Sensitive dependencies and separation distances for genetically modified herbicide-tolerant crops

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The amount of land available for the coexistent growing of both organic and genetically modified herbicide-tolerant (GMHT) crops depends on the separation distance between the two types of crop. The form of the decline in the proportion of land available for growing one of these crop types due to increasing separation distance is linear on a suitable scale, but with a slope and intercept that are sensitively dependent on the proportion of the other crop already present. Spatially explicit simulations from realistic scenarios indicate that a major increase in separation distances, currently under review by the UK government, may have serious implications for the future coexistence of organic and GMHT crops in the UK.

Keywords: separation distance; genetically modified crop; herbicide tolerance; sensitivity; agriculture

1. INTRODUCTION

Separation distances (Ingram 2000; Agriculture and Environment Biotechnology Commission 2001) between genetically modified herbicide-tolerant (GMHT) crops and conventional or organic crops of the same species are used to create buffer zones, to reduce the chance of cross-pollination below a certain defined threshold. There is considerable debate in Europe (Eastham & Sweet 2000; Kessler 2001) and worldwide (ERMA New Zealand 2001; CBAC 2001) concerning the efficacy of the distances used to prevent contamination of seed or genetically modified (GM) content in food. The UK government recently recognized (DEFRA 2002) that, given the amount of GM crops grown worldwide, it will be very difficult to guarantee that any product or seed is completely GM-free. Sweden, France and Germany, as well as Britain, were affected by the Advanta Seeds contamination incident (Advanta Seeds UK 2000). In March 2001, the Italian Government impounded imported soya seed and maize seed suspected of GM content. The European Commission is currently considering new thresholds for the adventitious presence of GM seeds, although the levels have been criticized by expert scientific opinion (European Commission Scientific Committee on Plants 2001). The recent instance of contamination in Mexico (Quist & Chapela 2001) was initially thought to be due to long-distance pollen transport, although it is much more probable that it is due to illegal planting of GM seed by growers.

In the UK, The Agriculture and Environment Biotechnology Commission was recently asked by the UK government (Meacher 2001; Agriculture and Environment Biotechnology Commission 2001) to consider the issue of separation distances between GMHT crops (Firbank *et al.* 1999; Perry 2001) and conventional or organic crops of the same species. For example, the current distance used in the farm scale evaluations (Firbank *et al.* 1999) of 200 m for GMHT forage maize from organic crops is designed to limit cross-pollination to 1% (DETR & MAFF 2001). Recently, the UK government has suggested that a threshold of 0.1% might be more publicly

acceptable (Meacher 2001; Agriculture and Environment Biotechnology Commission 2001); this would require a greater separation distance, which is as yet undefined. The Soil Association, one of the bodies representing UK organic farming, has called for the separation distance to be increased to 3000 m (Soil Association and SOPA 2000) to attempt to ensure a zero threshold of GM content in organic crops. The current separation distance for GMHT from conventional fodder maize, 80 m, is less than that for organic maize and there is generally less pressure for substantial increases in separation distances of GMHT from conventional crops (Soil Association and SOPA 2000). There is currently insufficient data for accurate parameterization of relationships between small (less than 0.5%) threshold levels of cross-pollination, the probability of their exceedance and corresponding separation distances (Ingram 2000). However, regardless of the effects of gene flow, if separation distances are increased substantially there is a question of how much land would be available either to grow GMHT crops in the presence of existing organic crops of the same species, or to grow organic crops after previous cropping with GMHT crops (Soil Association and SOPA 2000). Indeed, there is uncertainty as to whether both types of agriculture could then be accommodated within the UK arable ecosystem. Here, I report simulations that study the dependence of the proportion of land available for the growing of one of these crop types on increasing separation distance, and how this relationship itself depends on the proportion of the other crop already present.

2. MATERIAL AND METHODS

The study area is an imaginary square 70×70 grid representing contiguous square fields of 3 ha, each with sides 173 m; the total length of the side of the area therefore exceeds 12 km. For simplicity, I consider just two types of crops, labelled X and Y. The proportion of fields of crop type X, denoted ϕ , is assumed to be known. The fields of crop X, numbering 4900ϕ in total, are distributed at random over the grid. All fields are identified that have any point on their boundary within the separation distance, d , of any point on the boundary of any field of

Figure 1. Example of a single simulation for 4900 fields, with proportion of crop type X, $\phi = 0.021$, and separation distance, $d = 450$, yielding the proportion of fields available for crop type Y, $p = 0.46$. Available fields sampled within boundary of inner 10×10 sub-grid, outlined in black. Black squares represent type X fields; grey squares are fields deemed unable to grow crop type Y; white squares are fields available to grow a type Y crop.

type X; such fields are deemed not available to grow crop type Y. The proportion of remaining fields, p , available to grow crop Y is recorded. To avoid edge effects, for each run, the value of p is derived only from fields within the inner 10×10 sub-grid in the centre of the study area, representing a 300 ha area. Simulations were run for particular values of ϕ , for values of d increasing from 200 to 3000 m, in increments of 80 m. Reported values of p are means calculated over 100 simulations. I report results for five scenarios, for values of ϕ (in brackets): A (0.0003), B (0.003), C (0.020), D (0.021) and E (0.14).

