Are There Yield Benefits With Genetically Engineered Corn?

Colin A. Carter, Xiaomeng Cui, and Dalia Ghanem

A New York Times article entitled "Broken Promises of Genetically Modified Crops," recently showed that U.S. and Western European corn yields have followed similar trends over the past two decades. This was taken as evidence that genetically modified (GM) crops have no yield benefits, since most of Western Europe does not grow GM corn. We believe this conclusion is inaccurate because the yield comparison is flawed.

Genetically modified (GM) crops (developed through the application of biotechnology to agriculture) are currently grown on more than 460 million acres worldwide, including about 175 million acres in the United States. Most of the global area sown to GM (or genetically engineered) crops is devoted to corn, soybeans, cotton, and canola. This relatively new technology has tremendous potential for agriculture because it introduces desirable traits into plants and produces new varieties of plants more quickly and efficiently than traditional plant breeding. Furthermore, genetic engineering can develop plant traits that could not be achieved through traditional plant breeding.

Even though enhanced global food security is somewhat dependent on the uptake of GM crops, the technology remains controversial. The U.S. has rapidly adopted certain GM crops (including corn, soybeans, cotton, and sugar beets), but the European Union has slowed the introduction of biotech crops in Europe and elsewhere. In particular, the Europeans have discouraged developing countries from adopting GM technology. This goes against the wisdom of the late Dr. Norman Borlaug, agronomist and Nobel Peace Prize laureate, who argued that global food insecurity will not disappear without this new technology.

One of the various benefits associated with genetically modified organisms (GMOs) is the expectation of higher yields, largely due to better pest and weed control. This is due to the fact that some GMOs are resistant to herbicides (i.e., weed control) and some are resistant to insects (i.e., pest control). An article in the New York Times (NYT) last year, "Broken Promises of Genetically Modified Crops," questioned whether GMOs actually help improve global food security by raising crop yields. This piece by Danny Hakim argued that GMOs have not boosted crop yields in the United States, a conclusion that was reached by visually comparing corn yield trends in the U.S. to those in Western Europe and judging that the two trend lines are very similar.

To be fair, Hakim also drew support from a 2016 National Academy of Sciences (NAS) report, which found little evidence that U.S. corn yields increased at a higher rate after GMOs were introduced, compared to before. The NYT claim that the adoption of GMOs has failed to improve yields is partly based on the data shown in Figure 1 below, which reports average corn yields in the U.S. and Western Europe from 1985 to 2014.

GM corn was first grown in 1996 and by 2006 it accounted for over 50% of the U.S. corn plantings. The date of introduction of this technology is shown on Figure 1, but keep in mind that the GM corn adoption rate did not reach 80% in the U.S. until about 2008.

At face value, the two solid plotted lines in Figure 1 suggest that GMO adoption did not alter the trend line in average corn yields, as there is not much difference between the trend lines in Western Europe and in the United States. However, this does not imply that a difference in trends, or lack thereof, could be attributed solely to GMO adoption.

Surprisingly, the yield analysis in the NAS report was no more sophisticated than what subsequently appeared in the NYT article. While the NYT compared U.S. against European yields, instead the NAS publication

