PERSPECTIVES: AGRICULTURE

Genetically Modified Crops and Farmland Biodiversity

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The decline in farmland biodiversity is a serious conservation issue in Great Britain (*1*). So, it is not surprising that the decision to allow commercial introduction of genetically modified herbicide-tolerant (GMHT) crops has been delayed until after the completion of farm-scale evaluations of the effects of these crops on farmland biodiversity (*2*). On page 1554 of this issue, Watkinson *et al.* (*3*) propose a mathematical model that seeks to measure the impact of GMHT sugar beet crops on weed populations in British fields and the consequences for farmland birds that are dependent on the weed seeds for food. Their model ties together weed population dynamics, farmer decision-making, and regional impacts on farmland birds (see the figure).

In their model, a conventional (that is, not genetically modified) sugar beet crop is grown in a 5-year rotation: Winter cereals are grown for 4 years and then conventional sugar beet is grown in the fifth year. The weed that Watkinson and colleagues selected to investigate in their model, *Chenopodium album* (lambsquarters or fat hen), is found worldwide and its seeds are an important food source for farmland birds. The seeds of this annual weed stay dormant in the soil for several years; each year a proportion of this weed seedbank germinates. The modelers assume that weed control is perfect during the years that cereals are grown so that new weed seeds are produced only during the 1 year in 5 that sugar beet is cultivated. They also assume that the numbers of skylarks (*Alauda arvensis*) that feed on *C. album* seeds is greatest in fields where lots of the weed seeds are available. Although the authors selected just one weed and one bird for their model, they presume that their model reflects a wider range of farmland birds and the weeds that are their food source. With the help of existing data from herbicide trials, the modelers examined what happens to the population density of *C. album* when GMHT rather than conventional sugar beet is grown in the fifth year of the crop rotation. They calculate how the altered use of herbicides with the GMHT crop affects the growth of *C. album* and hence its seed production, and how this will impact the skylark that feeds on these seeds.

Weeds, seeds, and hungry birds. Roger Duncan, a farmer near Hancock, Minnesota, is a strong advocate of GMHT crops. Behind him is a field of conventional sugar beet that was grown after 4 years of GMHT glyphosate-tolerant soybean and glufosinate-tolerant corn. Note that the weed, *Chenopodium album* (the large green bush in the foreground), whose seeds form an important food source for farmland birds, is still abundant. **(Right)** Thistles, such as *Cirsium arvense*, are another important food source for birds. They are often controlled well in fields of GMHT glyphosate-tolerant soybean by herbicides such as glyphosate, but not, however, in this instance where the herbicide was applied only once.

The model considers a population of British farms, most starting with a small weed seedbank and the remainder starting with far higher densities of weed seeds. The use of GMHT sugar beet by the farmers is assumed to depend on their attitude to the new technology and on whether they wish to apply it to fields where the weeds are already well under control, or to fields that are particularly weedy. Watkinson *et al.* attempt to mimic this in their model by assuming different weed seed densities before the introduction of the GMHT crop. Their model assumes that overall seed production by the weed is a function of the efficiency of weed control by herbicide during growth of the GMHT crop relative to that during growth of a conventional sugar beet crop. The seeds of *C. album* are considered to be the principal food for wintering skylarks that congregate to fields according to the density of the weed seedbanks.

Watkinson *et al.* have provided us with an elegant way to exploit existing data on herbicide treatment of conventional and GMHT crops and to calculate the impact of herbicide use on weed seed production and farmland bird numbers. However, their conclusion that "consequent effects on the local use of fields by birds might be severe" if GMHT crops are introduced commercially is questionable in light of experiences with growing GMHT maize, soybean, canola, and sugar beet in the United States (*4*).

In the state of Minnesota, sowing dates for conventional crops and their

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GMHT counterparts are the same, as are the patterns of weed germination. Early weed emergence can be controlled by pre-emergence herbicides in both GMHT and conventional crops. Typically, herbicides are applied at least twice to conventional crops (more if the crop is sugar beet), often using different chemicals in sequence to control different weeds. In the case of GMHT crops, a single broad-spectrum herbicide can be applied without killing the crop and is used only once or twice after weeds have emerged. The model considers whether herbicides are applied only when the weed population density reaches a certain threshold or whether they are applied regardless of weed density (which is probably more typical). When GMHT crops are first introduced, weeds are generally well controlled (*5*). However, some weed species (for example, *Amaranthus rudis*) escape control by germinating after the application of herbicide, and others by being somewhat tolerant to it (including, ironically, *Chenopodium album*, which can become tolerant to glyphosate, the herbicide most widely used with GMHT sugar beet) (*6*). There is also the potential for herbicide-resistant weed varieties to develop over time. Such species will produce more seeds, changing the weed spectrum and reducing the control achieved with sowing GMHT crops.

Data from the southern United States, where GMHT crops have been grown since the mid-1990s, show that there is sometimes less success with weed control when growing GMHT crops than when cultivating conventional varieties (*7–9*). An informal poll that we conducted among weed scientists indicates that farmers who grow GMHT soybean do so not because weed management with this crop is more effective, but because it is simpler (fewer types and fewer applications of herbicide are needed, and timing of applications is often less critical).

