# THE MAGIC BULLET CRITICISM OF AGRICULTURAL BIOTECHNOLOGY

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ABSTRACT: One common method of criticizing genetically modified organisms (GMOs) is to label them as "magic bullets." However, this criticism, like many in the debate over GMOs, is not very clear. What exactly is the "magic bullet criticism"? What are its origins? What flaw is it pointing out in GM crops and agricultural biotechnology? What is the scope of the criticism? Does it apply to all GMOs, or just some? Does it point to a fatal flaw, or something that can be fixed? The goal of this paper is to answer these questions and clarify the magic bullet criticism of agricultural biotechnology. It is hoped that the results of this exercise will be helpful in advancing deliberation over the role GMOs and agricultural biotechnology should play in twenty-first-century agriculture.

Genetically engineered crops are sometimes criticized as being "magic bullets." For example, in his essay, "The Myths of Agricultural Biotechnology," the UC Berkeley agroecologist, Miguel Alteiri writes:

> By challenging the myths of biotechnology, we expose genetic engineering for what it really is; another "technological fix" or magic bullet aimed at circumventing the environmental problems of agriculture (which themselves are the outcome of an earlier round of technological fixes) without questioning the flawed assumptions that gave rise to the problems in the first place.[1]

It is clear from these comments that Alteiri does not think genetically modified organisms (GMOs) mark a substantial break with the environmentally harmful past of technologically intensive agriculture. According to this position, biotechnological solutions to the environmental problems of industrial agriculture will be ineffectual because they arise from a flawed research paradigm, which focuses on magic bullets and technological fixes.

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While it is not clear in the above remarks, the notion of a "magic bullet" is conceptually distinct from that of a "technological fix." In general, the magic bullet criticism aims to expose a conceptual flaw in the dominant research paradigm in agriculture that causes it to generate environmental side effects. The technological fix criticism aims to expose flaws in the research paradigm that cause it to generate social side effects. The goal of this paper is to clarify the magic bullet criticism of agricultural biotechnology.

In this effort to clarify the magic bullet criticism of biotechnology, it will be helpful to look at the origins of the term in modern biomedicine. Paul Ehrlich, one of the founders of the modern biomedical paradigm coined the term "magic bullet." He writes: "antibacterial substances are, so to speak, *charmed bullets* which strike only those objects for whose destruction they have been produced."[2] Ever since Ehrlich's day a central objective of biomedical research has been to discover magic bullets through controlled laboratory experiments. These therapeutic agents are designed to target specific disease-causing agents without affecting the healthy parts of an individual's body. This approach is related to an agent-host-environment epidemiological model, which evolved out of the work of Ehrlich, Pasteur, Koch, and other nineteenth-century researchers. This model sees the "host" and the "environment" as modifying rather than causal factors.[3] In so doing, it reduces *the* cause of the disease to a specific agent. Further, this approach gives rise to the doctrine of specific etiology, which enshrines the search for "magic bullets" as a central puzzle-solving task of normal biomedical science.

Ironically, it is narrowness of this approach that proves to be both its greatest strength and greatest weakness. For example, thirty years or so ago addressing bacterial infection with antibiotic magic bullets was seen as an unqualified success. However, taking the long-view this approach may ultimately undermine its "early" successes. To briefly explain, as noted above, this research paradigm places cultural, ecological, and evolutionary factors in the background; in so doing, the effects of these factors are not sufficiently anticipated. For example, the side effect of antibiotic resistant strains of bacteria arose because the cultural reality of antibiotics use was not adequately modeled in relation to bacterial evolution and ecology.

In sum, the magic bullet approach, as guided by the doctrine of specific etiology, was too narrow to anticipate and prevent the unintended consequence of resistant strains of bacteria. For these reasons, biomedicine is now on an anti-biotic treadmill: as the efficacy of one antibiotic is diminished another generation must be developed, as their efficacy is diminished, yet another must be developed, and so on. But this treadmill is ultimately dangerous, expensive, and unsustainable. Success in getting off it has only been made by widening the focus of research to include the cultural, ecological, and evolutionary factors.

Generalizing from the above discussion, the "magic bullet" criticism aims to expose the narrowness of a research paradigm. The essence of the criticism is that an approach that targets specific problem-causing agents with specific technological solutions, without adequately modeling cultural, ecological, and evolutionary factors leads to a technological, treadmill phenomenon. Moreover, the treadmill phenomenon is dangerous, expensive, and unsustainable.

The application of the magic bullet criticism to the current research paradigm in agriculture seems appropriate, at least in places. There are relevant parallels between the puzzle solving activities of normal biomedical science and normal agricultural science. In agriculture, as in biomedicine, the conceptual flaw with this research paradigm is its narrowness: it does not adequately model cultural, ecological, and evolutionary factors. This inadequacy leads to the multiplication of unintended consequences and the technological treadmill phenomenon. Agricultural scientists, like medical scientists, are continually forced to create technologies to address side effect problems created by previous technologies. The clearest example of this is the so-called pesticide treadmill.

