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Agricultural Biotechnology Can Help Mitigate Climate Change

Steven Sexton and David Zilberman

Agricultural biotechnology is vigorously opposed by most environmental groups because of uncertain environmental risks. In this paper, we consider the ways agricultural biotechnology adoption addresses a more certain environmental risk and principal concern of policymakers and environmentalists alike, namely, global climate change.

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Smallholder Livestock Production and the Global Disease Risk

Some environmentalists continue to fight the spread of agricultural biotechnology due to uncertain risks of engineered crops escaping the farm and impacting natural plant species and ecosystems. The accumulated evidence from fourteen years of experience with genetically engineered (GE) crops suggests, however, that environmentalists should perhaps champion the technology as a way to mitigate a risk that most agree is more likely and potentially more damaging: global climate change.

The National Research Council (NRC) reported recently that interspecies gene flow "has not been a major concern" in the U.S., a leader in adoption of genetically engineered crops. Meanwhile, a growing body of economic and agronomic research suggests that the adoption of existing agricultural biotechnology reduces greenhouse gas emissions from agriculture by boosting carbon sequestration on cropland, lessening the pressure for cropland expansion, and reducing the use of carbon-intensive inputs like fuel, insecticides, and, in some instances, herbicides.

Boosting Carbon Sequestration

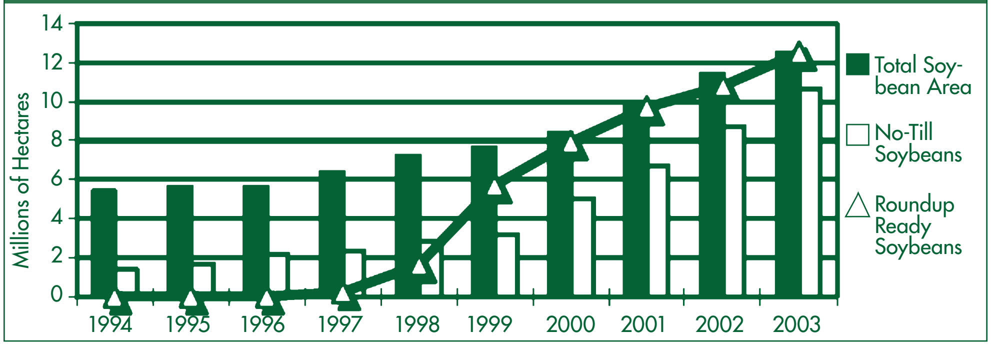
The adoption of herbicide-tolerant (HT) crops, such as Roundup Ready soybeans, sugarbeets and rapeseed, permit farmers to substitute application of broad-spectrum herbicides, like glyphosates, for tilling operations that not only degrade the soil and potentially increase farm chemical run-off, but also reduce soil carbon sequestration. HT crops allow farmers to use non-selective chemicals to control weeds after crop emergence, which reduces the risks associated with conservation tillage or no-till strategies.

Undisturbed soils absorb carbon and convert it into organic matter in the ground. If left undisturbed for several years, the organic matter becomes a stable sink for carbon. Even a single tillage pass, however, aerates the soil and releases carbon back into the atmosphere. One report estimates that an acre of no-till land stores 0.64 metric tons more carbon each year than an acre of land in conventional tillage.

The Conservation Technology Information Center reported that since the commercial introduction of GE soybeans in 1996, the amount of no-till, full-season soybean acreage in the U.S. has grown 69% to constitute 39% of full-season soybean acres. By one estimate, no-till acres more than doubled around the world from 1999–2009, with much of the expansion occurring in Brazil and Argentina, the second and third most aggressive adopters of agricultural biotechnology in the world after the U.S.

A lack of reliable data makes it difficult to determine the extent to which agricultural biotechnology is responsible for the growth of reduced- and no-till practices. As the NRC reported, farmers who use no-till are more likely to adopt HT seeds than those who use conventional tillage, and farmers who use HT seeds are more likely to adopt no-till than those who use conventional seed. Figure 1 depicts the high correlation

Figure 1. Soybean Area in Argentina: Total, No-Till, and Roundup Ready



between no-till growth and the spread of genetically engineered (GE) seeds in Argentina. Conservation tillage likely would have grown in popularity absent GE technologies, as farmers became increasingly aware of the soil degradation associated with tilling operations. Still, the introduction of HT seeds has provided alternative to tillage that fueled the expansion of no-till practices.

Brookes and Barfoot estimate that the increased use of no-till and reduced-till operations boosted carbon sequestration by 101,613 million tonnes of carbon dioxide from 1996 to 2008. In 2008 alone, an additional 3.9 million metric tons of carbon was sequestered because of the growth of conservation tillage, according to their report. This is equivalent to removing 6.4 million family cars from the road for one year.

The authors were unable to distinguish between land that is permanently in no-till or reduced-till (and therefore highly productive in terms of carbon sequestration) and land that is tilled periodically. Furthermore, attributing all growth in conservation tillage since 1996 to agricultural biotechnology likely overstates its role in reducing tilling operations. Thus, these estimates constitute an upper bound on the effect of GE seeds on carbon sequestration. They nevertheless provide valuable insights as to the order of magnitude of these effects.

Avoiding Cropland Expansion

Demand for food and feed is expected to grow considerably by 2050, as the world population reaches nine billion people and incomes in developing countries climb. Unless crop-yield growth returns to the high rates of the last century, either additional land will need to be brought into production or food security will decline. Cropland expansion poses risks of biodiversity loss and reductions in ecosystems services, but the ensuing carbon emissions render land use changes ever more problematic.

To convert natural land to farmland, existing biomass must be removed either by burning or by clear-cutting. Combusting biomass releases the carbon it had been storing. Similarly, when biomass is cut, cleared and abandoned, carbon is slowly released as it decays. In addition, as the new cropland is leveled and tilled to make it suitable for crops, carbon that had been sequestered in the ground is also released.

Agricultural biotechnology lessens the pressure for land use changes by increasing yields on existing land, due to reduced crop damage and by promoting more intensive use of existing land, e.g., double-cropping.