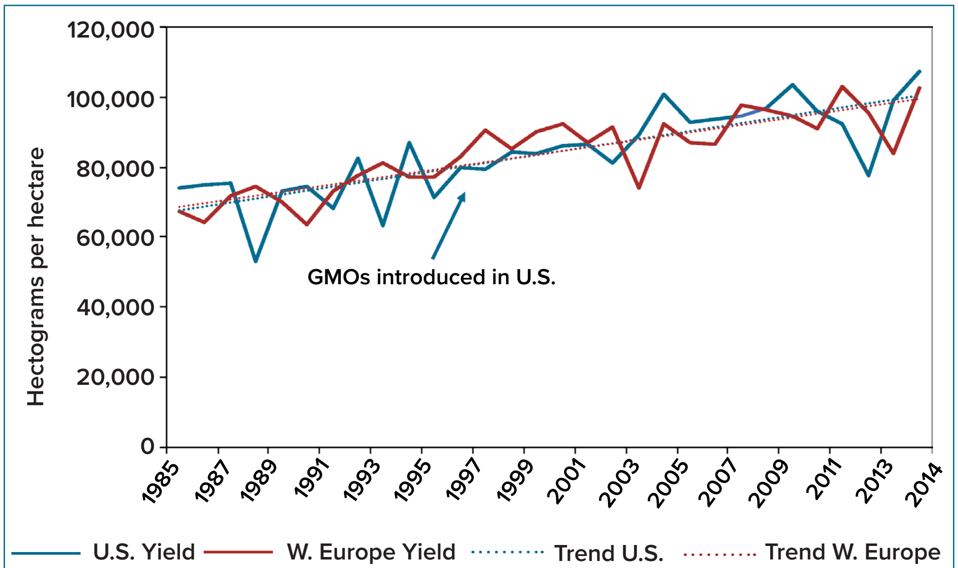

Figure 1: Historical Corn Yields in the United States and Western Europe, 1985–2014

Source: Compiled from FAO data

examined U.S. crop yields before and after the introduction of GM corn in 1996. Slightly different approaches, but both were visually looking for a change in trends without controlling for any other yield-related factors that may have been changing at the same time.

The figure used in the NAS study is reproduced below as Figure 2. The NAS described their visual inspection of Figure 2 as showing that after the introduction of GM traits in the U.S., yields remained on the same linear trend line as before. This may be true, but it is not a serious attempt to answer the question of whether or not genetic engineering has boosted yields.

In other words, the NAS report merely looked for a change in the slope of the trend in yields after 1996, for some evidence that genetic engineering caused an increase in yields. The NAS authors saw no change in the slope of the trend line in Figure 2 and then they improperly concluded that it implied that there was no evidence that GMOs have improved yields.

A Similar Trend is Not Evidence of Causal Effects

In order to make a claim about the causal effect of GM crop adoption in the U.S., we must know the counterfactual, i.e., what would have happened to U.S. corn yields if GMOs were not adopted. Of course, we cannot observe this counterfactual. So in practice, as the NYT article did, we could use other countries as a "control group" that can provide such a counterfactual.

For an accurate comparison, this control group should have the same farming practices, corn varieties, soil quality, acreage trends, percent of irrigated corn fields, weather, and climate trends—simply everything that could affect yield has to be the same in this control group as in the U.S., except for GMO adoption. The question that we raise is whether Western Europe constitutes an appropriate control group for the U.S. in the case of corn yields.

In the United States, over 92% of the corn acreage is now planted to GMOs. Beginning in the late 1990s, the rate of GM corn adoption was 50% by 2005, 80% by 2008, and 90% by 2013, with both herbicide tolerant (HT) and insect resistant (IR) traits.

Although most corn in Western Europe is non-GMO, Spain has adopted GM corn varieties since 1998. Approximately 25% of the corn acreage in Spain is devoted to GM corn, and Spain accounts for almost 20% of total corn production in Western Europe. Therefore, Western Europe violates the basic definition of a control group, since some of its corn is produced using GM seeds that are insect resistant (also known as Bt corn). In addition to Spain, Portugal also plants GM corn and about 10 years ago France grew a limited amount of GM corn.

