Impacts of GE Crops on Biodiversity

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The potential impact of genetically engineered (GE) crops on biodiversity has been a topic of interest both in general as well as specifically in the context of the Convention on Biological Diversity. In a recent review, I took a biodiversity lens to the substantial body of literature that exists on the potential impacts of GE crops on the environment, considering the impacts at three levels: the crop; farm; and landscape scales[1]. Overall, the review finds that currently commercialized GE crops have reduced the impacts of agriculture on biodiversity, through enhanced adoption of conservation tillage practices, reduction of insecticide use, and use of more environmentally benign herbicides. Increasing yields also alleviate pressure to convert additional land into agricultural use.

Crop diversity

Crop genetic diversity is considered a source of continuing advances in yield, pest resistance, and quality improvement. It is widely accepted that greater varietal and species diversity would enable agricultural systems to maintain productivity over a wide range of conditions. With the introduction of GE crops, concern has been raised that crop genetic diversity will decrease because breeding programs will concentrate on a smaller number of high value cultivars. Three studies have analyzed the impact of the introduction of GE crops on within-crop genetic diversity. Studies of genetic diversity in cotton and soybean in the U.S. both concluded that the introduction of GE varieties was found to have little or no impact on diversity. In contrast, the introduction of Bt cotton in India initially resulted in a reduction in on-farm varietal diversity due to the introduction of the technology in only a small number of varieties, which has since been offset by more Bt varieties becoming available over time. From a broader perspective, GE crops may actually increase crop diversity by enhancing underutilized alternative crops, making them more suitable for widespread domestication.

Farm-scale diversity

Plants have a major influence on soil communities of micro- and other organisms that are fundamental to many functions of soil systems, such as nitrogen cycling, decomposition of wastes, and mobilization of nutrients. The potential impact of Bt crops on soil organisms is well studied. A comprehensive review of the available literature, by Icoz and Stotzky, on the effects of Bt crops on soil ecosystems included the results of 70 scientific articles[2]. The review found that, in general, few or no toxic effects of Cry proteins on woodlice, collembolans, mites, earthworms, nematodes, protozoa, and the activity of various enzymes in soil have been reported. Although some effects, ranging from no effect to minor and significant effects, of Bt plants on microbial communities in soil have been reported, they were mostly the result of differences in geography, temperature, plant variety, and soil type and, in general, were transient and not related to the presence of the Cry proteins. Studies published since the Icoz and Stotzky review have reached similar conclusions, including novel studies on snails.

Crop production practices also have significant effects on the composition of weed communities. Changes in the kinds of weeds that are important locally are termed weed shifts. Such shifts are particularly relevant for managing weeds in herbicide tolerant crop systems in which tillage practices and herbicide use both play major roles in shaping the weed community. There are reports in the literature of fourteen weed species or groups of closely related species that have increased in abundance in glyphosate resistant (GR) crops. At the same time, in a survey of corn, soybean, and cotton growers in six states, between 36% and 70% of growers indicated that weed pressure had declined after implementing rotations using GR crops.

The use of herbicides can also result in changes to weed communities through the development of herbicide tolerant weed populations. Globally, GR weeds have been confirmed for 21 weeds in 15 countries. Most of these cases have been reported where GR crops are commonly grown. The development of weeds resistant to glyphosate will likely require modification to weed control programs where practices in addition to applying glyphosate are needed to control the resistant populations.

Landscape-scale diversity

The most direct negative impact of agriculture on biodiversity is due to the considerable loss of natural habitats, which is caused by the conversion of natural ecosystems into agricultural land. Increases in crop yields allow less land to be dedicated to agriculture than would otherwise be necessary. A large and growing body of literature has shown that the adoption of GE crops has increased yields, particularly in developing countries. A review of the results of global farmer surveys found that the average yield increases for developing countries range from 16% for insect-resistant corn to 30% for insect-resistant cotton, with an 85% yield increase observed in a single study on herbicide-tolerant corn[3]. On average, developed-country farmers report yield increases that range from no change for herbicide-tolerant cotton to a 7% increase for herbicide-tolerant soybean and insect-resistant cotton. Researchers have estimated the benefit of these yield improvements on reducing conversion of land into agricultural use. They estimate that 2.64 million hectares of land would probably be brought into grain and oilseed production if biotech traits were no longer used[4].

The most direct landscape-level effects of growing Bt crops would be expected for target pest species for which the crop is a primary food source and that are mobile across the landscape[5]. Area-wide pest suppression not only reduces losses to adopters of the technology, but may also benefit non-adopters and growers of other crops by reducing crops losses and/or the need to use pest control measures such as insecticides.

Several studies have investigated the impact of the introduction of Bt corn and cotton on regional outbreaks of pest populations, reporting evidence of regional pest suppression in Bt corn and cotton in various areas of the U.S. and in Bt cotton growing regions of China.

