10

Sustainable Food and Farming

When Public Perceptions Depart from Science

Robert Paarlberg

10.1 The Political Economy of Science Acceptance in Farming

The acceptance and use of agricultural science has a political economy all its own, one in which farmers and non-farmers often play opposing roles. Many non-farmers who tell us to “follow the science” when it comes to climate change and COVID-19 take the opposite approach when it comes to food and farming, complicating the global pursuit of food system sustainability. This chapter reviews four examples where critical public views emerged that were not supported by science: the Green Revolution, industrial farming, synthetic farm chemicals, and rDNA crops (GMOs). By looking at when the public misgivings emerged—either after a technology was in wide use or before— it is possible to explain why public views did or did not make a difference. GMOs were unique because they triggered public resistance almost immediately, before most farmers had a chance to plant GMO seeds and experience the on-farm benefits, making the technology easier to block.

In the past, resistance to modern science usually came from religious authorities, but this is no longer the case. The influence of religious authorities is much weaker today, partly because of the remarkable stream of material benefits science has been able to deliver (Harrison 2017). Science, however, can never replace religion, because it does not satisfy non-material human needs such as the quest for spiritual or ethical purpose. As alluded to in Chapter 2, values such as these can be just as important as material gain or scientific fact, and some values, such as respect for the natural world and social justice can actually raise new hurdles for science, since unregulated science or science in the wrong hands can damage the natural world and worsen social injustice.

Those motivated to protect natural landscapes, and to protect the vulnerable populations engaged in food production, can therefore mistrust agricultural science today. One central fear has been a replacement of nature’s resilient biodiversity with crop monocultures that are chemical-dependent and unsustainable. Another fear is the use of novel methods to alter the genetics of traditional crops and animals, methods of uncertain safety that are mistrusted by non-scientists.

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Protecting the natural environment first emerged as a powerful social movement only a half-century ago. Prior to 1970 there was no Environmental Protection Agency in the United States, and nobody had celebrated an Earth Day. In Europe, Green Parties and advocacy organizations like Greenpeace and Friends of the Earth did not yet exist. The United Nations did not create its Environment Program until 1972, and the first Earth Summit in Rio de Janeiro did not take place until 1992. Today, driven by the universal and accelerating threat of climate change, environmental advocacy has become a fully institutionalized trans-national social movement, with no fewer than 679 separate environmental non-governmental organizations (NGOs) now participating formally in the UN's Rio Conventions. Media-savvy and deeply networked with each other, these organizations speak with a powerful political voice within multiple global governance platforms (Partelow et al., 2020).

Green Parties dedicated to environmental protection have gained considerable strength in many rich countries, especially those in Europe with multi-party systems. They now hold legislative seats in 13 different European countries, and they have become members of ruling coalitions in six (McBride 2021). Farm lobbies in Europe that once dominated politics within the agricultural sector now face growing Green Party opposition.

As an important background change, the virtual elimination of food shortages in rich countries has also undercut the political influence of farm lobbies. Obesity has replaced hunger as the leading dietary health challenge; obesity rates in the United States have tripled since the 1960s, and now stand at 42 percent of adults. Under these circumstances, why do we need more agricultural production, or still more agricultural science? Public support for agricultural science in rich countries has fallen as a result. The growth rate in public spending for agricultural R&D dropped from 9.1 percent in 1960–70 to just 1 percent between 2000–09. In these countries public agricultural research spending actually peaked in 2009, and it has now fallen by 6 percent since then (USDA, Economic Research Service 2020). In the United States, public agricultural R&D has fallen by a third since 2002. Private investments continue to be made in agricultural science, but public funding support has fallen.

In combination, these changes have moved the balance of political power against modern agriculture. As one illustration in Europe, both the Council of Ministers and the European Parliament voted to approve a 2020 European Green Deal "Farm to Fork" strategy designed to reduce farm chemical use and expand the role of organic farming. As discussed in more detail in Chapter 13 of this volume, this Strategy will also fund a variety of "eco schemes" designed to fallow land, promote high-diversity (not high productivity) farming landscapes, and build semi-natural wildlife habitat on farms (European Commission 2021). The German Farmers' Association (DBV) called Farm to Fork a "general attack on the whole of European agriculture" (Appunn 2021), and the EU's general farm lobby, Copa-Cogeca, pressed hard to weaken the strategy, but Green Party leaders prevailed when the Strategy went before the European Parliament in October 2021, winning approval by a vote of 452 to 170 (Wax and Anderson, 2021).

A stronger political voice for environmental protection has long been needed in the farming sector, where agriculture has been a leading threat to nature, but environmental advocates are wrong to fear that applications of modern agricultural science will make the problem worse. In fact, modern science-based methods usually damage less habitat and pollute less compared to the more traditional methods they replaced, for every ton of food produced. Serious environmental damage continues to be done by farming in rich countries, but this usually reflects how much more is now being produced, not the modern production methods in use.

The practical impact of this growing strength of Green Parties relative to farm lobbies has in most instances been small so far. It has strongly influenced cultural elites and shaped media commentary on what sustainable farming should look like, but it has done little to bend modern commercial agriculture away from a science-intensive trajectory. We see below that only in the case of genetically engineered crops and animals (GMOs) have the non-farmer critics of modern agricultural science been able to keep the latest tools out of farmers' hands.

10.2 Defining Sustainable Food

According to the United Nations Food and Agriculture Organization (FAO), a "sustainable" food system must meet economic, social, and environmental conditions (FAO 2018). A fully sustainable system must be,

- Profitable throughout (economic sustainability)
- Must deliver broad-based benefits for society (social sustainability)
- And must deliver a positive or neutral impact on the natural environment (environmental sustainability).

Clearing all three hurdles at the same time is now difficult due to the continued increases in food demands driven by population growth plus income-linked dietary enrichment, especially in today's low- and middle-income countries (LMICs). This creates a need for better production methods that can reduce the economic, social, and environmental cost of every added ton of output. Fortunately, applications of modern science are now helping to meet this difficult challenge with methods that sharply reduce the amount of land, labor, water, chemicals, and energy required for each bushel produced.

This science-forward "eco-modern" path to sustainability (Asafu-Adjaye et al. 2015) is one that traditional advocates for the environment often miss. They prefer to protect nature not by using science to increase productivity (i.e., more output per unit of input), but instead by preserving the traditional methods they associate with times of less damage, ignoring the much greater harm these methods actually did to nature for every ton produced.