Some genetically engineered traits provide crops insect resistance (IR) by producing within the crop plant the naturally occurring pathogen, *Bacillus thuringiensis* (Bt), which is toxic to some common pests. Other crops are bred to be herbicide tolerant (HT), permitting the use of broad-spectrum chemicals that kill common weeds but also kill conventional crops.

The magnitude of yield gains due to GE seed adoption varies across regions, with those that suffer from large pest populations and that lack effective alternatives to genetically engineered pest control experiencing the largest yield gains. Qaim reported that yield increases due to the Bt gene ranged from 9% in Mexico to 37% in India for cotton, and from 5% in the U.S. to 34% in the Philippines for corn.

In our own econometric analysis of GE seed adoption and crop yields throughout the world, we estimated that GE adoption boosted yields relative to conventional crops—45% for corn, 12.4% for soybeans, 25% for canola, and 65% for cotton. These effects are statistically significant, as well as economically significant, in every instance.

Our analysis controlled for country-specific effects that could cause yields in a given country to change across a number of crops, as well as year-specific effects that would cause yields of a given crop to change across all countries.

The literature is full of controlled experiments that estimated GE trait impacts at field level. We were interested in the gain to farmers and regions that actually adopted GE seeds, which leads to some biases. Specifically, those who choose the technology are expected to gain more than those who do not. Therefore, our estimates are best interpreted as the effect of GE adoption on yields of adopters, i.e., an average treatment effect on the treated. They differ from previous estimates in that they don't isolate just the effect of the GE gene, but rather estimate an aggregate effect of adoption that also incorporates the yield effects of other farm management changes that result from GE adoption.

While our estimates may overstate the magnitude of gains that non-adopters would experience, they offer a good basis for determining how much additional land would have had to be farmed in order to produce our food supply without the GE yield gains. We estimate that an additional 21 million acres of land would have been needed to produce the world corn crop in 2008. Likewise, without GE soybeans, an additional 27 million acres would have had to be planted to soybeans. Combined, these areas are roughly equal to the entire area planted to wheat in the U.S. in 2009, or to the size of the state of Kansas.

Double-cropping: GE crops help to avoid land-use change by making double-cropping a viable practice on more farms. The practice of planting a winter crop is often complicated by fallow periods between crops. Tillage can cause delays, as can the persistence of chemical herbicides with high residual activity. HT seeds reduce the fallow period between crops in two ways. First, because HT seeds allow post-emergence glyphosate applications, farmers can substitute no-till or low-till and glyphosate applications for tilling operations. Second, because glyphosates have a low residual activity relative to alternatives used on conventional crops, HT seed adoption reduces the persistence of chemicals in the field.

Double-cropping has become particularly prevalent in Argentina, where it is estimated that the planting of late-season soybeans after wheat has created a virtual expansion of arable land on the order of 10 million acres since 1996, enabling Argentine soybean production to keep pace with Chinese import demand (Figure 2).

HT rapeseed and soybeans also permit double-cropping with wheat and sorghum in other regions like the U.S. and Canada, but there is no reliable data on the extent of these practices. Brazil, which has also been a major adopter of GE soybeans, has not experienced the same dramatic increase in double-cropping because the agronomic conditions are not as well suited to the production of a late-season crop.

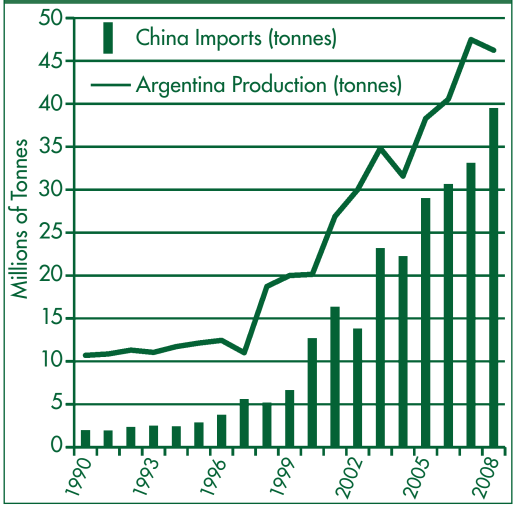
Determining the carbon emissions savings from avoided land conversion, whether due to yield gains or double-cropping, is difficult for several reasons. First, general equilibrium effects would offset the demand for new land in the absence of GE seeds. For instance, food prices would rise, reducing demand for food, and thereby reducing demand for land for food production. Second, the carbon costs of land conversion depend on the type of land that is converted. Where dense biomass must be cleared for cropland, the carbon costs are greater. Foregone carbon sequestration on natural lands is greater where forests are young and growing quickly. The carbon emissions savings from avoided land conversion range from 12–74.8 metric tons of carbon per hectare in the U.S. and 8–90 metric tons in Latin America.

Based on this analysis, then, GE seed adoption in 2009 generated carbon emissions savings in the range of 480–5,400 million metric tons, or the equivalent of annual carbon emissions from 800–9,000 million family cars.

Lowering Demand for Inputs

Chemicals: Agricultural biotechnology also generates carbon emissions savings by reducing farmer demand for some carbon-intensive inputs. Pesticide applications are lower on fields planted to GE seed than on fields planted to conventional seed. Because the GE seed is coded to produce the Bt toxin, caterpillars are controlled without the application of topical insecticides. While farmers growing Bt crops may still apply chemicals to control other pests, empirical evidence from field trials and farmer surveys confirm that overall pesticide use declines.