The pesticide treadmill roughly parallels the anti-biotic treadmill in biomedicine. To explain, in the resent past, the narrow focus of the research paradigm in pest management did not factor in how synthetic insecticides would actually be used by farmers, nor how their actual use would interact with the ecological and evolutionary dynamics in the field. In any given field there exists a dynamic equilibrium between consumers and producers, predators and prey. Insects become classified as pests when their numbers become great enough to significantly impact profitability. Synthetic insecticides approximate the ideal of a magic bullet in that they kill the pest while leaving the crop unharmed. However, they also kill a broad range of nontarget insects. This disrupts the ecological dynamics in the field, as both pests and beneficial insects (i.e., insects that prey on the pest, keeping their numbers in check) are exterminated. After the spraying, because not all the pests are killed, their population rebounds and surges due to the lag time in the return of beneficial insects. For this reason another round of spraying is required, creating a pattern of dependence on the technological solution of toxic chemicals for pest management. All this spraying creates a strong selective pressure favoring the evolution of strains of pests that are resistant to the insecticide; hence, in time, rendering the insecticide useless. Scientists must then develop new insecticides—another round of magic bullets—to control the pest, thus initiating the technological treadmill phenomenon. As in the case of antibiotic resistance in biomedicine, this treadmill is hazardous, expensive, and ultimately unsustainable.

The sustainable, agroecological response to the pesticide treadmill is to replace the narrow, magic bullet approach with a multi-factorial research paradigm that better models cultural, ecological, and evolutionary factors. Integrated Pest Management (IPM) is the name given to this approach. IPM has now been in use for over thirty years and it is acknowledged as being a scientifically sound approach. The University of California's IPM Web site describes this alternative paradigm in pest management, as an

> ecosystem-based strategy that focuses on the long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and the

> use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organisms.[4]

It is appropriate to call IPM an alternative paradigm. If widely adopted, the change to IPM qualifies as the kind of gestalt switch that Thomas Kuhn describes as a paradigm shift. Kuhn writes that, "Paradigm changes do cause scientists to see the world of their research-engagement differently."[5] Hence, looking at the problem of pest management in terms of "long-term prevention" in light of the dynamics of cultural, ecological, and evolutionary factors creates a new set of puzzles for normal agricultural science to solve. Generally speaking, the primary puzzle-solving activity for scientists is to discover ways of manipulating cultural and ecological factors to prevent pest populations from reaching harmful numbers. This is in contrast to the magic bullet approach where the primary puzzle solving activity is to develop toxins to target specific pests. In sum, IPM is an effort to get off the pesticide treadmill by prioritizing the management of cultural and ecological factors over the "magic bullet" solution of insecticides. The goal is not to eradicate the pest, but to keep its numbers in check by controlling the ecological dynamics in the field between pests and beneficial insects. In this management plan insecticides are used sparingly and judiciously.

There are clear parallels between IPM and the strategy proposed by the Center for Disease Control (CDC) to get off the antibiotic treadmill. The CDC's plan calls for "accelerating research that focuses on . . . developing infection control strategies to prevent disease transmission.[6] Also, it calls for educating "physicians to prescribe antibiotic more prudently."[7] In other words, antibiotics must no longer be seen as magic bullets. To preserve the efficacy of antibiotic they can no longer be used liberally. This strategy requires a new research paradigm that better models cultural, ecological, and evolutionary factors, and, further, one that seeks to develop strategies to prevent infection and promote the limited and carefully regulated use of antibiotics. Clearly, the wonderful technological innovation of antibiotics is not driving the treadmill phenomenon; it is the narrow magic bullet model. To make another generalization, it is not new technologies that are driving the technological treadmill; it is the narrowness of the inherent magic bullet approach of much modern medical and agricultural research.

With the magic bullet criticism hopefully clarified, and some possible reactions to it identified, it is time to turn to the magic bullet criticism of agricultural biotechnology.

