That represents an increase of 40% in irrigated land with a corresponding 250% increase in yield. Maize productivity on rainfed land increased during the same period but at a much slower pace, growing 35%, from 1.63 mt/ha to 2.2 mt/ha (SIAP 2012b).

**Figure 6.**




Stewardship of Mexico's total of 31 million hectares of farmland and its resources has been notoriously poor. Several failures are worth noting:

1. Although hill agriculture covers approximately 13 million hectares (about 50 percent of rainfed farmland), protection against rainfall erosion is practically nonexistent (Turrent Fernández 1986). For example, in the Los Tuxtlas region in the state of Veracruz, which registers 1,500 mm per year in total rainfall, farmlands are often sloped and an estimated 146 tons of sediments per hectare are lost to erosion each year (Francisco Nicolás, Turrent Fernández et al. 2006).

2. Despite the explicit promise in the lead-up to NAFTA, public investment in expanded irrigation has failed to materialize, stifling potential productivity gains for thousands of farmers . Irrigated maize land is 20-25% below its peak levels in 1993-4, and although it is now 40% higher than it was in 1999-2000, irrigated maize land has barely increased since 2005 (see Figure 6).

3. Irrigation technology is poor on the 6.3 million irrigated hectares, with average irrigation efficiency of just 46 percent (Arreguín Cortés et al., 2004). This is both an ecological problem, given current water shortages, and a productivity issue.

4. Modern farming is poorly regulated and is not held accountable for its growing externalities. For example, intensive monocrop cultivation with high levels of chemical inputs causes pollution from runoff water, which goes to the Sea of Cortes and is the

primary cause of eutrophication (Committee on the Causes and Management of Coastal Eutrophication 2000; Manning 2002).

5. The absence of basic extension services has resulted in wasteful and harmful practices on both large and small farms. Most producers do not have access to basic soil analysis, resulting in excessive fertilizer application or the misapplication of fertilizers and other chemical inputs. This has negative effects on both productivity and the environment.

6. Public programs have provided minimal support to the vast majority of farmers who till smaller plots, reducing their productivity and their contributions to national production.

### Distribution of Mexican Maize Production

There is also an important geographical component to Mexican maize production. One can categorize producers according to four groups (described below) based upon maize production, productivity, use of hybrids, and rural population (see Turrent Fernández and Serratos Hernandez 2004 for detail, including a map). Eighty-four ethnic groups in Mexico have been long-term stewards of the distinct 59 Mexican races of maize, and among traditional farmers yield stability and kernel quality are described as a priority over high yields. As the center of origin for maize, virtually all parts of Mexico show the presence of native landraces.

- Group I, in the central and southern parts of the country, contains 70% of Mexican landraces; this region has a high likelihood of preserving maize landrace diversity; comprises states with medium to very high shares of rural population, very low use of hybrids, medium to high production of maize with low to high yield.
- Group II, northern states that produce very little maize, includes states with very low to medium share of rural population, low to medium use of hybrids, and very low to med production and productivity of maize. Maize diversity is moderate.
- Group III represents just the state of Jalisco, singled out for the intensity of maize production there. The state is a high producer of maize with low-medium yield, high use of hybrids, and medium level of rural population; it also has a high number of landraces and *teosinte* populations.
- Group IV, the states of Sinaloa and Sonora and areas around the capital city, has high and very high production and yields of maize overall, however within the Federal District there is a very low use of hybrids and medium level of rural population, compared to high use of hybrids and medium-high rural population in Sinaloa and Sonora, which are the center of Mexico’s industrial maize agriculture. Maize diversity remains strong, even in these zones.

## Mexico's Untapped Maize Potential

What is Mexico's untapped potential to increase maize production? New strategies for raising both productivity and overall production involve closing the yield gaps on existing farms and bringing new or underutilized land under cultivation. The yield gap – the difference between potential and actual yields on a given plot of land – is not high on Mexico's large, industrialized maize farms. On these lands, high-yield technologies have already been adopted, capital is invested, and yields are comparable to highly productive regions of the United States. Additional land could be irrigated, and irrigation systems could be made more efficient, but these are the primary ways in which yields in this maize sector could be raised significantly through public investment. The much-touted promise that GM seeds, now approved for experimental plots in Mexico, will increase yields is not borne out by the evidence (see Benbrook 2002; Gurian-Sherman 2009 for a review of the evidence). (We return to this point later.) One detailed study of 2000-4 estimated that such large farms were then operating at nearly 90% of their productivity potential, leaving a relatively small yield gap (Turrent Fernández 2008).

Yield gaps are larger, however, among Mexico's mostly small and medium-scale farmers cultivating rain-fed lands. This is consistent with international assessments (FAO 2011; FAO, OECD et al. 2012). Because this sector has limited access to formal credit, lacks irrigation, and has received little in the way of extension services in the last two decades, farmers continue to produce at well below their potential. The sector also suffers from weak producer organizations, which are essential to raising productivity. The same study mentioned above estimated that rain-fed maize farms as a group were operating at only 58% of their productivity potential, leaving a yield gap of 43%. Most regions were operating at less than 50% of potential. Closing this gap would add more than nine million metric tons of production nationally (Turrent Fernández 2008).

In this section, we assess the evidence that Mexico could significantly increase its maize production.

### Survey data on maize potential

Turrent Fernandez has estimated that Mexico could become a net exporter of maize, basing his estimates of the country's maize potential on three substantive surveys conducted in 1977, 1991, and 2000. These surveys involved more than 4,100 field trials over roughly 50 years. We begin with these assessments.

From 1952 to 1977, researchers conducted 2,545 field trials on soil fertility in the principal rain-fed regions of Mexico, and another 819 trials in irrigated regions. The trials were typically on 0.3-0.5 hectares of land, and were grouped according to 72 maize agro-systems. The trials involved the planting of native and improved first generation seed varieties. Based on the yield increases in these tests, researchers projected that similar farming methods applied to 7.48 million maize hectares in Mexico (0.97 million irrigated, 6.51 rain-fed), would allow Mexico to double national production from its 1977 level of 10.05 million tons per year to 20.17 million tons per year (Turrent Fernández 1986).