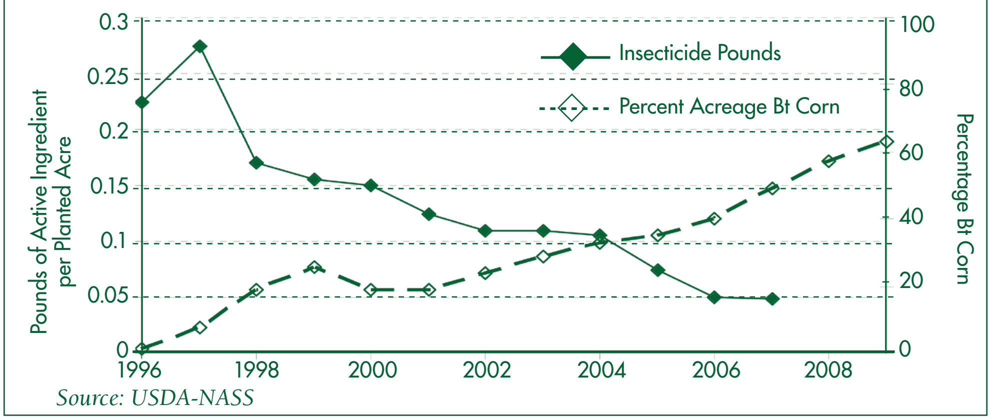
Figure 2: Soybean Production in Argentina and Imports in China



The magnitude of reduction depends on the region. Regions that experience high pest pressure and have a history of effective chemical control are expected to see the biggest decline in pesticide use with the adoption of IR seed. Regions that either do not have pest problems or that do not effectively control pest problems with chemicals will not see dramatic changes.

In his review, Qaim reported that IR maize varieties reduced pesticide use by 8% in the U.S., 10% in South Africa, and 63% in Spain. However, pesticide use did not change in Argentina. Adoption of IR cotton generated a reduction in pesticide use of 47% in Argentina, 36% in the U.S., and 77% in Mexico. Figure 3 shows the high correlation between the spread of IR corn varieties in the U.S. and the decline in total quantity of pesticides applied to corn.

Figure 3. U.S. Lbs. of Insecticide Applied per Planted Acre and % Acres of Bt Corn



Source: USDA-NASS

HT crops permit easier weed control through the use of glyphosates. The availability of glyphosate control on HT fields should induce substitution toward responsive chemical applications rather than preventive ones, leading to reductions in the amount of applied herbicides. However, the availability of post-emergence glyphosate applications increases the marginal productivity of herbicide applications because glyphosates have less residual activity and are effective against a greater range of weeds. Adoption of HT crops, therefore, may increase the total quantity of herbicides applied to fields because glyphosates are simply more effective. Even in these situations, glyphosates substitute for tilling operations and for more toxic and targeted chemicals that persist longer in the environment.

Estimates of the carbon emissions associated with production, packaging, and transport of agrochemicals range from 3.9 to 6.3 kilograms of carbon equivalent per kilogram of active ingredient. Based on estimates of pesticide use on U.S. cotton, this suggests IR cotton reduces annual pesticide applications by 3,600 metric tons, and, therefore, generates annual carbon emissions savings of 14,000 metric tons, equivalent to removing 23,000 family cars from the road. Similar estimates suggest the avoided pesticide applications due to IR corn reduce carbon emissions by 3,500 metric tons per year, or the equivalent of annual emissions from 5,800 family cars.

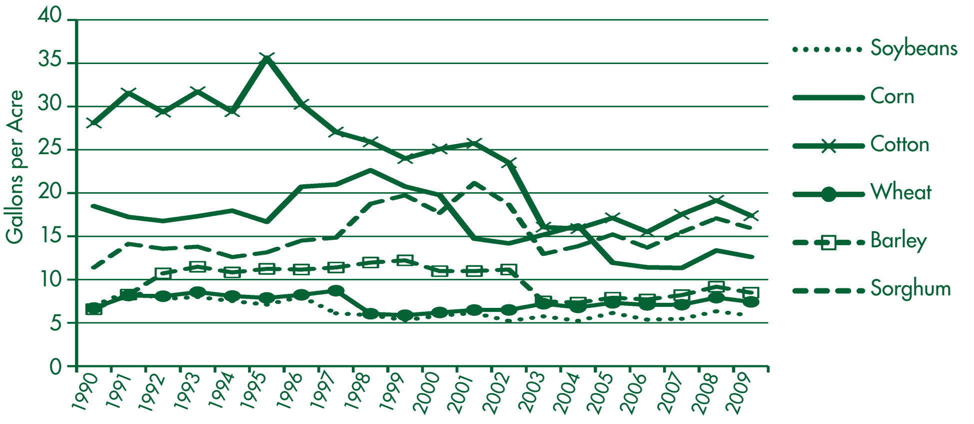
Fuel Use: To the extent agricultural biotechnology reduces tilling operations and chemical pesticide applications, it also reduces fuel use by decreasing the number of tractor passes on each field.

We estimated the effect of GE crop adoption on farm fuel use by exploiting the dynamic pattern of adoption in the U.S. and using USDA data on annual fuel expenditures by crop. We analyzed data for cotton, corn and soybeans—three crops with GE varieties—and wheat, sorghum, and barley, three crops without GE varieties. Fuel use per acre for each of these crops is plotted in Figure 4. Fuel use on crops with GE varieties fell relative to other crops at about the time GE crops were introduced in 1996. Our statistical estimates suggest that GE crop adoption reduces fuel consumption by 19% on average.

Possible Offsetting Carbon Emissions from GE Seeds

While the yield gains from GE crop adoption and the additional capacity for double-cropping reduce demand for cropland expansion, GE seeds may also induce some expansion by making it profitable to farm marginal land that is too costly to farm under conventional crops. Also, as noted, adoption of HT crops leads to an increase in herbicide applications in some situations. Furthermore, theory predicts that as GE crops reduce crop damage, the marginal productivity of directly productive inputs, like fertilizer, capital and labor, increases. Therefore, while GE seeds reduce chemical pesticide use, they may also cause increases in the use of other inputs. Fertilizer, in particular, is carbon-intensive.

Figure 4. U.S Fuel Use from 1990–2009, by Crop



In spite of possible offsetting effects, the preponderance of evidence suggests strongly that agricultural biotechnology helps to mitigate climate change. Future technologies may also help farming adapt to climate change by generating plants that tolerate extreme climatic conditions, like heat, frost and drought, and reduce input-intensity.

More research is needed across a number of disciplines in order to refine the analysis presented here. Nevertheless, the existing body of research is sufficient to estimate the orders of magnitude of carbon emissions savings due to GE seeds and conclude that the technology can play a valuable role in climate change mitigation.

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Brookes, G., and Barfoot, P. (2010). Global Impact of Biotech Crops: Environmental Effects, 1996-2008. *AgBioForum* 13(1): 76-94. Available at: http://www.agbioforum.org.

