DO GM CROPS MEAN LESS PESTICIDE USE?

Charles Benbrook of the Northwest Science and Environmental Policy Center at Sandpoint (Idaho, USA) gives his views on the contention than GM crops have led to a reduction in pesticide use in the USA

Introduction

Spirited debate in the USA continues over the impact of genetically modified (GM) crop varieties on pesticide use. Biotechnology proponents have claimed since the mid-1990s that both herbicide-tolerant and *Bt*-transgenic varieties significantly reduce pesticide use, despite much empirical evidence to the contrary. This contention lies at the heart of industry efforts in the U.S. and Europe to build public support for contemporary GM crop technologies.

Four years of official U.S. Department of Agriculture data are now available to test the claim that GM crops grown in the U.S. have significantly reduced pesticide use. Most independent analysts working with the USDA data have reached similar conclusions; with the possible exception of *Bt*-cotton, they have not.

Herbicide-tolerant varieties have modestly reduced the average number of active ingredients applied per acre but have modestly increased the average pounds applied per acre. So, those who choose to measure herbicide use based on the former metric conclude that herbicide-tolerant varieties reduce herbicide use; those who favor the latter metric reach the opposite conclusion. Both are reasonable but incomplete ways to assess the overall impact of herbicide-tolerant varieties on herbicide use and the performance and sustainability of weed management systems.

Bt corn and cotton account for most acres planted to *Bt*-transgenic varieties. Again, the insecticide use data are pretty clear. *Bt* cotton has reduced insecticide use in several states, whereas *Bt* corn has had little if any impacts on corn insecticide use.

These findings come as no surprise to astute farmers or pest management experts. Herbicide tolerant varieties are designed to make it possible for farmers to rely on post-emergence herbicides as the backbone of weed management programs. Any grower spending the extra money on such a variety is obviously going to rely more prominently on herbicides as the principle method for controlling weeds, in contrast to other farmers using multitactic integrated weed management systems that both spread out the burden in managing weeds and strive to reduce weed pressure in the first place.

Herbicide tolerant varieties have modestly increased herbicide use

Corn herbicides account for about 40% of the total pounds of herbicides, insecticides, and fungicides that are applied annually by U.S. farmers (Table 3.2, Economic Research Service [ERS], 1997). Soybean weed management is the second biggest market, accounting for about 68 million pounds applied annually. For this reason, attainment of national pesticide use reduction goals and minimizing environmental damage and public health risks in corn-soybean production areas depends in large measure on innovation in weed management systems in these two major crops.

Four years of USDA soybean herbicide use data (1997-2000) are available and support four conclusions (ERS, 1999; Duffy, 1999; Benbrook, 2001a):

- Slightly more pounds of herbicides are applied on the average acre of Roundup-Ready (RR) soybeans compared to the average acre planted to conventional soybean varieties.
- Fewer herbicide active ingredients are applied on the average acre of RR soybeans relative to the average conventional acre.
- Average per acre pounds of herbicide applied on RR soybeans exceeds by 2- to 10-fold herbicide use on the approximate 30% of soybean acres where farmers depend largely on low-dose imidazolinone and sulfonylurea herbicides.
- Herbicide use on RR soybean acres is gradually rising as a result of weed shifts, late-season weed escapes leading to a buildup in weed seedbanks, and the loss of susceptibility to glyphosate in some weed species (Hartzler, 1999; HRAC, 2001).

While RR soybean technology has not reduced herbicide use, it has certainly been a remarkable commercial success. Farmers have embraced the technology because it greatly simplifies soybean weed management and provides additional degrees of freedom in managing weeds (Gianessi and Carpenter, 2000; ERS, 1999).

RR technology has also given farmers a welcomed alternative to the use of low-dose herbicides that are plagued by often-serious problems. These include high costs; frequent control problems; a long and growing list of resistant weeds; and, a tendency to trigger crop damage if not applied with considerable care and precision (Fernandez-Cornejo and McBride, 2000; Gianessi and Carpenter, 2000). RR soybeans are especially popular on problem fields where weeds have proven tough to manage (Gunsolus *et al.*, 2001). Over 65% of soybeans planted in the U.S. in 2001 are RR soybean varieties.