A subsequent 1991 evaluation raised this estimate to 25.77 million tons per year for 1985-1989, and rising to 28.62 million tons per year for 2005-2009. The new trials tested nationally developed hybrids and increased planting density, with fertilization levels kept constant. Researchers estimated potential yield increases from 3.63 mt/ha to 6.15 mt/ha for up to one million hectares of irrigated land. On rain-fed land the yield increases were lower but still significant: an increase from 2.88 mt/ha to 4.3 mt/ha on rain-fed land deemed "very good" quality, and from 2.88 mt/ha to 3.8 mt/ha on "good" quality rain-fed land (Turrent Fernández, Aveldano Salazar et al. 1996; Turrent Fernández 2011).

In 2000, researchers added estimates for additional maize production that could come from bringing new or underutilized land into maize production and providing irrigation, a proposal that follows up on an abandoned government project in the late 1980s. The estimates came from field trials in eight of the poorer states in the south/southeastern part of the country, where farmers are poorly resourced, water is relatively abundant, and much land is unused or under-exploited in extensive cattle-grazing. Such development would help address the regional disparities in Mexico's economic development and living standards by bringing investment to an area that is home to large numbers of poor rural communities. Irrigation allows farmers to grow two crops per year, significantly increasing production, while also rotating crops (e.g. rice) to improve soil health. Irrigation would be expensive to install, in part because it would require an extension of the electric grid (or other electric power) to run the necessary pumps.

The maize production estimates, however, are dramatic. The trials suggested that farmers could get 8 million tons from one million hectares of underutilized land, and another 16 million tons from 2 million hectares of land now used for cattle-grazing (Turrent Fernández, Gomez Montiel et al. 1998; Turrent Fernández, Camas Gomez et al. 2004b; Turrent Fernández, Camas Gomez et al. 2004a).

The combined production estimates were published in 2009 with a 10-15-year time horizon: 53 million tons annually, 29 million from better-managed land currently planted in maize, and another 24 million tons from new irrigated production in the south/southeast (Turrent Fernández 2009). This potential production refers exclusively to the use of technology of public origin and with non-transgenic maize varieties. As noted, however, it would represent a significant public investment as well as a major program to upgrade production from extensive cattle ranching to integrated farming involving confined cattle and land farmed to produce feed and food crops (Turrent Fernández 2009).

Turrent Fernández updated his estimate a final time in 2011 to account for the increase from earlier estimates in the number of irrigated hectares of land. This brings the estimated potential to 57 million tons annually (Turrent Fernández 2011). This would be more than enough to satisfy Mexico's growing domestic demand for maize, which is projected to reach 39 million mt/year by 2025 (FAPRI 2011).

As noted earlier, 6 million of the current 9 million hectares used for maize production are far from ideal for industrial agricultural use due to geographical and edaphoclimatic conditions. The 3 million hectares of better land – half irrigated, half high-quality rain-fed land – are already close to their full yield potential. Increased production from the remaining 5 million hectares − 3.5 million hectares of medium quality land, plus 1.5 million hectares of marginal land− would be based primarily on better management of open-pollinated improved varieties, native maize landraces and several genetic materials bred by farmers from both sources of germplasm for medium quality land. Only native landraces thrive on marginal land. Traditional maize breeding programs have not succeeded in on farms with more challenging conditions, such as high elevation, drought, excessive rain, steep slopes, or shallow soils. In the next section, we review the evidence that production can increase significantly on such lands.

## Reviewing the evidence

Given the presence in Mexico of CIMMYT, the international maize and wheat research center associated with the CGIAR (Consultative Group on International Agricultural Research) system,[3] and Mexico's own agricultural research institute, INIFAP, considerable attention has been given to the development and release of hybrid maize varieties in Mexico. Since 1963, INIFAP has

[3] For a detailed history of CIMMYT's work in Mexican maize, please see "Meeting World Maize Needs" and "Impacts of Maize Breeding Research in Latin America" Morris, Michael L.; Lopez-Pereira, Miguel A. (1999). Impacts of maize breeding research in Latin America, 1966-1997. Mexico, D.F., Mexico, International Maize and Wheat Improvement Center, Pingali, Prabhu L. , Ed. (2000). Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector CIMMYT 1999/2000 World Maize Facts and Trends. Mexico City, Mexico, CIMMYT.

released more than 200 varieties of maize, suited to the different climatic regions of Mexico (Espinosa, Tadeo et al. 2009). As noted earlier, however, the promotion of high-yielding hybrid varieties has been only partially successful, with adoption rates reaching only 30% and showing little growth in the last two decades. Such seeds are now in use on most of the best land, including most irrigated land.

### Productivity of maize hybrids

Not surprisingly, most of the research on maize productivity in Mexico has focused on this minority of farmers and maize land. Though we found no comprehensive summary of the gains in yield in Mexico attributable to the development of maize hybrids and other improved varieties, there is a well-developed literature on hybrid performance. For example:

- Studies have documented the optimal population density for different hybrids, with yields up to 12 mt/ha (Certantes-Santana, Oropeza-Rosas et al. 2002). Another examined optimal distance between plants for two hybrids (Tinoco Alfaro, Ramirez Fonseca et al. 2008).
- Many studies compared the productivity of different hybrids in different regions. Several of these studies revealed yields of 10-21 mt/ha (Martinez Gomez, Gaytan-Bautista et al. 2004; Gaytan-Bautista, Reyes-Muro et al. 2005; Sierra Macias, Cano Reyes et al. 2005; Tosquy-Valle, Palafox Caballero et al. 2005).
- INIFAP's Maize Genetic Improvement Program of Chiapas Campo Experimental Center studied its own maize hybrid, finding a potential yield of 15 mt/ha under irrigation (Coutino Estrada, Ramirez Fonseca et al. 2006).
- Studies have documented yield improvements in more difficult humid regions of the country, showing a 15% yield improvement (nearly 9 mt/ha) with an improved hybrid over a previously released hybrid (Sierra Macias, Cano Reyes et al. 2005).
- Other studies have demonstrated yield gains of 40% from non-conventional hybrids compared to their landrace progenitors and to conventional open-pollinated improved varieties (Espinosa Calderon, Tadeo Robledo et al. 1999).

Studies such as this last one are used to justify the continued focus on improved hybrid varieties, despite Mexico’s stagnant adoption rates for such improved seeds. The value of such research is limited because most of it was conducted either under irrigation or on some of the country’s best rain-fed land. Thus, these results offer little guidance on efforts to raise productivity on Mexico’s less productive or marginal land.