3. RESULTS

Figure 1 shows an example of a single run for $\phi = 0.021$, $d = 450$. The boundary of the inner 10×10 sub-grid is outlined in black. There were two contiguous type X fields within the subgrid, out of a total of 103 in the entire study area. There were 46 fields available to grow a type Y crop within the subgrid, so $p = 0.46$. Figure 2 shows fitted linear regressions that summarize the simulations. In all cases, the response variable, p , the proportion of land available for crop type Y, declines linearly on a probit scale as d , the separation distance, is increased ($p < 0.001$, all regressions). Both the intercept and slope of the fitted lines are very sensitive to ϕ , the proportion of fields of crop type X.

4. DISCUSSION

These scenarios may be interpreted either in terms of how much land would be available either to grow GMHT crops in the presence of existing organic crops of the same species, or to grow organic crops after previous cropping with GMHT crops (Soil Association and SOPA 2000).

Figure 2. Fitted linear regressions, on probit scale, of: p , proportion of fields available for crop type Y, on d , separation distance; and for five scenarios, A–E with ϕ , proportion of crop type X, equal to 0.0003, 0.003, 0.020, 0.021, 0.14, respectively. All regressions are significant at $p < 0.001$.

However, as GMHT crops are not grown commercially in the UK, the interpretations explored here cover the former case only.

As an example, consider maize. The average size of a field of fodder maize is about 3 ha and for maize there is unlikely to be a great difference in field size between organic and conventional agriculture. If organic maize fields were represented by type X, then scenario A could be regarded as approximating to the current situation, in which about 3% of fields within an arable region are organic, and up to 1% of these might be in organic maize, yielding a proportion of 0.0003 organic maize fields overall. Scenario B might represent a moderate increase in the proportion, say to 10%, of current organic farmers growing maize, whilst scenario D could depict the majority, say 70%, of organic farmers opting to grow maize.

From 2000 to 2001, the area of organically managed land in the UK grew by 33%; in some policy targets it is projected to grow to 30% of total agricultural land (Organic Targets Bill Campaign 2001). There is some doubt about the effect of economic cost-benefit constraints on the probable future proportion of organic growers in the UK, but there is little doubt that it will increase. If, say, 20% of fields were assumed to be organically farmed in the future, then scenario C could represent 10% and scenario E 70%, respectively, of future organic fields in maize, yielding overall proportions of 0.02 and 0.14, respectively.

Whatever the precise proportions are, it is clear that it is only in scenario A that effective coexistence between organic and GMHT maize seems possible, were d to be increased to the maximum studied distance of 3000 m. Given a rough doubling of the current separation distance, say to 440 m, then under scenario B there would be only a slight predicted reduction in the proportion of land available for GMHT maize, from 0.95 to 0.89, but under scenarios C and D, predicted values of p would fall substantially, from 0.66 to 0.41 and 0.60 to 0.33, respectively.

Under scenario E, $p = 0.05$ for $d = 200$, so there would be little scope for growing any GMHT maize, even at the current separation distance.

These results apply to an idealized situation only and specific interpretations should be treated with caution. The proportion of organic growers varies considerably across regions of the UK, as do field sizes. Furthermore, for many crops other than maize, organic fields tend to be smaller than conventionally farmed fields. Also, although it may be reasonable to postulate that types of land suitable for growing an organic crop are similar to those for growing a conventional or GMHT crop of the same species, it should be noted that suitable land for a specific crop will only ever form a proportion of the total arable land available. Furthermore, whilst the location of fields with such suitable land has been taken here to be random, in practice they will have more aggregated spatial distributions, although simulations suggest that this leads to only slight increases in predicted values of p . However, even after allowing for all these factors, the sensitive dependencies reported above should be quite robust to changes to the underlying model designed to introduce further realism.

The simple methods outlined above apply particularly to the patchy, heterogeneous, fragmented, fine-grained mosaic of cropped fields, semi-natural habitat and non-agricultural land use that characterize UK farmland (Haines-Young *et al.* 2000). However, they may find ready application elsewhere, to the many ongoing studies across Europe on gene flow in maize (Sweet 2000), oil seed rape (Chèvre *et al.* 2001; Colbach *et al.* 2001; Thalmann *et al.* 2001), beet (Bartsch *et al.* 1999; Vigouroux *et al.* 1999; Biancardi & Bartsch 2001), lettuce (Van de Wiel *et al.* 2001), rice (Gressell & Rotteveel 2000; Lupotto 2000) and other transgenic crops.

Other relevant recent results (Perry 2002) not presented here relate to the relationship between achievable threshold percentage GM contamination and separation distance for unusually long-range pollination, such as that mediated by convection currents, turbulent conditions or weather fronts (Emberlin *et al.* 1999) or insects (Ramsay *et al.* 1999). Very simple mathematical models may be built in the form of a mixture of two frequency distributions, to represent the effect of this long-range mechanism when it operates simultaneously with the more usual, relatively short-range, wind-borne transport responsible for most pollination. Such models demonstrate that if as few as 1 in 200 pollination events is mediated by the former, this may have a profound and deleterious impact on the ability to force contamination thresholds to very low levels, and that, depending on the threshold levels required, this might only be achieved with separation distances of the order of kilometres. Models are required because current data do not exist to relate adequately separation distances to pollination thresholds for values of the former above about 200 m and values of the latter below about 0.5%. Such data are necessarily expensive to obtain because of the need to obtain adequate precision for events occurring with such small probabilities, but are required urgently to inform policy and deliver reliable consumer choice.

The UK government has recently stressed (DEFRA 2002) its commitment to ensuring the coexistence of GM,

organic and conventional farming, should GM become commercialized. The relationships described here between the proportion of land available for cropping and separation distance imply that a major increase in separation distances, currently under review by the UK government, may have serious implications for this policy of coexistence.

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