Qaim, A. (2009). The Economics of Genetically Modified Crops. *Annual Review of Resource Economics* 1, 665-694.

Sexton, S. and D. Zilberman (2011). "How Agricultural Biotechnology Boosts Food Supply and Accomodates Biofuel." in Perloff, J. and J.G. Zivin. *Agricultural Economics.* NBER. Forthcoming 2011. Draft accessible via http://www.nber.org/books/perl10-1.

Toward Sustainable Use of Nitrogen Fertilizers in China

Fredrich Kahrl, Li Yunju, David Roland-Holst, Xu Jianchu, and David Zilberman

Nitrogen fertilizer use in China is an environmental problem of global proportions, but unique aspects of China's farm sector and the fertilizer industries will make this problem difficult to tackle.

China is the world's largest consumer of inorganic nitrogen fertilizers, accounting for about one-third of total global consumption. The use of nitrogen fertilizers has played an important role in maintaining food security in China by allowing large increases in both grain and non-grain yields. Despite claims that it would starve the world, China has continued to be relatively self-sufficient in food production over the last three decades.

Since the 1990s there has been growing recognition that high levels of nitrogen fertilizer use in China are contributing to local, regional, and global environmental problems, including: deteriorating water quality, soil acidification, greenhouse gas (GHG) emissions, and a substantial perturbation of the global nitrogen cycle.

China's first national pollution survey, completed in early 2010, identified agriculture as a major polluter, increasing domestic pressure on policymakers to limit the environmental consequences of fertilizer use. As policymakers weigh options for reducing GHG emissions growth in China, improving the efficiency of nitrogen fertilizer use could be a cost-effective mitigation strategy.

Reconciling the food security and environmental dimensions of nitrogen fertilizer use will pose unique challenges for China because of the distinctive nature of China's farm sector and fertilizer industry. Although the U.S. and Chinese agricultural sectors are quite different, there is an important role for U.S. research institutes and extension services in assisting China to develop the technological and institutional innovations to address its fertilizer challenges.

Nitrogen Fertilizers and the Environment

The vast majority of the Earth's nitrogen resides in the atmosphere as an inert gas, an essential ingredient for life but for most of the planet's history only available to plants and animals on a limited scale through nitrogen-fixing bacteria and algae. Since the early 20th Century, the use of inorganic fertilizers and fossil fuel combustion have greatly increased the amount of nitrogen transferred from the atmosphere to terrestrial and aquatic ecosystems, with the amount of nitrogen fixed by humans now exceeding natural fixation by almost a factor of two.

Inorganic nitrogen fertilizer use in China is an important part of the anthropogenic transformation of the global nitrogen cycle, contributing to an estimated 15% of anthropogenic nitrogen creation in 2005. To put the scale of fertilizer-derived nitrogen flows in China in perspective, in 2008 the amount of fertilizer-nitrogen lost to the atmosphere through volatilization in China was larger than the total amount of nitrogen fertilizer consumed in all of Africa.

Massive inputs of nitrogen fertilizer in China are having local, regional, and global impacts. Nitrogen run-off and leaching into lakes and rivers has had severe impacts on water quality. Many of China's major lakes are badly degraded as a result of nitrogen and phosphorous pollution, with five of China's largest freshwater lakes either eutrophic or hypotrophic. Red tides, resulting from the run-off of fertilizer nutrients, are increasingly commonplace in China's coastal waters. Several studies have shown high levels of fertilizer-derived nitrate in groundwater in China, with measured values as high as 30 times U.S. EPA-allowed levels in a large study in northern China.

Ammonia-based (e.g., ammonium nitrate) or ammonia-forming (e.g., urea) fertilizers can affect soil acidity by increasing hydrogen ion concentrations in the soil. Analysis of data from China's national soil surveys indicates that the average pH of soils in China declined sharply from the 1980s to the 2000s, with nitrogen fertilizer use as the main culprit. Soil acidification will have longer-term impacts on crop yields if not corrected.

Nitrogen fertilizer production and use in China is also a major source of GHG emissions. For reasons we describe below, China's nitrogen fertilizer industry is significantly more energy- and carbon-intensive than the global average. In a recent paper, we estimated that the application of nitrogen fertilizers in China led to mid-range GHG emissions (embodied CO_2 and N_2O) of 400 million tons CO_2 equivalent in 2005, equivalent to 8% of China's energy-related CO_2 emissions. To a greater extent than in other countries, improving the efficiency of nitrogen fertilizer production and use in China could be an important GHG mitigation strategy.

China's Nitrogen Fertilizer Industry

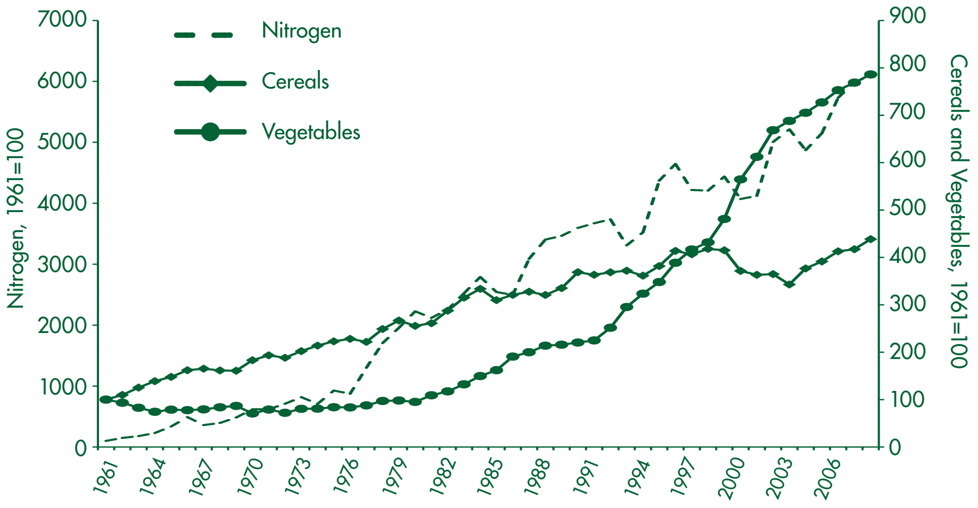
China's nitrogen fertilizer industry is unique in three respects. First, small- and medium-sized manufacturing plants have historically accounted for a significant share of output, whereas in most of the world nitrogen fertilizer is manufactured in large, centralized facilities. Second, ammonium bicarbonate, a low analysis (17% N) and relatively unstable nitrogen fertilizer, has historically been an important fertilizer in China but was never widely used elsewhere. Third, in China coal has been the primary feedstock for producing ammonia, the source of nitrogen in chemical fertilizers, while the rest of the world has relied primarily on natural gas since the early 1960s.

