1999 AAEA Annual Meeting, Nashville, Tennessee, August 8-11, 1999 Session 3

Managing Pest Resistance: the Potential of Crop Rotations and Shredding

By

Bruce Babcock
Department of Economics
Iowa State University
260 Heady Hall
Ames, IA, 50011
Phone: (515) 294-5764
Fax: (515) 294-6336
babcock@iastate.edu
(Primary contact)

Silvia Secchi
Department of Economics
Iowa State University
260 Heady Hall
Ames, IA, 50011
Phone: (515) 294-8612
Fax: (515) 294-0221
secchi@iastate.edu

Keywords: biotechnology, common property resource, crop rotation, European Corn Borer, externalities, insecticide resistance, integrated pest management, intertemporal optimization.

Abstract

The current debate over resistance management plans mandated by the Environmental Protection Agency for transgenic crops ignores management practices that are complementary to refuge schemes. A dynamic production model is developed that measures the costs and benefits of crop rotation and shredding in terms of delaying resistance to *Bt* corn.

Introduction

The use of agricultural biotechnologies is increasing dramatically in the United States. Among the most successful crops are *Bt* plant-pesticides, engineered to express the *Bacillus Thuringiensis* (*Bt*) δ-endotoxins. Because of high levels of concern on the possible development of resistance to *Bt* by the targeted pests, the Environmental Protection Agency (EPA) requires farmers who want to grow *Bt* cotton to plant refuges. Refuges are portions of the field in which non-*Bt* seed is sown, and *Bt* insecticides are not sprayed, so as to allow the interbreeding of pests susceptible to *Bt* with resistant pests. This causes resistance development to slow down. Refuges are encouraged for potatoes, while in the case of corn, the EPA registration is conditional. And by 2001, EPA-approved refuge plans will have to be implemented. In practice, the industry is already requiring that farmers plant refuge acres through producer-grower contracts (EPA, 1998). The current refuge recommendations are based on certain fundamental assumptions. At the farmer's level, the premise is that the grower will plant continuous corn or cotton, without using cultural practices which could impact resistance, and that high compliance will be achieved. At the market level, the conjecture is that market penetration will be complete, or alternatively, that no externalities deriving from pest mobility will occur. These assumptions are quite restrictive, and may not fully reflect the reality within which the policy operates. For instance, the use of refuges poses serious compliance problems, since the farmers may not perceive the intertemporal relation between planting refuge and controlling resistance development. Farmers will tend to behave myopically in relation to resistance especially if the pest in question is relatively mobile, as the pest population then becomes a common property resource among farmers (Miranowski and Carlson, 1986). Moreover, refuge sizes and locations may be hard to monitor, and the costs of planting refuge may be substantial for the farmer[1]. He or she has to follow proximity rules which can be quite complicated in irregular fields, and the *Bt* seed must be put in clean planters.

This paper is part of a wider research project aimed at analyzing the effects of altering some of the assumptions the current policy is based upon, and at examining the economic trade-offs involved in using resistance management instruments other than refuge so as to facilitate compliance. The paper uses a dynamic economic model that includes population genetics to analyze the costs and benefits of using two mechanisms complementary to refuges in resistance management plans: crop rotations and shredding after harvest in the *Bt* fields. Rotation with a crop that is not a host to the target pests helps break down the pest population reproductive cycle. Shredding crop residue in the *Bt* fields also breaks the reproductive cycle because up to 90% of overwintering larvae are killed, thereby reducing the absolute pest population level. The model is used to compare three scenarios appropriate to corn grown in Midwestern states: continuous corn, corn-soybean rotations, and continuous corn with shredding on the *Bt* fields. The use of crop rotations to slow down the exhaustion of a natural resource has been illustrated in the case of soil erosion (Miranowski, 1984). An application of crop rotation to pest management issues is given by Lazarus and Dixon (1986), who use a nonlinear

---

[1] Some evidence of the existence of compliance problems is already available. See Hurley *et al.* (1999).

programming model with corn–soybean rotations to manage resistance development for the corn rootworm.