We explore here four cases where non-material values and misrepresentations of agricultural science have created popular resistance to farm production methods that are actually more sustainable than traditional methods. In the first three of these cases—the Green Revolution, "industrial" agriculture, and synthetic chemical use—popular disapproval did little to alter the widespread use of the methods in question, mostly because the popular objections did not increase until after farmers were already using these methods with success and declined to give them up. Only in the fourth case (GMO crops) did popular resistance emerge before most farmers had a chance to try the new seeds and experience their benefits. A technology farmers had not yet learned to value became one that was easy for regulators to block.

A more recent 2012 biotechnology innovation, genome-editing, presents an interesting variation on the GMO case. As with GMOs, gene-edited crops attracted activist opposition almost from the start, before farmers had a chance to experience the benefits, which opened political space for a blockage effort, particularly in Europe. Yet because most gene-edited crops will contain no "foreign DNA" they will be more difficult for governments to detect and regulate, as well as less frightening to ordinary consumers. They are also cheaper, faster, and easier to develop compared to GMOs, both factors will favor widespread uptake.

In reviewing these four cases, several political economy patterns will emerge. In each case, popular resistance to new agricultural science arose first among well-fed citizens in affluent countries. Also in each case, civil society organizations were instrumental in promoting this science resistance, and eventually projecting it into countries that were not yet affluent. But only in the case of GMOs did governmental authorities join the resistance. Civil society objections to the Green Revolution, to industrial farming, and to agricultural chemicals enjoyed less success because they were not launched until after these innovations were in widespread use on farms.

10.3 Case 1: "Green Revolution" Farming

Bringing the latest agricultural science to poor countries was a popular idea in the 1960s. The introduction of high-yielding "Green Revolution" seeds into countries with unmet food needs was hailed initially as a triumph for both science and ethics. Only later did civil society organizations brand it as a source of economic, social, and environmental harm. On the environmental front, they accused the new seeds of requiring "huge amounts of groundwater" (EWG 2009) plus an excessive use of chemicals, including a "sixfold rise in fertilizer use per acre" (Rossett et al. 2000).

Such assertions continue to dominate progressive popular discourse, even though they are scientifically mistaken.

The Green Revolution wheat and rice seeds arrived on farms in Asia beginning in the 1960s. Supported by the Rockefeller Foundation (this was not a corporate initiative), scientists working in Mexico had used conventional crop breeding methods (not GMO methods) to introduce new "dwarfing" traits into wheat plants. Scientists working in the Philippines did the same with rice plants. The dwarfed plants, with shorter stems, devoted less growth energy to producing leaves and straw, and more to producing grain, which roughly doubled grain yields per hectare when adequate water and fertilizer were provided.

This was a yield breakthrough that came at just the right time for India, where lagging grain production and a two-year drought in 1965/66 had brought the country to the brink famine, a tragedy only avoided due to a tripling of wheat imports from the United States. When the new seeds were introduced and spread quickly after 1965, wheat production nearly doubled in just five years. Once India began planting the new rice varieties, production in the states of Punjab and Haryana also nearly doubled, between 1971 and 1976 alone (Paarlberg 1994). India became a small net exporter of rice by 1973, and by 1978 also a net exporter of wheat. Norman Borlaug, the American scientist who led the original wheat breeding effort in Mexico, was awarded the Nobel Peace Prize in 1970.

The Green Revolution package (new seeds, irrigation, and chemicals) was nature-protecting as well as lifesaving. If India had tried to produce its 1993 wheat crop by using the pre-Green Revolution methods of thirty years earlier, it would have had to plow up an additional 36 million hectares of land (Swaminathan 1994). Some environmental advocates did recognize this as a major gain. In May 2002, James Lovelock, the creator of Gaia Theory, and Patrick Moore, the co-founder of Greenpeace, signed a "Declaration in Support of Protecting Nature with High Yield Farming and Forestry." They declared that high yield farming was not just the best way to increase food production to keep pace with market demand; they said it was also good for the "preservation of the natural environment and its biodiversity through the conservation of wild areas and natural habitat." (Russell 2009).

For these reasons, when a powerful new global environmental movement began forming in the 1970s, it should have welcomed the Green Revolution, but instead the opposite happened. Prominent activists, following the lead of Vandana Shiva (identified by *Forbes Magazine* as one of the Seven Most Powerful Women on the Globe), attacked the new seeds. In 1991, Shiva wrote a book-length polemic accusing the Green Revolution of introducing an unsustainable new farming model (Shiva 1991). She said the new seeds required more irrigation water and chemicals, forcing farmers to borrow the money to purchase these inputs, pushing them into debt. Worse, the production gains would be unsustainable because the genetic base of the new seeds was too narrow: "The destruction of diversity and the creation of uniformity simultaneously involves the destruction of stability and the creation of vulnerability… (Shiva 1991, p. 29).

Shiva's influential critique misunderstood several basics. Scientists had shown that the new seeds did not require more water and fertilizer; to the contrary, the yield gains they provided in response to inputs were so large that water and fertilizer requirements per ton of production actually *decreased*. The United Nations FAO confirmed later that the Green Revolution rice varieties increased water productivity—output per unit of water inputs—threefold compared to traditional varieties (FAO 2003). As for fertilizer, the new Green Revolution varieties produced more than 20 pounds of added grain for each added pound of nitrogen, while traditional rice and wheat varieties produced only 10, so the need for fertilizer fell roughly in half for each pound of added grain production (Borlaug 1970).

These gains were hard for non-specialists to appreciate because input use did increase in absolute terms, even though falling relative to total production. In some cases, the increase in water and chemical use was excessive, but the reason was not a requirement of the new seeds. It resulted instead from needlessly high government subsidies designed to promote input use. For example, excessive insecticide spraying became a problem in Indonesia in the 1970s when the government subsidized farm chemical purchases by as much as 85 percent. Indonesia eventually solved this problem by removing the subsidy, but it knew better than to stop using the new seeds themselves (FAO 1988).