As noted earlier, the yield gap on Mexico's better-developed lands is comparatively small. This is not to say that production will not increase on Mexico's better-endowed farms, nor that improved varieties could help raise their productivity. Improved seeds have the potential to increase productivity by perhaps 1% per year. Improved irrigation efficiency would improve yields in some areas. But declining water availability due to climate change will exert downward pressure on yields. In any case, in this sector private investment is plentiful and the yield gap remains low, so gains from public investment are likely to be more significant on rain-fed lands with small and medium-scale producers.

## Productivity of native maize landraces

As noted earlier, maize from native landraces still covers half the land planted in maize and involves a significant majority of producers. Such farming takes a variety of forms. Mexico is the center of origin for maize and contains 59 distinct native landraces, some specific to a particular region or climate, others to a particular food or other use. On such farms, yield is only one of many factors of value to farmers.

Mexican plant-breeders and researchers tend to focus exclusively on the yield of dry matter of grain. Little consideration is given to the pluricultural uses of maize in Mexico. Even though the tortilla is very important as food, there are many other maize preparations, just as other cultures have multiple preparations from wheat and rice. One cannot make a *pozole* preparation, for example, with any of the modern varieties; only Cacahuacintle and Maíz Pozolero can be used for that.

In common usage in Mexico, any non-hybrid or non-open-pollinated modern variety of maize is referred to as "creole," a term that is misleading. It includes native maize landraces and the product of their genetic interaction with modern varieties.[4]

One can find such native landraces in virtually any part of Mexico and in a wide variety of farming practices. The traditional *milpa* system, with the intercropping of maize with beans, squash, and other complementary crops, has been abandoned in many parts of Mexico despite

[4] The term creole is a poor and imprecise reference to native maize or native maize landraces. Introduction of modern varieties of maize: hybrids and open pollinated modern varieties interacts with maize landraces in two ways: a) very few ears are taken as a parent material to the farm unit, where both seeds, native and introduced, are purposely mixed and planted together so as to bring traits that the farmer judges adequate so as to improve the native landrace. This is a part of autochthonous maize breeding that goes back to the early stages of maize domestication; b) an improved variety, hybrid or open-pollinated, is planted, harvesting its seed from the same plot for several generations. This material is known as a "creolized hybrid" or "a creolized improved variety." In the latter case, the maize landrace works as a parent material. Some qualities of the landrace such as the quality for direct use as food not necessarily kept in the progenies. Frequently the creolized hybrid is sold on the market.

its virtues as a sustainable source of a balanced diet and proven way to maintain soil health. A modified *milpa* system may intercrop just maize and beans. One can also find native landraces planted in monoculture, or planted by a farmer in a separate plot from land planted in hybrid varieties. Often the native maize is for different uses.

Traditional and indigenous farming systems are still widely recognized for their productivity and energy efficiency (IAASTD 2009b). Their characteristics and typologies vary widely (Clawson 1985; Thrupp 1998; Toledo 2001). For example, in the 1950s the *chinampas* system in Mexico yielded 3.5-6.3 tons of maize per hectare, while at the time the United States was producing only 2.6 mt/ha (Sanders 1957). U.S. yields would not reach 4 mt/ha until 1965 (Altieri 1999).

Intercropped systems can be far more productive than traditional yield measures suggest, because such figures measure the production of only one crop rather than the full range of crops produced. Productivity benefits from these traditional techniques are various and well-documented (Trenbath 1976; Francis and Smith 1985; Vandermeer 1989). Traditional and/or indigenous producers have been shown to be 20-60% more productive in terms of overall harvestable product than monoculture systems (Beets 1982). In Mexico, it has been estimated that one would need 1.7 hectares planted in monoculture maize to produce the same amount of food as one hectare intercropped with maize, squash, and beans (Gliessman, Engles et al. 1998).

Traditional/indigenous systems are also characterized by favorable rates of output per unit of energy input. For example, in slash and burn systems which depend on manual labor in the mountains of Mexico the rate of energy efficiency (unit output per unit input) was estimated at 10:1 (Pimentel and Pimentel 1979; Altieri 1999), compared with just 4.5:1 on a conventional mechanized maize farm in Iowa, and well above the rate of 7.3:1 on an organic mechanized maize farm in Iowa (IAASTD 2009b, page 51).

### Reviewing limited evidence

The research on the productivity of these systems is limited, as has been the Mexican government's investment in its improvement (Turrent Fernández, Cortés Flores et al. 2010). Some of the research, though, demonstrates why hybrids are slow to be adopted by such farmers. One study of farmer practices found that farmers chose to plant native landraces over improved varieties/hybrids because the native varieties were perceived to have additional benefits beyond yield, notably adaptation to climatic conditions, culturally specific uses, and low cost of inputs (Guillen-Perez, Sanchez-Quintanar et al. 2002).

Hybrids often bring yield gains too limited to justify their higher costs. In one study, researchers compared average yields obtained from hybrids, from locally developed, open-pollinated improved varieties, and from native landraces in the highlands of Central Mexico(Arellano Hernandez and Arriaga Jordan 2001). The two hybrids they tested produced yields of 5.25 mt/ha and 5.32 mt/ha, lower than one of the three local improved varieties (5.37 mt/ha) and barely higher than the others (5.06 and 4.45 mt/ha) or than the native variety (4.16 mt/ha). Most farmers seem to feel, justifiably, that such minor yield gains do not compensate the added risk or cost associated with adoption of hybrids. The costs are associated with dependence on purchased inputs – seeds, chemical fertilizers and pesticides, etc. – while the risks are associated with monoculture planting in variable growing conditions to which local varieties have been adapted.[5]

Some native maize landraces have been better researched than others because their high yield potential has made them the basis for modern maize breeding in Mexico and elsewhere. The Chalqueño, Tuxpeño, and Celaya landraces, for example, are widely grown in Mexico and have been used to develop non-conventional hybrids. As a result, there is more research on the yield potential of these native varieties, often testing the yields of their hybrid offspring against those of the native parents.