The model

The model is based on pest population dynamics that allow the direct measurement of resistance development following the Hardy-Weinberg principle, and it builds on Hurley *et al.* (1997). The pest population is composed of homozygote susceptible (SS), heterozygote (RS) and homozygote resistant (RR) individuals. The major differences with the Hurley *et al.* (1997) model are that a random element is introduced to mimic weather conditions, and that the possibility of pest mobility is introduced. The stochastic shocks do not represent pest mobility, since they are assumed to impact the pest population within the field and do not alter the field's genetic make-up. As in Hurley *et al.* (1997), the pest population's reproductive cycle consists of two generations a year (bivoltine), but the model is easily generalizable to uni-or multi-voltine populations. More generally, this framework is easily applicable to all diploid pests which exhibit some degree of mobility, from insects to weeds and fungi. It can also be readily extended to other cropping systems typical of the production pattern in other U.S. regions, such as corn and cotton in the South, which are both ECB hosts. The model is based on two fields, one of which - always the same one[2] - is planted with non-*Bt* corn. Following Onstad and Guse (1999) and Mason *et al.* (1996), the damage function of the ECB is linear, but differentiated across generations. The farmer planting the non-*Bt* corn has the choice of applying a (non-*Bt* based) pesticide. The cost of applying the chemical

---

[2] This appears to be a non trivial question when analyzing resistance development. See Peck *et al.* (1999).

input is fixed, and the pesticide has a maximum efficacy bound (Mason *et al.*, 1996). For simplicity, the non-*Bt* farmer can apply the pesticide only once, in order to control the first generation of ECB. Since the pest population modeled is in the high range, the farmer will always use the option of spraying. The *Bt* corn farmer, on the other hand, will plant *Bt* on a given percentage of refuge which is left unsprayed. The percentage of refuge is given by 20% of the field. This is consistent with current EPA regulation, and with a recent statement endorsed by the National Corn Growers Association and the industry. Following Hurley *et al.* (1997), this proportion of the field is constant throughout the time horizon.

The profit per acre from planting *Bt* corn is given by:

$$p_y Y[1-(E_{G1}N_{G1}-E_{G2}N_{G2})]- C- P - T \quad (1)$$

while the non-*Bt* farmer maximizes:

$$p_y Y[1-E_{G1}N_{G1}(\alpha(1-S))-E_{G2}N_{G2}]- C- p_s S \quad (2)$$

s.t. $S \in \{0,1\}$

where[3]:

p_y =\$ 2.35, real corn price per bushel at 1992 prices

Y = pest free average yield, 130 bushels per acre

N_{G1} and N_{G2} = number of pests per plant, first and second generation

E_{G1} and E_{G2} = damage per pest per plant, $E_{G1} = 0.05$ and $E_{G2} = 0.024$

C = costs of production net of the spraying price, \$185 per acre

P = *Bt* premium (technology fee), \$20 per acre

T = cost of shredding, \$7.00 per acre

S = non-*Bt* spray application

p_s = cost of the spray application, \$14 per acre

α = maximum efficacy of the non-*Bt* spray, fixed at 65% of the population

The effects of the pest population dynamics and the changes in its genetic make-up are embodied in equation (1). Increases in the pest population's size directly increase N_{G1} and N_{G2}, thereby reducing yield. The effects of increases in the genetic frequency of resistant pests are also reflected in equation (1). As resistance increases, there is a decrease in the effectiveness of the *Bt* toxins, so that a higher number of pests survives and are able to damage the crop. The model is based on the assumption that the resistant and susceptible pests cause the same damage to the crop, and are more in general identical in their behavior.

The rate of interest utilized to calculate the net present value of production is 3%. The returns from soybeans (excluding returns to management) are calculated from 1990 ERS soybeans budgets deflated to 1992 dollars with NASS price indexes. They are an average of the returns for ECBs bivoltine states (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota), and they amount to \$92.52 per acre. Since evidence exists that soybeans are a secondary host of ECBs (Mason *et al.*, 1996), one in ten million corn borers are assumed to survive in the soybean-planted field. It is also assumed, conservatively, that shredding kills 80% of the 5th instar larvae. (See Mason *et al.*, 1996.) The model is programmed in MATLAB.

