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Bt Crops Can Increase Yields Substantially in Developing Countries

by

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Genetically modified cotton with Bt has a high yield effect in experimental plots in India. Although Bt cotton has been widely adopted in the United States, its impact on yields has been modest. This study shows that the high yield effect in India suggests that the technology can be of much value in developing countries.

A debate continues concerning the use and future of genetically modified (GM) crop varieties. These varieties are costly to develop and their replication may entail environmental risk. Critics of these technologies argue that based on their past performance, their value to developing countries is limited because, thus far, applications of GM crops in the United States, China and Argentina have resulted in rather modest increases in yield. The main benefit from using GM varieties in the United States has been the reduction in the use of chemical pesticides, which has led to important economic and environmental gain. However, it has often been argued that GM crops have little to offer the poorest countries, where there is a need for increased local agricultural output on a limited amount of farmland.

We argue, herein, that this generalization is wrong, both on conceptual and empirical grounds. We first use basic principles of production economics to suggest that impacts of technologies may vary by location depending upon their economic and ecological conditions, and thus, GM varieties may have significant yield-increasing effects in developing countries, while having different effects in developed countries. Then, using the example of Bt (*Bacillus thuringiensis)* cotton in India, we show that GM crops can have significant yield effects, which are most likely to occur in the developing world, especially in the tropics and sub-tropics. The evidence in India supports a general principle that a pest-control strategy, in this case biotechnology, has a strong yield effect in locations where the damage is substantial and alternative controls are not used.

Pest Control as Damage Control Agents

A significant body of economic theory focuses on the economics of pest control. It models crop output as "potential output" (maximum output produced by labor and inputs such as water and fertilizers without pest damage) minus damage. Pest damage is the outcome of pest infestation, and the application and effectiveness of pest control such as chemical pesticides, biological controls, etc. Pest damage in some cases may reach 70 percent of potential output, if the climatic conditions support a large pest population, e.g., a humid climate and when pesticides are not applied or are ineffective. Some plant-breeding

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activities have increased potential output (maximum amount that can be produced without any damage). For example, Green Revolution dwarf wheat varieties sometimes doubled potential yields. Future applications of biotechnology aim to improve potential yields by, for example, increasing crop capacity to utilize water, including saline water. Thus far, the major applications of agricultural biotechnology have been pest-control related. They include both pest resistant varieties where Bt was inserted into cotton, corn and soybeans, and herbicide-resistant varieties, where, through genetic manipulation, plants tolerated applications of herbicides. While these GM varieties do not increase potential output, they may nevertheless increase actual output where pest damage has been substantial. In the case of the United States, in most crops, traditional pest control has limited yield losses up to 15-20 percent, and thus, the potential for yield gain through Bt is modest. Indeed, the main incentive to develop GM varieties was to reduce chemical pesticide use, and reduce cost of operation because of the simplicity of the technology. On the other hand, the theory suggests that in locations where pest damage is high and effective pest control cannot be used, the yield effect of GM varieties may be substantial. This hypothesis was tested in a case study of the yield effect of Bt cotton in India.

The Case Study in India

Bt cotton provides a fairly high degree of resistance to the American bollworm (*Helicoverpa armigera*), the major insect pest in India. The technology was developed by Monsanto and was introduced into several Indian hybrids in collaboration with the Maharashtra Hybrid Seed Company (Mahyco). Field trials with these Bt hybrids have been carried out since 1997 and, for the 2002/03 growing season, the technology was commercially approved by the Indian authorities. Its performance during the first commercial season in India is hotly disputed among biotechnology advocates and opponents, but an independent scientific assessment has not been carried out so far.

For our analysis, we used data from on-farm field trials that were carried out during the 2001/02 growing season as part of the regulatory procedure. On 157 farms in three different states, Bt cotton hybrids were planted next to an isogenic line without the Bt gene and a local hybrid commonly grown in the particular district. All three plots were managed by the farmers themselves, following customary practices. Apart from official data that were collected by local researchers for biosafety evaluation, we used our own questionnaire to obtain details on input-output relationships from participating farmers.