Shiva's warning about increased crop vulnerability due to less diversity was also off target. According to a 2019 study in *Global Change Biology*, crop diversity in India, measured both in numbers of different crops grown and the dispersion of those different crops across cultivated area, actually showed a "remarkable increase" after the 1960s (Aizen et al. 2019). Just as important, the genetic base of wheat and rice production in India was not narrowed. Plant breeders value *pedigree complexity*, which is the number of different crop selections originally bred into a variety of wheat or rice (Rosegrant and Hazell 2000). One of the Green Revolution rice varieties ("IR 66") actually had 42 different pre-Green Revolution selections in its parentage, so it had multiple sources of resistance to pests and diseases. As Thomas R. DeGregori has pointed out, a field planted to a monoculture of Green Revolution seeds can actually be more diverse genetically than a polyculture of traditional varieties (DeGregori 2004). In 1996, Melinda Smale and Tim McBride confirmed that "yield stability, resistance to rusts, pedigree complexity, and the number of modern cultivars in farmers' fields have all increased since the early years of the Green Revolution" (Smale and McBride 1996).

The Green Revolution was most of all economically sustainable, since it increased the income of farmers both large and small while reducing food costs for consumers. By one estimate, if the modern seed varieties had not been introduced after 1965, annual crop production in the developing world as a whole in the year 2000 would have been almost 20 percent lower than it actually was, and this would have pushed food prices one-third to two-thirds higher. An added 6 to 8 percent of children in the developing world would have been malnourished (Evenson and Gollin 2003).

Small farmers took up the seeds alongside larger farmers, satisfying an important requirement for social sustainability. The percent of harvested rice area in South Asia under modern Green Revolution varieties increased from zero to 71 percent between 1965 and 2000, and the share of wheat area increased to 95 percent. In East and Southeast Asia, modern variety coverage for rice by 2000 was more than 80 percent, and for wheat nearly 90 percent, indicating broad small farm participation (Gollin et al. 2005). In one study of 30 rice-growing villages in Asia between 1966 and 1972, more than 90 percent of both small and large farms adopted the modern rice varieties within a decade after they became available, with smaller farms actually reaching this cumulative adoption level more quickly than large farms (Ruttan 2004). The seeds worked well on small farms because they could be planted and harvested by hand, with no need for expensive mechanical equipment.

It has now been more than a quarter century since Vandana Shiva branded the Green Revolution unsustainable, yet crop yields have continued to increase. Data from FAO show that average wheat yields in India in 2019 were 52 percent higher than when Shiva wrote in 1991 (FAOSTAT 2019). A 2021 *Journal of Political Economy* study concluded that if the original Green Revolution had simply been delayed for a decade, incomes in the developing world would be 17 percent lower today (Gollin et al. 2021).

Despite these well-documented gains over five decades, Green Revolution approaches continue to be rejected by a preponderance of global civil society organizations. In Rome in 2002, an independent NGO forum blamed the Green Revolution for what it described as a rise in world hunger, even though the only place hunger was rising was Africa, where Green Revolution methods were not in wide use. Two years later, a coalition of 670 separate NGOs attacked the Green Revolution by name once again, this time branding it a “tragedy” (NGO/CSO Forum 2002).

In fairness, the introduction of improved seeds did not bring social sustainability everywhere. In much of Latin America subsistence farmers lacked formal land rights, so when the introduction of profitable new seed and chemical technologies made the land they were squatting on more valuable, it was sold out from under them by large estate owners who gave way to a new class of commercial growers. Poor peasants were pushed off in large numbers and forced to migrate to urban slums (Williams 1986). This was a serious malfunction, but one linked to unjust semi-feudal land ownership patterns, not to the science that had produced the improved seeds.

Civil society organizations have continued to campaign against the Green Revolution. They oppose the Alliance for a Green Revolution in Africa (AGRA), a project launched in 2006 by the Bill and Melinda Gates Foundation (AGRA 2020), and in 2021 they stayed away from the UN Food Systems Summit in part because the Special Envoy to the summit, Dr. Agnes Kalibata, was also the President of AGRA. The alternative they prefer is "agroecology," an approach intended to imitate nature by mixing crops, animals, and trees together, usually based on labor-intensive hand-gardening. Agroecology methods can work well enough at the project level, but they do not scale up with actual farmers because they require too much human labor. Even strong advocates for agroecology acknowledge the high labor costs (Altieri 1999, p. 202).

The Green Revolution lost popular favor in part because it worked so well in Asia. When the widespread famine fears of the 1960s disappeared, it was possible for non-specialists to begin imagining that the new seeds had never been necessary. Fears of environmental damage were replacing fears of food shortage. More agricultural science was actually the proper response to this threat as well, but most environmental advocates embraced artisanal methods instead.

10.4 Case 2: Industrial Farming

Most Green Revolution critics would prefer a return to small local farms producing a wide variety of both crops and animals, a traditional model that dominated even in rich countries prior to the second half of the twentieth century. Yet the greater sustainability of this earlier model is an illusion, because farms then were producing only a small fraction of what is needed today, and they did so at barely a poverty-level income for most farmers.

Modern commercial farm methods not only produce much more food and much higher income for farmers; they also use fewer natural resources per ton of production, making them better for the environment. Precisely because today's commercial farms are large, specialized, and highly capitalized, they can afford new "precision agriculture" technologies that help reduce a wasteful, polluting use of inputs. These precision methods include drip irrigation, no-till seeding, satellite-based global positioning systems (GPS), soil mapping, variable-rate water and chemical applications, unmanned aerial vehicle (UAV) scouting and imaging, artificial intelligence (AI) and robotics, machine learning, and also big data. These tools are all information-intensive rather than resource-intensive; they are now making so-called "industrial" farming into an increasingly post-industrial activity.

As one example, a real-time kinematic (RTK) base station on a modern farm can log small errors detected from incoming GPS satellite data and send correction signals to the roving equipment in the field, via radio or cellular modem. This allows the equipment to know its precise location in real time with *sub-inch* accuracy

(Condliffe 2016). This information is then linked through on-board computers to a digital map of soil moisture and soil chemistry variations, telling the equipment to put down chemicals, water, and seeds at an optimal rate for each specific location. Cutting unneeded applications saves the farmer money, while also reducing polluting runoff.