---

[3] For the specific values see Mason *et al.* (1996), Onstad and Guse (1999), Hurley *et al.* (1997) and Jose

Results and discussion

The baseline scenario analyzed assumes there is zero inter-field mobility. As Table 1 shows, without either shredding or rotation, the final frequency of susceptible pests is substantially lower than at the start of the production period (the starting frequencies are the same as the final ones in the non-*Bt* field, since no *Bt* is used there and there is no pest migration from field to field). However, the population levels in the *Bt* field are still very low, and the new technology remains valuable, as the difference between the net present values of production in the *Bt* and non-*Bt* field clearly illustrates.

Table 1 – Simulation results with zero mobility, 20% refuge[4]

	Final frequencies			Net Present Value of production per acre ($/acre)
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	
Bt field	0.038900	0.316800	0.6443	882.97
Non-*Bt* field	0.000001	0.001998	0.9980	792.99

The introduction of shredding after harvest substantially reduces the incidence of resistance (Table 2). This comes at the cost of $60/acre of net present value. Note however that, even with these added costs, the *Bt* technology is still profitable for the farmer as compared to the use of traditional hybrids.

Table 2 – Simulation results with zero mobility and shredding, 20% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Bt field	0.018420	0.234600	0.7470	821.47
Non-*Bt* field	0.000001	0.001998	0.9980	792.99

---

and Brown, 1996.

[4] Frequencies may not sum up to one exactly because of rounding.

Crop rotation appears to be extremely effective in slowing down resistance build-up, as Table 3 shows. The net present values of production is around $35/acre lower than in the baseline case of Table 1, but the frequency of homozygote resistant pests is over ten times lower, and heterozygotes are over thirty times less numerous. Once again, the use of the new technology is worthwhile for the farmer, even with this added cost, giving him over $55/acre of increased returns.

Table 3 – Simulation results with zero mobility and crop rotation, 20% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Bt field	0.002730	0.099050	0.8982	848.45
Non-*Bt* field	0.000001	0.001998	0.9980	792.99

The zero mobility scenario analyzed above is indicative of what would happen in case of a 100% market penetration in a region concentrating on corn production. In such a case, there would be no secondary hosts for the ECBs, and the issue of mobility would become irrelevant, since all farmers would be growing the same crop, thereby offsetting each other's externalities. More spatially explicit modeling is needed to analyze the effects of rotation, but, in policy terms, these results suggest that crop rotation may be a valuable instrument for slowing down the buildup of resistance. However, a scenario more representative of the actual situation in the Midwest, which is likely to be prevalent for some time, should include market penetration at less than 100%, and some level of pest mobility across fields. In the next case analyzed, the levels of inter-field mobility are assumed to be very low, at one in a thousand. And, in line with entomological evidence, it is assumed that only the first generation moths fly across fields (Dr. David

Andow, personal communication). This form of effective pest mobility is essentially a reduced form that subsumes two types of variables. Firstly, it represents purely biological factors such as the insects' capacity to fly. The more mobile the pest, the more it will migrate across fields. Secondly, the variable incorporates farm size and arrangement effects. The bigger the average farm size in the area considered, the less likely pests are to create an externality by migrating from one farm to the next. The insects will tend to fly within the perimeter of the farm and the fields that it consists of, so that the externalities created will be low. Similarly, if a farm is made up of scattered fields, it is more likely that pests will fly from one farm to the next, thereby creating an externality. Since this is a first attempt at quantifying the effects of mobility, and there has been little entomological fieldwork on its magnitude, simulations have been conducted assuming very low levels of mobility.