The May 2001 report "Troubled Times Amid Commercial Success for Roundup Ready Soybeans: Glyphosate Efficacy

 DOI: 10.1039/b108609j

is Slipping and Unstable Transgene Expression Erodes Plant Defenses and Yields" provides a recent update of the commercial success of RR soybeans and their impacts on herbicide use, prices, yields, and plant health (Benbrook, 2001a).

Corn herbicide use trends have been remarkably stable. Since 1971 the number of distinct herbicide active ingredients applied on the average acre of corn has risen from 1.09 actives to 1.75 in 1982 and 1.98 in 1991 (NASS, multiple years). The trend continued gradually upward throughout the 1990s and reached 2.7 herbicides in crop year 2000.

In addition, the dominant corn herbicides have changed very little throughout this period, measured either by percent acres treated or pounds applied. Each year atrazine has alone accounted for about 30% of all corn herbicide acres treated and about 35% of pounds applied (Benbrook, 2001b). The acetanilide herbicides alachlor (largely replaced by acetochlor in 1994–1995 in the U.S.) and metolachlor (replaced by S-metolachlor in 1998–2000) have together accounted for another approximate 30 percent of total acres treated and over 40% of pounds applied.

The average pounds of herbicides applied to corn peaked in 1982 at almost 3 pounds per acre and hovered in the 2.6 to 2.8 pounds range from 1991 through 1997. The first significant reduction in pounds applied occurred in 1998, when rates dropped from 2.63 pounds per acre to 2.47 pounds, based on USDA/NASS data.

Roundup Ready (RR) corn hit the market in 1997. There are no accurate public sources of data on the acres planted to RR corn. A rough estimate of acres planted can be inferred from review of USDA corn pesticide use data. Assuming no-till usage of glyphosate remained the same in 1999–2000 as it had been in previous years, USDA data suggests that about 4% of corn acres must have been planted to Roundup Ready varieties.

Monsanto's recommended RR corn systems include several optional herbicide programs ranging from a total-glyphosate system, to systems combining a pre- or at-plant residual herbicide followed by Roundup post-emergence, or a total post-emergence program involving applications of a residual post-product plus Roundup (Monsanto, 2000a and 2000b). In the total Roundup program, glyphosate is applied on average about 2.0 times. In 1999 the average application was about 0.7 pounds, resulting in 1.4 pounds of Roundup applied on the average acre of RR corn.

An estimated 70% of RR corn acres were managed under the "Residual Herbicide Applied" program. Either before or at-planting in such programs, farmers apply a tank-mix containing a residual broadleaf product like atrazine at about 0.8 pounds per acre, plus an acetanilide herbicide at a rate of about 1.2 pounds per acre on average, mostly for grass weed control (see recommended rates on either Roundup labels or the labels of several herbicide products containing mixtures of atrazine and an acetanilide).

Total corn herbicide use under the "Residual Herbicide Applied" program averages about 2.75 pounds per acre, with Roundup accounting for 0.75 pounds of this total. USDA data suggest that average per acre use on RR corn acres has risen from about 2.5 pounds in 1999 to 2.75 pounds in 2000 (Benbrook, 2001b). On conventional acres, about 2.25 pounds were applied in 1999 and 2.08 pounds in 2000. Accordingly, in 2000 the average RR corn acre was treated with about 30% more herbicide than the average non-GM corn acre.

Four years of experience and data show that RR weed management systems require a modest to moderate increase in per-acre herbicide use. Moreover, use rates are trending upward because of shifts in the composition of weeds toward species less responsive to a contact herbicide like glyphosate; loss of susceptibility and/or the emergence of resistance in some weed species; and, greater weed pressure as a result of more frequent late-season weed escapes in RR crops.

Bt-transgenic varieties perpetuate heavy reliance on treatments

Bt-transgenic technology uses a natural plant toxin and a novel delivery system to mimic chemical-based pest management systems. The impacts of *Bt*-varieties on insecticide use are complex and changeable.

In the case of *Bt*-corn, USDA data show that corn insecticide applications directly targeting the European corn borer (ECB) have risen from about 4% of acres treated in 1995 to about 5% in 2000. In addition, several other insecticides are applied that control both the ECB and rootworm complex. A portion of these treated acres must therefore be counted as part of ECB-driven insecticide use (EPA Benefits Assessment, 2000).

About 7.3% of corn acres were treated for ECB control in 2000, up from about 6.75% in 1995. Corn insecticide use targeting all pests has remained steady in the 1990s at about one-third of corn acres planted (Environmental Defense and Union of Concerned Scientists, 2001a).