The evolution of China's nitrogen fertilizer industry was driven in large part by resource and political constraints. Decentralized, small-scale production allowed China to overcome constraints on investment capital, foreign exchange, lead time, and distribution requirements characteristic of larger plants—all reinforced by the country's diplomatic isolation during the 1960s. The invention by Chinese chemists in the early 1960s of a relatively simple, low-cost process to produce ammonium bicarbonate allowed rapid deployment of small-scale, decentralized production facilities. Finally, coal-intensive ammonia production accords with China's resource endowments; only 1% of the world's proven natural gas reserves, but 14% of the world's coal reserves. This unique trajectory has allowed China to create the world's largest nitrogen fertilizer industry, but has also meant that this industry is significantly less energy and carbon efficient than the world average.

Fertilizer and Farming in China

Unlike the land-abundant and labor-scarce U.S., China's agricultural sector is highly labor- and input-intensive, with around 200 million small, poor farmers cultivating plots of land that are often smaller than an acre. The terrain and quality of farmland in China vary dramatically, from subsistence grain production on steep mountain slopes to triple cropping on some of the world's most productive farmland. Because of the scarce availability of high-quality farmland, food security and the need to achieve ever-higher yields have long been a preoccupation in Chinese agriculture.

Figure 1. Growth in Nitrogen Fertilizer Consumption and Cereal and Vegetable Output, 1961–2008 (1961=100)



Source: FAOSTAT

China's agricultural sector has undergone a radical transformation over the last three decades. Beginning with collectivization in the 1950s, agriculture was governed by a procurement system that kept crop prices and returns to agriculture artificially low to maintain a supply of cheap food for cities. In the early 1980s, the government relaxed this procurement system to allow farmers to sell above-quota output at higher prices. By 1992, the procurement system had been largely dismantled and since then the government's role in agriculture has been increasingly indirect.

Agricultural input markets were reformed using a similar strategy. Under central planning, fertilizer was allocated under a rationing system that supported priority crops in high-yield regions. The price system implicitly subsidized fertilizer producers, but did not provide fertilizer subsidies to farmers. As a result, under this government allocation system, inorganic fertilizer use remained relatively low. With the scaling back of central planning, government fertilizer allocation was first supplemented with a dual track system and then more completely liberalized.

Fertilizer subsidies are still directed primarily at producers, largely through preferential electricity and natural gas prices that range from 30–50% below those paid by other industrial producers. As a result of producer subsidies and controls on retail prices, nitrogen fertilizer prices in China are lower than world prices, but the influence of subsidies on retail prices is difficult to gauge because China's nitrogen fertilizer industry is so different from other countries. One example is farm prices for urea in China which were around US$0.12–0.13 per pound in early 2008, whereas farm prices for urea in the U.S. spiked to $0.28 per pound in the same period.

In the past two years, China's central government has begun efforts to curtail fertilizer producer subsidies, restructure the fertilizer industry, and liberalize retail fertilizer prices. As part of these efforts, the government will aim to shift fertilizer subsidies from producers to farmers through a "general agricultural input subsidy," which was created in 2006 and is intended to offset increases in input prices for grain farmers.

Nitrogen Fertilizer Use Efficiency in China

Since the late 1970s, growth in nitrogen fertilizer use has outpaced grain production in China (Figure 1). While this aggregate relationship might suggest declining use efficiency, in fact most of the increase in nitrogen fertilizer use can be explained by sustained increases in yields and significant growth in non-grain acreage. Early market reforms gave Chinese farmers more discretion in planting decisions, and they shifted rapidly to crops with higher value and income elasticities. Vegetable production, for instance, has grown nearly eight-fold since the early 1980s (Figure 1).

The expansion of fruit and vegetable acreage in China has important implications for nitrogen fertilizer use because these crops tend to be more fertilizer intensive than grain crops. Continued increases in fruit and vegetable acreage will increase total nitrogen fertilizer use even if application rates for individual crops remain constant.

The relatively small contribution of declines in nitrogen use efficiency to growth in nitrogen fertilizer consumption does not suggest that current levels of nitrogen application in China are agronomically efficient. Nitrogen use efficiency in China is generally thought to be much lower than in the U.S., and a growing number of field trials suggest that application rates for grain crops in China could be reduced by 20–30% while either maintaining or increasing yields.

Even so, current nitrogen application levels in China may be economically efficient, given the conditions and constraints that farmers face. If this is true, incentivizing farmers toward more socially optimal levels of nitrogen fertilizer use will require identifying and overcoming barriers to efficiency improvements.

Food Security and the Environment

Improving nitrogen fertilizer use efficiency is crucial to balancing food production goals and environmental sustainability in China. Improvements of this kind will require policy initiative along two parallel tracks. First, subsidies for fertilizer producers need to be scaled back, allowing retail fertilizer prices to better reflect resource and environmental costs. Reducing energy price subsidies and relaxing retail price constraints can also facilitate a restructuring of China's nitrogen fertilizer industry that would likely reduce its environmental footprint.

Second, extension and other agricultural services will need to be improved to ensure that farmers, and the agricultural system more broadly, have the ability to adapt to higher input prices. The required price adjustment is considerable. If, for example, urea farm prices in China were allowed to rise to U.S. levels (from US$0.14 per pound to $0.20 per pound, based on 2010 prices), farmers would need to reduce urea application rates by more than 30% to maintain fertilizer expenditures at current levels.

