**DO GENETICALLY MODIFIED ORGANISMS IN AGRICULTURE WORK?**

*The case of corn*

Everyone has an opinion about food. What we should grow, how we should grow it, how much of it should we eat, and, most pressingly, how we plan to feed 9 billion people in 2050. For the very reason that food is one of the most unifying features of the human experience, it is also the most divisive.

At the center of food-related controversy in the 21st century are genetically modified organisms (GMOs) -- biological organisms with genomes intentionally altered by humanity. On any part of the political spectrum, you will find people with strong feelings against GMOs: they’re unsafe, unethical, unholy, ineffective, or “it just doesn’t feel right”. Perhaps the only group consistently advocating for GMOs (aside from the CEOs of big agricultural companies with billions of dollars at stake) are the scientists fueling the advancement of this technology. Personally, I find myself torn on GMOs in my food: as a molecular geneticist, I want to advocate for the utility and promise of a technology I know so intimately; but as a food-eating human, I am empathetic to the “it just doesn’t feel right” sentiment. Food is sacred and adjusting our relationship to what we eat should not be taken lightly.

Given the sanctity of food, many of these GMO-related concerns deserve our honest thought and consideration. However, it seems most sensible to me to start with the question: do GMOs in agriculture actually work? That is to say, **do GMOs improve the state of agriculture WITHOUT compromising our environmental values (e.g., maintaining biodiversity, minimizing spillover into non-agricultural land)?** Only if GMOs are in fact a technical improvement to our food system should we then confront the underlying ethics and more visceral concerns over genetically modifying what we eat. In other words, if GMOs don’t actually work, then why spend our time wrestling with the harder, philosophical questions?

I’ve found that answering whether GMOs actually work is not as easy as one would hope. In the scientific literature, there are countless studies published in glossy journals that have assessed the efficacy of GMOs but, at the scale of individual studies, it is difficult to ascertain general truths and patterns. To understand the efficacy of a particular genetic modification in a particular crop grown in a particular part of the world, one should go to the scientific literature. These studies, however, will not give you the answer to the broad question of whether GMOs work. As I moved away from the scientific literature and towards news sources, I found GMO-related articles insufferably biased, as each one would pick out a couple citations that fit their agenda and then proceed to fill a page with overconfident paragraphs.

Frustrated by these two ends of the spectrum, I decided to do my own research and write my own narrative to hopefully land somewhere in the middle. I do not intend to make any rigorous claims of causation akin to what can be found in the scientific literature, nor do I hope to persuade a reader of one side with persistent arguments as in news articles, but instead to use broad, quantitative patterns to illustrate a narrative of how our food systems have changed with the adoption of GMOs. I believe it is with this birds-eye view that we are best-suited to form an opinion of our own because, whether you like it or not, as you’ll see, our food is becoming only more genetically modified.

***The case of corn***

As mentioned above, answering the question of whether GMOs work is complicated in part since there isn’t just one type of genetic modified crop -- there are many crops that are genetically altered in many ways. To account for the diversity in GMOs while also maintaining broad and general applicability, I’ve decided to focus my efforts on genetically engineered (GE) corn grown in the US. Corn is an ideal model crop for my purposes because 1) most Americans consume or use US-grown corn on a regular basis (an unfortunate fact of the high-fructose corn syrup phenomenon), 2) corn farmers have widely adopted genetic engineering in the past two decades, and 3) the United States Department of Agriculture (USDA) makes corn agriculture data publicly available on their website. I was thrilled to come across these data posted by the USDA, and I recommend anyone interested in agriculture to utilize this resource. Most of the data presented in this paper can be found in some format on the USDA website, although I’ve improved the interpretability here by combining related datasets and emphasizing the relevant trends.

***Have agricultural outputs increased since the adoption of GMOs?***

We are primarily interested in whether GMOs have in fact improved the efficacy of agriculture. Do GMOs allow us to feed more people with the same or less resources dedicated to agriculture? This question is of fundamental importance for a human population rapidly approaching its carrying capacity.

The first plot shown below has US corn yield (bushels/acre) plotted for each year going back to the mid 19th century, with each point/year colored according to the percentage of corn planted that was genetically modified. The first pattern that struck me was the consistency of corn yields for almost a century (~1850-1945) followed by an explosion in corn yields in the mid 20th century. Placed within the context of 20th century history, this massive increase in corn yields aligns with the advent of steam engines and large-scale chemical synthesis technologies that allowed for industrial agriculture. Although I may have expected this general pattern, I did not expect to see that corn yields have unwaveringly increased at about the same rate since the mid 20th century (keep in mind that the y-axis controls for increases in land dedicated to agriculture). The industrial/technological agricultural revolution that took place in the mid-20th century did not just produce increased yields, but, more importantly, initiated a rate of “progress” (i.e. the increase in corn yields from the previous year) that has remained constant ever since.

How has the adoption of GE corn influenced the annual corn yields? As indicated by the legend, I’ve colored each point on a gradient scale according to the percentage of GE corn seed planted that year. Firstly, it never fails to shock me how quickly genetic engineering permeated agriculture: in the span of a decade farmers transitioned from planting little-to-no to near 100% GE corn. Secondly, throughout the period of time in which GE corn was rapidly adopted, the rate of yield increase remained the same as it Chart, scatter chart

Description automatically generatedhad the previous five or so decades. In other words, the slope of the line does not change with increased GE corn usage. Upon seeing this trend, the molecular geneticist in me was disappointed: GMOs had not *revolutionized* agriculture, at least in the case of corn. There is certainly something to be said about keeping up with the rate of yield increase, but an agricultural revolution would entail that line becoming consistently steeper (akin to the shift in 1945).

