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Transgenic Insecticidal Corn: The Agronomic and Ecological Rationale for Its Use

We agree with Obrycki et al. (2001) that a broad-based ecological approach for new pest management technologies is desirable, but we unanimously and strongly disagree with some of their assumptions and conclusions about Bt corn.

Bt corn is corn that has been genetically engineered to produce insecticidal proteins from the bacterium *Bacillus thuringiensis*. Because Bt corn is important for effective and ecologically sound management of lepidopteran pests of corn, we provide here relevant data, some of which is new, to help clarify the issues raised by Obrycki et al. (2001).

Obrycki et al. (2001), citing Barry and Darrah (1991), claim that traditional plant breeding has developed corn plants that adequately protect against European corn borer. However, Barry and Darrah (1991) reported only "some resistance to whorl leaf feeding...[or] some resistance to sheath and sheath collar feeding," which is not comparable with the nearly complete protection provided by Bt corn. Carpenter and Gianessi (2001) estimated that, nationally, during "10 of the 13 years between 1986 and 1998, European corn borer infestations...were such that corn growers would have realized a gain from planting Bt corn." Similarly, the Environmental Protection Agency (USEPA 2000) estimated a net benefit to growers of $8.18 per hectare on 8 million hectares of Bt corn planted in 1999, or a national benefit of $65.4 million (USEPA 2000). Even considering the inherent year-to-year variability in pest population density, the EPA estimated the annual benefit to corn growers at $38–$219 million (USEPA 2001).

Bt corn has proven to prevent yield loss, reduce mycotoxin levels, and reduce the use of insecticides on corn (Munkvold et al. 1999, Munkvold and Hellmich 2000, Carpenter and Gianessi 2001). Applications of foliar insecticides are used to control populations of European corn borers and southwestern corn borers on non-Bt corn. But they are not used extensively because of difficulty in scouting and timing treatments to control the larvae before they bore into the plant. Consequently, growers have endured lower yields and higher mycotoxin levels. Obrycki et al. (2001) stated that "the use of transgenic corn will not significantly reduce insecticide use in most of the corn-growing areas of the Midwest." On the contrary, a survey of Bt corn producers ($n = 7265$) from six states (Illinois, Iowa, Kansas, Minnesota, Nebraska, and Pennsylvania) documents that growers did reduce insecticide use for European corn borer during the first three growing seasons after commercial introduction of Bt corn. Approximately half of the farmers did not use insecticides to manage European corn borers on their farms. Of those growers using insecticides during the previous 5 years for European corn borer control, the percentage decreasing their usage of pesticides during the 3-year period nearly doubled from 1996 to 1998 (13.2% to 26.0%) (Hellmich et al. 2000). Take Iowa with 5 million hectares of commercial corn as an average example: With 30% of the hectares planted in Bt corn, allowing 26% of the Bt producers to reduce or eliminate European corn-borer insecticide use, hundreds of thousands of hectares were not sprayed with a broad-spectrum insecticide. This benefit is easily overlooked: Figure 2 in the article by Obrycki and colleagues (2001) includes all insecticides, whereas most use was granular insecticides for control of corn rootworms, *Diabrotica* spp. Considering the benefits pointed out above, concurrence within the scientific community that there are real benefits to ecosystems and human health, including those from a reduction in use of more broad-spectrum foliar insecticides, becomes clear (AMA 2000, APS 2001, Pool and Esnayre 2000).