Table 4 – Simulation results with 0.1% mobility, 20% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Bt field	0.0000020	0.0027900	0.9972	882.93
Non-*Bt* field	0.0000009	0.0018950	0.9981	793.04

Table 4 shows that 0.1% mobility is enough to dramatically decrease the final frequency of resistance in the *Bt* field without substantially diminishing profits. The rationale for this result is that the *Bt* technology is extremely effective, so that the pest pressure in the *Bt* field is very low compared to that in the non-*Bt* field. Very low levels of mobility are enough to allow the migration of an comparatively high absolute number of susceptible pests to the *Bt* field to substantially alter its genetic composition. The reverse flow, on the other hand, is too small in absolute terms to produce a significant increase in the number of homozygote resistant pests, even though it increases the frequency of heterozygotes.

Tables 5 and 6 show how both shredding and crop rotation become relatively redundant tools in this scenario. It is worth noting that the externality appears to be significant in only one direction, since the non-*Bt* field is not affected regardless of the technology used in the *Bt* field.

Table 5 – Simulation results with 0.1% mobility and shredding, 20% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Bt field	0.0000019	0.0027210	0.9973	821.44
Non-*Bt* field	0.0000009	0.0019080	0.9981	793.04

Table 6 – Simulation results with 0.1% mobility and crop rotation, 20% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Bt field	0.000002	0.003138	0.9969	848.43
Non-*Bt* field	0.000001	0.001998	0.9980	793.02

Increasing the level of mobility tenfold to 1% simply reinforces the results. The mobility effects dominate the local population dynamics in the *Bt* field, so that resistance does not develop, while the non-*Bt* field is only very marginally affected, because the pests migrating from the *Bt* field are still very few. These results underscore the importance of further field-level entomological studies on pest mobility, since very low levels are enough to make the use of instruments complementary to refuge unnecessary.

The efficacy of crop rotation and shredding is hard to analyze with low refuge sizes in the absence of mobility, because the consequence of all these strategies is to sharply decrease the absolute numbers of the pest population. Their combined effect tends to make the pest population collapse. Population models better able to describe the capacity of pest populations to recover are needed to assess the impact of low refuges[5]. Table 7 shows the effects of the various strategies for a 30% refuge. As in the 20% case discussed before, crop rotation is less costly to the farmer than shredding, and it yields better results in terms of resistance. However, the table also shows that the marginal benefits of these techniques are low at this refuge size, because the refuge by itself is very effective at delaying resistance.

Table 7 – Simulation results with zero mobility, at 30% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Baseline case	0.0027930	0.1001	0.8971	882.93
Shredding	0.0008904	0.0579	0.9412	821.45
Rotation	0.0005140	0.0443	0.9552	848.39

The effects of lower refuges can be analyzed if some very low level of mobility is assumed, so as to allow the pest population in the *Bt* field not to dwindle. In such cases, as for the higher refuge, crop rotation is more efficient than shredding, and it is again more effective in terms of resistance. However, mobility, even at levels as low as one in one thousand, dominates the local population dynamics so that the marginal benefits of these techniques tend to be low. Table 8, for instance, illustrates what happens at 0.1%

---

[5] See Secchi and Babcock (1999) for some preliminary results on alternative population dynamics.

mobility with refuge fixed at 10%. The effects on the non-*Bt* field are negligible and therefore are not reported.

Table 8 – Simulation results with 0.1% mobility, at 10% refuge

	Final frequencies			
	RR Homozygote resistant	RS Heterozygote	SS Homozygote susceptible	Net Present Value of production per acre ($/acre)
Baseline case	0.0000002	0.0008852	0.9991	882.96
Shredding	0.0000002	0.0008804	0.9991	821.47
Rotation	0.0000001	0.0007665	0.9992	848.46