For example, a 2004 study compared agronomic characteristics, grain yield, and seed quality of 24 landrace varieties of Chalqueño blue maize in the State of Mexico with the hybrid H-139, finding the yields from the two highest yielding landraces (5.1 and 5.4 mt/ha) to be lower than the hybrid (6.5 mt/ha) (Antonio Miguel, Arellano Vazquez et al. 2004). Other research has documented the yield potential of Chalqueño maize (see, for example, de Jesus Perez de la Cerda, Cordova Tellez et al. 2007). Other researchers compared quality and yields for the landraces Palomero Toluqueño (4.2 mt/ha), Cacahuacintle (4.59-5.29 mt/ha) with several hybrids (7.4-9.04 mt/ha) (Gonzalez Huerta, Vazquez Garcia et al. 2007).

To reiterate, the limitation of this research is that it is primarily focused on documenting the improved performance of hybrids on high-quality land rather than on improving the productivity of native landraces or other open-pollinated varieties widely used by Mexican farmers. One exception is a small literature on so-called "creolization," which involves the

[5] For additional discussion of farmer's practices (which varieties - traditional or improved – they choose to plant), see Perales, Hugo, S.B. Brush and C.O. Qualset (2003a). "Dynamic Management of Maize Landraces in Central Mexico." Economic Botany **57**(1): 21-34, Perales, Hugo, S.B. Brush and C.O. Qualset (2003b). "Landraces of Maize in Central Mexico: An Altitudinal Transect." Economic Botany **57**(1): 7-20, Damian Huato, Miguel Angel, Jesus Francisco Lopez Olguin, Benito Ramirez Valverde, Filemon Parra Inzunza, Juan Alberto Paredes Sanchez, Abel Gil Munoz and Artemio Cruz Leon (2007). "Productivity and Possession of the Land: The Case of the Producers of Maize of the State of Tlaxcala, Mexico." Cuadernos Desarollo Rural **4**(59): 149-177.

incorporation into native landraces of traits from higher yielding hybrids. The goal is to create new higher yielding open-pollinated varieties that farmers can experiment with and sustain each year without purchasing new seeds. (See earlier footnote.)

Bellon, for example, shows that in areas where multiple maize types are planted (hybrids, landraces, and creolized varieties), farmers do not perceive an overall superior maize type; all types have advantages and disadvantages, which entail trade-offs (Bellon and Risopoulos 2001; Bellon, Adato et al. 2005; Bellon, Adato et al. 2006). One of these studies examined the extent of adoption and farmers' perceptions of an improved variety (V-524) in a community in Chiapas over a nine-year period in which the improved variety became creolized through farmers' management. Farmers' estimates of expected yield, based on their experience, was 1.93 mt/ha for the hybrids, compared to 1.767 mt/ha for the creolized variety tuxpeño criollo, both somewhat higher than yield perceptions for the native varieties olotillo blanco (1.50 mt/ha) and olotillo amarillo (1.43 mt/ha) (Bellon and Risopoulos 2001).

Researchers concluded from the results that the creolized variety, tuxpeño criollo, provided farmers with nearly the same level of advantageous characteristics as the hybrids (e.g. higher yield, less lodging, and shorter maturity) with fewer disadvantages (e.g. more management intensity and higher risk and cost) (Bellon and Risopoulos 2001). (Still, the results do not measure yield stability over time, which becomes evident only when a variety is adopted by farmers over several seasons. Yields from such crosses often deteriorate with time.)

Other research demonstrated how lines modified with germplasm from teosinte, the wild parent of maize, can develop favorable alleles for grain yield and less unfavorable alleles for other agronomic traits (Casas Salas, de Jesus Sanchez Gonzalez et al. 2001). Researchers in Mexico continue to work on improvements to native landraces in open-pollinated settings.

### Limited research on improving *milpa* productivity

If the literature on productivity improvements for farmers using open-pollinated varieties is limited, the literature on improvements in the traditional *milpa* is even sparser. In fact, government programs have actively sought to eliminate pre-Columbian agricultural systems or let them whither into extinction (Turrent Fernández, Cortés Flores et al. 2010).

Where *milpa* survives, it has often suffered a reduction in agro-biodiversity among the crops being planted (i.e. fewer types of crops). One study in Veracruz found that the traditional *milpa* system there that used to have an average of eight crops (e.g., maize, beans, peppers, bananas, watermelon, yucca, pineapple, mangos or lemons) has almost disappeared, with the few remaining *milpa* producers now planting just maize and beans. This produces more maize and beans but undermines some of the traditional methods of soil management and pest and weed control, resulting in the increasing use of chemical inputs, such as pesticides and fertilizer (Nadal and Garcia Rano 2009). In slash-and-burn systems, fallow periods have been shortened from more than 18 years to about 7 years, and have been decreasing, leading to a productivity collapse in the system (Cuanalo-de la Cerda and Uicab-Covoh 2006; Parsons, Ramirez-Aviles et al. 2009).

Nevertheless, according to Nadal and Rano, the greater variety of crops still results in better performance of each crop than in the case of monoculture: yields are 40-50% higher for maize and beans and 20-30% higher for other crops (Nadal and Garcia Rano 2009).

There are some documented studies of productivity improvement in *milpa*. One looked at modification of traditional slash and burn *milpa* on yield and soil health. Researchers found that “slash and no burn *milpa,*” with moderate use of fertilizers and herbicides and use of traditional crops as cover crops, is an economic, and sustainable, alternative. Although the productivity of maize dropped, the overall cost/benefit ratios for the farmers improved (Cuanalo-de la Cerda and Uicab-Covoh 2006). Other researchers examined alternative fertilization and weed-control in the Yucatan, finding potential gains from alternative management practices (Parsons, Ramirez-Aviles et al. 2009).

Some non-governmental organizations have documented success working at the local level. The Grupo de Estudios Ambientales, for example, has had success implementing a Sustainable Food Systems (SAS) program with farmers in Guerrero. SAS includes activities all along the food supply chain, from ecological production (soil conservation, organic fertilizers, organic control of pests) to selection and improvement of seeds, seed banks for native varieties, grain storage, creation of preserves and dried fruits/vegetables, processing, fair trade marketing, and healthy consumption. Over a five-year period from 2002-6 they found strong and growing yield improvements on experimental parcels as sustainable practices built soil quality (Marielle 2008).