In addition, contrary to concerns regarding monarch butterflies (Losey et al. 1999), comprehensive new studies show that Bt corn pollen poses little risk to monarchs on a national scale (Hellmich et al. 2001, Oberhauser et al. 2001, Pleasants et al. 2001, Sears et al. 2001, Stanley-Horn et al. 2001). Collectively, these results validate EPA's original and subsequent evaluations of the potential risks posed to nontarget butterflies and moths. As for other potential nontarget effects of Bt corn, the EPA risk assessments relied on laboratory and field trial data from representative organisms that are routinely used in assessment of ecological toxicity, including avian species (quail), aquatic species (catfish and daphnia), beneficial insects (honeybee, parasitic wasp, green lacewing, ladybird beetle), soil invertebrates (springtails and earthworms), and mammals (mice) (USEPA 1995, 2000, 2001). These tests represent toxicological endpoints for single-species components of a larger ecological system and may not necessarily predict all possible interactions. Yet

Letters to the Editor
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they are important because they provide a basis for establishing acute toxicity in indicator organisms and for developing longer-term community studies. One must keep in mind, though—regardless of whether one uses a resistant plant, a biological control agent, an insecticide, a cultural technique, or any other method to control a pest—that if the pest population is reduced, there will be some impact on the biological community.

Positive and negative impacts of new technologies must be compared with those of existing technologies. All possible impacts of any technology or farming practice are impossible to foresee, but we can focus on known and probable risks. When risks of a technology are characterized as low, based on actual data, then the potential impact should be evaluated proportional to that level of concern. This reasonable approach should reduce the chances of rejecting safe technologies simply because they are new and unfamiliar. Ultimately, the goal is to replace current pest management practices with ones that are more economical and sustainable, as well as environmentally safer. A dynamic equilibrium between benefits and risks will be developed as a result of this ongoing process. Over time, this equilibrium will change as improved practices are developed. In the meantime, if unexpected problems should occur, failsafe mechanisms exist. Any pesticidal technology registered by the EPA can have its registration suspended or canceled when an unreasonable adverse effect is identified.

The scientific community has examined the risks and benefits of Bt plants more than any other novel agricultural technology developed over the past two decades, as demonstrated by the vast body of literature, scientific discussions, and numerous public meetings facilitated by the EPA, the US Department of Agriculture, and the US Food and Drug Administration on this subject. We find the evidence to date supports the appropriate use of Bt corn as one component in the economically and ecologically sound management of lepidopteran corn pests.

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Response from Obrycki and colleagues: We agree with our colleagues (Ortman et al.) that the appropriate use of Bt transgenic corn can be one component in an economically and ecologically sound management program for lepidopteran corn pests. However, we disagree that the current use of Bt corn represents ecologically based management of lepidopteran pests of corn. We argue that planting 20%–30% of the corn acreage with Bt corn as a prophylatic treatment for lepidopteran pests is not ecologically based management. This approach is analogous to continuous spraying of up to 30% of the field corn in the United States with a selective insecticide every year, just in case there is an infestation by a lepidopteran pest.

We acknowledge that this technology is relatively new, and that data being collected will provide a clearer understanding of the benefits and risks of transgenic Bt corn. For example, a recent study has determined that nine transgenic Bt corn hybrids, developed from two separate transformation events, have significantly higher lignin levels than isogenic hybrids (Saxena and Stotzky 2001). We welcome the engagement of our colleagues in meaningful discussions of this technology and its role in pest management. We respond to several aspects of the letter from Ortman and colleagues to clarify points made in our original paper.

In Obrycki et al. (2001) we stated that "most corn hybrids already have substantial resistance to corn borers." We do not believe that this statement means that we "claim that traditional plant breeding has developed corn plants that adequately protect against European corn borer." Unfortunately, shooting at a straw man that has very little relation to original statements is all too common a tactic in scientific discourse (Collins and Pinch 1998), and it is of particular concern regarding an issue as important as the appropriate use of biotechnology (Shelton and Roush 1999). Corn plants express varying levels of resistance at different life stages, a fact that plays a vital role in the management of corn borers. In addition, modern corn hybrids have relatively high levels of tolerance to corn borer feeding. The combination of partial resistance and tolerance in modern corn hybrids contrasts with "the nearly complete protection provided by Bt corn." Is complete protection—virtually 100% mortality of corn borers—a goal of ecologically based pest management?

