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Lecture

Evaluating the Contribution of Genetically Engineered Traits to Crop Yield: Adoption or Alternatives for Agricultural Policy?

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Session

Reality Checks

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Increasing food prices, inadequate food distribution, rapid population growth and poverty - and more recently, climate change - are all central issues for global food production. While agricultural research has long been focused on the goal of increasing yields, effective and sustainable means to increase crop productivity can be highly context dependent in different growing regions and socioeconomic conditions. Genetic engineering (GE) of crop plants has been promoted as an important means for dramatically improving the yields of staple food crops, and has enjoyed widespread public perception as an important means for improving yields. Teasing apart the contribution of the different variables that affect crop productivity has rarely been considered in evaluating the way forward in agriculture. A recent investigation has attempted to understand the contribution of genetic engineering to increases in crop yield.

The report *Failure to Yield* (Gurian-Sherman 2009) shows that, despite tremendous effort and expense, genetic engineering (specifically looking at soy and maize productivity) has only succeeded in measurably increasing the yield of one major food or livestock feed crop in the USA - and this contribution has been small compared with other methods available. Based on this report, it seems that data to date on GE's contribution to yield has not justified the massive investment of resources that has gone into their research and development. In this presentation, the findings in *Failure to Yield,* based on over a decade of cultivation and dozens of studies on yield from the USA, will be discussed. The report draws four distinct, empirically based conclusions:

1. Genetic engineering has not increased intrinsic yield.

No currently available transgenic varieties enhance the intrinsic yield of any crops. The intrinsic yields of maize and soybeans did rise during the twentieth century, but not as a result of GE traits. Rather, they were due to successes in traditional breeding.

2. Genetic engineering has delivered only minimal gains in operational yield.

Herbicide-Tolerant Soybeans and Maize. Although not extensive enough to develop precise yield estimates, the best data show that transgenic herbicide-tolerant soybeans and maize have not increased operational yields, whether on a per-acre or national basis, compared to conventional methods that rely on other available herbicides. Given that herbicide-tolerant soybeans have been so widely adopted suggests that factors such as lower energy costs and convenience also influence farmer choices, and may produce benefits unrelated to yield.

Bt Maize to Control Insect Pests. Combining the values for Bt European corn borer maize and Bt rootworm maize gives an estimated operational yield increase from the Bt traits of 1.3–5.5 percent. An increase of about 3.3 percent, or a range of 3–4 percent, is a reasonable intermediate. Averaged over the 13 years since Bt maize was first commercialized in 1996, this equates roughly to a 0.2–0.3 percent yield increase per year.

[1] in cooperation with Dr. Doug Gurian-Sherman, Union of Concerned Scientists, USA

3. Most yield gains observed are attributable to non-genetic engineering approaches.

In the past several decades, overall maize yields in the United States have increased an average of about 1 percent per year, or considerably more in total than the amount of yield increase provided by Bt maize varieties. More recently, U.S. Department of Agriculture data indicate that the average maize production per acre nationwide over the past five years (2004–2008) was about 28 percent higher than for the five-year period 1991– 1995, an interval that preceded the introduction of Bt varieties - an average of close to 2 percent per year[2]. But our analysis of specific yield studies concludes that only 3–4 percent of that increase is attributable to Bt, meaning an increase of about 24–25 percent must be due to other factors, such as conventional breeding and the number of maize plants per unit area. Yields have also continued to increase in other major crops, including soybeans (which have not experienced increases in either intrinsic or operational yield from GE) and wheat (for which there are no commercial transgenic varieties). Comparing yield increase over recent intervals, the increases were about 16 percent for soybeans and 13 percent for wheat. Overall, as discussed above, GE crops have contributed modestly (at best) to yield increases in U.S. agriculture in comparison to that provided by breeding practices.