Van Dusen (2000) studied *milpa* in the Sierra Norte of Puebla as part of a larger *milpa* research initiative by the McKnight Foundation’s Collaborative Crop Research Program. He documented the pervasive disenchantment among farmers with the prospects for viable maize production, in part due to high input prices and low crop prices. The McKnight study, though, offers hopeful results for improved *milpa* productivity. Researchers showed that maize breeding experiments with farmers using a modified mass-selection technique produced yield gains that increased steadily for six years at a rate of 2-3% per year. These gains did not compromise the basic landrace morphology or adaptation (Bye 2005). One long-term project in the State of Mexico estimates yield gains over a ten-year period of 35-45% from a combination of improved seed selection and improvements to native seeds (Castillo-Gonzalez, Ramirez-Vallejo et al. 2010).

INIFAP and Colegio de Postgraduados continue to develop a system for small farming units that introduces fruit trees into a modified *milpa* system. Known as MIAF (Milpa Intercalada en Árboles Frutales), the goal is to plant soil-stabilizing fruit trees that can provide cash crops for famers while improving the overall productivity of the *milpa*. The system is being developed for both hilly and flat land, though it has mainly been tested on land with good access to water. This system develops natural terraces and decreases water runoff, with infiltration maximized on the uphill side of the tree line. Unpublished data from Turrent y Cortés (2012) show average yields of 5.4 tons of maize, 0.8 tons of dry beans and 4.0 tons of peaches in one hectare of an irrigated MIAF experimental plot in the 2002-2005 period. Average yields in single-cropping of maize and dry beans were respectively 9.6 and 2.0 t/ha. The total income from MIAF, though, was $7,920, compared to $6,240 from the single-cropped maize ($3,840) and dry beans ($2,400). Experiments with a similar system dramatically reduced soil erosion, from 146 t/ha/year to just 2 t/ha/year. Runoff was reduced from 29% to 15% (Turrent Fernández and Cortes-Flores 2012).

From a broad range of test plots, the demonstrated benefits of the MIAF system include increases in soil fertility, reduction in the use of chemical fertilizers, erosion control, and biodiversity conservation (Juarez Ramon, Fragoso G. et al. 2008). The system has also been shown to increase carbon accumulation (from 0.87 to 1.85 t/ha per year). On test plots, maize yields nearly doubled from 1.2 mt/ha to 2.2 mt/ha, while peach yields reached seven mt/ha, a significant boost to cash income from *milpa* farming (Cortes-Flores, Turrent Fernández et al. 2005).

## Evidence from beyond Mexico

As the IAASTD report documented, there is strong evidence for improved productivity of maize and other basic grains through low-input and traditional farming systems (IAASTD 2009a). Some is worth noting in this review. Jules Pretty's project on the "sustainable intensification of agriculture" documents a wide range of such practices (Pretty 2001; Pretty, Noble et al. 2006).

These include farmer-led participatory research projects, such as the Comité de Investigación Agrícola Local (CIAL) in Colombia. A case study showed maize yield increases from 820 kg/ha to 1400 kg/ha following adoption of agro-ecological approaches. Resource-conserving agricultural practices in Cuba, following the Soviet collapse, achieved yield increases of 150-280% from polycropped cassava-beans-maize, cassava-tomato-maize, and sweet potato-maize (Pretty 2001). In East Africa, so-called push-pull methods for managing pests were adopted by more than 30,000 farmers, raising maize and sorghum grain yields from below 1 mt/ha to about 3.5 and 2 mt/ha respectively (Khan 2006; Khan 2008a; Khan 2008b).

Fertilizer Tree Systems, similar to Mexico's MIAF techniques, have been shown to raise crop yields, reduce food insecurity, enhance environmental services, and strengthen resilience (see Garrity, Akinnifesi et al. 2010). A recent meta-analysis conducted across several regions in Africa found that such techniques doubled yields of maize relative to the control (maize without fertilizer) in most cases, especially in sites with low-to-medium potential and under good management (Sileshi G 2008).

### Which way forward for Mexico?

How then can Mexico achieve the widely accepted goal of reducing its dependence on imported maize by increasing national production? Based on the evidence reviewed here, what strategies are most likely to achieve results? There are two components to any strategy to increase maize production: increasing the productivity of current land and bringing new or underutilized resources under cultivation. We now examine these two areas. For the first, we focus on three programs that are currently in development or underway. For the second, which involves significant public investments not currently contemplated by the Mexican government, we propose priorities for such an initiative.

Because the future production of maize in Mexico will be affected by resource constraints aggravated by climate change, any strategies need to take account of the changing climate. This will require increased resilience in adapting to changing growing conditions (IAASTD 2009a; Royal Society 2009). Fortunately, Mexico has great capacity for resilience given its ecological and agricultural diversity, particularly its maize diversity, as the center of origin for the domestication of maize.

### Increasing the productivity of current land

Mexico is currently involved in three programs designed to increase maize production. One focuses on the introduction of transgenic crops, a highly controversial program now in pilot and experimental stages in the northern part of the country. This is designed to raise productivity on Mexico's large-scale commercial farms. The second is the new MasAgro program focused on raising the productivity of small and medium-scale producers primarily through the dissemination of improved seeds and the promotion of conservation agriculture. The third is a farmer-run program funded by the agriculture ministry to provide extension services to small and medium-scale producers who have the potential to significantly increase yields. Only the third shows significant promise for closing the yield gap and increasing maize production.

**False and dangerous promise: the introduction of transgenic maize**

Mexico is moving quickly toward the approval of commercial planting of transgenic maize varieties in parts of the country. The government reasons that this will increase productivity and allow Mexico to better adapt to a changing climate. We do not have the space here for a full discussion of the controversy over transgenic maize, but a few key points need to be made.

First, most evidence suggests that transgenic maize has not generally been responsible for increases in yield (see Gurian-Sherman 2009 for a good overview of the evidence). Nor has genetic engineering done a better job than traditional breeders in producing varieties that are more resistant to the kinds of water scarcity Mexico regularly experiences, a phenomenon likely to increase with climate change (Gurian-Sherman 2012).

Second, transgenic maize is designed for industrial-scale production on prime farmland. As noted earlier, the yield gap in this sector is not large, and traditional hybrids have shown continued yield improvements, with irrigated maize yields in Sinaloa growing from 9.05 mt/ha in 2001-5 to 10.12 mt/ha in 2006-10 (SIAP 2012b). Transgenic crops hold little promise to do better than this on large-scale farms and the technology has not proven particularly useful for smaller-scale farmers.