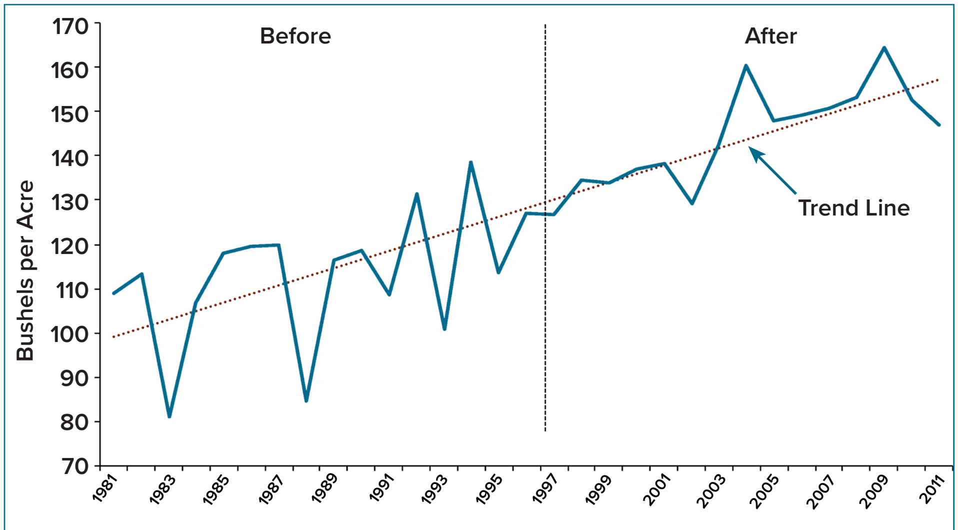

Figure 2: Historical Corn Yields in the United States, 1981–2011

Source: United States Department of Agriculture, National Agricultural Statistics Service

Another issue associated with comparing the U.S. to Western Europe is that Europe does not use the same corn varieties as in the United States. The germplasm in European corn varieties may differ from that in the U.S. varieties, and improvements in germplasm through plant breeding is largely a separate issue from the insertion of genetic material into existing germplasm through genetic engineering. Therefore, any comparison of yield trends should control for genetic improvement of the varieties over time, separate from the role of biotechnology.

We know that any yield improvement for corn could be attributed to either plant breeding and/or genetic engineering. Of course, it is possible that GMOs do not boost yields if weeds or insects are not a problem. Since GMOs allow for zero or minimum tillage, this could also raise yields compared to conventional corn, due to soil moisture conservation.

It is also important to note that Western Europe is a relatively small producer of corn, compared to the United States. Farms are much smaller in Europe and crop-input intensity is higher. The added intensity will enhance yields in Europe. In addition, U.S. corn acreage expanded from 66.8 million acres in the early 1990s to around 86 million acres recently, an increase of over 19 million acres. Over the same time period, corn acreage in Western Europe went from 5.6 to 6.4

million acres, an increase of only 0.8 million acres. Therefore, comparing "average" yields in these two regions is like comparing apples to oranges.

Most corn expansion in the U.S. occurred in the northern region, like the Dakotas. The colder climate in these areas limits the total amount of heat accumulated over a growing season, which is expected to result in lower corn yields than in the Corn Belt. Furthermore, the large expansion of U.S. corn acreage is likely to bring more marginal land into production and lead to changes in crop rotations, which can put downward pressure on corn yields.

The U.S. and Western Europe have also experienced very different weather trends over the time period that GMOs have been grown. Figure 3 plots growing season temperature and precipitation trends in the U.S. Corn Belt, France, and Spain. The top panel shows temperature trends. Even though there was considerable year-to-year fluctuations in temperature, Figures 3 shows that there was a warming trend in France.

On average, the (growing season) temperature is now about 0.50°C higher than what it was in the mid-1990s. A warmer France would be favorable for corn yields, especially since the absolute temperature in France is relatively low. In comparison, Spain and the U.S. Corn Belt had much smaller temperature changes—about 0.25°C in Spain and 0.20°C in the U.S. Corn Belt.

Precipitation trends shown in Figure 3 are relatively stable, but they do show that, on average, France and Spain have received less rainfall during the growing season since 1996. Alternatively, the U.S. corn belt has become wetter, receiving more annual rainfall, on average, than what it received two decades ago. The difference is about 2 inches. Given the importance of temperature and precipitation for corn yield, any analysis of the yield impact of GMO adoption should control for weather patterns.