Modern industrial farms have reduced labor and land use most of all. Total corn production in the United States has increased fivefold since 1940, but the acreage planted to corn has actually declined by one-fifth (Ausubel 2015). Other inputs have also declined. For every bushel of corn produced since 1980, irrigation water use has fallen 46 percent, energy use 41 percent, and greenhouse gas emissions 31 percent (Field to Market 2016).

Chemical use in modern agriculture has also declined over the past four decades. Total fertilizer use in American farming peaked in 1981, and since then it has remained essentially flat, even while total crop production grew 44 percent (USDA, Economic Research Service 2019). The total pounds of pesticide applied to American crops declined by 18 percent in absolute terms between 1980 and 2008, and insecticide use is now more than 80 percent below its 1972 peak (Fernandez-Cornejo et al. 2014).

Modern precision agriculture (PA) methods are also delivering results in Europe. A 2013 study in Hungary found that the overall environmental burden from agriculture declined thirty percent with the embrace of PA. An earlier German study found that PA decreased herbicide use by more than half. A 1996 study of variable rate applications on corn and soybeans in the US and Denmark found insecticide use decreased by roughly one-third, which helped prevent the emergence of insects resistant to the chemicals (Cornell 2016, p. 18).

Considerable environmental damage is still being done by modern farming in rich countries due to today's larger volume of total output, so the gains from PA have gone mostly unrecognized by popular critics. Farms in the United States today are producing nearly three times as much output as in 1948 (USDA 2021a). If output had tripled using 1948 production methods, the environmental damage would have been far greater. In some cases, in fact, total damage was actually greater in the past despite lower production. Early in the twentieth century, American farmers plowed up the drought-prone Southern Plains in order to grow more wheat. When the rains failed in the 1930s, the topsoil blew away creating a disastrous Dust Bowl, forcing 2 million farmers to become environmental refugees.

Fragile lands were saved from this kind of cropping expansion only after new hybrid seeds and fertilizers began boosting yields on less fragile lands already plowed. Farmland area in the United States finally stopped increasing in 1950, and since then total agricultural output has nearly tripled, with no more Dust Bowls.

Modern industrial farming is widely criticized for being economically and socially unsustainable as well, since small farms were consolidated into large farms producing an exodus of rural dwellers and shuttering many small towns. Popular media continue to see this as a problem. In 2019 *Time Magazine* warned that America's rural "decline" was being hastened by a continuing disappearance of small farms (Aemuels 2019).

In fact, returning to a small farm model would be a social and economic step backward, because small farms typically earn far less income. In America in 1910, average household income on farms was less than two-thirds that of non-farm households, and in the 1930s farm income briefly dropped to just one-third the non-farm level (Gardner 2002). This rural poverty problem was not solved until modern "industrial" methods, led by gas-powered mechanization, made it possible to produce food with much less human labor. Farm children could then spend more time in school, graduate, and leave to seek better-paying work in town, including new factory jobs with regular hours, union contracts, and summer vacations. When the older generation eventually stopped farming and sold the land to a neighbor who expanded, a retirement nest egg was the final benefit.

As a result of this consolidation process, America today has many fewer farms, yet very few are poor. The median income for farm families in America in 2021 was 30 percent above the median for all households, and the average net worth of households operating farms was an impressive $2.1 million (USDA, Economic Research Service 2022). Genuine social and economic hardship can be found in rural America today, but it has not been caused by a disappearance of small farms. Instead, it reflects job losses in manufacturing due to outsourcing and automation, which too often leads to family breakdown and substance abuse, but these factors are essentially unrelated to the replacement of small farms by large farms (Green 2020).

Most who are attracted to small farms have never tried to support a family based only on small farm income, or feed a family on what small farms produce. In the United States, New England has a large number of small, diverse farms, often selling directly to consumers through local farmers markets and community supported agriculture (CSA) subscriptions. This model can look appealing, until we consider how little food these farms produce. The commercial sales made by all of the farms, large and small combined, in Massachusetts, Connecticut, Maine, New Hampshire, Vermont, and Rhode Island make up less than one percent of total national farm sales (USDA 2017).

10.5 Case 3: Organic Food

Organic food is a third example of popular opinion departing from science. Foods grown "organically," without synthetic chemicals, are considered by many consumers to be better for the environment, safer to eat (no synthetic pesticide residues), and more nutritious. Roughly 40 percent of Americans say some or most of the food they eat is organic, and this increases to 63 percent among those who claim to eat with a focus on health and nutrition (Pew 2016).

These popular perceptions lack a solid scientific foundation. Science tells us a shift from conventional to organic production would do little or nothing to improve food safety or nutrition, and it would actually harm dietary health by making nutritious fruits and vegetables significantly more expensive. The average retail price (by volume) for organic produce in the United States is 54 percent higher than for conventional (Kang 2019). A scale up of organic methods would also harm the environment, by requiring the use of more land.

In order to be labeled "organic," foods must be grown only using chemicals found in nature, avoiding anything manufactured ("synthetic"). Organic farmers can fertilize crops using the nitrogen found in composted animal manure, but not with nitrogen taken from the atmosphere through the industrial Haber-Bosch process (first introduced in 1909). Synthetic products to help farmers control weeds, crop disease, and insect pests are also barred under the organic rule.

The modern organic food movement was launched in the 1920s by an Austrian mystic philosopher named Rudolf Steiner, who objected to the use of synthetic chemical fertilizers because he said they lacked an imagined "biodynamic" life force (Bechtel and Richardson 1998). Steiner also promoted a number of other ideas not supported by science; he believed in human reincarnation, the lost world of Atlantis, and an earlier lost continent named Lemuria (Steiner 1959).

A second organic advocate early in the twentieth century, an English agronomist named Albert Howard, had been well-trained in agricultural science, but he strayed beyond his scientific competence by making claims connecting soil nutrient replacement to human health (Conford 2001). While working in colonial India, Howard came to believe that composted manures were essential for building the "health" of soils, which he viewed as the essential foundation of human health. In his 1943 book, *An Agricultural Testament*, he endorsed what he called "Nature's farming," based on nurturing plants with composted animal waste, including human waste (Howard 1943).