The effects of GE crops on above-ground non-target invertebrates have been the subject of a large number of laboratory and field studies. By the end of 2008, over 360 original research papers had been published on non-target effects of Bt crops[6]. A comprehensive review of the literature by Naranjo included 135 laboratory-based studies on nine Bt crops from 17 countries and 63 field-based studies on five Bt crops from 13 countries, which were analyzed using meta-analysis techniques. In general, laboratory studies identified greater levels of hazard than field studies, at least partially explained by differences in organisms studied, and frequently higher protein exposure in lab studies compared to exposure levels in the field. Field studies demonstrated few harmful non-target effects, with the non-target effects of insecticides being much greater than Bt crops. More recent literature on the non-target impacts of Bt crops are largely consistent with Naranjo's conclusions.

Studies on the non-target impacts of herbicide tolerant crops, such as the UK Farm Scale Evaluations (FSE), have found that the effects on various groups of arthropods followed the effects on the abundance of their resources. Where weed control was more effective, the reduction in weeds and weed seeds led to decreases in insects that live in or on weeds, and vice versa. Other studies on the non-target impacts of herbicide tolerant crops, conducted for HT soybean and corn in the U.S. and HT canola in Canada, have reached similar conclusions.

The bird survey results of the FSE were in accord with differences in food availability found in the studies. Specifically, a greater abundance of granivores was found on conventional than genetically engineered herbicide tolerant sugar beet, as well as on genetically engineered herbicide tolerant maize after application of herbicides to the GE HT field. No differences were detected in spring oilseed rape. In the subsequent winter season, granivores were more abundant in fields where conventional sugar beet had been grown than on GE HT fields. Several bird species were more abundant on maize stubbles following GE HT treatment.

Indirect indicators

The introduction of herbicide tolerant crops has been associated with the increased adoption of conservation tillage practices, which decreases run-off, increases water infiltration, and reduces erosion. Trends in the adoption of conservation tillage have been studied in the U.S. and Argentina, the largest growers of herbicide tolerant crops. While conservation tillage was already being adopted by some growers prior to the introduction of GE herbicide tolerant crops in both countries, studies have shown a positive two-way causal relationship between the adoption of conservation tillage and the adoption of GE herbicide tolerant crops.

The pest management traits that are embodied in currently commercialized GE crops have led to changes in the use of pesticides that may have impacts on biodiversity. If the planting of GE pest-resistant crop varieties eliminates the need for broad-spectrum insecticidal control of primary pests, naturally occurring control agents are more likely to suppress secondary pest populations, maintaining a diversity and abundance of prey for birds, rodents, and amphibians. In addition to the studies on the non-target impacts of GE crops compared to conventional practices, many studies have quantified changes in pesticide use since the introduction of GE crops. Reductions ranging from 14% to 75% of total active ingredient have been reported for Bt crops compared to conventional crops in Argentina, Australia, China, India, and the U.S.

Fewer surveys have captured changes in herbicide use in GE herbicide tolerant crops, perhaps because the impact of GE herbicide tolerant crops has largely been a substitution between herbicides that are applied at different rates, and therefore, changes in the amount of herbicide used is a poor indicator of environmental impact. Several studies have been done to apply environmental indicators to observed changes in pesticide use related to the adoption of both insect resistant and herbicide tolerant crops, which all show a reduction in the environmental impact of pesticides used on GE crops.

Conclusion

Knowledge gained over the past 15 years that GE crops have been grown commercially indicates that the impacts on biodiversity are positive on balance. By increasing yields, decreasing insecticide use, increasing use of more environmentally friendly herbicides, and facilitating adoption of conservation tillage, GE crops have contributed to increasing agricultural sustainability.

Previous reviews have also reached the general conclusion that GE crops have had little to no negative impact on the environment. Most recently, the U.S. National Research Council released a comprehensive assessment of the effect of GE crop adoption on farm sustainability in the U.S. that concluded, "[g]enerally, [GE] crops have had fewer adverse effects on the environment than non-[GE] crops produced conventionally"[7].

GE crops can continue to decrease pressure on biodiversity as global agricultural systems expand to feed a world population that is expected to continue to increase for the next 30 to 40 years. Due to higher income elasticities of demand and population growth, these pressures will be greater in developing countries. Both current and pipeline technology hold great potential in this regard. The potential of currently commercialized GE crops to increase yields, decrease pesticide use, and facilitate the adoption of conservation tillage has yet to be realized, as there continue to be countries where there is a good technological fit, but they have not yet approved these technologies for commercialization.

In addition to the potential benefits of expanded adoption of current technology, several pipeline technologies offer additional promise of alleviating the impacts of agriculture on biodiversity. Continued yield improvements in crops such as rice and wheat are expected with insect resistant and herbicide tolerant traits that are already commercialized in other crops.

Technologies such as drought tolerance and salinity tolerance would alleviate the pressure to convert high biodiversity areas into agricultural use by enabling crop production on suboptimal soils. Drought tolerance technology, which allows crops to withstand prolonged periods of low soil moisture, is anticipated to be commercialized within five years. The technology has particular relevance for areas like sub-Saharan Africa, where drought is a common occurrence and access to irrigation is limited. Salt tolerance addresses the increasing problem of saltwater encroachment on freshwater resources.

Nitrogen use efficiency technology is also under development, which can reduce run-off of nitrogen fertilizer into surface waters. The technology promises to decrease the use of fertilizers while maintaining yields, or increase yields achievable with reduced fertilizer rates where access to fertilizer inputs is limited. The technology is slated to be commercialized within the next 10 years.

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