Enhancing agricultural services to support fertilizer efficiency improvements will pose a non-trivial challenge for China. China's agricultural sector is huge, diverse, decentralized, and unorganized, with limited extension support and little regulation. Additionally, a number of studies, including work that we have done in Yunnan Province, indicate that nitrogen application rates vary significantly across households and regions. Barriers to higher use efficiency, therefore, are also likely to be household and region specific.

Tackling fertilizer and other sustainability challenges in China's agricultural sector will require a rethinking and reorienting of public service support to agriculture, as well as an exploration of funding mechanisms to support those services. China's agricultural extension system, which has historically been an arm of central government policy and has never had an explicit environmental mandate, will need to improve its capacity to identify local environmental problems and design local solutions—in particular through stronger linkages with research institutes. Funding mechanisms to support sustainability programs might include payments for environmental services or the creation of a domestic or participation in an international GHG offset program.

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For additional information, the authors recommend:

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science* 320(5878): 889-892.

Gao, C., Sun, B., Zhang, T., 2006. Sustainable Nutrient Management in Chinese Agriculture. *Pedosphere* 16(2), 253-264.

Ju, X., Xing G., Chen X., Zhang S., Zhang L., Liu X., Zhen C., Yin B., Christie P., Zhu Z., Zhang F., 2009. Reducing Environmental Risk by Improving N Management in Intensive Chinese Agricultural Systems. *Proceedings of the National Academy of Sciences* 106 (9), 3041-3046.

Kahrl, F., Li, Y., Su, Y., Tennigkeit, T., Wilkes, A., Xu, J., 2010. Greenhouse Gas Emissions from Nitrogen Fertilizer Use in China. *Environmental Science and Policy*. In Press.

A Look at California's Organic Agriculture Production

Karen Klonsky

California leads the nation with the highest number of organic farms, land in organic production, and organic sales. Two-thirds of organic sales in California are from produce, one-fourth from livestock, and the remainder from field crops. The vast majority of organic farmers in California plan to increase or maintain their current levels of organic production.

The 2008 Organic Production Survey (OPS), administered by the National Agricultural Statistics Service, was a follow-up to the 2007 Census of Agriculture and was the first survey of organic agriculture in the United States. The target population included all farms and ranches meeting the standards of the National Organic Program (NOP), administered by the Agricultural Marketing Service (AMS) of USDA, to be certified organic, organic but exempt from certification, or transitioning to organic.

Organic farmers are exempt from the certification requirement if they gross less than $5,000 from sales of organic products. "Transitioning farms" refers to the three-year transition period during which the requirements of the NOP must be adhered to before a farm can market production as organic. In other words, a transitioning farm follows the NOP rules but cannot sell anything as organic during the transition period.

The mailing list was built from several sources, including responses to questions in the 2007 census and the 2008 AMS list of certified organic farmers. The survey was mailed to 29,000 farms, including roughly 5,000 in California. The response rate in California was 85%, yielding 2,220 usable responses. The OPS provides information about organic production in the United States and California's unique role. The results presented in this paper refer to certified and exempt organic farms in California. Transitional operations are not included.

Organic Agriculture in California

California leads the nation in terms of number of organic farms, land in organic production, and organic sales. Overall, California represents 19% of all organic farms and 36% of all organic sales.

Over one-third of all organic farmgate sales derived from California farms come from only 12% of all organic acres and 19% of all farms (Table 1). These numbers suggest that California specializes in high-value crops and that there are a large number of small organic farms. By crop category, California produces more than two-thirds of organic fruits, vegetables and nuts, but only garners 11% of field crop sales.

Organic sales from farms in California are distributed 75% from crops and 25% from livestock and livestock

Table 1. Farms, Land Use, and Sales of Organically Produced Commodities on Organic Farms—CA and U.S., 2008

	California			United States			CA % of Total		
	Farms	Acres (1,000)	Sales ($Mil)	Farms	Acres (1,000)	Sales ($Mil)	Farms	Acres	Sales
Land Use									
Total	2,691	470.9		14,307	4,077		19	12	
Cropland	2,600	275.8		13,625	2,230		19	12	
Pasture & Rangeland	319	195.1		5,362	1,848		6	11	
Crops and Livestock Sales									
Total	2,714		1,148.7	14,540		3,165	19		36
Livestock			309.7			1,123			28
Crops*	2,438		839.0	11,891		1,942	21		43
Livestock and Poultry Categories									
Animals	191		145.7	3,353		316.5	6		46
Products	182		163.9	3,015		906.2	6		18
Crop Categories									
Berries	216	1.8	56.9	1,596	5.5	83.2	14	33	68
Fruit	1,539	45.5	218.0	3,279	78.4	413.8	47	58	53
Tree Nuts	335	10.4	27.7	573	16.0	30.9	58	65	90
Vegetables	546	62.3	457.3	3,948	132.8	689.9	14	47	66
Field Crops		98.8	75.8		1,354.0	708.9		7	11
Greenhouse & Nursery	80		3.3	583		15.5	14		21

** Including nursery and greenhouse*

Table 2. Organic Crops for Which CA Produces 90% or More of the U.S. Sales

Crop	CA Sales	U.S. Sales	% CA
	--$ Millions--		
Lettuce	175	187	94
Grapes	111	122	91
Strawberries	40	44	92
Broccoli	30	33	91
Celery	26	27	97
Cauliflower	17	18	95
Avocados	15	15	98
Almonds	12	12	100
Plums & Prunes	11	12	96
Walnuts	11	11	99
Dates	9	9	100
Lemons	7	7	99
Figs	4	4	99
Artichokes	1	1	99

products, compared to a roughly two-thirds/one-third split nationally. Vegetables account for 40% of California sales and another 26% is from fruit, nuts, and berries (Figure 1). This compares to only 22% of sales nationwide from vegetables and 17% from fruit, nuts, and berries.

Crop Production. California produces more than 90% of all U.S. organic sales for 14 different commodities, including 99% of walnuts, lemons, figs and artichokes, and 100% of almonds and dates (Table 2). Of the top 20 organic crops grown in California based upon sales revenue, two are fruits (grapes and oranges), two are berries (strawberries and raspberries), two are field crops (rice and potatoes), and two are nuts (almonds and walnuts). The other 12 are vegetable crops. All of the top 20 crops have over $10 million in sales. Lettuce sales are at $175 million (from 190 farms) and all grapes are at $111 million (from 525 farms)—representing the leading two crops.

