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Agriculture and Biodiversity Loss: Genetic Engineering and the Second Agricultural Revolution

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Genetic engineering has many and varied effects on biodiversity, but its likely long-term result will be a decrease in genetic variability of crops and other species. In a narrow sense, the large-scale deployment of genetically engineered crops that began in the mid-1990s has increased the genetic diversity of target crops by introducing wholly novel DNA segments (transgenes). When successfully introduced from another species, a transgene causes a plant to express a new trait, with little or no change in diversity among the 10,000 to 100,000 other genes native to the species. Probably more significant than the direct effect of gene insertion, however, are the indirect effects of transgenes on the biodiversity of the target crop, other crops, and other life forms. Hard data are scarce, and the direction and magnitude of biotechnology's effect on biodiversity will be evaluated accurately only after transgenes have been deployed for decades. The eventual consequences will depend on the biotechnological techniques employed, the genes selected for manipulation, and the ways in which transgenic crops are used. Nevertheless, when viewed as an extension of industrial agriculture, genetic engineering is likely to accelerate homogenization of the biosphere.

The explicit goals of biotechnology, like those of traditional plant breeding, are to increase agricultural productivity and profitability, and often to improve human nutrition. The consequences for biodiversity are largely unplanned and indirect. Although some predictions can be made, virtually all results of research on biotechnology's environmental impact are hotly debated among scientists.

Early research suggested ways in which transgenes could expand the diversity of crops and associated species. By increasing productivity on land already under cultivation, transgenic crops could forestall expansion of agriculture and the displacement of more diverse natural vegetation. Introduced genes for pest resistance have augmented the collections of naturally occurring genes available to plant breeders, giving them more options in developing sustainable resistance. Genetic resistance, in turn, may reduce the use of broad-spectrum pesticides and the consequent loss of diversity in nontarget species. Engineering of minor crop species to produce economically valuable enzymes, vaccines, or hormones could allow farmers to diversify the range of crops they grow. Manipulation of genes that control chromosome pairing or other aspects of meiosis could allow breeders to produce fertile hybrids between previously incompatible species.

These potential contributions likely will be canceled out in the long term by genetic engineering's negative effects on biodiversity. Historically, a phenomenon known as genetic erosion has occurred when crop varieties with high yields or other traits desired by farmers have displaced more genetically diverse traditional varieties. Transgenic technology is the latest in a long line of genetic tools developed over the past century, and it will enhance the power of modem plant breeding to cause genetic erosion. In the United States, seed of nontransgenic maize, soybean, and cotton, for example, is now less available because of the wide adoption of transgenic hybrids and varieties.

Diversion of research funds from traditional plant breeding into genetic engineering can further restrict the genetic diversity of farmers' seed sources. Development of a transgenic variety can cost more than twenty times as much as the breeding of a variety through the traditional route of hybridization and selection. Given such a ratio, a breeding program could release to farmers either five transgenic varieties or 100 nontransgenics for an equivalent investment. Whatever their agronomic performance, the 100 varieties are almost certain to encompass more genetic diversity than the five transgenics.

Transgenes may cause ecological disruption and loss of biodiversity that goes well beyond genetic erosion in the farmer's field, however. Some evidence for this comes from the first transgenes to be deployed over large areas of cropland □ a gene for resistance to the herbicide glyphosate in soybean and one coding for the *Bt* toxin that confers insect resistance in maize and cotton. Spraying a field with glyphosate eliminates virtually every plant of every species, except for engineered crop plants carrying the resistance gene. Evaluating the consequences for local or regional biodiversity will require many years, but some computer models have predicted reduction of plant and animal populations. Transgenic maize or cotton plants that produce the *Bt* toxin in all plant tissues at all stages of growth can dramatically reduce local populations of toxin-susceptible insects. Research has demonstrated toxicity to parasites and predators that attack insects feeding on *Bt* crops. Concern is compounded by reports that the toxin persists well after harvest, bound to soil particles where it could alter populations of soil microorganisms. However, despite such studies, the long-term effect of *Bt* on diversity is unknown. Some loss might be avoided by engineering *Bt* genes to produce the toxin only when the plant is being attacked and only in the tissue being eaten by the insect.

There is widespread evidence of gene flow through natural cross-pollination between crops and related weed or wild species, and transgenes will be transferred in the same way. There is no consensus, however, on what that will mean for biodiversity. In one catastrophic scenario, an escaped transgene might allow a wild or weed species to increase its density and range greatly, displacing other species. Evolutionary theory suggests that a randomly introduced gene has a higher probability of reducing than of increasing a weed's fitness, but whatever the average effect of a particular gene on fitness, we cannot rule out the possibility that a "superweed" may emerge once many different species are exposed to trans-genes in many different ecosystems.

Monocultures lack the inherent protection against fungi, bacteria, viruses, arthropods, and weeds that comes with the genetic variability of natural ecosystems or some traditional farming practices. Genetically uniform crops must be protected against pests, and that is most often accomplished through incorporation of resistance genes through breeding, or by the use of chemical control. As illustrated by the transgenes for glyphosate resistance and the *Bt* toxin, biotechnology is an enhanced method for applying these same control strategies. Therefore its successful application can permit farmers to continue sowing monocultures, instead of turning to pest-control methods that employ genetic diversity, such as variety blends, polycultures, or crop rotation.

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