Objections to the use of synthetic nitrogen fertilizer lack a scientific foundation, because nitrogen is the same chemical element no matter where it comes from. Synthetic nitrogen production soon became essential to feeding the human population, which is now four times larger than when Steiner and Howard formed their views. Vaclav Smil has estimated that without manufactured nitrogen fertilizer, 40 percent of the increase in food production to meet today's population needs would never have taken place. For at least one-third of those living in today's most populous countries, the use of nitrogen fertilizers in the twentieth century made the difference between an adequate diet and malnutrition (Smil 2000).

The mystical organic ban on synthetic materials also does little or nothing to improve food safety. We should always limit exposure to pesticides with toxic properties, but the organic ban doesn't cover naturally occurring toxins (like copper sulfate), and halting chemical use entirely is scientifically unnecessary. This was well understood by Rachel Carson, who criticized the *excessive use* of synthetic pesticides in her 1962 book, *Silent Spring*. As a scientist she knew that "the dose makes the poison," so she never endorsed the rigid organic insistence on going to zero. In *Silent Spring* she said, "The ultimate answer is to use less toxic chemicals so that the public hazard from their misuse is greatly reduced" (Carson 2002, p. 184). When Carson later testified to Congress in 1963, she said, straight out, "I think chemicals do have a place" (Griswold 2012).

The best practice in agricultural pest control is "integrated pest management" (IPM), a method that employs both biological and chemical controls, a method the chemical-prohibiting organic standard makes impossible. Through IPM methods, improved crop genetics, and precision application technologies, the United States has been able—without going organic—to reduce its total applications of insecticide by more than 80 percent since 1972, as noted earlier.

Anxieties persist in rich countries over pesticide residues on food, but toxicologists and food scientists find little or no risk. In the United States in 2003, the FDA analyzed several thousand food samples from the marketplace and found that only half of one percent had chemical residues exceeding regulatory tolerance levels. Those levels had in turn been set conservatively, at only one one-hundredth of an exposure that still did not cause toxicity in laboratory animals. Looking at this evidence, food scientists at the University of California-Davis concluded, "[T]he marginal benefits of reducing human exposure to pesticides in the diet through increased consumption of organic produce appear to be insignificant" (Winter and Davis 2006).

Advocacy organizations nonetheless continue promoting pesticide residue fears. The Environmental Working Group (EWG) issues an annual "Dirty Dozen" report, listing the fruits and vegetables with the highest pesticide residue levels (EWG 2019). This report fails to mention that these "dirtiest" products are all essentially clean. It's like warning patients away from the "dirtiest" operating room in a modern hospital. One paper published in 2011 looked at average pesticide exposures on that year's "Dirty Dozen" products and found all were well below the EPA tolerance level, with the vast majority at less than 0.01 percent of that reference dose (Holsapple et al. 2017).

Advocates for organic foods, including the Organic Trade Association that promotes the industry, also like to claim nutrition benefits, yet independent nutrition scientists do not support this either. In 2012, a review of data from 237 studies conducted through the Center for Health Policy at Stanford University concluded there were no convincing differences between organic and conventional foods in nutrient content or health benefit (Smith-Spangler et al. 2012).

While the public continues to favor organic foods, very few commercial farms have switched to organic methods, mostly because of the higher land and labor costs per bushel of production. Less than one percent of harvested cropland in the United States today is organically certified (OTA 2019). In the European Union, where roughly 9 percent of farmland area is certified organic, a new 2020 “Farm to Fork” strategy wants to convert “at least” 25 percent of farmland to organic methods by 2030 (EU 2020). This is being advanced as a “green” initiative, but organic cereal yields in Europe are only 60–70 percent as high as conventional yields (FAO 2002), so any large switch would require much more European land in farming, releasing more carbon from the soil and causing more forest and habitat loss, hardly a green outcome. In one study of a hypothetical switch to organic in England and Wales, total food output would fall to only 64 percent of the pre-switch baseline (Smith et al. 2018). If Europe goes in this direction, a significant increase in food imports (probably non-organic) would be needed to prevent a steep spike in prices. Organic farming can remain a popular idea in Europe only so long as most farms decline to adopt its restrictive methods.

10.6 Case 4: Genetically Modified Organisms (GMOS)

A fourth example of divergence between scientific consensus and popular perception is GMO crops, which are developed using rDNA genetic engineering. Popular disfavor pushed GMO foods out of the European market soon after they were first introduced in the mid-1990s, and they remain excluded today even though all the leading European science academies have said they are safe. Most other countries around the world followed Europe’s path, including countries with poor farmers who might have gained from the new agronomic traits provided by GMO crops.

The scientific consensus on GMO crop safety is remarkably strong. The Royal Society in London, the British Medical Association, the French Academy of Sciences, and the German Academies of Science and Humanities have all said, in writing, they find no convincing evidence of any new risks to human health or to the environment from any of the GMO crops developed so far (DeFrancesco 2013; Nicolia et al. 2013). Even the EU Commission officially endorses this consensus. In 2010, the Research Directorate of the European Union concluded that, “biotechnology, and in particular GMOs, are not per se riskier than e.g., conventional plant breeding technologies” (EU 2010).

Official scientific bodies in the United States say the same thing. In 2016 a committee at the National Academies of Science concluded the following: “The committee carefully searched all available research studies for persuasive evidence of adverse health effects directly attributable to consumption of foods derived from GE [genetically engineered] crops but found none” (NAS 2016).

GMO crops are created by moving genes carrying desired traits from unrelated organisms into the living DNA of crop plants. GMO corn and cotton varieties were originally engineered to contain in their tissues a protein from a soil bacterium that some insects cannot digest (these were called *Bt* crops, after the name of the bacterium). *Bt* crops reduce the need for insecticide sprays, bringing an environmental benefit along with lower production costs. A 2009 USDA study concluded that global plantings of *Bt* corn and cotton between 1996 and 2006 had made possible a 29.9 percent reduction in the use of insecticide active ingredients (Naranjo 2009).

Soybean plants were also genetically engineered in the 1990s, to survive applications of an herbicide named glyphosate. These modified plants made weed control possible without the use of more toxic pre-emergent herbicides, and with less plowing and therefore less burning of diesel fuel. Thanks to the availability of GMO soybeans, the land area under no-till farming in Argentina increased from less than 1 million hectares in 1991 up to 22 million hectares by 2008 (Trigo et al. 2009).