Bt-cotton, on the other hand, has reduced insecticide use markedly in several states. Close to half cotton insecticide acre-treatments either solely or partially target the budworm-bollworm (BBW) complex of insects, the target of *Bt* cotton. The average cotton acre received 2.21 acre-treatments with insecticides targeting the BBW complex in 1992. Reliance peaked in 1995 at just over 3 acre-treatments and has fallen to just 0.77 in 2000 (Environmental Defense and Union of Concerned Scientists, 2001a).

In terms of pounds applied, insecticide use targeting the BBW complex has fallen from about one-half pound per acre in the early 1990s to 0.28 pounds per acre in 2000. Two factors clearly account for this large reduction – the boll weevil eradication program and second, *Bt* cotton, especially in the western U.S.

Cotton insecticide use trends must be studied carefully to accurately identify cause-effect relationships. The biggest reductions in bollworm-budworm complex insecticide use have occurred in the use of methyl parathion, profenofos, and thiodicarb. The former two are highly toxic OPs that have triggered resistance problems and regulatory restrictions. As a result, most of the reduction in their use had occurred by the end of the 1996 season, prior to widespread use of *Bt*-cotton.

In some high adoption states, especially Arizona, BBW applications have fallen dramatically from over 3 acre-treatments per acre in 1994 to just 0.1 in 2000 (see state-level tables in Environmental Defense and Union of Concerned Scientists, 2001a). Remarkably, only 2000 pounds of BBW complex insecticides were applied in 2000 in Arizona, down from 397,000 in 1995. Much of this decline is likely attributable to *Bt* cotton, which was planted on over 75 percent of acres planted (revised EPA benefits assessment, Table E.8).

But in Alabama, another high *Bt*-cotton adoption state (62% acres planted), BBW insecticide applications almost doubled from 1997 to 2000. Moreover, there was a clear shift in Alabama toward very toxic, broad-spectrum materials. Similar dramatic changes have occurred in Mississippi cotton insect pest management. In the first half of the 1990s, cotton farmers made eight to nine applications per acre targeting the BBW complex, with the highly-toxic OP methyl parathion accounting for over 40% of acre-treatments and pounds applied. *Bt* cotton has helped Mississippi growers reduce BBW insecticide acre-treatments from over 9.36 in 1995 to just under 0.6 in 2000. Pounds applied fell from 2.76 pounds to 0.2 pounds per acre.

Some low-adoption *Bt*-cotton states have also markedly reduced BBW acre-treatments. Texas cotton (7% *Bt*-cotton), for example, was treated an average 1.3 times with BBW insecticides in 1995 and 0.65 times in 2000 – about a 50% drop.

GMO crops in perspective

Lessons learned from five-decades of insecticide-based cotton pest management are relevant in assessing the likely longer-run impacts of GM crops on pesticide use.

Three major families of chemistry have accounted for most cotton insecticide use from the 1960s through 1980s – the organochlorines, or chlorinated hydrocarbons (DDT, aldrin/dieldrin, toxaphene, chlordane/heptachlor); the organophosphates (parathion, malathion, chlorpyrifos, among many others); and carbamates (aldicarb, carbofuran, carbaryl, oxamyl). In the mid-1980s the synthetic pyrethroids came into use (permethrin, cypermethrin, esfenvalerate). Changes in reliance across families of chemistry are shown in Table 1.

Resistance began driving down the use of chlorinated hydrocarbons (OCs) in the mid-1960s. In the late 1970s, use of this family of chemistry collapsed and now accounts for a trivial share of total cotton insecticide use.

The collapse of the OCs coincided with the introduction of the organophosphates (OPs) and carbamates. OPs and carbamates are applied at lower rates (0.3 to 0.8 pounds a.i. per acre) compared to the OCs (1.0 to 1.5 pounds per application). Still, multiple annual applications of the OPs and carbamates have added up to significant pounds and major environmental impacts.

OP and carbamate pounds applied doubled from the mid-1960s to the mid-1970s. Excessive use brought on resistance with a vengeance, leading to the collapse in OP and carbamate use from 1976 to 1982. The huge spike in OP use in 2000 was caused by the approximate 24 million pound increase in malathion use in USDA-sponsored boll weevil eradication programs.

