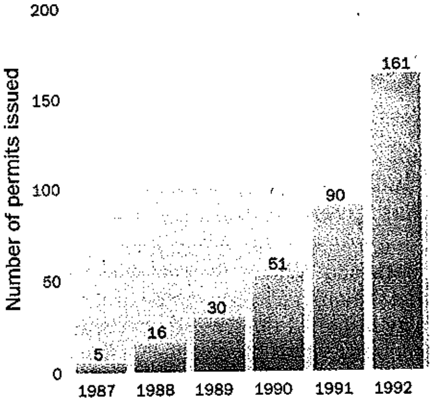
AGRICULTURE

Transgenic plants on trial

Peter Kareiva

READERS curious to see what a landmark paper looks like should turn to page 620 of this issue[1]. There Crawley and colleagues describe an ecological study which will bring one of the hottest debates about the use of genetically engineered plants in agriculture into the realm of rational discourse. The debate centres on the possible invasiveness of such plants into places where they are not wanted. What Crawley *et al.* do is show just how to go about the business of assessing the risks concerned.

Since the US Department of Agriculture started regulating field trials involving transgenic plants, more than 370 permits in 35 states have been issued[2] (see figure). Genes for a wide variety of agriculturally valuable traits have been inserted into over a dozen crops, as listed in the table, and many of the resultant cultivars have performed well enough to send companies back to the USDA seeking deregulation of these recombinant genotypes. Deregulation results in a recombinant variety being treated the same as a conventional crop and is, of course, a prerequisite for commercialization of transgenic crops. But environmentalists want to be assured that the ecological risks are minimal. One of those risks is of a new crop escaping from cultivation and invading natural vegetation, a possibility which has been discussed largely in terms of anecdote and platitude based on ideology. Crawley and his team at Silwood Park have finally added what has been glaringly missing from these discussions — a quantitative experimental study of invasiveness in a transgenic plant, the plant concerned being oilseed rape.



Number of permits issued per year for field trials involving genetically engineered plants in the United States and Puerto Rico. Because many of the permits cover a single recombinant variety being planted at several sites, the 353 permit-based trials that had been conducted by the end of 1992 actually represent more than 700 sites. (Data from the USDA APHIS BBEP Biotechnology Permits Unit.)

Major cultivars that have been modified using recombinant DNA technology, and the agronomically valuable traits that have been inserted into them

Alfalfa	Herbicide tolerance, virus resistance
Apple	Insect resistance
Oilseed rape (canola)	Herbicide tolerance, insect resistance, modification of seed oils
Canteloupe	Virus resistance
Corn	Herbicide tolerance, insect resistance, virus resistance, wheat germ agglutinin
Cotton	Herbicide tolerance, insect resistance
Cucumber	Virus resistance
Melon	Virus resistance
Papaya	Virus resistance
Potato	Herbicide tolerance, virus resistance, insect resistance, starch increase, and modification to make a variety of non-potato products such as chicken lysozyme
Rice	Insect resistance, modified seed protein storage
Soybean	Herbicide tolerance, modified seed protein storage
Squash	Virus resistance
Strawberry	Insect resistance
Sunflower	Modified seed protein storage
Tobacco	Herbicide tolerance, insect resistance virus resistance
Tomato	Virus resistance, herbicide tolerance, insect resistance, modified ripening, thermal hysteresis
Walnut	Insect resistance

This list is abstracted from ref. 2, and includes only traits that have been field tested and not traits such as markers that are often placed in crops in the early stages of product development. When a cultivar has several traits next to it, it does not mean that that cultivar has been modified to include all those traits simultaneously. Traits referred to as insect or virus resistance and herbicide tolerance, are often quite specific and do not apply to all insects, all viruses or all herbicides (details are available from USDA).

To appreciate the value of this new contribution, one needs to recall the disputes that have haunted conferences dealing with the release of genetically engineered organisms. On one side are environmentalists reminding us of the many exotic species that have become pests throughout the world, and pointing out that a genetically engineered organism is in a sense a new type of 'exotic' — a type that may combine traits in ways that could create new pests. On the other side are agronomists boasting of a long history of modifying plants by classical breeding with no ecological disasters on their record.

Both sides are somewhat disingenuous in their arguments. Horror stories about exotic species are not a fair analogy for single-gene modifications in crops that have been domesticated for hundreds or even thousands of years; conversely, the 'good record' of classical breeding is no guarantee of what will happen to plants with traits that go beyond those that have previously been available, especially if the cultivar — sunflower, strawberries, mustards, bermuda grass, for instance — starts with feral tendencies. The battle lines are all the less clear cut because we simply do not know for sure what traits will dramatically enhance invasiveness[3], and because of the observation that, in fact, some non-transgenic cultivars have become pests[4] (which makes one wonder whether crop varieties obtained from conventional breeding programmes ought to be of regulatory concern). No amount of barneying will reconcile these different concerns.