Third, the risks are particularly high for a country such as Mexico, with its large (and threatened) reservoir of maize biodiversity. There is evidence that transgenic maize and its production technology, with accompanying herbicides, may be harmful to mice, as a surrogate model for humans, (Séralini, Spiroux de Vendômois et al. 2009) and to humans (Paganelli, Gnazzo et al. 2010), since glyphosate is a proven endocrine disruptor. Research has also shown that transgenic maize cannot coexist with native maize landraces without genetic interaction in Mexico. In the long run, it will cause irreversible accumulation of transgenic DNA in native maize landraces and their wild relatives (Turrent Fernández, Serratos Hernández et al. 2009). In fact, a thorough investigation by a NAFTA-created environmental commission into transgenic contamination of native landraces recommended strong precautionary policies to protect Mexico’s maize diversity (NACEC 2004).

Fourth, the strategy of relying on transgenic maize to adapt to climate change, for example through new drought-resistant varieties, is deeply flawed. Such varieties imply high risk for smallholders and they have not performed as well as native varieties in the field. And they may displace the landraces whose diversity offers Mexico (and other countries) greater resilience in the face of a changing climate. As Mercer et al. (2012, p. 501) note: "Rather than transgenic seeds, what is needed in our view is an intensive climate change research and adaptation program governed by an evolutionary agroecological perspective. Such a program would center on participatory breeding within an evolutionary breeding framework to adapt local landraces to climate change, while maintaining the very diversity that makes landraces resilient to environmental flux. It would also emphasize the sustainable management of water and soil resources, seed networks, and maintenance of a diversity of crops. Such a program should complement the strategies maize farmers already employ."

## MasAgro: Sustainable Modernization of Traditional Agriculture

The Mexican Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) and CIMMYT in 2011 launched MasAgro, which intends to assist (mostly smallholder) farmers in Mexico to test and use better maize and wheat varieties, and to promote conservation agriculture cropping practices and other technologies that raise their yields and incomes while reducing costs, risks, and environmental impacts (Berry 2011). The initiative, with a budget of $138 million over ten years, aims to increase annual rain-fed maize production in Mexico by five-to-nine million tons by 2020, and to increase maize productivity among small-scale Mexican producers by 8-40% through training in improved precision and conservation practices and improved seed performance (SAGARPA, CIMMYT et al. 2011).

MasAgro focuses on the right farmers (at least on paper) and advocates laudable improvements in natural resource management, but it is unlikely to achieve its desired results. In part, that is because the budget is far too low to create the kinds of production increases MasAgro promises. Simply put, $14 million per year over ten years – or even twice that amount – represents an investment of just $1.50-$2.80 per year per additional metric ton of expected production. The kind of investment needed to, for example, raise production on a small farm from two to three metric tons per year would far exceed these sums.

More important, the program focuses on two priorities that have already been tried in Mexico and have shown limited results. The first is improving productivity through the more widespread use of improved seeds. As noted earlier, Mexico's more traditional farmers have refused to adopt hybrid seeds despite many government incentives. Adoption rates have remained below 30% and it is reasonable to think this plateau is an indication that Mexico has reached its adoption limit. MasAgro promises that a new set of hybrids developed from more advanced biotechnology will deliver more appropriate seeds to farmers, but it is difficult to see such seeds overcoming the costs and risks associated with adoption, displacing the native landraces currently being grown by most small-scale farmers. Nor would this necessarily be a positive development, since most observers view Mexico's vast diversity of locally adapted maize varieties to be a key source of resilience in the face of climate change. Under the program guidelines, many of the improved seeds would be commercially distributed by multinational seed firms, further reducing the likelihood of their long-term adoption.

The second misplaced priority is the excessive promotion of conservation agriculture to small-scale producers. Resource conservation is much needed. But the practices of "conservation agriculture" involve no-till or minimum tillage, plant residues left in the field, and long-term crop rotation (Dumansky J., Peieretti et al. 2006). Such practices have proven successful on larger mechanized farms on flat or rolling landscapes, but they have proven more problematic for small-scale producers on small, hilly plots.

The reasons are clear. Soil compaction that accompanies no-till soil management creates an environment in which the weak-rooted native maize landraces fail to thrive. Furthermore, no-till management over time comes to require more powerful mechanized seed-planting equipment to penetrate the increasingly compacted soil, equipment to which small-scale farmers do not have access. The compacted soil, which absorbs water adequately on flat land and rolling slopes, can increase run-off and soil erosion on steep-sloping farmland, such as one finds in many parts of Mexico. Furthermore, since small units are mostly devoted to growing maize for subsistence, they are poor candidates for the kind of long-term crop rotations associated with true conservation agriculture. They could well be better off returning to intercropping under the *milpa* system, which may have more advantages for smallholder resource use than does conservation agriculture (Ortega García and Fernández Rive 2007; Giller, Witter et al. 2009).

Indeed, a conservation-agriculture program was tried earlier in Mexico with limited success. FIRA-BM (Fideicomisos Instituidos en Relación a la Agricultura del Banco de México) conducted an aggressive and well-financed "no tillage project for maize" in the 1980s, but traditional farmers failed to adopt the measures on a permanent basis (Novel Guízar 2000; Ortega García and Fernández Rive 2007).

Paradoxically, MasAgro's efforts to promote conservation agriculture would be welcome and much-needed on the country's large-scale industrial farms, where such practices are rare and where resources are poorly conserved. Still, as laudable as the program's goals are, they are unlikely to produce the desired results on Mexico's smaller farms.

## Investing in what works: Farmer-led extension

The Mexican government's promotion of MasAgro and transgenic maize has diverted attention from a strategy and program that has demonstrated consistent results in recent pilot programs supported by the Mexican government itself. The Strategic Project for High-Yield Maize (PROEMAR, by its Spanish acronym) has provided basic extension services to small and medium-scale producers on medium-to-high-quality rain-fed land since 2008. Such programs feature basic soil analysis and precision fertilizer application.

Such programs are not new in Mexico, and they have demonstrated good results. In the late sixties, CIMMYT and Mexico's Postgraduate College coordinated an effort to increase maize yields and net income among small farmers of the State of Puebla. Using a participatory research model to train extension agents and provide service, the project doubled maize yields for 43,300 small-scale farmers on rain-fed land and increased family incomes by 24%. At the time, it was considered a model for Mexico and for other countries.(Felstehausen and Díaz-Cisneros 1985)

Extension programs like the Puebla Project fell out of favor in the 1980s despite their proven success (CIMMYT 1974).More recent international agricultural development strategies again emphasize the importance of public extension programs in raising productivity and improving resource use (IFAD 2011; FAO, OECD et al. 2012). Many stress the importance of public investment in training and research, and the involvement of farmers and other stakeholders in the design and implementation of extension programs (World Bank 2005; World Bank 2012). The countries that have done best are those with high investments in agricultural R&D linked to strong and well-funded extension programs (Fuglie 2012).