The answer to whether GMOs have in fact improved the efficacy of agriculture is, of course, not so straightforward. While GMO usage DOES correlate with an increased agricultural output, the rate of increase is no different from the previous five decades. These historical data from corn suggest that GMOs haven’t been revolutionary from the perspective of quantitative yield. However GMOs have arguably had greater impacts on *how* farmers grow corn crops, and the extent to which these new farming methods are, in our eyes, better or worse speaks directly to whether GMOs have improved agriculture.

***How has the adoption of GMOs altered agricultural practices? Do these alterations introduce or mitigate potentially negative consequences?***

For centuries, farmers have battled two main agricultural foes: herbivorous insects and resource-greedy plants (i.e. weeds). With the advancements of agricultural chemistry in the 20th century, farmers added chemical insecticides and herbicides to their arsenals and greatly improved their yields. Unfortunately, these increases in productivity came with a cost and clear negative side effects were eventually exposed by environmentalists. Most famously, Rachel Carson published ‘Silent Spring’ in 1962 documenting the negative effects of chemicals on non-human life and the environment. Environmental awareness has only grown since the publication of Silent Spring, and additional USDA data illustrates how GMOs have both appeased and exacerbated these environmental concerns.

*Insecticides*

Major environmental concerns over insecticides are mostly related to off-target effects on non-herbivorous insects. Many insects play vital roles in the human ecosystem (not to mention broader ecological roles), making it imperative for insecticides to solely target the undesirable insects. There are two ways for this goal to fail with chemical insecticides: 1) pesticide drift: when it is sprayed, there is some amount that drifts by wind to neighboring locations, and/or 2) pesticide runoff: the chemicals runoff the plants and into the soil, which can negatively impact organisms in the ground.

Chart, line chart

Description automatically generatedGE insecticides offer a clear solution to both issues. By engineering a crop, such as corn, to synthesize the insecticide compound within itself instead of requiring an external spray, both concerns are bypassed. The GE insecticide approach further benefits the farmer because they no longer must spend the time spraying their crops. Altogether, although the overall yields most likely wouldn’t drastically increase with the use of GE versus chemical insecticides, potential negative consequences are mitigated and farmer labor is reduced. With this in mind, we should celebrate the graph to the left, which shows the near complete transition from chemical (blue) to GE (red) insecticides in corn.

*Herbicides*

Compared to insecticides, the story of GE vs chemical herbicides is not as celebratory. The graph below (left panel) shows that herbicide usage steadily increased throughout the 20th century and now hovers close to 100%. Almost all corn grown in the US is sprayed with an herbicide. Why has chemical herbicide not fallen off since the adoption of genetic engineering as with insecticides? The answer lies in the type of herbicides used and their mechanism of action. The right panel of the graph shows the amount of one herbicide used - Glyphosate - versus all other herbicides from 1997 - 2007, which shows that Glyphosate has taken over. The reason for this is most likely due to GE corn that is resistant to Glyphosate, which allows farmers to spray the incredibly effective Glyphosate and only kill the weeds. On the one hand, herbicide usage is now much more effective and efficient for farmers to apply; on the other hand, the impact of GE corn on chemical usage is the exact opposite of insecticide: it has made chemicals even more effective. With this in mind, concerns about the effects of Glyphosate on human health make this effect of GMOs on agriculture particularly grim.

Chart, line chart

Description automatically generatedAvid anti-GMO critics often point to these patterns as evidence of GMOs being ineffective, a hoax, and a lie. On the face of it, they’re right. GMOs are often touted as a path for us to be environmentally conscious AND pragmatic about agricultural outputs, and yet, these trends suggest that is a false promise. However, I would not conclude that this is evidence to reject the technology, but rather evidence of a dysfunctional agricultural system. GMOs did what a new technology is supposed to do: improve upon a previous system. GM technology will only ever be as good as the system to which it is applied, and so the answer in my mind is NOT to denounce GMOs in this case, but to seek to improve our agricultural systems.

***The future of agriculture and the role of GMOs***

One thing is for certain: GMOs are not leaving agriculture. Other staple crops such as wheat and soybean have adopted a similar GM profile to corn and, going forward, more crops will follow suit and new modifications will be incorporated into the cocktail of mainstream modifications. Should we celebrate this outlook? What should we be concerned about? From just these few broad trends in GM technology uncovered above in U.S. corn, it’s clear to me that an all-embracing endorsement is not appropriate, nor is a flat-out rejection.

GM crops CAN improve agriculture – e.g. increasing yields or freeing up a farmer’s workday – but they also have the potential to exacerbate previous issues as well as introduce new ones. To ensure that GM technology does more to improve than to worsen agriculture (and more broadly, our societies), we need to start asking ourselves the hard questions, both practically and philosophically.

From a practical standpoint, the state of agriculture needs to be thoroughly evaluated. To this end, we can learn from the twentieth century, which experienced great technological advances followed by ethical pushback. The need to feed our population is omni-present, but we must figure out *how* to best do it. While the “right” way to do it will always be elusive, there are certainly many “wrong” ways that we should avoid as we continuously invent new technologies, such as genetic engineering.

Philosophically, we now must turn to the infinitely more difficult question: how should we feel about eating GM food? Are we tampering with areas of existence not worth altering? Will we further sever any emotional connection to the non-human world if we continue to view it through a utilitarian lens? These questions are hard because they don’t have answers to be unveiled by data, yet they are arguably most important to explore going forward.