Human-derived selective forces have been identified as one of the most important evolutionary factors on the planet (Palumbi 2001). Recently, the molecular bases of two different Bt resistance mechanisms were identified (Gahan et al. 2001, Griffitts et al. 2001). Planting approximately 25% of the corn in the United States with Bt corn that causes almost 100% mortality of corn borers does not appear to be a wise use of this biotechnology from either an ecologically based approach for population management or an evolutionary perspective relative to maintaining suseceptible genotypes of the pest.

Ortman and colleagues state that the use of Bt corn over the last 5 years has reduced the level of insecticide use. This is puzzling, because Carpenter and Gianessi (2001) state that "attributing any observed changes in insecticide since 1995 to the introduction of Bt corn is necessarily problematic for several reasons." One difficulty in demonstrating any difference in insecticide use is that the level of insecticide use before the introduction of Bt corn was minimal (Rice and Ostlie 1997, Wintersteen and Hartzler 1997, Carpenter and Gianessi 2001). For example, from 1995 to 1998, 1%–2% of the corn grown in Iowa was treated with insecticides for corn borer infestations. If Bt corn is replacing insecticides, we might expect 2% of the corn to be planted to transgenic Bt corn. Furthermore, Ortman and colleagues cite data that indicate only 26% of growers who planted Bt corn in 1998 actually used less insecticide to control the European corn borer (Hellmich et al. 2000).

As stated by Rice and Pilcher (1998), the economic benefits of this technology will vary with a number of factors related to levels of corn borer infestations, value of field corn, and cost of transgenic Bt seed. Ortman and colleagues cited the following from the National Center for Food and Agricultural Policy Web site (Carpenter and Gianessi 2001): In "10 of the 13 years between 1986 and 1998, European corn borer infestations...were such that corn growers would have realized a gain from planting Bt corn." Extracting this single phrase out of context presents several potential misconceptions. If data for 1999 are added, then some farmers would have made a profit in 10 of 14 years. We emphasize the word "some," because even in years with relatively high European corn borer levels, many fields will not exceed economically damaging levels. Recent evaluations of Bt transgenic corn have not demonstrated consistent economic benefits (Hyde et al. 1999, Archer et al. 2000). We believe that the data collected over 2 years in replicated field studies under natural infestations of corn borers (Rice 1998, Farnham and Pilcher 1998), as cited in our paper, are some of the best data to evaluate the performance of transgenic Bt corn hybrids in comparison with nontransgenic lines. Carpenter and Gianessi

(2001) summarize data showing that in 1997 there was a net benefit for Bt corn, but in 1998 and 1999, when the percentage of Bt corn planted increased from 18% to 26 %, there was an aggregate net loss for growers who planted transgenic Bt corn.

Ortman and colleagues state that Bt corn hybrids that are being widely planted do not appear to have major effects on monarchs outside of corn fields because of the relatively low expressions of Bt toxins in their pollen. The conclusion that Bt corn poses negligible risk to monarchs rests on the assumption that monarchs consume only pollen and not other corn tissue (Hellmich et al. 2001). However, within cornfields both pollen and anthers are deposited on milkweeds, which are relatively common in cornfields (Hartzler and Buhler 2000, Oberhauser et al. 2001). Milkweeds growing in agricultural fields are a major food source for monarchs in the midwestern United States (Oberhauser et al. 2001). Corn anthers contain higher levels of Bt toxins compared to pollen, and when studies have considered mixtures of pollen and anthers, negative effects on monarch larvae have been reported (Losey et al. 1999, Jesse and Obrycki 2000, Hellmich et al. 2001). Field observations and experimental evidence suggest that monarchs may be exposed to higher levels of corn anther material than previously assumed. The incidence of transgenic Bt corn anthers on milkweed plants in cornfields and previous studies demonstrating detrimental effects of pollen–anther mixes on monarch larval survival and development (Losey et al. 1999, Jesse and Obrycki 2000) suggest to us that questions about the nontarget effects on monarchs and other lepidopteran species require further examination.