Mexico's PROEMAR program forms part of the larger Program for Maize and Beans (PROMAF), which provides services to nearly one million producers, mostly in southern Mexico. By implementing technologies such as increased planting density, improved seed use, and bio-fertilizers offered by PROMAF, the farms in the program increased their maize production by 3.3 million tons and bean production by 80,000 tons from 2007-9. There was a 35% increase in average yields of maize, from 3.35 mt/ha to 4.54 mt/ha, according to government sources (SAGARPA 2010).

PROEMAR focuses on maize specifically and has demonstrated dramatic results when implemented in conjunction with a strong, accountable farmer organization. The National Association of Commercial Enterprises (ANEC) has been one of the partners, focusing the program on small and medium-scale producers planting both hybrid and native seeds on rain-fed lands in diverse regions of Mexico. Over three years, the project provided technical assistance and trained farmer-extension specialists to implement low-cost improvements in farm management, such as soil analysis, seed treatment, change in density and distribution of planted seeds, calibration of planters, foliar analysis, and balanced fertilization. Introducing new improved seeds was not a significant part of the program. In this pilot phase, ANEC worked with 1,500-2,000 farmers per year on 13,000-15,000 hectares of land (ANEC 2011).

The results were dramatic, demonstrating that the yield gap can be closed quickly, largely by applying existing technology and knowledge through publicly supported programs, in effect filling wide gaps in extension left by the earlier withdrawal of public support for the small-farm sector. The program contributed to improved resource management, training farmers in soil analysis and more precise (and often more limited) applications of fertilizer.

Overall, the program saw yield gains of 55% in 2009, even in a year when weather conditions made production difficult. Average yields in 2010 were an impressive 8.32 mt/ha across the program. Interestingly, yields increased significantly even in some of the regions with less favorable growing conditions, smaller farms, and a greater prevalence of native varieties. In the Costa Chica and Costa Grande regions of Guerrero state, for example, producers using more traditional methods raised yields 70% from 2009-2010, from 3.17 mt/ha to 5.35 mt/ha.

The changes required a 17% increase in costs of production for these Guerrero producers, which was made possible through ANEC's credit program. But the income gains exceeded the added costs by 65%. Overall, the benefit-cost ratio for the ANEC PROEMAR project was 5.6:1, with income gains to producers of $9.3 million on an investment of just $1.7 million (ANEC 2010; ANEC 2011). Early indications suggest that in 2011 the results were even better.

An independent evaluation completed by the Inter-American Institute of Cooperation for Agriculture confirmed the program's results and attributed the success of ANEC's PROEMAR work partly to the involvement of the producers in the development of the program, as well as the relationship between the lead organizations, the producers and the technicians. Researchers faulted inadequate public resources for some of the technical difficulties in the program and environmental problems such as drought and soil degradation as factors that prevented even better results (Solorzano and Caamal 2010). Another evaluation lauded the project's farmer-led model (Rudiño 2011).

ANEC's own evaluation of the project suggests that if the Mexican government invested in the widespread diffusion of ANEC's PROEMAR model, Mexico could achieve self-sufficiency in maize production easily. The project shows, according to ANEC, that it is entirely possible to increase maize yields significantly on small and medium-sized plots, on rain-fed land, in short seasons, among producers using native maize varieties and with limited access to advanced technology, in ways that better conserve resources, and without the introduction of transgenic seeds nor even new hybrids (ANEC 2010).

### Mobilizing new resources for maize production

Mexico has significant reserves of farm land, fresh water, and climate resources but it will take significant long-term infrastructure investments to bring them into production. Research strongly supports the long-term value of such investments, particularly in irrigation, electrification, transportation, and communications (Fan 2008; Mogues and Benin 2012). With climate change, water system investment is critical (OECD 2010; OECD 2012). As Mexico's own commissioned study for the G-20 emphasized, there is an urgent need for "infrastructure investment to build, modernize and upgrade existing irrigation and water delivery systems in most developing countries and some OECD countries" (FAO, OECD et al. 2012, p 64).

Mexico has 32 million hectares of medium to high quality farmable land either reachable with irrigation or that are favorably rain-fed. (SARH 1988) Only 23.4 million hectares of that quality land are currently farmed −6.3 million hectares under irrigation and 17.1 million hectares that get rain-fed; additionally, 8.4 million hectares of marginal land are also cultivated (Turrent Fernández 2012).

Nearly 9 million hectares of quality land are not farmed. Most of this land is underutilized in extensive ranching in tropical, southeastern Mexico, the region that has most lagged in economic development in the last two decades. Additionally in the south, nearly two million hectares of farm land are cultivated only in the spring-summer season but remain idle in the frost-free but drier, fall-winter season.

The average annual fresh water endowment of Mexico is 1,528 billion cubic meters (Arrueguín Cortés, Martínez Austria et al. 2004). One hundred and forty-seven billion cubic meters (BCM) are retained in the national dam network, 394 BCM flow underutilized to the sea, while the rest is either evapo-transpired or deep infiltrated into the ground. Fifty percent of the fresh water flow to the sea concentrates in the southern part of Mexico that accounts for 20% of the country's territory (Ibid. pp 251) (Arrueguín Cortés, Martínez Austria et al. 2004). Calculations by the authors of this paper suggest that this water resource would be sufficient to irrigate almost 5 million hectares.[6]

[6] This computation excludes aquifers and assumes a) using 60% of total water flow of the southern region, b) with 60% irrigation efficiency, and c) 1.5 x 10,000 cubic meter/ha irrigation intensity.

As noted earlier, scientists at INIFAP conducted research on irrigated maize planted in the Fall-Winter season in the period 1998-2001. This research concentrated on public technology, but included some private non-transgenic technology. Results in the southern states of Veracruz, Tabasco, Campeche, Quintana Roo, Guerrero, Oaxaca, and Chiapas showed that fully irrigated maize yields could be on the order of 10 mt/ha (Turrent Fernández, Gómez Montiel et al. 1998; Turrent Fernández, Gómez Montiel et al. 2001; Turrent Fernández A, Camas Gómez et al. 2004b; Turrent Fernández A, Camas Gómez et al. 2004a).