In fact, organic vegetable production in California is dominated by lettuce, which comprises 38% of all sales dollars. Lettuce, tomatoes, spinach, broccoli, and celery together account for two-thirds of all organic vegetable sales. Grapes similarly dominate the organic fruit category, comprising half of the sales. The other four fruit crops garnering over $10 million are strawberries, oranges, avocados, and plums. Interestingly, 546 farms reported organic vegetable sales in California, compared to 1,539 farms reporting fruit sales. This indicates a relatively high number of small, organic orchards and vineyards in the state.

California leads the nation in all of the major crop categories defined by NASS except field crops. Most notably, California farms did not produce any organic soybeans, even though this crop had $50 million in sales nationally. The most important field crops in California are rice and hay, with $19 million and $16 million in sales, respectively, which represents 69% of all organic rice and 15% of organic hay sold in the United States.

Livestock, poultry, and products. The most important organic livestock commodity for California and the nation is milk from cows (Table 4). Production of organic milk from cows was reported in 37 states and over 2,000 farms. California is the leading state with $134 million in sales reported from 92 farms, followed by Wisconsin at $85 million in sales from 479 farms. Sales figures for Colorado, another large organic milk producer, could not be disclosed due to confidentiality restrictions that could otherwise reveal the income of the three farms reporting sales.

Broiler chickens are the second most important organic livestock commodity in California, posting $129 million in sales, two-thirds of all U.S. sales, from only 17 farms. California also produces 20% of organic eggs, with $30 million in sales from 80 farms. Pennsylvania is the next most important state for both broiler chickens and egg production.

Production Challenges

Survey participants were asked what they considered to be their primary challenge as an organic farmer. The most important challenge identified by organic farmers in California was regulatory problems (38%)(Table 5). These include paperwork and record-keeping for certification, inspections, finding a certifier, and the cost of certification. Also, in California, unlike any other state, any farm marketing its product as organic is also required to register with

Table 3. Top Twenty California Organic Crops

Commodity	Farms	Acres	CA Sales	U.S. Sales	CA%
			--$ Millions--		
Lettuce	190	33,431	174.9	186.6	94
Grapes	525	22,762	110.9	122.2	91
Strawberries	117	1,178	40.1	43.7	92
Tomatoes	274	6,854	36.0	59.4	61
Spinach	100	6,882	32.0	37.4	86
Broccoli	111	4,289	30.2	33.2	91
Celery	44	1,443	26.2	27.1	97
Sweet Potatoes	16	2,749	20.6	24.7	84
Rice	73	15,068	18.9	27.5	69
Oranges	269	3,778	17.4	22.7	77
Cauliflower	66	1,859	16.8	17.7	95
Hay	109	28,778	15.7	107.8	15
Avocados	284	3,556	14.9	15.2	98
Onions	108	1,342	13.4	33.6	40
Fresh Herbs	93	4,661	13.0	27.4	48
Almonds	95	4,934	12.5	12.5	100
Plums/ Prunes	133	3,067	11.5	11.9	96
Raspberries	59	284	11.4	12.9	89
Walnuts	205	4,279	11.1	11.2	99
Potatoes	106	1,977	10.5	30.0	35

the state Organic Program, administered by the California Department of Food and Agriculture, and pay annual registration fees, in addition to the cost of certification by a third-party certifier. Despite this additional regulatory burden in California, organic growers in California were only slightly more likely to indicate regulatory problems as their primary challenge than organic farmers in the United States as a whole.

About one-fourth of organic farmers in California said that price issues (low premiums, lack of price information, or inconsistent prices) or market access (too much competition, not enough volume produced, or lack of buyers) were their greatest challenge. Contrary to popular perception, production problems fell below regulatory and market issues as the major challenge to organic farms (Table 5). Arguably, this reflects the efficacy of organic farming practices, availability of information, and access to organic inputs.

Marketing Practices

The vast majority of organic sales from California farms (81%) are made to wholesalers. Three-quarters of sales to wholesalers are made to a processor, distributor, wholesaler, or broker. The rest are sold to retail chain buyers, other farms, or grower cooperatives. Only 7% of organic sales are made directly to consumers. Almost three-quarters of the direct sales are either on site (farm stands or U-pick operations) or at farmers' markets. Other direct-to-consumer outlets include mail order and Community Supported Agriculture, where consumers typically pay a monthly fee and receive a weekly box of products from the farm.

The remaining 14% of California's organic sales are direct to retail, primarily natural food stores and conventional supermarkets. Direct sales to restaurants, hospitals, and schools make up only a small part of direct sales to retailers. The first point of sale for half of organic sales in California was within 100 miles of the farm. Of course, this included sales to wholesalers who may subsequently ship out-of-state or internationally. The first point of sale is direct to an international buyer for only 2.5% of organic sales.

Farm and Household Income from Organic Sales

Respondents were asked what percent of the total market value of production from their farms is comprised of organic sales. In essence, this is a measure of the percent of farms that are 100% organic, versus mixed operations that have both organic and conventional production. The results show that in California, almost two-thirds of all farms with organic sales are 100% organic and the other third are "mixed" operations (Figure 2). This does not shed light on what percentage of total organic sales is from 100% organic operations, unfortunately.