The "pesticide treadmill" cycle began anew in the late 1970s as resistance eroded OP/carbamate efficacy, an event that fortunately coincided with the introduction of the synthetic pyrethroids. These insecticides are applied at even lower rates – from 0.03 to 0.2 pounds per application per acre. Hence, the total synthetic pyrethroid pounds applied appear modest in Table 1, when in fact this family of chemistry now accounts for nearly as many acre-treatments as the OPs (not counting the 35.6 million acre-treatments of malathion in 2000).

The introduction of the synthetic pyrethroids in the 1980s gave cotton farmers a badly needed new family of chemistry to rotate with the OPs and carbamates. The same can be said of the registration of *Bt*-cotton in 1996.

The OP, carbamate and synthetic pyrethroid doom-to-bust cycles each lasted about a decade. Despite today's *Bt*-crop insect resistance management (IRM) plans, there is no reason to expect that resistance will take much longer to emerge in regions where *Bt* crops are planted extensively (for recent overview of new science lessening confidence in *Bt*-crop IRM plans, see Environmental Defense and Union of Concerned Scientists, 2001b). The reason why was explained in a seminal article in the *Proceedings of the National Academy of Sciences* entitled "A Total System Approach to Sustainable Pest Management" (Lewis *et al.*, 1997):

> "Genetic engineering and other such technologies are powerful tools of great value in pest management. But,

Table 1. Changes in cotton insecticide use by family of chemistry (million pounds a.i.)

	1964	1966	1971	1976	1982	1992	1998	2000
Organochlorines	54.6	45.4	33	18.6	1.2	1.2	0.3	0.5
Organophosphates	15.6	14.3	28.6	31.4	12.9	13.4	11.3	36.1
Carbamates	6.2	4.5	10.3	12.2	3.5	4	2.7	3.5
Pyrethroids	0	0	0	0	0.8	0.9	0.4	0.3
Other	1.6	0.7	1.5	2	1	0.3	0.1	0.1
Total pounds applied	78	64.9	73.4	64.2	19.4	19.8	14.8	40.5

*Totals may not add due to rounding.
Source: Calculated from USDA Chemical Use Surveys, multiple years.

> if their deployment is to be sustainable, they must be used in conjunction with a solid appreciation of multi-trophic interactions and in ways that anticipate countermoves within the systems. Otherwise, their effectiveness is prone to neutralization by resistance in the same manner as pesticides." (Lewis *et al.*, 1997).

They argue that the central problem plaguing pest management has been failure to recognize the need – and opportunities – to manage natural plant-best-beneficial interactions, and that any toxin-based intervention will be met by "countermoves that *neutralize* their effectiveness." (Lewis *et al.*, 1997). They glean a key lesson from the last 5 decades of pest management:

> "The use of therapeutic tools, whether biological, chemical, or physical, as the primary means of controlling pests rather than as occasional supplements to natural regulators to bring them into acceptable bounds violates fundamental unifying principles and cannot be sustainable." (Lewis *et al.*, 1997).

Similar concerns have been voiced since the introduction of today's GM crops (*e.g.*, see the biotech sections of Benbrook *et al.*, 1996). Both herbicide tolerant and *Bt*-transgenic varieties entail novel mechanisms to enhance the ability of farmers to more fully rely on pesticides. Both technologies simplify pest management systems and hence are more prone to the "countermeasures" highlighted by Lewis *et al.* (1997) In addition, the technologies tend to heighten reliance on one or a few active ingredients or toxins, further increasing the likelihood of resistance.

Both technologies allow farmers and pest management experts to postpone reckoning with the fundamental problems plaguing contemporary, treatment-oriented pest management. The technologies have been very costly to develop, commercialize, and market and their benefits are likely to be short-lived.

"Do GM crops reduce pesticide use?" is really not the important question. Instead, we should be asking how biotechnology can lead the way toward prevention-based biointensive pest management systems that rest largely on low-impact ways to manage natural biocontrol processes and interactions (Benbrook *et al.,* 1996).

The greatest long-term pest management benefits from agricultural biotechnology may well be process- and management based, as opposed to product-based. Sophisticated pest management systems in the future will rely on biotech to help evoke, and sometimes strengthen, natural plant defense mechanisms. Biotech will make it possible for farmers to subtly tip the competitive balance within agricultural systems toward beneficial organisms at the expense of pests (for a review of promising technologies, see Benbrook, 2000). It will expand the range and deepen the effect of a new era of "countermeasures" that together might finally pull the plug on the pesticide treadmill.