GMO soybeans nonetheless attracted criticism in Europe, because the American company selling the patented seeds, the Monsanto Company, was also selling the patented Roundup herbicide used with the seeds, which raised a concern about corporate control. These new GMO soybeans also began arriving in European ports in March 1996, at exactly the moment when European officials admitted that eating meat from animals with BSE (mad cow disease, unrelated to GMOs) was possibly fatal. Officials had earlier said the meat was safe, so consumers wondered if they could trust assurances from the same officials that the soybeans were safe. It was easy under these circumstances for activists to mobilize popular opposition to GMOs (Bernauer and Meins 2003).

Hoping to calm popular fears, the EU announced in June 1997 that any foods with GMO ingredients would have to carry an identifying label, but this was taken as a sign that there must indeed be a danger. By 1998, popular anxieties forced EU regulators to impose an informal moratorium on new approvals of GMO crops, and by 2004 the EU was requiring all operators in the marketplace to maintain, for five years, a complete "audit trail" record showing where all the GMO products they handled came from, and where they went. To avoid this burden, along with the stigmatizing labels, food companies eliminated any remaining GMO ingredients from their products, including oil from American soybeans and starch from American corn (Levidow and Bijman 2002).

It is revealing that the same Europeans who sought to avoid GMO foods had no objections to GMO medical drugs. Genetic engineering had been widely used in commercial medicine since 1982, when the FDA in the United States first approved a recombinant form of human insulin. European drug companies soon began to incorporate similar genetic engineering techniques, with no popular objections (Paarlberg 2008). What made the GMO drugs acceptable in Europe was not an absence of new risks, since genuine risks were routinely detected during clinical trials and fully disclosed; the key instead was a promise of direct benefits to the consumer.

The first generation of GMO crops introduced in the 1990s did deliver strong benefits to farmers, by making it cheaper and easier to protect against insects and weeds, but for final food consumers the GMO varieties of corn and soy didn't look or taste any better, they didn't have better cooking properties, they weren't any more nutritious, and once mixed into packaged food products they were not noticeably cheaper. Because final consumers did not see any clear benefit from these products, even imagined and unproven risks could turn opinion against them.

A few early and widely publicized research studies did suggest new risks from GMO crops, based on allergic reactions to corn chips, tumors in lab rats, and dead monarch butterfly caterpillars, but when public agencies reviewed these studies, they concluded all were badly designed or otherwise unconvincing. For example, a 2012 study published in the journal *Food and Chemical Toxicology*, found tumors in rats that had eaten GMO corn, but this study had used Sprague-Dawley rats that were unusually prone to tumors. The study was formally dismissed by the European Food Safety Agency (EFSA) and Germany's Federal Institute for Risk Assessment in Berlin, and the journal later retracted the paper (Casassus 2013).

The United States opted not to regulate GMO foods and crops as strictly as in Europe, even though many American consumers—when asked—expressed parallel worries (Hallman et al. 2003). GMOs encountered less official blockage in the United States in part because politically powerful corn, soybean, and cotton farmers quickly learned to value the new seeds. Because fewer European farmers planted these three crops, they did not complain when tight regulations blocked planting. Europe remained willing to import GMO soybeans for animal feed, in deference to its large and influential livestock industries.

GMO corn, soybeans, and cotton were mostly used as animal feed, auto fuel, or for industrial purposes, rather than as human food, so their cultivation spread widely in some countries, but GMO varieties of staple food crops like wheat, rice, and potato, plus GMO fruits and vegetables, have scarcely been planted at all, even in the United States. Some United States growers planted GMO potatoes and tomatoes for a time after 1998, but then they stopped doing so when retailers and fast-food chains began refusing these products in the hopes of avoiding activist protests. Many processed food products in America's supermarkets today do contain oils, starches, and sweeteners from GMO maize, soybean, and also sugar beets, but nearly all the unprocessed foods in these stores are completely non-GMO. So, in the United States, almost as much as in Europe, GMO crops intended for direct human consumption have largely been driven out of the marketplace.

This global rejection of GMO food crops has taken potential benefits away from Africa, where poor farmers are in need of new ways to protect crops against insects, crop disease, and drought. Farmers in Africa struggle every year against stalk borer infestations that reduce their yields of white maize, a leading food crop. If it were legal for them to plant *Bt* maize, crop yields would go up and pesticide use would also go down. For years the Republic of South Africa was the only country in the world to have approved *Bt* white maize for commercial planting, and when small farmers adopted the seeds, their yields roughly doubled (Shew 2021). Kenya finally approved *Bt* maize in 2022, but in much of the rest of Africa, even conducting research on GMO maize has remained illegal. In Tanzania in 2018, a tightly confined government experiment with drought-tolerant *Bt* maize was arbitrarily shut down by official order, and the planting materials had to be destroyed.

The developers of GMO seeds were initially baffled when so many governments with unmet food needs decided not to allow their use. One particularly frustrating moment came in 2002, when southern Africa was struck by a severe drought that left 15 million people across seven different countries in need of international food aid. Yellow corn from the United States—which happened to be GMO—had until then been welcomed in Africa as emergency food aid, but in August 2002 the Government of Zambia turned it down. Zambia's president, Levy Mwanawasa, later explained his decision: "Simply because my people are hungry, that is no justification to give them poison, to give them food that is intrinsically dangerous to their health" (BBC News 2002).

Zambia's mistrust of GMOs had been heavily stoked by civil society groups funded from abroad. At one open meeting, a local NGO leader told her fellow Zambians, "Yes, we are starving, but we are saying no to the food the Americans are forcing on our throats" (Phiri 2002). Her organization received its funding from the Swedish embassy in Lusaka, the Norwegian embassy, and the Danish foreign assistance agency, DANIDA (WFC 2007).

American officials sought to reassure the Zambians by inviting a government delegation on a fact-finding visit to the United States, but the Zambians were also invited to visit Europe. There they met with groups hostile toward GMOs, including Greenpeace, Friends of the Earth, the UK Soil Association (promoting organic), Norway's Institute for Gene Ecology, and an organization named Genetic Food Alert. Greenpeace warned the visiting Zambians that their organic produce sales to Europe would collapse if the nation opened itself up to GMOs, and Genetic Food Alert warned of the "unknown and un-assessed implications" of eating GMO foods. An organization from the UK named Farming and Livestock Concern warned the Zambians that GMO maize could introduce a retrovirus similar to HIV (Wilson 2002). A spokesperson for the Zambian delegation, upon returning home, said the trip had confirmed his anxieties about GMOs (Zambia, Government of Zambia 2002).