To begin: In what sense are GMOs open to the magic bullet criticism? The GMOs most obviously open to the magic bullet criticism are those designed to be resistant to pests. At present, the class of GMOs designed to manage pests are genetically engineered with a gene from a common soil bacteria, *Bacillus thuringinesis* (*Bt*).[8] This microbe secretes a protein that is toxic to caterpillars, as they have an enzyme in their gut that activates the toxin. Hence, *Bt* is an excellent approximation of Koch's ideal of a magic bullet—its activity is specific to the problem-causing agent.[9] By far, the most commercially significant crops engineered with the *Bt* gene are corn and cotton. However, insecticide data indicates that *Bt* corn "has had little if any impacts of corn insecticide use."[10] But *Bt* cotton has led to a significant reduction in the use of synthetic insecticides in several Western states.[11]

So, focusing on *Bt* cotton, in the recent past, cotton farmers have annually sprayed their fields with millions of pounds of highly toxic insecticides to control tobacco budworm and cotton bollworm. In addition, ever since the Sixties they have been on the pesticide treadmill. The average life for a class of synthetic insecticides has been about a decade before insects evolve resistance.[12] Replacing synthetic insecticides with GM cotton would seem to indicate progress toward addressing many of the environmental side effects associated with pesticide use in industrial agriculture. For example, *Bt* cotton only kills the organisms feeding on the plant and susceptible to the toxin, while spraying with synthetic insecticides kills a broad range of insects, including beneficial ones.[13] In addition *Bt* degrades quickly and is not toxic to mammals, birds, or fish as these animals do not have the necessary enzyme in their gut to activate the toxic protein. Therefore, this GMO addresses several of the side-effect problems associated with the use of synthetic insecticides. However, these considerable benefits could be short-lived if pests develop resistance to the *Bt* toxin. If this happens, then *Bt* cotton represents just another round on the pesticide treadmill.

This is theoretically possible, as laboratory studies have demonstrated that resistance to *Bt* can evolve if "selection pressure is strong enough.[14] Therefore, many scientists are convinced that it is only a matter of time, perhaps a decade, until *Bt* cotton will no longer be effective in fighting pests. This supposedly revolutionary technology may only be a temporary fix and not progress toward the long-term goal of environmental sustainability. Also, there is no guarantee that a new generation of GM crops can be engineered with an environmentally friendly compound like the *Bt* toxin. As medical researchers will attest, the number of magic bullets found in nature is finite. Finally, if GMOs merely perpetuate the treadmill phenomenon, then all the excitement about biotechnology will have dangerously delayed the transition to a more sustainable paradigm, such as IPM.

One reason to be pessimistic about the future of *Bt* crops is they were conceived and implemented under the narrow magic bullet model. Admittedly, *Bt* crops are a much better magic bullet for certain crops than synthetic insecticides. In addition, ad hoc provisions were made to prevent insects' from evolving resistance. However, it is doubtful that these ad hoc provisions adequately modify the magic bullet approach to prevent the treadmill phenomenon.

According to Daniel Charles's history of the biotech industry, the scientists who created *Bt* crops were attempting to make magic bullets. Charles writes that, "the genetic engineers [working on inserting the *Bt* gene into plants] spoke of 'permanent solutions' to the insect problem" (Charles, 2001: p. 82). This is similar to the way scientists once spoke of magic bullets in medicine—as permanent solutions to the problem of bacterial infection. However, biologists who study the evolution of pesticide resistance knew better. Charles comments:

> Evolutionary biologists don't believe permanent solutions exist in biology. There is only adaptation, moves and countermoves, in a game of chess that never ends. For them, dreams of technologcal solutions, so common among chemical companies, are the standard object of ridicule. "Its just another silver [sic. magic] bullet," they say dismissively. Silver bullets do not work for long. (Charles, 2001: p. 82)

From Charles's remarks, it is clear there was a conflict in research paradigms between biotechnologists working for agrochemical companies and the evolutionary biologists researching resistance. The importance of this conflict is key in understanding how cultural, ecological, and evolutionary were finally included in the ad hoc management plan for *Bt* crops.

In creating these GMOs the biotech industry did not initially consider the evolution of resistant strains of insects. These concerns were only considered as an afterthought, and then reluctantly. Specifically, Charles attributes industry's acknowledgement of the potential for the evolution of resistance to the efforts of concerned academic scientists. These scientists saw in a glance that if *Bt* crops were widely planted, resistance would quickly evolve, thus rendering this highly beneficial, naturally occurring pesticide useless. In other words, industry would have squandered, for short-term profit, the long-term benefits of this unique group of proteins.

