ECOLOGY

Harvesting Data from Genetically Engineered Crops

More than a billion acres have been planted with genetically engineered crops in the USA since 1996, but we do not fully know their ecological costs and benefits.

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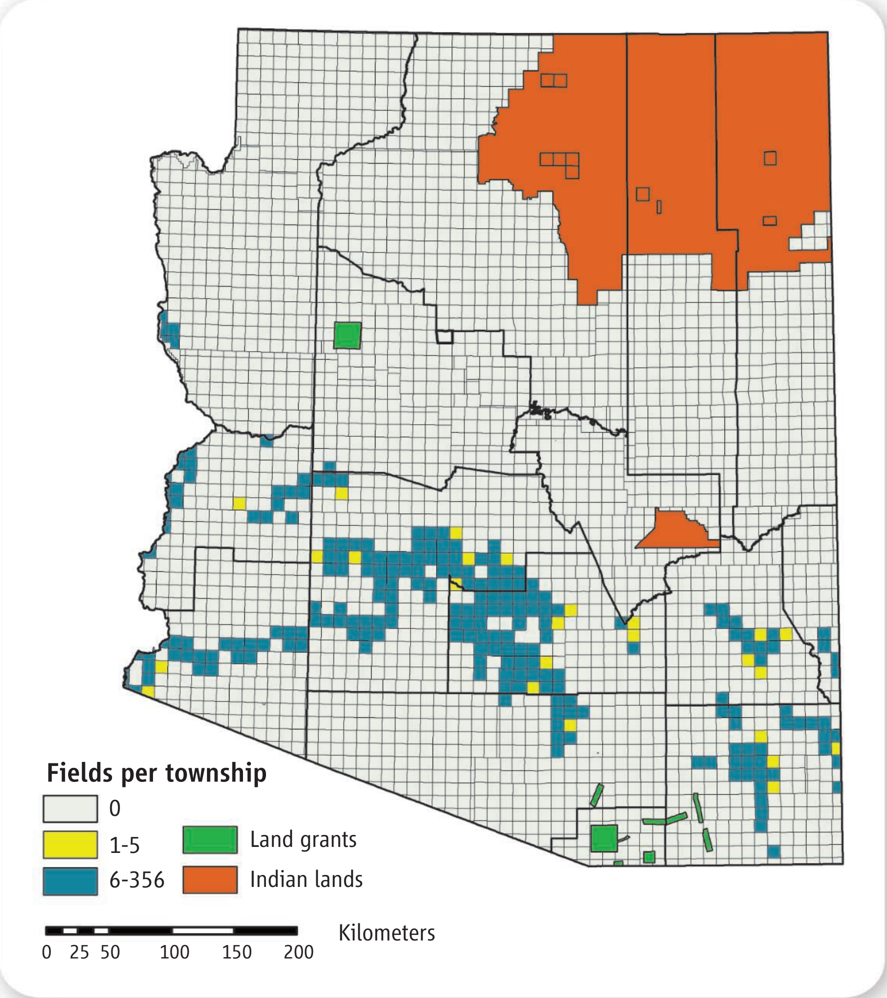
Agricultural output must keep pace with a steadily increasing human population, yet must do so without destroying critical habitat for biodiversity or severely impairing ecosystem services. Genetically engineered (GE) crops may help meet these demands. However, a full accounting of the relative costs and benefits accrued from the widespread planting of GE plants is still unavailable. Uncertainties about the long-term, large-scale effects of GE crops are fueling a polarized debate. One side perceives that excessive regulation is slowing the delivery of benefits (*1*); the other is concerned that adoption is proceeding hastily and without adequate safeguards (*2*). The widespread planting of GE crops in the United States since 1996 represents a grand experiment that could provide the information necessary to resolve much of this debate. Unfortunately, this experiment cannot be analyzed because we lack well-documented maps depicting the varying prevalence of crops with specific GE traits each year.

Data documenting acreage planted to various crop species are annually collected by the U.S. Department of Agriculture's (USDA) National Agricultural Statistical Service (NASS) in all 50 states (*3*), and a more extensive census of U.S. agriculture is conducted every 5 years (*4*). Since 2000, a randomly selected subset of farmers has been asked annually if they planted GE varieties of corn, cotton, or soybean, the most widely planted of the GE crops in the United States. Although the NASS annually interviews >125,000 farmers about their land use, the data regarding acreage devoted to various GE crops are aggregated to the level of individual states—a spatial resolution too crude to allow assessments of the environmental consequences, either positive or negative, of GE crops.



Distribution of agricultural fields in 2005 in Arizona counties and townships. Counties are delimited by thick lines (mean area = 19,700 km^2), and townships by thin black lines (mean area = 85.2 km^2). With some exceptions, land grants and Indian lands are not divided into townships. The mean number of fields per township for the 261 townships with at least one field was 96; 25 had 1 to 5 fields (yellow), 236 had 6 to 356 fields (blue). Privacy would be preserved by mapping the distribution of GE crops by county, or in many cases by townships with >5 fields. [Mapped data are from the Arizona Geographic Information Council and the Arizona Cotton Research and Protection Council]

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Data on the geographic distribution of GE crops would be more informative and useful if it were aggregated and publicly released at the spatial scale of counties, of which two-thirds are <2000 km^2. In western states such as Arizona, with some counties >10,000 km^2, townships would be a more appropriate spatial scale (see figure, above). Annual data regarding crop acreage are already available at the scale of counties for the entire nation. We are proposing that the NASS also report the proportion of acres planted to GE varieties at this scale. This would permit analyses that could illuminate the trade-offs associated with alternative agricultural practices, while maintaining farmer pri-

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vacy (see figure). If generating these estimates at the scale of counties should prove too costly, the relevant information could be obtained from seed sale records. For example, the U.S. Environmental Protection Agency (EPA) requires corporations to report annual sales of certain insect-resistant GE varieties by county as a condition of registration (*5*, *6*).