While there was no significant difference in the number of sprays against sucking pests, Bt hybrids were sprayed three times less often against bollworms than the conventional hybrids. On average, insecticide amounts on Bt cotton plots were reduced by almost 70 percent, which is consistent with studies from other countries. The difference in India, however, is that Bt cotton also led to a significant yield effect. During the field trials, average yields of Bt hybrids exceeded those of non-Bt counterparts 80 percent and 87 percent, respectively.

The results in India are consistent with our theoretical construct that the gain in yield associated with the use of Bt is because of the avoided crop losses. Under Indian conditions, bollworms have a high destructive capacity, which is not well controlled in conventional cotton. At average pesticide amounts of 1.6 kg/ha (active ingredients) on the conventional trial plots, crop damage in 2001/02 was about 60 percent. Bt does not completely eliminate pest-related yield losses. Yet, to achieve the same level of damage control without the technology would require a triplication of currently used pesticide quantities.

The 2001/02 season had high bollworm pressure in India, so that average yield effects will be somewhat lower in years with less pest problems. Moreover, although the trials were managed by farmers, experimental results cannot simply be extrapolated to commercial agriculture. But even when discounting for these aspects, yield advantages of Bt cotton will remain bigger in India than in the United States or China.

Analysis of factors influencing yield impacts of new, effective pest control technologies suggests that they depend on local pest pressure, availability of alternatives for pest control and farmers' adoption of these alternatives. Generally, pest pressure in tropical and sub-tropical regions is higher than in temperate zones, while pesticide-use intensities are much lower, due to technical and economic constraints. In India, pesticides are available on local markets, but their effectiveness is limited

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because bollworms have developed resistance to many of the common products. Furthermore, small-scale cotton producers are often credit-constrained and do not have access to chemicals at the necessary point in time.

The high yield effect of Bt cotton makes this technology especially appealing to the small farmers in India. Even though the likely prices of the GM hybrids are higher than the traditional cotton hybrids because of the yield effect, we expect profit to increase five-fold with the adoption. The profit gain may be smaller in years with lower pest infestation and lower cotton prices, yet clearly Bt cotton seems extremely attractive for the Indian grower at the present.

Table 1. Expected Yield Effects of Pest-Resistant GM Crops in Different Regions

Region	Pest pressure	Availability of chemical alternatives	Adoption of chemical alternatives	Yield effect of GM crops
Developed countries	low to medium	high	high	low
Latin America (commercial)	medium	medium	high	low to medium
China	medium	medium	high	low to medium
Latin America (non-commercial)	medium	low to medium	low	medium to high
South and Southeast Asia	high	low to medium	low to medium	high
Africa	high	low	low	high

Conclusion

Our finding for the case of Bt cotton in India, confirms our theoretical prediction and is likely to be more representative of GM crop impacts in developing countries than predictions based on the performance of Bt cotton in the United States and China. Table 1 generalizes our theory and suggests that the impact of Bt on crop yield varies by location. The table also reflects the pest pressure, and the availability and use of alternative pest control in varying locations.

Almost all GM crop technologies were initiated by commercial firms in the industrialized world, targeting the needs of farmers who are able to pay for them. Some varieties were transferred to the commercial sectors of Latin America and China, where agroecological conditions and pesticide application rates are similar. In all cases, yield effects have been low to medium, while there have been significant gains from pesticide substitution.

However, with careful adaptation and effective regulation, these same technologies can also be introduced to other developing-country regions, where yield effects will be more pronounced. Pest-resistant GM crops are easy to manage at the farm level, and they could substantially reduce current gaps between attainable and actual yields, especially in smallholder farming systems. Preliminary evidence from Indonesia and South Africa is in line with this hypothesis. For example, there is a 40 percent reported yield increase associated with the use of Bt cotton by small farmers in South Africa. Agricultural biotechnology offers many more applications for developing countries beyond pest control, but we show that the GM crops developed thus far can already have significant impacts. It is a major policy challenge to invest more in public research and address the existing institutional constraints, so that promising biotechnologies can reach the poor at affordable prices on a larger scale.

A more detailed article about this research has been published by M. Qaim and D. Zilberman in *Science*, Vol. 299 (7 February 2003), pp. 900-902.

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