In regard to cotton, the efforts of concerned scientists resulted in a management plan requiring farmers to set aside at least 4 percent of their land as a refuge, where *Bt* cotton is not planted (Charles, 2001: p. 183). The idea, of course, is that this would prevent the evolution of resistant strains of insects. Charles summarizes how these refuges came about. He writes:

> These refuges were the result of a campaign waged by scientists who believed that, without restrictions, new strains of insects would soon emerge that were resistant to Bt. Biotech companies, which wanted to sell as much genetically engineered seed as possible, pushed for smaller refuges. Many scientists believed that much larger refuges were necessary to preserve Bt as a useful tool; because once Bt failed, this gift of God would be gone forever. (Charles, 2001: p. 181)

There are at least two important points that can be learned form the way the management plan for *Bt* cotton came about. The first, as indicated above, is that the setting aside of refuges is merely an adjustment to the magic bullet approach. It bears only a superficial resemblance to the IPM paradigm. The use of an insecticide remains the primary means for controlling pests rather than preventing outbreaks by manipulating cultural and ecological factors. As has been often noted, *Bt* crops "mimics the chemical-based management system."[15] The second point exposes a clash between the market model of the biotech industry, where most of the development of GMOs is taking place, and the evolutionary model used by concerned scientists.[16]

Looking more closely at this point: on the one hand, if *Bt* cotton, for example, is to be profitable, the competitive, market model indicates that the refuges cannot be too large. On the other hand, if the evolution of resistant strains is to be avoided, the evolutionary model indicates that the refuges cannot be too small. Hence, industry fought for the smallest possible refuges to maximize profits, and the concerned scientists fought for the largest possible reserves to minimize resistance. As seen above, a compromise solution was implemented.

However, many scientists felt that the size of the refuge was much too small, that at least 10 percent was needed, and some scientists argued for as much as 50 percent. The compromise of 4 percent, which was forced by microeconomics, is not necessarily sound evolutionary biology, which, of course, best tells us how to lower the probability of resistance developing. Therefore, because evolutionary factors were implemented via this ad hoc compromise, the likelihood that, sooner or later, insects will evolve resistance to *Bt* crops is much greater. Hence, the likelihood that *Bt* crops will initiate another turn of the treadmill. Significantly, for the microeconomics of the biotech industry this is not an unfortunate result. As long as the treadmill can be sustained, the magic bullet approach is justified by the competitive market model. The reason being that this approach demands maximum use of their products and when those products fail, they will supply another.

By way of summary, it should be noted that the magic bullet criticism is not a blanket critique of agricultural biotechnology. It only applies to a narrow range of GM crops that are designed along the lines of the doctrine of specific etiology in medicine. The essence of the criticism is to point out the dangers of using too narrow of a research paradigm; specifically, one that fails to adequately model cultural, ecological, and evolutionary factors. As discussed above, the most obvious place the criticism applies is at GM crops engineered to contain pesticides. However, there may be other GMOs where the criticism is appropriate. The magic bullet criticism points out flaws in a research paradigm, and not specific technologies per se. So there is no reason why GM crops engineered to contain pesticides are necessarily flawed in the same way that antibiotic technology in medicine is necessarily flawed. It is possible that when placed in the right context *Bt* crops, for example, can be a useful tool in working toward the goal of environmental sustainability. Finally, one important factor that is preventing a move away from the discredited magic bullet model is the positive relationship between this approach and the competitive market model of the biotech industry.

## NOTES

1. Alteiri, 2001.
2. Dubos, 1993, p. 156, emphasis added.
3. Norell, 1984, p. 134.
4. University of California, IPM Web site, accessed 1/15/04.

5. Kuhn, 1970, p. 111.

6. Schuman, 2003, p. 85.

7. Ibid.

8. Japanese scientists identified *Bt* during an epidemic in the silkworm industry at the turn of the twentieth century. Krimsky and Wrubel, 1996, p. 57.

9. *Bt* has been safely used ever since the late 1950s as an insecticidal powder. At present six major groups of *Bt* proteins have been isolated. Their range of toxicity is small, targeting caterpillars, fly larvae, beetle larvae, and nematodes. In 1991 the worldwide sales in dollars of *Bt* insecticides represented only a tiny fraction ($10^{-5}$) of that of synthetic insecticides. Nonetheless, while *Bt* is not commercially that significant, it is an important tool for organic farmers. *Bt* toxins are naturally occurring, less likely to harm nontarget organisms, and they degrade quickly in water and sunlight. In sum, the *Bt* toxin does not generate many environmental side effect compared to synthetic insecticides. However, their limited range of activity and the fact that they degrade quickly has made them less attractive an option to the vast majority of insecticide using farmers. Krimsky and Wrubel, 1996, p. 56.

10. Benbrook, 2001.

11. Ibid.

12. Ibid.

13. Krimsky and Wrubel, 1996, p. 57.

14. Ibid, p. 64.

15. Benbrook, 2001.

16. Krimsky and Wrubel combine these two points to make the following observation. They write: "Agriculture would best be served by a policy of well-thought-out use of environmentally compatible control agents to conserve their effectiveness. This is in direct conflict with the competitive structure of the agrichemical and, in this case, biotechnological industry. Their purpose is to sell as much product as quickly as possible to recover the investment in research and development. Our analysis reveals, however, that one cannot separate the problem of pest control from the problem of pest resistance." Krimsky and Wrubel, 1996, p. 67.

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