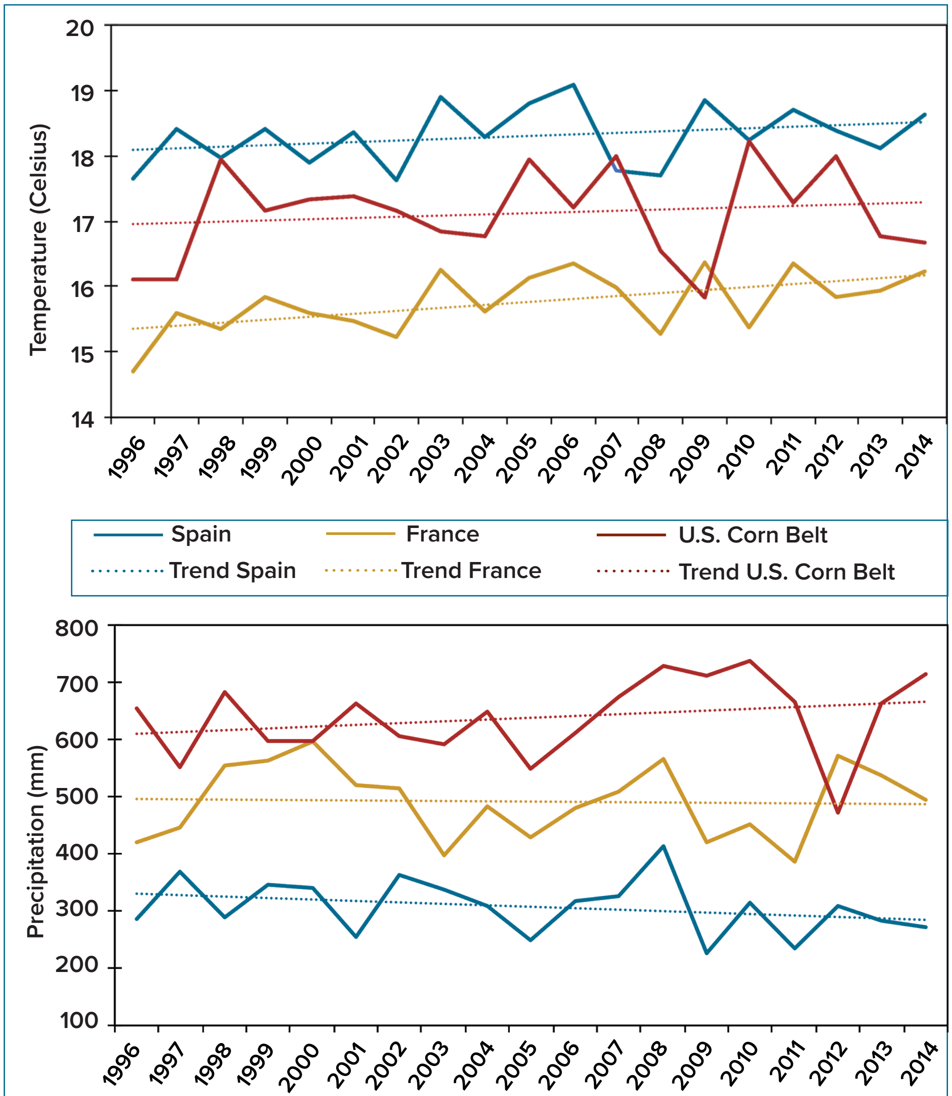

Figure 3: Temperature and Precipitation Trends in the U.S. Corn Belt, France and Spain: Growing Season

Source: World Bank for Europe data and U.S. data from NOAA

For all of the above reasons, a simple comparison of yield trends in the U.S. and Western Europe as shown in Figure 1 does not provide credible evidence regarding the effect of GM adoption. A more reliable approach would be to compare GM-adopted and GM-free counties (or provinces in Spain). However, even in this case, without accurate information on soil quality and other differences between counties, such a comparison may overlook important confounding factors.