Table 4. Organic Livestock, Poultry, and Products—CA and U.S., 2008

Commodity	Farms	CA Sales	U.S. Sales	CA %
		--$ Thousands--		
Livestock and Poultry				
Total	191	145,749	316,470	46
Chickens, Broilers	17	129,171	195,817	66
Milk Cows	96	3,984	33,466	12
Turkeys	8	2,670	8,675	31
Beef Cows	56	433	6,141	7
Goats	36	41	229	18
Sheep & Lambs	35	26	970	3
Chickens, Layers	102	*d*	2,197	
Hogs & Pigs	17	*d*	3,945	
Livestock and Poultry Products				
Total	181	163,868	906,207	18
Milk from Cows	92	133,505	750,149	18
Chicken Eggs	80	30,342	154,817	20
Wool	11	8	35	21
Goat Milk	4	*d*	801	
Mohair	4	*d*	3	

d- information not reported to protect confidentiality

Respondents were also asked what percentage of their net household income came from organic

Figure 1. Farmgate Sales by Commodity Group, CA and the U.S., 2008

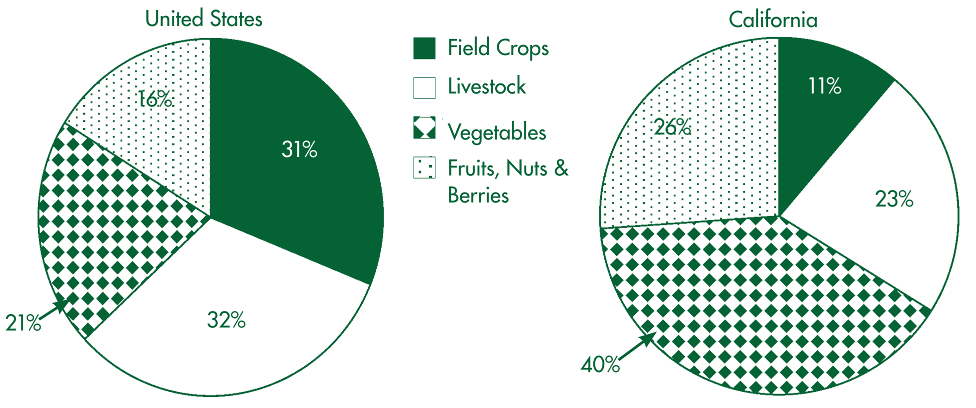
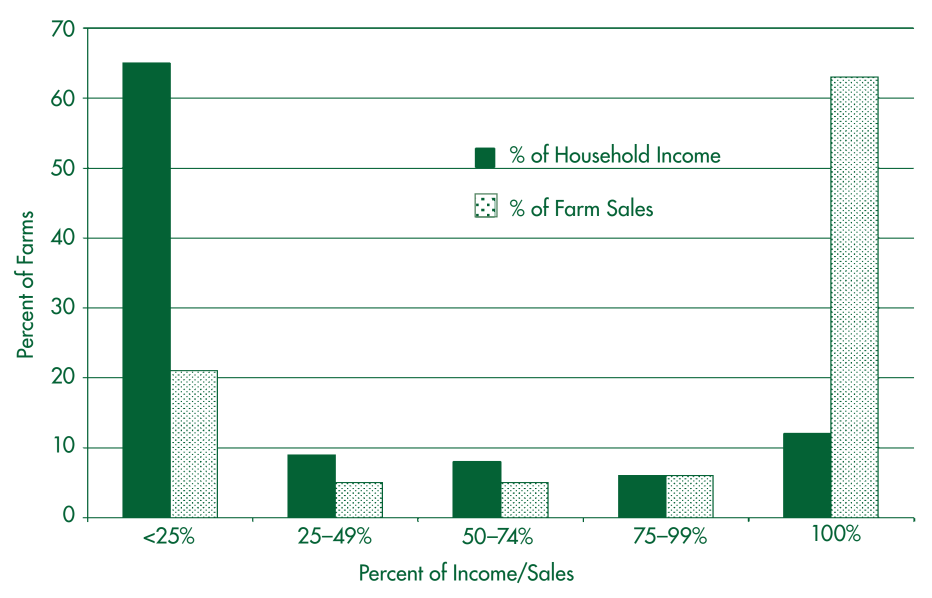


Table 5. Production Challenges for Organic Farms in CA and the U.S.—Percent Reporting in 2008

	CA%	U.S.%
Regulatory Problems	38.1	35.1
Price Issues	14.3	10.3
Production Problems	19.1	19.7
Market Access	10.0	9.9
Management Issues	8.7	12.8

Figure 2. Percent of Net Household Income from Organic Sales and Percent of Gross Farm Income from Organic Sales



sales. In this case, two-thirds of the farms reported that less than 25% of their household income came from organic sales. Only 12% said that all of their household income was from organic sales (Figure 2).

Five-Year Production Plans

Respondents were asked about their five-year production plans with respect to organic production. Only 1% said they were getting out of farming altogether and 14% said they didn't know their plans. Another 3% said that they were going to discontinue organic production and another 5% of the farms planned to decrease production. The rest were either planning to increase production (32%) or maintain their current level (44%).

Implications

The first Organic Production Survey follow-up to the most recent Census of Agriculture reveals California's dominance in organic production. California is most prominent in fruit, vegetable, nut and berry production, with lettuce and grapes being the highest revenue crops. California is also the top producer of livestock and livestock products, with broiler chickens and milk from cows the most important commodities. Despite the dominance of these four commodities, the results reveal an extremely diverse subsector. Virtually all of the commodities produced conventionally in California are also produced organically.

About one-third of the farms classified themselves as mixed operations with both organic and conventional production. This implies that the organic market is an important opportunity for diversification for many conventional California farms. The vast majority of respondents also pointed to plans to maintain or expand their organic production, indicating that the subsector is financially healthy despite the economic downturn in the United States. However, it is unlikely that many "mixed" operations are moving towards becoming entirely organic. Rather, organic continues to be a niche market, albeit a profitable one.

The dominance of wholesale outlets both in California and the U.S. as the first point of sale suggests a complex marketing structure for organic production and dispels the image of organic products being sold primarily at farmers markets and roadside stands. The survey results also challenge the perception that organic farms face their greatest challenges at the farm production level. In fact, the responses imply that organic farming practices are well developed and that access to information on organic practices and availability of organic inputs are not crippling constraints. The body of research on organic production, delivery of information, and available technical assistance seem to be keeping up with grower needs.

Instead, organic farmers in California and the United States point to regulation as their greatest constraint, with added record-keeping and expenses for certification and registration. The implications are that the USDA certification cost-share program for organic farmers is critical to many organic growers for staying in organic production. Further, the continued effort of the National Organic Program to modify, clarify, and communicate organic regulations is essential to the continued growth of the organic industry.

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