4. Experimental high-yield genetically engineered crops have not succeeded.

Several thousand experimental GE-crop field trials have been conducted since 1987. Although it is not possible to determine the precise number of genes for yield enhancement in these trials (given the confidential-business-information concerns among commercial developers), it is clear that many transgenes for yield have been tested over the years. Despite these efforts, still only the Bt and herbicide-tolerance transgenes and five transgenes for pathogen resistance have been commercialized on limited acreage, and only Bt has had an appreciable impact on aggregate yields[3].

What Are Genetic Engineering's Prospects for Increasing Yield?

Genetic engineers continue to identify new genes that might raise intrinsic and operational yields. How likely is it that these genes will produce commercially viable new crop varieties? Given the variety of transgenes tested, it would expected that some of them may eventually be successful in increasing yield. But in light of their biological and physiological complexity, and their unpredictable side effects, it is uncertain how many will become commercially viable, and their past track record for bringing new traits to market suggests caution in relying too heavily on their success. To summarize, the only transgenic food/ feed crops that have shown significant improvement to yield in the USA are varieties of Bt maize, and they have contributed gains in operational yield that were considerably less over their 13 years than other means of increasing yield. Further, the emerging evolution of resistance by the target pest (Tabashnik et al. 2009) – prompting some farmers to spray pesticides on their Bt crops - suggests that this effect may be short lived.

[2] Operational and intrinsic yields cannot be distinguished in these aggregate yield numbers.

[3] Virus-resistant GE papaya has prevented substantial yield loss, but it is grown only on several thousand acres in Hawaii and therefore has not contributed significantly to overall agricultural yield in the United States.

Discussion: Alternative approaches to increasing yield

Given the large investment and little return by GE to significantly improve crop yield, it may be time to look more seriously at the other options in the agricultural toolkit. In order to invest wisely in the future, we must evaluate agricultural tools to see which ones hold the most promise for increasing intrinsic and operational yields and providing other resource benefits. Several recent studies have shown that low-external-input methods such as organic can improve yield by over 100 percent in these countries, along with other benefits (Badgley et al. 2007). Such methods have the advantage of being based largely on knowledge rather than on costly inputs, and as a result they are often more accessible to poor farmers than the more expensive technologies (which often have not helped in the past). Meanwhile, conventional breeding methods, especially those using modern biotechnology approaches (often called marker-assisted selection and distinct from GE), have the potential to increase both intrinsic and operational yield. Also, more extensive crop rotations, using a larger number of crops and longer rotations than current ecologically unsound maize-soybean rotations, can reduce losses from insects and other pests.

Implications and future options

Where can investment of R&D in agriculture yield the most benefits and fraught with the fewest risks and regulatory burden? What types of agricultural development can lead to the most sustainable solutions in a given context? What access, ownership and stewardship regimes will most contribute to future food security? The evidence reaffirming the importance of breeding and genetic diversity of crop plants should put the effects of consolidation of access and ownership of the world's crop genetic diversity clearly as a priority issue for national and international agricultural policy. Therefore, putting too many of our crop-development eggs in the GE basket could lead to lost opportunities. National, state and local agricultural agencies, and public and private universities should consider redirecting substantial funding, research, and incentives toward approaches that are proven and show more promise than genetic engineering for improving crop yields, especially intrinsic crop yields, and for providing other societal benefits. These approaches include modern methods of conventional plant breeding as well as organic and other sophisticated low-input farming practices. Improving the genetic basis of yield increase and maintenance of genetic diversity, through breeding and selection (which may or may not include biotechnology) will likely be essential for sustainable crop production.

Biotechnology will undoubtedly have a distinct role to increase future crop yield, but the evidence to date suggests that genetic engineering (as only one form of biotechnology) is not likely to contribute substantially to sustainable or predictable benefits to yield. Given the uncertainties of climate change and in the sustainability of dominant models of agriculture, it seems that traditional breeding and selection still possesses the greatest capacity to ensure both a sustainable and productive global food harvest for the foreseeable future.

References

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