Ortman and colleagues list species included in EPA nontarget testing of transgenic Bt corn. We note that the monarch butterfly, *Danaus plexippus*, and the black swallowtail, *Papilio polyxenes*, two species that occur in and near cornfields in the midwestern United States, were not included in the initial EPA tests. These omissions demonstrate the need to broaden EPA testing to consider organisms in a more ecologically based approach that goes beyond a strict toxicological view of potential nontarget effects. In addition, we question a registration process that approved event 176 transgenic Bt corn, which produces relatively high levels of Bt toxin in pollen. Studies have shown negative effects of this pollen on the survival and development of monarch larvae and sublethal effects on growth of black swallowtail larvae (Jesse and Obrycki 2000, Hellmich et al. 2001, Zangerl et al. 2001). Fortunately, event 176 has not been widely planted because of temporal reductions in expression of the Bt toxin in leaves and stems. Does this example show that the EPA system works, because event 176 will probably not be reregistered, or that the EPA system failed to identify potential nontarget effects from relatively high levels of Bt toxin expression in event 176 pollen?

Finally, although the letter above has numerous signatories, it is important to note that there is not, as Ortman and colleagues state, "concurrence within the scientific community that there are real benefits" stemming from the use of Bt corn to control the European corn borer. While we readily agree that there are some potential benefits, we also believe, along with other scientists, that more research is necessary before concluding that potential benefits outweigh potential risks (Hails 2000, Wolfenberger and Phifer 2000, Marvier 2001, Letourneau and Burrows 2001). We conclude by restating the final two sentences of our article (Obrycki et al. 2001): "We are not advocating the elimination of Bt corn, nor do we discount the potential benefits of biotechnology for agriculture. We do argue, however, that a balanced examination of Bt corn suggests ways to improve the regulatory process and to incorporate this technology into an integrated control framework, and we caution against the acceptance of yet another silver bullet for pest management."

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Supporting a Cautious Approach to Agricultural Biotechnology

We applaud Obrycki and colleagues (2001) for addressing the promise and potential pitfalls of transgenic insecticidal corn developed to control lepidopteran pests. Commercially grown varieties of such corn each produce a protein encoded by a gene from the bacterium *Bacillus thuringiensis* (Bt). The primary target of currently grown Bt corn is the European corn borer, *Ostrinia nubilalis*. Obrycki and colleagues cite evidence that insecticide use against this pest was relatively low before the introduction of Bt corn, especially in Iowa and Minnesota. We agree that when insecticide use against a particular pest is low, transgenic crops designed to control that pest are unlikely to substantially reduce insecticide use. However, contrary to the boxed statement in large type at the beginning of the article, we propose that analysis of currently available Bt corn cannot be extrapolated to evaluate the potential risks and benefits of genetic engineering for insect pest management.

As Obrycki and colleagues (2001) note, Bt cotton has significantly reduced insecticide use. For example, Bt cotton in Arizona has been extremely effective against pink bollworm, *Pectinophora gossypiella*, and helped to reduce the number of insecticide applications per hectare from six in 1995 to two in 1999 (Tabashnik et al. 2000, Carrière et al. 2001). A new type of Bt corn that is not yet on the market produces two novel Bt proteins that kill the major coleopteran pest, western corn rootworm, *Diabrotica virgifera virgifera* (Moellenbeck et al. 2001). Because farmers use enormous amounts of insecticide for rootworms, this new Bt corn has great potential for reducing insecticide use (Pimentel and Raven 2000, Ostlie 2001).