Hopefully the GM food-technology debate will move on to define and pursue these sorts of new era, management-system based applications of biotechnology. In the meantime, the debate over whether GMO crops reduce pesticide use will go on.

References

Benbrook, C. (2000). *Who Controls and Who Will Benefit from Plant Genomics?,* invited paper AAAS Annual Meeting, 2000 Genome Seminar, electronically enhanced version accessible at http://www.biotech-info.net/AAASgen.html

Benbrook, C. (2001a). Troubled Times Amid Commercial Success: Glyphosate Efficacy is Slipping and Unstable Transgene Expression Erodes Plant Defenses and Yields, Ag BioTech InfoNet Technical Paper Number 4, accessible at http://www.biotech-info.net/troubledtimes.html

Benbrook, C. (2001b). Factors Shaping Trends in Corn Herbicide Use, Ag BioTech InfoNet Technical Paper Number 5, accessible at http://www.biotech-info.net/corn_reduct.html

Benbrook, C. M.; Groth, E.; Halloran, J. M.; Hansen, M. K.; Marquardt, S. (1996). *Pest Management at the Crossroads*, Consumers Union, Yonkers, New York. Accessible at: http://www.pmac.net/order.htm

Duffy, M. (1999). "Does Planting GMO Seed Boost Farmers' Profits?", Leopold Center for Sustainable Agriculture, Iowa State University. Accessible at: http://www.leopold.iastate.edu/newsletter/99-3gmoduffy.html

Economic Research Service (ERS), 1997. *Agricultural Resources and Environmental Indicators, 1996-97*, USDA-ERS Agricultural Handbook Number 712, Washington, D.C.

Economic Research Service (1999). "Genetically Engineered Crops for Pest Management," ERS, U.S. Department of Agriculture, updated October 27, 1999. Accessible at: http://www.econ.ag.gov

Environmental Defense and Union of Concerned Scientists (2001a). *Appendix 3: Benbrook Benefits Assessment*, submitted in response to the EPA revised risk-benefit assessment of *Bt*-crops. Accessible at: http:www.biotech-info.net/Bt_rereg.html

Environmental Defense and Union of Concerned Scientists (2001b). *Appendix 2: Benbrook IRM Analysis*, submitted in response to the EPA revised risk-benefit assessment of *Bt*-crops. Accessible at: http:www.biotech-info.net/Bt_rereg.html

Fernandez-Cornejo, J.; McBride, W. D. (2000). *Genetically Engineered Crops for Pest Management in U.S. Agriculture*, Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report Number 786, April 2000.

Gianessi, L. P.; Carpenter, J. E. (2000). *Agricultural Biotechnology: Benefits of Transgenic Soybeans*, National Center for Food and Agricultural Policy, Washington, D.C., April 2000.

Gunsolus, J.; Durgan, B.; Becker, R. (2001). *Cultural and Chemical Weed Control in Field Crops – 2001*, University of Minnesota Extension Service. Accessible at: http://www.extension.umn.edu/distribution/cropsystems/components/DC3157.pdf

Hartzler, B. (1999). *Are Roundup Ready Weeds In Your Future?,* Department of Agronomy, Iowa State University Extension. Accessible at: http://www.weeds.iastate.edu/mgmt/qtr98-4/roundupfuture.htm

Herbicide Resistance Action Committee (HRAC) (2001). *International Survey of Herbicide Resistant Weeds*, Weed Science Society of America. Accessible at: http://www.weedscience.org/in.asp

Lewis, W. J.; van Lenteren, J. C.; Phatak, S. C.; Tumlinson, J. H. (1997) A Total System Approach to Sustainable Pest Management, *Proceedings of the National Academy of Sciences*, **94**, 12,243–12,248.

Monsanto (2000a). The Roundup Ready Corn System: The Most Cost-Effective Choice for Absolute Weed Control, Monsanto Company, St. Louis, Missouri.

Monsanto (2000b). 2000 Technology Use Guide: Technical Information About Monsanto Technologies, Plaines Region, Monsanto Company, St. Louis, Missouri.

National Agricultural Statistics Service (NASS). "Agricultural Chemical Usage: Field Crops Summary," [multiple years], USDA, Washington, D.C. Accessible at http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/#field