Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA
V. 14 no. 2 • Nov/Dec 2010

Agricultural Biotechnology Can Help Mitigate Climate Change

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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.

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

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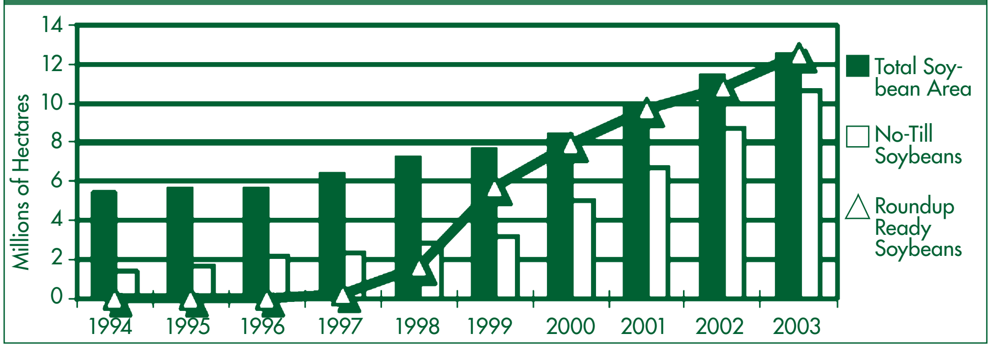
Figure 1. Soybean Area in Argentina: Total, No-Till, and Roundup Ready



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.

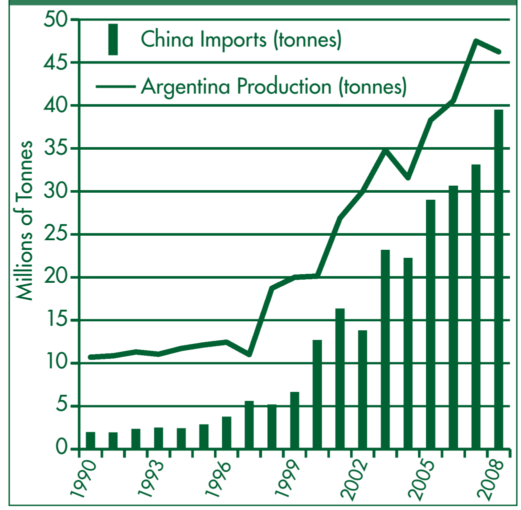
Determining the carbon emissions savings from avoided land conversion, whether due to yield gains or double-cropping, is difficult for several reasons. First, general equilibrium effects would offset the demand for new land in the absence of GE seeds. For instance, food prices would rise, reducing demand 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.

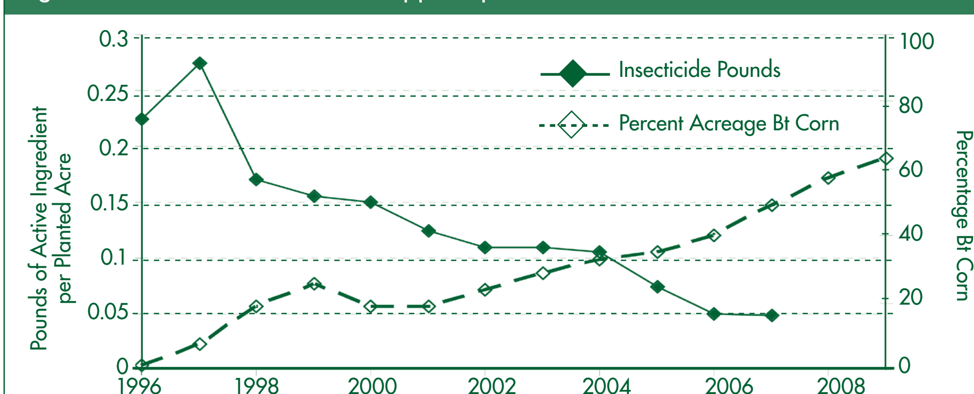
Figure 2: Soybean Production in Argentina and Imports in China



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 soybean—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.

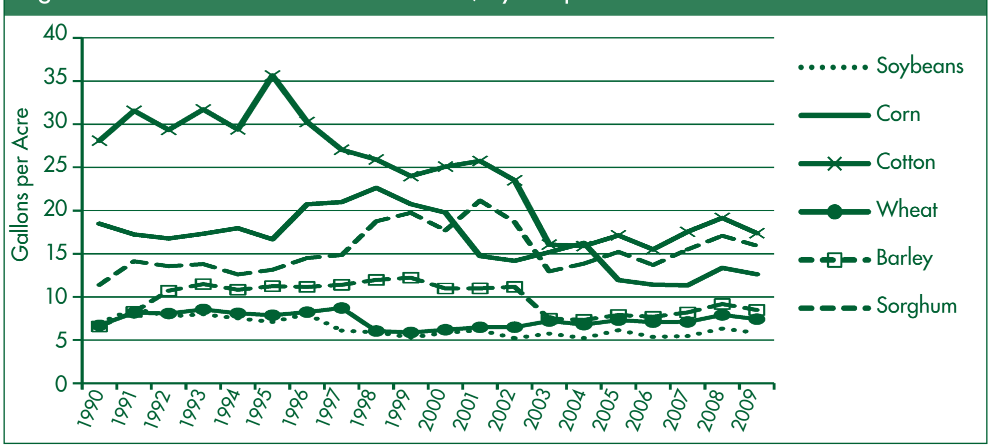
Possible Offsetting Carbon Emissions from GE Seeds

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.

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.

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



Suggested Citation:

Sexton, S. and D. Zilberman. 2010. "Agricultural Biotechnology Can Help Mitigate Climate Change" *ARE Update* 14(2):1-4. University of California Giannini Foundation of Agricultural Economics.

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For additional information, the authors recommend:

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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.