In addition, finer resolution is needed about the characteristics of the GE crops. The NASS annually reports acreages for GE crops lumped into four crude categories: insect-resistant, herbicide-resistant, stacked (meaning resistant to both insects and herbicides), and "all biotech varieties." However, this classification masks substantial variation. For example, 12 different combinations of one to three insecticidal proteins that kill caterpillars, beetles, or both are produced by different varieties of GE corn and cotton currently registered in the United States (*7*). It is essential to discern whether a particular transgenic variety and its traits are associated with environmental patterns such as changes in water quality, biodiversity, or pest resistance. Therefore, we recommend that the NASS keep and make available to environmental scientists records regarding the specific transgenic varieties planted. For completeness, GE field trial locations (again, at the county level, to avoid vandalism of plots) and accidental releases of GE organisms should also be included in a spatially explicit database.

Analyses of the consequences of GE crops must be interpreted in the context of other farming practices. Fortunately, information regarding agricultural practices such as the use of insecticides and herbicides is already being collected on a sufficiently fine scale in several states (*8*–*10*), and such efforts could be merged into national maps. Although cause-and-effect relationships would be difficult to determine, the prevalence of GE crops varies widely among counties within states (*11*), which produces spatial and temporal contrasts that can be analyzed as large-scale experiments. More nuanced investigations are possible by drawing on regularly monitored environmental attributes such as water quality, soil erosion, and land-use patterns, which are reported by the USDA, EPA, and other federal and state agencies (see table, above).

Variable	Frequency	Spatial scale	Agency or organization
Use of insecticides, herbicides, and fungicides*	Annually Every 5 years Annually	States Counties Counties	USDA NASS† USDA NASS State agencies
Use of chemical fertilizers and manures‡	Every 5 years	Counties	USDA NASS
Other farming practices§	Annually	States	USDA NASS
Water quality‖	Approx. hourly to every 4 years	Site, watersheds, basins	USGS NAWQA, EPA¶
Aquatic organism surveys**	Every 3 to 4 years	Site, watersheds, basins	USGS NAWQA, EPA
Amphibian research and monitoring	Annually	Nested catchment	USGS
Breeding bird survey	Annually	Site	USGS
Christmas bird count	Annually	Site	USGS
Endangered species distributions	Irregular	Counties	NatureServe

*By active ingredient and crop. †See www.pestmanagement.info/nass/. ‡By crop. §Includes summer fallow vs. continuous cropping, irrigated vs. not, crop rotations (for specific crops). ‖Includes pesticide residues, suspended sediments, physical and chemical attributes. ¶See http://water.usgs.gov/nawqa/ and www.epa.gov/storet. **Biomonitoring of macroinvertebrates and fishes.

Examples of existing public information. When integrated with spatially explicit data on the use of GE crops, such information could allow assessment of the benefits and drawbacks of these crops. Although these data are not all at the spatial scale of counties or townships and data quality is variable, this list provides a starting point for the types of analyses we envision. Many relevant spatially explicit datasets can be downloaded from http://water.usgs.gov/lookup/getgislist. "Site" refers to a transect, river segment, or other relevant sampling unit. In all cases, sites are smaller than the scale of counties (or townships), and therefore, data from sites could potentially be aggregated to the scale of counties (or townships).

Some important lessons have already been learned from analyses similar to those proposed here. For example, cotton growers in Arizona have collaborated with researchers (under an agreement preserving farmers' privacy) by providing detailed statewide maps of fields of conventional and GE cotton. These maps have allowed researchers to show that insect-resistant GE cotton has fostered long-term suppression of a major insect pest and has helped to reduce insecticide use while maintaining crop yield (*12*, *13*). Diversity of nontarget insects was decreased by insecticide use, but was not directly affected by cultivation of GE versus conventional cotton.

By linking maps of agricultural practices with existing monitoring of birds, fish, and amphibians, one could also examine associations between agricultural practices and trends in species abundances across both space and time (see table). Agriculture is the dominant land use in the USA and in most of the world. Regulations, public policy, and financial incentives are often aimed at making agriculture more sustainable or more productive (*14*, *15*). Yet, rarely do we have data to know the actual consequences of different farming practices. GE crops are a new technology that promises to revolutionize agriculture for the good of humankind. To inform our choices about agricultural options, we must seize the chance to collect and assess data that are relatively easily obtained. The key will be to balance the rights of privacy for individual farmers and corporate concerns regarding confidential business information with the public good that can come from analyzing these data.

The approach we advocate will help us identify which agricultural practices maximize benefits to farmers and society while minimizing environmental risks. The United States has the world's most extensive history of using GE crops and one of the world's best continental-scale programs in environmental monitoring. Combining these two sources of information provides an opportunity to lead the world in identifying agricultural pathways for the future that best serve people and the environment. Providing scientists access to data on GE crop use at the county scale is a small and relatively inexpensive step with enormous scientific and public benefits.

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