Although transgenic crops can reduce pest population densities and thereby suppress natural enemies, we doubt that Bt corn "could lead to the types of resurgence and secondary-pest outbreaks that are associated with misuse of synthetic broad-spectrum insecticides" (Obrycki et al. 2001). By definition, these problems occur when insecticides kill large proportions of natural enemy populations (Van den Bosch and Messenger 1973). Unlike broad-spectrum insecticides, Bt proteins are specific in their toxicity and typically cause little or no direct mortality to natural enemies (Charles et al. 2000). Thus, sprays of Bt proteins have long been valued in organic farming and in integrated pest management (Mellon and Rissler 1998). Results of studies evaluating interactions between natural enemies and Bt corn listed in Table 1 of Obrycki et al. (2001) show 13 examples with no effect, three with negative effects, and two with positive effects.

In conclusion, we support a cautious approach to agricultural biotechnology, including thorough evaluation of advantages and disadvantages on a case-by-case basis. This approach can avoid the naïve optimism that accompanied the advent of broad-spectrum insecticides while increasing the chances that the potential benefits of transgenic crops will be realized.

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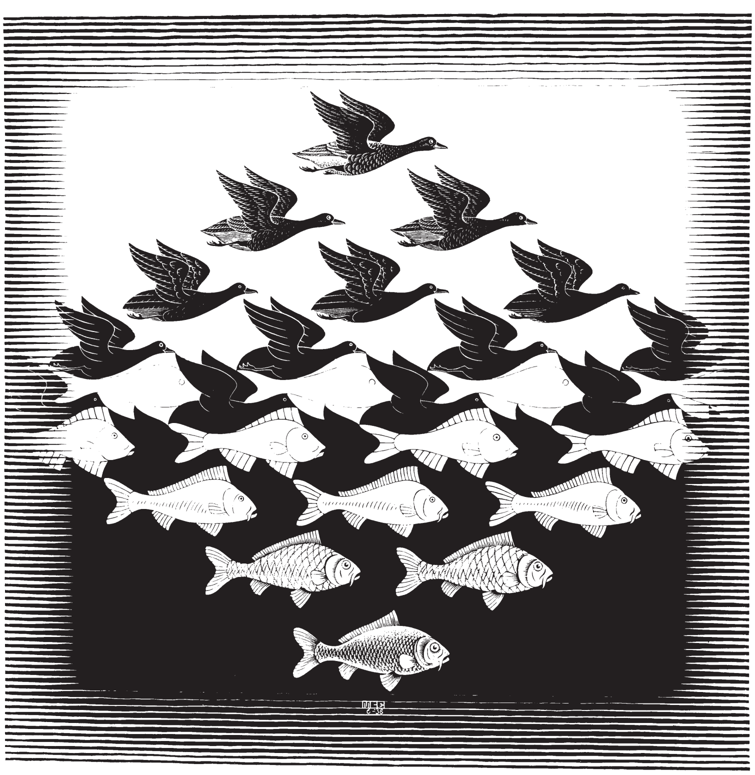

Response from Obrycki and colleagues: Our intended focus in the boxed statement at the beginning of our article was Bt transgenic corn developed for lepidopteran insects pests. As Tabashnik and colleagues pointed out, this was not clearly conveyed by our statement. The second point raised by Tabashnik and colleagues questions the possibility that Bt corn could lead to similar types of ecological problems observed with the overuse of insecticides, because Bt toxins do not have broad-spectrum activity, thus natural enemies will not be directly killed. We agree that because of the selective nature of the Bt toxins, direct mortality of natural enemies will not occur. However, we argue that alternative mechanisms—for example, elimination of hosts for natural enemies within transgenic fields because of high levels of Bt toxin expression in transgenic hybrids—may play a role in ecological processes, leading to pest resurgence and replacement. These ecological and evolutionary processes will proceed within the currently defined planting regimes for resistance management and will require continued study. We strongly agree with the conclusion of Tabashnik and colleagues that a cautious approach to each type of transgenic crop is needed, including Bt corn developed for corn rootworms (Gray 1999, 2000). Our article was an attempt to outline this type of approach for transgenic Bt corn developed for lepidopteran insect pests.

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