Africa's rejection of GMOs was also shaped by "biosafety" training programs funded by European donors, including a highly precautionary "model law" developed for the African Union through a German assistance program (Keetch et al. 2014). Instead of teaching Africans the science of GMOs, these programs taught regulators how to keep the technology out of African hands. Africa's policy-making elites are susceptible to European influence in part because of fears—largely exaggerated—that commercial farm sales into the European market will suffer if any GMO production is allowed (Gruere and Sengupta 2009). A lingering sense of post-colonial deference also plays a role. As one local Kenyan leader said in 2006, "Europe has more knowledge, education. So why are they refusing [GM foods]? That is the question everyone is asking" (Hand 2006). These Africans were seldom told that Europe's own science academies had found no evidence of any new risks from GMOs.

The advocates for GMO crops in Africa—agricultural scientists, for the most part—believe they are now seeing some policy change. In 2018, Nigeria finally approved *Bt* cotton for commercial planting, and it approved insect-resistant *Bt* cowpea in 2021. Kenya approved *Bt* cotton in 2019. Ghana had earlier given technical approval *to Bt* cowpea, yet Ghana's agricultural minister undercut this approval by saying his country didn't really need the technology, mentioning along the way that many of his countrymen were staunchly opposed to GMOs (Gakpo 2019). Late in 2022, under pressure from an extreme drought, Kenya' new president announced the lifting of a 10-year ban on importing and planting GMO maize, yet as also highlighted in chapter 5, a majority of Kenyans continued to express doubts about the safety of GMOs (Kagoe 2022).

10.7 When Will Popular Resistance Block Uptake?

In each of the cases above, agricultural methods based on modern crop science have been met by popular disapproval. This by itself is curious, since most people routinely welcome new applications of science in fields such as transportation, communication, and human medicine. But when will popular disapproval block the uptake of science-based farming practices? It did in only one of these four cases—GMO. What is the explanation?

One key factor is timing. Popular disapproval can prevail if it arises immediately, before most farmers have had a chance to profit from the new science. This was the case with GMOs. But if popular disapproval arises only after farmers have had a chance to taste a science-based benefit, the new science will be nearly impossible to take away. This was the case with the Green Revolution, industrial farming, and also synthetic chemical fertilizers.

The Green Revolution was broadly popular when it was launched, and it enjoyed several decades of rapid and successful uptake before Vandana Shiva galvanized the opposition with her 1991 manifesto. By then, however, millions of farmers had already tasted the benefits and did not want to go back to labor-intensive, low-yield methods. Today's farmers in LMICs have continued to improve on the original Green Revolution, by combining the improved seeds with "sustainable agricultural intensification" (SAI) methods that use inputs with greater precision, and employ IPM, micro-irrigation, and reduced tillage.

These methods scale up because they save labor and reduce input costs without sacrificing yields. Farmers have already put this kind of SAI to use on 453 million acres, or about nine percent of agricultural land worldwide (Pretty et al., 2018).

In similar fashion, "industrial farming" survived popular disapproval because it did not begin coming under strong criticism in rich countries until the 1970s, after the process of small farm consolidation had largely been completed. By then both the farmers remaining on the land and the ex-farmers who had taken jobs in town had seen their incomes rise. The commercial farmers, private investors, regulators who recognized this as progress shrugged off the criticism that came later, mostly from non-farmers. A 2016 review in the journal *Horticulturae* summed it up this way: "Despite the call for alternative methods of production over the years, the paradigm of industrial or conventional agriculture still dominates and permeates most mainstream academic and policy discussions about the future of agriculture" (Valenzuela 2016).

Timing was also an important factor in the failure of organic farming to replace synthetic chemical use. Broad popular anxieties about chemical use on farms did not solidify until after a series of pesticide residue scares in the 1980s, and by then returning to zero use of all synthetic chemicals to become organic was commercially unthinkable. Conventional farmers today remain eager to reduce the unnecessary use of synthetic chemicals to save money, but they know that cutting all the way back to zero, to gain organic certification, will bring costs that organic price premiums cannot cover. This is why less than one percent of harvested cropland in the United States is organic (Bialik and Walker 2019). The EU Farm to Fork strategy hopes to increase organic cropland from 9 percent today up to 25 percent of the total by 2030, but the economic cost to both farmers and consumers, plus the adverse land use implications, will make such a shift improbable. According to one German study, this shift would shrink cereals production in the EU by 21.4 percent. One and a half million hectares of European forest land would be lost, with an additional 5 million hectares lost beyond Europe, where other countries would expand production (mostly non-organic) to meet Europe's new food import needs (Henning and Witzke 2021).

Only in the case of GMO crops did popular resistance to innovative farm science prevail. It was able to do so because it emerged before large numbers of farmers had been given a chance to plant the seeds, and to appreciate the material benefits. In 1996 when popular fears first arose in Europe, most farmers around the world had never used the technology, making it easier for politicians to block uptake. Science academies in Europe did not find any new risks from GMOs, but early popular fears brought on stifling government regulations which kept GMO food crops out of farm fields, not just in Europe but also in most countries hoping to export to the European market. One young environmental campaigner against GMOs in the UK (who later recanted his opposition) observed ruefully that his early anti-GM work was "the most successful campaign I have ever been involved with" (Lynas 2013).

There may be a deeper pattern behind these timing issues. In the case of the Green Revolution, industrial farming, and synthetic chemicals, each of these science-based innovations was introduced and widely taken up before the emergence in the 1970s of a strong global environmental movement. Since we can assume this environmental movement will remain politically strong going forward, maybe crop science breakthroughs will remain more difficult to take up. We are now watching a significant test of this question, with the contested uptake of genome edited crops.

10.8 Will CRISPR Crops Become GMO 2.0?

Since 2012 scientists have mastered a new method to improve crops more quickly and at a lower cost, using genome editing tools such as CRISPR (which stands for Clustered Regularly Interspaced Short Palindromic Repeats). The beneficial edits can be accomplished without introducing any "foreign DNA," so the changes are similar in many ways to common natural mutations. This should have made gene editing more acceptable to the public, but it did not prevent environmental advocates in Europe, led by Friends of the Earth, from mounting a legal against CRISPR crops, branding them "GMO 2.0."