It would require a stepwise, long-term plan to develop the necessary infrastructure in the southern region. Part of that investment involves installing access to electricity to run the small-to-medium scale pumps for irrigation. A good place to start would be developing such irrigation infrastructure on the one million hectares currently planted with maize only in the fall-winter season to allow a second crop. This, in combination with the previously noted investments in the small-scale farming sector, would be enough to eliminate Mexico's current annual maize deficit of 10 million tons.

Such infrastructure investments should also extend to improving irrigation efficiency. Climate change will reduce the availability of irrigation water in the northern semiarid region of México, where the main irrigation infrastructure is located. At the same time, it will increase the demands of crops for water. That will dry out some of the irrigation districts if they are not made more efficient. The current water use efficiency of irrigation districts is as low as 37 percent (Arrequín-Cortés *et al*., 2004; Mejía-Sánchez *et al*., 2002; Wang *et al*., 2011).

## Conclusion

Mexico now runs a production deficit of roughly 10 million mt/year and an import bill for maize of more than $2.5 billion/year. This review has demonstrated that Mexico has the potential to regain self-sufficiency in maize relatively quickly based on existing technologies and without relying on controversial transgenic maize varieties. Turrent's surveys remain the most comprehensive guide to Mexico's maize potential, suggesting that within 10-15 years Mexico could increase annual production from current lands to 33 million/mt; irrigation and infrastructure projects in the southern part of the country could add another 24 million mt/year. This would be more than enough to meet Mexico's growing demand for maize, estimated to reach 39 million mt/year by 2025 (FAPRI 2011). Additional research confirms the viability of these estimates.

Following the prevailing international consensus, public investment should go where the yield gaps are the greatest, among small-to-medium-scale farmers. This is also where private investment is scarce and where market failures are prevalent. Indeed, the most promising improvements identified in this review came from the provision of basic farmer-led extension services on rain-fed lands using existing technologies. Such programs do not rely on the introduction of new improved seeds and they have been proven to improve resource use and promote conservation. In fact, researchers recently published in *Nature* a study estimating that closing yield gaps through improved nutrient and water management could increase production by 30% while reducing inefficient use of inputs (Mueller, Gerber et al. 2012).

While the MasAgro Program's focus on smallholders and resource conservation is laudable, the program is unlikely to meet its goals with its small budget and its overreliance on improved seeds and the promotion of conservation practices poorly suited to small-scale farms and marginal lands. "Conservation" and "no-till" practices should, however, be encouraged on Mexico's larger farms, where such methods have shown excellent results in resource conservation.

Little research has been carried out on how to improve the productivity of Mexico's vast diversity of native landraces. This review documents the potential for such public investment and extension services. Evidence also points to the importance of such diversity in adapting to climate change, which is expected to strain Mexico's water resources.

Public investment is desperately needed in irrigation efficiency, particularly in the northern part of the country where water resources are scarcer and where climate change is expected to reduce water availability. Investment in new irrigation in southern Mexico would represent a wise long-term investment in both maize productivity and resource management in the region of the country that most needs economic development and sustainable livelihoods. This would be a major national project and would require decisive leadership.

In light of the above evidence, Mexico's current rush to expand the use of transgenic maize is unnecessary and ill-considered. Its yield potential is limited, particularly for smaller scale producers, and its risks are high, as recognized in a well-documented report by NAFTA's Commission for Environmental Cooperation (NACEC 2004).

This study has focused on the evidence that Mexico can regain greater self-sufficiency in maize production and reduce its import dependence and costs. We have not focused on the broader conditions necessary for this potential to be realized. The maintenance of stable and remunerative prices will be key to any such effort, a distinct departure from the many years of low prices, through 2005, followed by the recent years of price spikes. This would involve a comprehensive review of trade and reserves policies, among others, It will also be important to address the excessive levels of concentration throughout agricultural value chains, which distort agricultural markets in ways that harm both producers and consumers.

Mexico’s current transition to a new government offers an opportunity to address the country’s maize dependence. High international prices provide a strong incentive. The import savings are substantial and the market is providing strong incentives for farmers to adopt productivity-enhancing improvements. Ambition is needed, backed by public investment.

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**Food Sovereignty: A Critical Dialogue**

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# FOOD SOVEREIGNTY: A CRITICAL DIALOGUE INTERNATIONAL CONFERENCE PAPER SERIES

A fundamentally contested concept, food sovereignty has — as a political project and campaign, an alternative, a social movement, and an analytical framework — barged into global agrarian discourse over the last two decades. Since then, it has inspired and mobilized diverse publics: workers, scholars and public intellectuals, farmers and peasant movements, NGOs and human rights activists in the North and global South. The term has become a challenging subject for social science research, and has been interpreted and reinterpreted in a variety of ways by various groups and individuals. Indeed, it is a concept that is broadly defined as the right of peoples to democratically control or determine the shape of their food system, and to produce sufficient and healthy food in culturally appropriate and ecologically sustainable ways in and near their territory. As such it spans issues such as food politics, agroecology, land reform, biofuels, genetically modified organisms (GMOs), urban gardening, the patenting of life forms, labor migration, the feeding of volatile cities, ecological sustainability, and subsistence rights.

Sponsored by the Program in Agrarian Studies at Yale University and the Journal of Peasant Studies, and co-organized by Food First, Initiatives in Critical Agrarian Studies (ICAS) and the International Institute of Social Studies (ISS) in The Hague, as well as the Amsterdam-based Transnational Institute (TNI), the conference "Food Sovereignty: A Critical Dialogue" will be held at Yale University on September 14–15, 2013. The event will bring together leading scholars and political activists who are advocates of and sympathetic to the idea of food sovereignty, as well as those who are skeptical to the concept of food sovereignty to foster a critical and productive dialogue on the issue. The purpose of the meeting is to examine what food sovereignty might mean, how it might be variously construed, and what policies (e.g. of land use, commodity policy, and food subsidies) it implies. Moreover, such a dialogue aims at exploring whether the subject of food sovereignty has an "intellectual future" in critical agrarian studies and, if so, on what terms.

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