Solving the Problem of Sustainable Use of Bt Crops

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Poster prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011

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Introduction

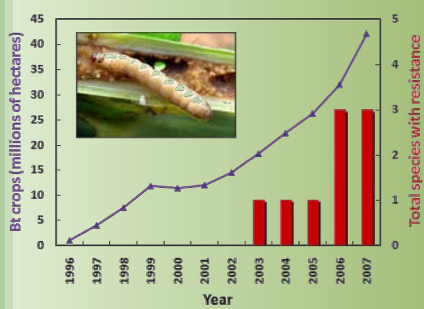

Fig 1. Global adoption of Bt crops and evolution of insect resistance. Resistance in the field has been detected in three species: *bollworm to Bt cotton in the* southeastern United States in 2003, *fall armyworm to Bt corn* in Puerto Rico in 2006, and *stem borer to Bt corn in South Africa* in 2006.
Source: Tabashnik B E PNAS 2008;105:19029-19030

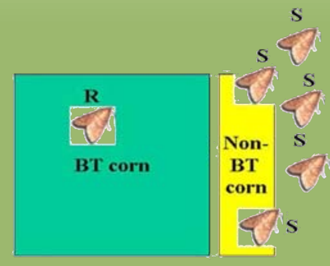

Fig 2. Diagram of the Bt refuge strategy
Beginning in 2000, the EPA requires that farmers growing Bt corn must plant at least 20% of their total corn acreage to a non-Bt variety. R = resistant European corn borer adult; S = susceptible adult. The rationale is that the few Bt-resistant insects surviving in the Bt field would likely mate with susceptible individuals that have matured in the non-Bt refuge. Thus, the insect genes (alleles) for resistance to Bt would be swamped by the susceptible alleles.
Source:http://cls.casa.colostate.edu/transgeniccrops/current.html

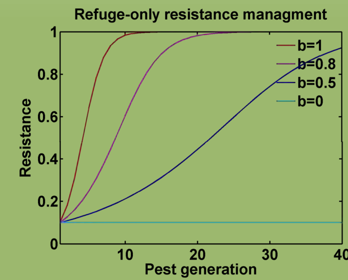

Fig3. Refuge-only resistance management.
The graph shows the frequency over time of the r allele for different Bt proportion (b) planted. The initial r allele frequency was assumed to be 0.1, the costs and benefits of resistance were fully recessive ($n_{sr}=n_{ss}=1$), with resistant homozygotes having relative fitness of 0.4 on Bt crops (w_{rr}) and 1 fitness on non-Bt corps (n_{rr}). Other genotypes are partially susceptible to the Bt toxins($w_{ss}=0.1$, $w_{sr}=0.2$). With these parameters, decreasing b (increasing the proportion of refuge) can **slow down** yet never decrease the development of resistance over time.

Methods

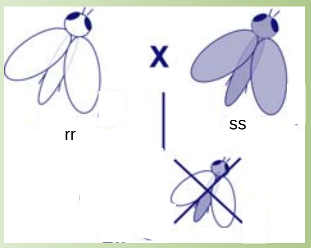

Fig 4.Mass release of wild type homogygotes susceptible (ss) pests. By mating with survivors (rr) of Bt crops, this method can dilute the pest population so that slow down or even **reverse** the evolution of resistance.

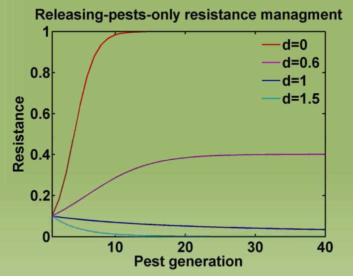

Fig5. Releasing-pests-only resistance management. The graph shows the frequency over time of the r allele for different release ratio (d) . The initial r allele frequency was assumed to be 0.1, the costs and benefits of resistance were fully recessive ($\nu_{sr}=\nu_{ss}=1$), with resistant homozygotes having relative fitness of 0.4 on Bt crops (ω_{rr}) and 1 fitness on non-Bt corps (ν_{rr}). Other genotypes are partially susceptible to the Bt toxins($\omega_{ss}=0.1$, $\omega_{sr}=0.2$). With these parameters, increasing d can slow down or even reverse the development of resistance over time.

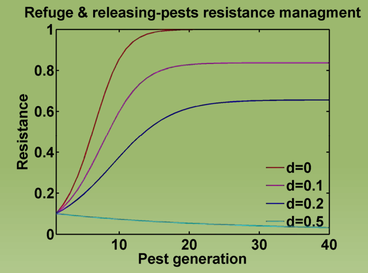

Fig6. Refuge-releasing-pests resistance management. The graph shows the frequency over time of the r allele for different release ratio (d) with proportion of Bt crop planted (b) is 0.9 . Assuming the same parameters as used in Fig 5, smaller d is needed to slow down or even reverse the development of resistance over time compared to Fig5 (the case of no refuge).

Simulation Results

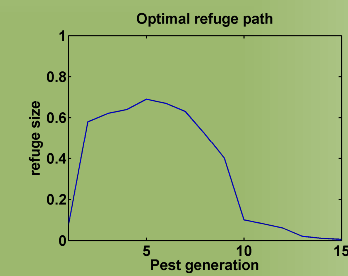

Fig7. The graph shows the optimal dynamic refuge path. If the resistance is irreversible, the optimal pest resistance management path is to invest more in the early time period to slow down the development of resistance and decrease investment as resistance level approaches 1.

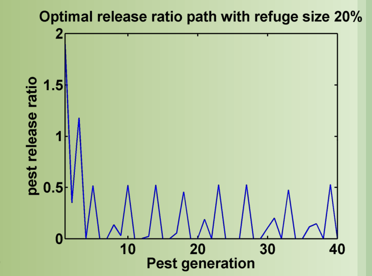

Fig 8. The graph shows the optimal pest release ratio path. A cycling of resistance control is desired, that is, no resistance control is used for some time, and then resistance control is started once the resistance level crosses some threshold.

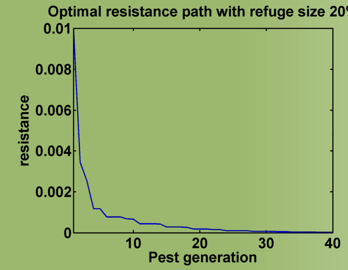

Fig 9. If the resistance is reversible, a steady state of resistance (here slightly above zero) can be obtained. Theoretically, the steady state of resistance level can be any number between 0 and 1, depends on different parameters and functional forms employed in the model.

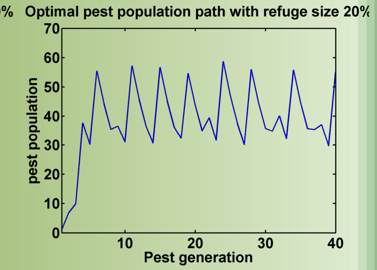

Fig 10. The graph shows the optimal pest population path. The pest population is almost stable except the peaks that associated with each pest release event.

Conclusions

- Resistance will eventually develop with the refuge only policy.
- Release susceptible pests can reverse resistance, and so may serve as a resistance mitigation strategy.
- Release of susceptible pests combined with refuge allows continual use of Bt crops, with an oscillating pest population and a steady resistance frequency.
- Optimal threshold depends not only on initial pest population and genetic parameters, but also on the cost of monitoring resistance and rearing and releasing.