UNDERSTANDING WESTERN CORN ROOTWORM FIELD-EVOLVED RESISTANCE TO BT CORN AND BEST MANAGEMENT PRACTICES

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Transgenic Bt corn hybrids that produce insecticidal proteins from the soil bacterium *Bacillus thuringiensis* (Bt) have become the standard insect management tactic across the U.S. Corn Belt. In 2012, 67 percent of 96.4 million acres of corn planted in the U.S. contained a Bt trait (USDA ERS, 2012; USDA NASS, 2012). Widespread planting of Bt corn creates intense selection pressure for target insects to develop resistance. Evolution of resistance diminishes the efficacy and benefits of Bt corn technology.

Because Bt traits are pesticidal substances produced by plants, the U.S. Environmental Protection Agency (EPA) registers Bt crops through the Federal Insecticide Fungicide and Rodenticide Act (EPA, 2012). Recognizing the threat of evolution of insect resistance, the EPA requires registrants (seed companies) to include an insect resistance management (IRM) plan when applying to register a Bt crop. The goal of the IRM plan is to reduce selection pressure associated with Bt crops and prevent, or at least delay, development of resistance in the target insect population. Growers are required to implement the IRM plan on-farm by planting a refuge. The refuge provides a corn crop habitat that allows target pest insects to develop without exposure to the Bt trait. Mating between susceptible insects from the refuge and potential resistant insects from the Bt corn minimizes the chance of resistance developing in the population.

Thus far, field-evolved resistance has not been detected for the European corn borer even though this species has been exposed to Bt proteins since 1996. The primary reason relates to the use of hybrids that offer a high dose of Bt protein expression for European corn borer. The refuge (historically 20%) and high-dose Bt expression have worked in tandem very well to prevent resistance development in the European corn borer population (Tabashnik, 1994; Gould, 1998).

The IRM situation is unfolding differently for Bt corn and western corn rootworm (*Diabrotica virgifera virgifera*; WCR). The evolution of WCR resistance to all Bt rootworm proteins currently registered has been demonstrated in artificial laboratory and greenhouse selection experiments (Meihls et al., 2008; Oswald et al., 2008; Meihls et al., 2001; Lefko et al., 2008). To date, field-evolved resistance to Bt Cry3Bb1 has been confirmed for 11 populations of WCR in Iowa. In each of these cases (adult WCR collected from one field constitute a population), the problem fields had been planted to the same single Bt rootworm trait for at least three consecutive years, and as many as seven consecutive years (Gassmann et al., 2011; Gassmann et al., 2012).

Despite the requirement that growers plant a refuge to delay or prevent resistance development, the evolution of WCR field resistance to the Cry3Bb1 protein occurred in a relatively short period of time. Why? Insufficient planting of refuges and non-recessive inheritance of resistance for WCR may have contributed to resistance (Gassmann et al., 2011).

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Additionally, all of the Bt hybrids registered for corn rootworm are low- to moderate-dose events, ensuring some corn rootworm survivors in every field (EPA, 2002; Storer et al., 2006; Hibbard et al. 2010).

When enough heterozygotes (individuals with a resistant and a susceptible allele) survive and mate, a Bt-resistant population can begin to increase rapidly (assuming fitness costs are not extreme). In fact, fitness costs of WCR resistance to Bt Cry3Bb1 may be low (Meihls et al., 2008; Gassmann et al., 2011). Additionally, there is evidence of nonrandom mating for WCR and initial resistance allele frequencies in the WCR population may be much higher than initially assumed (Kang and Krupke, 2009; Onstad and Meinke 2010).

In March 2012, 22 corn entomologists from land-grant universities and USDA sent a letter to the U.S. EPA expressing concern over the development of WCR resistance to the Cry3Bb1 protein and providing integrated pest management (IPM) recommendations to sustain the effective use of Bt corn in the U.S. (Porter et al., 2012). In particular, these public sector scientists indicated that the durability of the Cry34/35Ab1 protein, used in conjunction with the Cry3Bb1 protein in pyramided Bt corn hybrids, could be compromised in areas where a resistant population of WCR is present. This concern is heightened because the refuge size has been reduced from 20% to 5% for these pyramided products. Additional concerns mentioned in the letter include the "insurance-based approach" to insect management – the standard practice across the U.S. Corn Belt.

Authors of the letter acknowledge challenges faced by U.S. corn growers in a high value corn commodity market. For example, Bt rootworm traits are incorporated into elite germplasm lines with highest yield potential, and growers report increasing difficulty obtaining non-transgenic seed with equally high yield potential. This can result in Bt rootworm hybrids planted prophylactically in areas or crop rotation sequence with little or no rootworm pressure. Moreover, widespread adoption of Bt technology has left many growers without the equipment necessary to apply soil insecticides to non-Bt corn at planting if necessary. The authors state that many growers have utilized a single-tactic approach for too many years and now unfortunate consequences are beginning to emerge. The letter provides specific integrated pest management (IPM) recommendations to help corn growers delay further corn rootworm resistance and conserve WCR susceptibility to Bt corn technology:

- Consider rotation to soybean or another non-host crop.
- Consider the use of a corn rootworm soil insecticide at-planting with a non-Bt hybrid.
- Consider the use of a Bt hybrid that expresses a different corn rootworm Cry protein than one which may have performed poorly in the past on a particular farm.
- Consider the use of a pyramided Bt hybrid that expresses multiple Cry proteins targeted against corn rootworms.
- Most importantly, implement a long term integrated approach to corn rootworm management that includes multiple tactics such as rotation of Bt hybrids that express different Cry proteins for corn rootworm, use of soil insecticides at-planting with a non-Bt hybrid, rotation to a non-host crop, adult suppression programs where appropriate, and field scouting information and knowledge of corn rootworm densities.

On-farm planting and other rootworm management decisions will alter the future course of resistance evolution. It is critical for industry, regulatory agencies and university and government scientists to work together to provide science-based, practical information to corn growers, crop consultants and the agricultural industry.

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