Turning back to the NAS report and their before and after comparison, many of the above comments directed at the NYT piece apply to NAS because other factors (such as the weather) may have changed in the before versus after time periods. For instance, NAS implicitly assumed that pest and weed pressure was identical before and after 1996, which may or may not be true. In other words, NAS did not account for the possibility that GM technology could have reduced pest or weed-associated yield losses.

If this were the case, it would be a yield benefit that can be attributed to genetic engineering. The NAS conclusion is based on the assumption that yield trends would have stayed the same in the absence of GM adoption. This is fundamentally unsubstantiated for all the aforementioned reasons.

Measuring the Causal Effect of GM Adoption

The ideal setting to answer the yield question is a situation where we can compare counties or provinces over time, some of which adopt GM and others that do not. By observing the same regions before and after GM adoption, we could control for factors that may change over time. Furthermore, we could use counties or provinces that never adopted GM to identify the change in crop yields in the absence of GM adoption.

A similar approach was used in a study conducted at Iowa State and Purdue University that found GMOs may have indeed increased U.S. yields. After netting out the effects of weather (temperature and precipitation), the adoption of GM corn was found in that study to be associated with a 17% yield increase (about 18 bushels per acre) in the United States.

This implies that the U.S. corn belt experienced unusually good weather for a period before GM varieties were adopted (i.e., the mid-1980s to mid-1990s), increasing the yield trend during that time period. However, this estimate of an 18 bushel/acre gain has a large confidence interval, ranging from 5 to 25 bushels. In other words, the yield gain could be as low as 5 bu/acre or as high as 25 bu/acre; hence, the exact magnitude of the effect is not precisely estimated.

The issue of GMO adoption and its impact on yields and other aspects of agricultural production is an important question, the answer to which can inform policy makers worldwide. However, there are many practical difficulties in measuring the causal effect of genetic engineering on yields. For instance, adoption rates are not necessarily recorded at the county-level, which can lead to substantial aggregation bias.

Furthermore, there are many different GM varieties typically tailored to specific locations that might have different benefits. Hence, without precise information on the GM seeds used and their expected benefit, it is difficult to interpret the yield effects of GMO adoption. Finally, GMO technology is meant to minimize crop failure and that is a potential benefit that should also be measured.

Conclusion

Genetically modified crops offer certain advantages over conventional varieties, such as reduced chemical load on the environment and reduced soil tillage. In addition, they may provide a yield advantage. It is not a simple task for an analyst to separate the effects of GMO traits from the effects of conventional plant breeding on yield. Yet some have assumed it is a simple exercise and they have questioned the yield advantage by examining simple national average yields in the United States or compared U.S. versus European yields.

We have shown that any conclusion from simple yield comparisons is unreliable for a number of reasons. We highlight this problem because the yield advantage is an important issue. The world's population is expected to increase by over 2 billion by 2050. The upward trend in population and accompanying urbanization will put increasing pressure on farmers to expand production, and the latest technology, including genetic engineering, will be required to meet the growing food demand.

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AUTHORS' BIOS

Colin Carter is a distinguished professor, Xiaomeng Cui is a PhD candidate, and Dalia Ghanem is an assistant professor, all in the ARE department at UC Davis. They can be contacted by email at cacarter@ucdavis.edu, ecui@ucdavis.edu, and dghanem@ucdavis.edu, respectively.

For additional information, the authors recommend:

"Broken Promises of Genetically Modified Crops" https://www.nytimes.com/interactive/2016/10/30/business/gmo-crops-pesticides.html

"Genetically Engineered Crops: Experiences and Prospects." National Academies of Sciences, Engineering, and Medicine. 2016. Washington, DC: The National Academies Press. doi: 10.17226/23395