Conclusion

The comparisons carried out in this paper tend to underestimate the value of the two resistance-delaying mechanisms examined because they do not explicitly consider the direct costs of monitoring and the consequences of non-compliance. The costs of monitoring pure refuge strategies may be extremely high, particularly because the corn planted on refuge is to have the same phenological characteristics of the *Bt* corn, so that the two are virtually indistinguishable. Laboratory tests would have to be carried out to determine what type of corn has been planted. Since the refuge is enacted via producer-grower contracts, the monitoring burden resides primarily on the seed producers. The industry faces a trade-off in monitoring resistance development. On the one hand, it is aware of the non-renewable nature of susceptibility and has therefore an interest in managing resistance. On the other hand, however, it does not want to unnecessarily increase the size of the refuge, since that would decrease sales of the *Bt* seed, which sell at a premium (technology fee). The EPA has established the need of instituting refuge on the grounds that *Bt* is used in spray form in organic and Integrated Pest Management

(IPM) crop production and that finding organically acceptable, low impact backstop technologies for *Bt* sprays may require very long time horizons (EPA, 1998). Therefore, in order to assess the total social costs of resistance, an explicit economic evaluation of the *Bt* technology in the spray form is needed. If such a comprehensive cost-benefit analysis confirms the need for resistance management plans, crop rotation and shredding are possible candidates to supplement refuge in preserving susceptibility. However, the results of the simulations conducted with some positive levels of mobility indicate that the risk of resistance development may not be elevated if market penetration is incomplete.

The most important factors affecting the comparisons between scenarios are the costs of implementing the alternative resistance-delaying mechanisms. This suggests that incentive mechanisms to facilitate their adoption could include target subsidies on traditional corn hybrid seed prices and shredding for farmers planting *Bt* crops.

References

Environmental Protection Agency, 1998, *The Environmental Protection Agency's White Paper on Bt Plant-pesticide Resistance Management*, Environmental Protection Agency, Washington D.C.

Hurley T.M., B.A. Babcock and R.L. Hellmich, 1997, Biotechnology and Pest resistance: An Economic Assessment of Refuges, Center for Agricultural and Rural Development, Working Paper 1997 WP 183, Iowa State University, Ames, IA.

Hurley T.M., S. Secchi, B.A. Babcock and R.L. Hellmich, 1999, Managing the Risk of European Corn Borer Resistance to Transgenic Corn: An Assessment of Refuge Recommendations, Center for Agricultural and Rural Development, Staff Report 99-SR88, Iowa State University, Ames, IA.

Lazarus W.F. and B.L. Dixon, 1984, Agricultural Pests as Common Property: Control of the Corn Rootworm, *American Journal of Agricultural Economics*, Vol. 66, pp.456-465.

Mason C.E., M.E. Rice, D.D. Calvin, J.W. Van Duyn, W.B. Showers, W.D. Hutchinson, J.F. Witkowski, R.A. Higgins, D.A. Onstad, and G.P. Dively, 1996, *European Corn Borer Ecology and Management*, North Central Regional Extension, Publication No.327, Iowa State University, Ames, IA.

Onstad D. W. and C. A. Guse, 1999, Economic analysis of Transgenic maize and Nontransgenic Refuges for managing European corn Borer (Lepidoptera: Pyralidae), mimeo, Center for Economic Entomology, Illinois Natural History Survey, Champaign, IL.

Miranowski, J.A., 1984, Impacts of Productivity Loss on Crop Production and Management in a Dynamic Economic Model, *American Journal of Agricultural Economics*, Vol. 66, pp.61-71.

Peck S.L., F. Gould and S.P. Ellner, 1999, Spread of Resistance in Spatially Extended Regions of Transgenic Cotton: Implications for Management of *Heliothis virescens* (Lepidoptera: Noctuidae), *Journal of Economic Entomology*, forthcoming.

Jose H. D., L. L. Brown, 1996, Costs of Harvesting and Hauling Corn Stalks in Large Round Bales, Cooperative Extension, University of Nebraska, Institute of Agriculture and Natural Resources, on the Web at http://www.ianr.unl.edu/pubs/nebfacts/nf310.htm.

Secchi S. and B. A. Babcock, 1999, A Model of Pesticide Resistance as a Common Property and Exhaustible Resource, mimeo, Center for Agricultural and Rural Development, Iowa State University, Ames, IA.