Onto this scene enter Crawley and a group of collaborators that includes mathematical ecologists, population biologists and community ecologists, supported by a consortium of industrial and UK government agencies. The team designed an ambitious field experiment in which the population growth of normal oilseed rape plants and genetically engineered genotypes were contrasted across a wide range of environments. 'Invasiveness' was precisely defined as the rate of population increase for oilseed rape from one year to the next, using a simple difference equation model.

The experiment itself is one of the most comprehensive population studies ever undertaken in plant ecology — it involved use of three climatically distinct sites and four habitats (wet versus dry, and sunny versus shady) in each site, making a total of 12 different environments. In each of these environments, various experimental treatments were established: presence or absence of vertebrate grazers, presence or absence of insect herbivores, presence or absence of fungal pathogens, and cultivated or uncultivated background vegetation. Invasiveness was assessed by contrasting population growth for untransformed oilseed rape, for the identical oilseed rape cultivar transformed with a kanamycin marker, and for oilseed rape transformed with both a kanamycin marker and resistance to the herbicide Basta.

The results are strikingly clear: under no environmental or experimental conditions did the transgenic cultivars exhibit different rates of population growth to those of their unmodified counterparts.

Too much should not be read into these results, however: by no means do they provide definitive answers for genetically engineered crops in general. First, history tells us that an ultimately successful invader might initially fail miserably, or barely persist for decades, before exhibiting explosive population growth[5]. Second, there are risks other than invasiveness to be considered — for example the escape of genes through pollen and hybridization could enhance the vigour of existing weeds. Another risk concerns the subtler ecosystem-level effects of widespread transgenic crops, which could come about because of degradation by-products in the soil or associated agricultural practices (such as increased herbicide usage). Finally, the finding of low invasiveness is less likely to apply to transgenic crops with traits that could confer advantages outside cultivation, such as stress tolerance or insect resistance.

The importance of the Silwood study comes not so much from its results, but from its scope and timeliness. In the United States, the USDA has just published its new guidelines for applications for transgenic crop deregulation[6]. These guidelines require firm evidence that the phenotype of the transgenic crop poses no greater risk than does the unmodified plant from which it was derived. Designing practical and consistent protocols to obtain data pertinent to such regulations, on a timescale commensurate with advances in biotechnology, is no small challenge — certainly we cannot expect to apply the Silwood design to every transgenic candidate for deregulation, but it does show the way.

In this context, it is a pity that opportunities to obtain appropriate data have been missed in the hundreds of completed field trials, which have emphasized agronomic performance and have been managed in a way that discouraged multigeneration observations on transgenic populations. So although more than 300 field trials have been carried out and no evidence of 'weediness' has yet emerged, that should not be interpreted as an especially comforting observation — we have been so thorough in containing or destroying all material in field trials that we could hardly expect to see any hint of problems from these studies. The real question is what will happen when transgenic seeds are widely broadcast year after year in many different habitats, as would be the case if genetically engineered crops are planted commercially.

The Silwood project is indicative of the increasing role of ecology in addressing environmental issues. Academic ecologists are renowned for arguing amongst themselves about all the things they do not know. But when it comes to designing an experiment to measure invasiveness or community impacts, or quantifying the likelihood of gene escape, population biologists and ecologists do know what to do. Moreover, ecology has been much more than a handmaiden to applied science in this experiment — the study is the largest demographic field experiment ever reported for a plant, and it tells us a great deal about the interplay of disturbance and natural enemies in dictating plant population growth. As ecologists seek answers to practical problems, our understanding of ecological processes is sure to improve. ☐

Peter Kareiva is in the Department of Zoology, University of Washington, Seattle, Washington 98195, USA.

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1. Crawley, M. J., Hails, R. S., Rees, M., Kohn, D. & Buxton, J. *Nature* **363**, 620–623 (1993).
2. United States Department of Agriculture, APHIS Biotechnology Permits Unit, database release 12 May 1993.
3. Williamson, M. *Experentia* (in the press).
4. Ellstrand, N. & Hoffman, C. *Bioscience* **40**, 438–442 (1990).
5. Drake, J. H. *et al. Biological Invasions: A Global Perspective* (Wiley, New York, 1988).
6. United States Federal Register, Part X, Department of Agriculture, 7 CFR Part 340, Final Rule, March 31 1993.