The Watkinson model considers weed densities at equilibrium. Yet, by the time this equilibrium is reached (presumably over several 5-year rotation cycles), weed control may be, on balance, comparable between GMHT crops and conventional varieties (if indeed the technology has not been replaced by other farming and weed management systems by that time). When equilibrium is reached, however, the composition of the weed community will have changed, translating into either gains or losses of food reserves for birds (*10*).

Although the assumptions of trophic relations between weed seeds and skylarks can be questioned in detail, the Watkinson *et al.* model is probably robust enough to be applied to many birds and arable plants. However, the dynamics between weed seeds and birds also depend on what happens after the seeds have been shed. Many weed seeds will be buried during harvest and cultivation of GMHT and conventional sugar beet alike, making them unavailable as food for birds during the winter (*11*). More to the point, the main problem for farmland biodiversity in the Watkinson model is perhaps less the effects of managing weeds during the cultivation of the GMHT beet crop and more the zero weed seed production during the 4 years of cultivating intensively managed cereals.

Their model considers the relation between adopting GMHT crops and the numbers of weed seeds in the soil. Experience in Minnesota demonstrates that farmers may adopt GMHT crops quickly in fields with both high and low weed seedbanks. This may have less to do with socioeconomic responses to new technology between farmers than with the desire to simplify weed control in general while clearing out weeds from fields with high seedbanks. This seems especially true for sugar beet farmers, who have found cost-effective weed control very difficult with non-GMHT crops. Therefore, the relative weed control efficiency factor in the model is actually a distribution of values, the shape of which may well be a function of both farmer behavior and the size of the weed seedbank. The model may not have captured these dynamics very well in detail, but it does demonstrate the potential sensitivity of farmland bird populations to the management of very weedy fields. We agree with Watkinson *et al.*'s suggestion that "the regional-scale consequences of farm-level decisions might be the key to predicting the impacts of GMHT crops on biodiversity"; this point has already been recognized within the site selection protocol for the farm-scale evaluation of GMHT crops in Britain (*12*).

The Watkinson model provides a welcome conceptual framework for assessing the impacts of GMHT crops on farmland birds. However, the authors have concentrated on assumptions and scenarios that emphasize harmful effects, to the exclusion of those that suggest benefits to biodiversity. For example, herbicide use in current GMHT crops is frequently later than in conventional crops, potentially favoring breeding birds. Also, sowing GMHT crops facilitates minimum tillage, which favors the conservation and biodiversity of soils, tends to keep more weed seeds near the surface, increases weed numbers and, again, changes the weed spectrum (*13*). Both GMHT and non-GMHT systems can be modified to favor biodiversity: Field patches can be left unsprayed to provide food for skylark chicks until they fledge, and winter stubbles and selective spraying can be used to help maintain bird food resources in the cereal phase of the rotation.

Are GMHT crops good or bad for wildlife? It is simply too soon to tell. Watkinson *et al.*'s model raises important scientific questions that only experiments can answer. As the authors note, these effects depend on the choices that individual farmers make as well as on the effects of particular crop management systems. In Britain, the farm-scale evaluations will provide data on the effects of GMHT crop management on weed populations and seed return across a representative range of crops and conditions, including those where the farmer may want to use the new technology to control high weed levels. The Watkinson analysis shows just how vital these evaluations will be for revealing the overall effects of growing GMHT crops on British wildlife.

References and Notes

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2. L. G. Firbank *et al.*, *Nature* **339**, 727 (1999).
3. A. R. Watkinson, R. P. Freckleton, R. A. Robinson, W. J. Sutherland, *Science* **289**, 1554 (2000).
4. We thank extension workers and farmers for sharing their experiences with us.
5. See also the references in (*3*).
6. Colleagues have reported these phenomena in the southern United States and Argentina as well as in Minnesota.
7. W. G. Johnson, P. R. Bradley, S. E. Hart, M. L. Buesinger, R. E. Massey, *Weed Tech.* **14**, 57 (2000).
8. A. S. Culpepper, A. C. York, R. B. Batts, K. M. Jennings, *Weed Tech.* **14**, 77 (2000),
9. M. J. Vangessel, A. O. Ayeni, B. A. Majek, *Weed Tech.* **14**, 140 (2000).
10. The arable plants that are important in the diets of farmland birds in Great Britain are reviewed by L. H. Campbell *et al.* [*A Review of the Indirect Effects of Pesticides on Birds* (Joint Nature Conservation Committee, Peterborough, UK, 1997), p. 148.
11. R. P. Freckleton and A. R. Watkinson [*J. Appl. Ecol.* **35**, 904 (1998)] modeled the dynamics of *Chenopodium* through the rotation, and Watkinson *et al.* assume that the seed numbers produced at the end of the sugar beet crop are available as food for birds in the winter crops, using the data of R. A. Robinson and W. J. Sutherland [*Ecography* **22**, 447 (1999)]. This assumption is untenable for a root crop like sugar beet, but it may be more robust for other crops, especially under minimum tillage.
12. For interim reports of the farm-scale evaluations, see www.environment.detr.gov.uk/fse/index.htm.
13. D. D. Buhler, R. G. Hartzler, F. Forcella, *Weed Sci.* **45**, 329 (1997). This possible interaction between GM cropping and tillage practice may mean that any reduction of weed seed production under GM crops may be compensated for in that a higher proportion of the seeds will stay nearer the soil surface to be available to feeding birds.
14. Supported by the Department of the Environment, Transport and the Regions (L.G.F.). We thank colleagues of the farm-scale evaluations for their ideas and comments.