In 2018 these critics secured a ruling from the European Court declaring that gene-edited crops should be regulated just like GMOs, under the same stifling requirements for case-by-case pre-market approval, labeling, segregation in the fields, and audit-trail tracing (Stokstad 2018). The Court said in its ruling that the risks from CRISPR crops "might prove similar" to the risks associated with GMO crops, a puzzling assertion since all of Europe's science academies, and even the EU Commission, had by that time found no new risks from GMOs (EU 2010). One researcher at the Heinrich Heine University in Germany predicted this Court ruling would be "the death blow for plant biotech in Europe" (Stokstad 2018).

In this case resistance to the new science from environmental advocates did raise a legal hurdle well before farmers had a chance to plant any gene-edited crops yet, for other reasons, this new technology should prove more difficult to block than GMOs. The absence of "foreign DNA" makes these crops seem more natural, and with no detectable transgenes they will also be harder for regulators to identify, trace, and segregate. CRISPR techniques in the lab are also much faster, easier, and less costly than transgenic GMO techniques (Chen, Et al. 2019), so beneficial applications are likely to proliferate, and since detection will be nearly impossible some of the improved crops might move into farm fields through simple stealth. This happened even with GMO seeds, when plantings of soybeans in Brazil and cotton in India spread rapidly without official permission, as a fait accompli. The seeds performed so well that government regulators were forced to give permission in the end.

Other factors will also be in play. Countries in Asia and Africa are less likely to follow Europe's regulatory lead with genome-editing, compared to transgenic GMO crops two decades ago, because they now have a much greater scientific capacity—better labs and more molecular biologists—to take advantage of this new crop science. The fact that genome editing is faster and cheaper compared to rDNA will also make the technology harder for big corporations to monopolize. Non-corporate scientists will be able to develop improved varieties of the "orphan crops" ignored until now because they are only locally significant, or only planted by poor farmers who can't afford to buy commercial seeds.

Because most gene-edited crops will have no foreign DNA and will not have to come from large profit-making companies, they will also be easier for both farmers and consumers to trust. They are less likely to be locked up by patents. In September 2021, Wageningen University in the Netherlands, a world leader in agricultural research, announced it would waive its patent rights on CRISPR technologies for non-commercial use to help get these technologies more quickly into the hands of the poor (Van der Oost, J., and Fresco, L., 2021).

The political geography of crop science regulation has also changed over the past two decades. The Western Hemisphere, led by the United States, Canada, Argentina, and Brazil, has remained friendly to new crop science, including genome editing. Argentina was among the first to set in place permissive regulations for gene-edited crops, along with the United States, and as early as 2013 Canada commercialized a gene-edited variety of canola. The UK, which left the EU in January 2020, is going forward with gene edited crops as well. Meanwhile Europe has lost influence and China, a strong supporter of gene editing, has gained global influence through its Belt and Road Initiative. In agriculture, specifically, China hosted a Forum on China-Africa Cooperation (FOCAC) in Beijing in 2000 and created 25 Agricultural Technology Demonstration Centers in individual African countries.

China still hasn't commercialized transgenic rice, maize, or soy, but it has shown little hesitation on genome editing. As early as 2018 China had nearly as many CRISPR patent applications and published scientific papers on CRISPR as the United States. China's interest in the latest crop science was clear in its recent purchase of the international biotech company Syngenta. Eager to capture CRISPR's benefits, China's Ministry of Agriculture and Rural Affairs released preliminary guidelines early in 2022 that exempted gene-edited crops from GMO regulations, so long as they had no "foreign" DNA (FAO 2022). Few of China's agricultural exports go to Europe, so it will worry less about market risks from commercializing CRISPR crops.

Other important Asian countries that previously followed Europe on GMO regulations are also being more open to CRISPR crops. Japan has decided that genome-edited crops must be registered, but they don't need to undergo separate safety or environmental testing, and in December 2020 Japan explicitly approved the sale to consumers of a genome-edited tomato (Houser 2022). In India, at least seven institutes and universities are now using gene-editing to improve rice, banana, groundnuts, wheat, soybean, and maize. India still prohibits the planting of any transgenic GMO crops other than cotton and mustard, but in 2020 its National Academy of Agricultural Sciences recommended that gene-edited crops without foreign DNA should be exempt from GMO regulations (FAO 2022).

Even in Africa, both Nigeria and Kenya have now published guidelines for scientists working with CRISPR, indicating that crops (and animals) with no foreign DNA will probably not be regulated as GMOs. Kenya's Biosafety Authority has even granted approval to seven different gene-editing research projects.

10.9 Conclusion: Even Unpopular Science Reaches Farmers, Most of the Time

The historical record shows that even when agricultural science becomes unpopular with cultural elites, it can go forward in the field. Sometimes this happens because the new science only encounters cultural resistance after it has already reached farm fields, by which time farmers will refuse to give it up. This was the case with Green Revolution seeds, highly capitalized industrial farming, and synthetic chemicals. GMO food crops were blocked from a broad uptake because cultural resistance arose before most farmers got the seeds. The new political power of environmental organizations might seem to make such outcomes more probable in the future.

On the other hand, agricultural science is learning to protect itself from elite cultural resistance by finding a home in countries where food production imperatives are still strong, and where the grim realities of pre-modern, pre-industrial farming are a more recent memory. Twenty years ago, Asia mostly followed Europe's lead in blocking the uptake of GMO crops, but today Asia is turning away from Europe's example and joining the Western Hemisphere in clearing a path for genome editing. Even Africa, much of which missed out on both the Green Revolution and GMOs, is joining this camp. Europe's resistance to modern crop science is thus becoming politically isolated. This will likely prove uncomfortable for Brussels. Green Parties in Europe attracted to pre-industrial, artisanal crop farming may have to accept compromise in the end.

In the future, it is likely that popular misgivings toward agricultural science will continue to arise, especially among the well-fed urban dwellers in rich countries who have little first-hand exposure to commercial farming. But the resulting suspicions will not have to alter outcomes on farms around the world, so long as scientists continue to deliver new tools that are safe to use, sustainable, and most of all profitable for farmers. It will be farmers, more often than not, who get the last word.

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