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Sustainable GMOs: An Oxymoron?

Contribution to GTI Forum Technology and the Future

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Can technologies, in and of themselves, be sustainable or unsustainable? The introduction of genetically engineered crops into agriculture in the mid-1990s has been heralded as the second coming of the Green Revolution. Among the expectations were high yields, fewer inputs like pesticides, and new nutritionally enhanced foods. Around the same period, the concept of sustainability was introduced into the working lexicon of many disciplines, practitioners, and corporations. To what extent, then, does such genetic engineering meet the standards of this new concept? A careful analysis of the principles of sustainability and their applications to agriculture shows that sustainability cannot be applied to a specific technology without considering the system in which it is embedded.

The introduction of genetically engineered seeds, beginning with insect-resistant and herbicide-tolerant crops, brought international opposition from environmental groups like Greenpeace as well as several nations. In response to the controversy over the introduction of genetically modified organisms (GMOs) into agriculture, the European Union established a regulatory system that included risk analysis, testing programs, and strict criteria for adoption of GMOs into agricultural production and presence in food shipments to European nations. In contrast, the United States did not require testing but began with the assumption of "substantial equivalence," considering GMOs as safe as traditionally bred crops unless proven otherwise.

The terms "sustainable" or "sustainability" are among the most widely used terms in the titles of scientific papers. From Web of Science, I found 122,744 titles containing one of those two words. In 2020 and 2021, the terms appeared in 20,760 and 14,896 titles in scientific papers, respectively, while 19,255 books had the root "sustainable" in their titles. Before we can ask "Is X sustainable?,"

where X is a product, system, or technology, we must be clear about what we mean when people use the term "sustainability."

The Brundtland Report, the culmination of the work of the World Commission on Environment and Development in 1987, referred to sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Specifically, with respect to sustainable agriculture, the report states that the rate of depletion of topsoil, fish stock, and forest resources should not exceed the rate of regeneration. The operative term is "regenerative agriculture," also referred to as "sustainable agriculture." When we ask whether the technology of genetically modified organisms (crops) supports agricultural sustainability, we shall refer to the protection of the agro-ecological system.

In Hawaii, papaya tree plantations were blighted by the papaya ringspot virus (PRV), which could not be controlled by pesticides or netting to stop its spread by the aphid vectors. A laboratory technique initially called "coat-protein gene-mediated transgenic resistance" was developed for papaya cells. Under the right conditions, plants can be sensitized with a coat protein of an invading pathogen, inducing an immune response against the invading pathogens. In some respects, it is akin to vaccination in mammals.

The GMO papaya has been widely heralded as a success, which can be adapted to any sized farm. Its use mitigates against the use of insecticides and other environmentally damaging methods to destroy the aphids carrying the virus.

The GMO papaya is already in use, but there are also potential applications of transgenic crops that show a favorable approach to sustainability, such as the genetic modification of bacteria and plants to extend nitrogen fixation to new plants. The massive application of inorganic nitrogen fertilizers in agriculture is a well-documented environmental contaminant. The fertilizers drift away from agricultural fields leaching into lakes, rivers, streams, and aquifers, creating eutrophication. The excessive nitrogen sources, providing a richness of nutrients in bodies of water, frequently causes a dense growth of plant life and results in the death of animal life from lack of oxygen.

One of the earliest projects for the new biotechnology industry during the last quarter of the twentieth century was the transformation of plants that cannot naturally fix nitrogen into nitrogen

fixers. This involved genetically modifying bacteria that are symbiotic to these plants with nitrogen fixation genes or genetically modifying the plants with such genes. While creating new plants with nitrogen-fixing properties would contribute to sustainable agriculture, doing so has faced many obstacles.

Other new positive social applications of GMOs enhance nutrition without causing any detriment to the environment; take, for example, Golden Rice. The rice genome was genetically modified to contain a precursor to vitamin A, which the body can turn into the vitamin. As blindness is common in vitamin A-scarce communities, this product could help reduce the worldwide prevalence of child blindness, and in 2019 it was approved for use as human food in the Philippines. The American Society of Human Nutrition reported that a cup of Golden Rice consumed daily could provide 50 percent of the Recommended Daily Allowance for vitamin A.

However, other GMO crops do not meet the criteria for sustainability. One of the earliest GMOs to enter commercial markets were herbicide-tolerant crops. The premise behind their development was that they would resist any damage from spraying herbicides, which could then be used to eliminate weedy competitors of the crops. Glyphosate-based herbicides (GBH) have proven to be highly controversial. In 2015 the International Agency for Research on Cancer (IARC), an independent research arm of the World Health Organization, issued a report that glyphosate is a probable human carcinogen. Other studies have found GBH deleterious to many species, including butterflies, quails, and frogs.

Given the extensive environmental impacts of GBH and its suspected effects on humans, this class of herbicides does not meet the standards of agricultural sustainability. Thus, the system in which GBH is embedded and with which it is co-dependent, namely, GMO transgenic crops, cannot be sustainable.

The prospects of genetically engineering plants with insecticidal proteins provided another approach to the management of insects. It has been estimated that 37 percent of what is planted is lost from insect herbivores. In the mid-1970s, scientists discovered a plasmid (circular piece of DNA) in the bacterium *Bacillus thuringiensis* (Bt), which encodes crystalline proteins that are toxic to specific insects.

Natural forms of Bt have been used by farmers since the 1920s and were approved in the form of granules or as a liquid under the organic standards as a natural microbial pest control agent. The terms "Bt-transgenic crops" refers to those that had the insecticidal properties of Bt built into the genome of the plant. The first approved Bt crops were introduced into commercial agriculture in 1995 and included potatoes, corn, and cotton, and Bt has since been expanded to many other crops.

The prospect that Bt transgenic crops would substitute for billions of pounds of chemical insecticides that are sprayed promiscuously on farmland leaching into waterways made these GMO crops a prospect for sustainable agriculture. However, several problems arose from the extensive use of Bt crops. First, insects became resistant to them. Once the insects became resistant to Bt crops, farmers had to either use chemical pesticides or accept crops that had more than one toxic protein. Thus, plants had to be genetically modified to contain a pyramid of toxic proteins, imposing additional risks on the crops and the environment. Many of the early gains of reduced insecticide use had diminished. Secondly, organic farmers, who used Bt sparingly at the times that insects were invading their crops could no longer use the pesticide because of the rise of Bt-resistant insects.

Sustainable agriculture is not premised on a particular crop of set of crops, but rather on an integrated ecological system. A GMO crop cannot be assessed for its sustainability by itself without considering the system in which it is embedded. While a single crop or procedure cannot turn a non-sustainable agricultural system into a sustainable one, it can turn a sustainable system into a non-sustainable one. The ethics behind sustainability is fundamentally in the selection of a system, where all the parts fit together to preserve the ecology for future generations.

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