2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

ADAPTING REFUGE STRATEGIES FOR BT COTTON TO THE NEEDS OF DIFFERENT COUNTRIES

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Abstract

Transgenic cotton that expresses the Cry1Ac protein for the control of lepidopteran insect pests (Bt cotton) has been commercialized in nine countries and is grown on over 5 million acres worldwide. Insect Resistance Management (IRM) is an important part of the global stewardship of this technology. The IRM needs for Bt cotton vary among countries because of differences in pest biology, farming practices, and farmer literacy and experiences. In this paper, we discuss these differences, and how they affect and constrain IRM options with particular reference to the refuge strategy. As an illustration, we contrast the need for farmer-planted refuges in the United States with smallholder-dominated agricultural systems in India and South Africa where alternative crop and weedy hosts, respectively, serve as natural refuge for Bt cotton.

Introduction

Genetic engineering has been used to introduce agronomically important traits into crop plant species. Some of the first genetically engineered crops, and some of the most widely used, have been modified to express insecticidal crystalline (Cry) proteins derived from the soil bacterium *Bacillus thuringiensis* (Bt). Transgenic cotton that expresses the Cry1Ac protein for the control of lepidopteran insect pests (Bt cotton) has now been commercialized in nine countries (Argentina, Australia, China, Colombia, India, Indonesia, Mexico, South Africa, and the United States) and is grown on over 5 million acres worldwide. Bt cotton is protected from the feeding of various groups of pest insects, including cotton bollworm (*Helicoverpa zea*), tobacco budworm (*Heliothis virescens*) and pink bollworm in the United States, and Old World bollworm (*Helicoverpa armigera*) in many other world areas. Bt cotton has been shown to provide effective and specific pest control where it is used, leading to substantial direct benefits for farmers and the environment (James 2001, 2002).

A critical part of the introduction of Bt cotton is to ensure that it is used appropriately. Over forty years of experience with conventional insecticides has produced some hard lessons. The development of insect resistance to any widely used insect control tactic is essentially inevitable, whether this involves chemical use, cultural controls, or even biological control tactics. Resistance leads, in turn, to increased insecticide use, as well as changes in cropping practices and crop failures. Resistance management is seen as a critical part of preserving the durability of any insect-control technology (Jutsum *et al.* 1998). Suitable IRM strategies have been developed for Bt cotton in all countries in which it has been commercialized. This has involved industry scientists working closely with academics and regulatory authorities. In this paper, the nature of these IRM strategies is discussed, with particular emphasis on how these strategies have been adapted to the needs of different countries and cropping systems.

The Components of IRM for Bt Cotton

The rate at which insect resistance evolves to Bt cotton expressing Cry1Ac will be determined by the same factors that affect the development of resistance to conventional insecticides. These factors can be divided into: (1) the nature of the product, its performance, and how it is used (pattern of Bt expression in the crop plant and penetration of the product into the market); (2) the genetics of insect resistance (initial frequency of the resistant allele, degree of dominance of that allele, and fitness costs of resistance); and (3) aspects of insect behavior that mediate how the product affects the target insects (insect movement and mating). Based on these factors, a general IRM strategy has been devised for Bt cotton that includes: suitable spatial and temporal expression of the Cry1Ac protein; some form of refuge for susceptible pest insects; use of alternative control measures (placement of Bt cotton into an integrated pest management context); monitoring and remedial action plans; and the development of subsequent products with different insecticidal mechanisms (e.g., Roush 1997, Shelton *et al.* 2000). The precise tactics used in any given crop and country, however, will vary because of local differences in pest biology, agronomics and many other factors. Some of these differences are obvious but others are subtle. For example, farmers in different countries will vary in their willingness to practice IRM, based upon such factors as: their familiarity with, and recognition of, resistance problems and IRM practices; what they perceive the costs and benefits of IRM to be; and numerous local cultural sensitivities. Farmers also will vary in their ability to practice IRM, based upon the time and equipment available to them during the planting window e.g., planters and ability to mix seed and insecticide. Because of these local differences in cropping systems and farmer behavior, IRM plans must vary with respect to: the nature of the refuge strategy (whether a structured refuge is needed and, if so, its size and placement); how farmer compliance is managed (whether incentives or disincentives are used, and how compliance is monitored); and the means by which farmers are educated on IRM (the medium used, the focal points for education, and the educational messages used).

IRM Strategies for Bt Cotton in Countries with Smallholders

Extreme differences exist in how cotton is grown in developing countries versus the United States. In countries like China, India and South Africa, average farm sizes are much smaller and cropping systems are more diverse than in the United States. In the United States, with large, continuous acres of Bt cotton, the risk of resistance development is relatively high and the planting of structured refuges by farmers becomes particularly important. On the other hand, coordinating structured refuges may not even be possible in countries with many small farms and millions of individual farmers. Consider the agricultural landscape in India. For 1994-1996, there were 180-190 million hectares of farmed land in India with over 14 major crops each accounting for at least one million hectares, and many others also accounting for substantial areas (Indian Department of Agriculture statistics). In any one region, many crops are grown, and most crops are grown in multiple climatic zones with varying agronomic practices (Sundaramurthy and Gahukar 1998). Most Indian farms are small in size; in 1990-1991, 63 million of 106 million total farms were less than a hectare in size, though that amounted to only 25 million of 166 million total hectares farmed (Indian Department of Agriculture statistics). A further 20 million farms were less than 2 ha in size. Any IRM approach must take into account both the large number of farmers involved in this case and the differences in their circumstances.

However, diverse cropping systems permit another approach to IRM for Bt cotton. If the target pests are utilizing a wide variety of these crops, and they are not being controlled using Bt sprays on these other hosts, then structured refuges for Bt cotton may not be necessary under these conditions; the alternative host plant species will act as an adequate source of refuge for the Bt cotton fields. In these cases, both cropping practices and the degree of polyphagy of the target insect species will be important. Even in relatively homogeneous cropping areas like parts of the southern USA, alternative hosts probably are an important source of refuge with respect to Bt cotton for highly polyphagous insects like *Helicoverpa zea* (Gould *et al.* 2002). In countries like India and South Africa where cropping systems are far more heterogeneous, alternative hosts will be more important still for polyphagous pest species of cotton like the *Helicoverpa armigera*. This species can be found on more than 150 plant species, including many of the major pulse crops, vegetables and tomatoes, and both dicotyledonous and monocotyledonous species. In particular, pulse crops like chickpea and pigeonpea are major hosts of *H. armigera* and are often planted in much greater amounts than cotton. In areas where weed management is limited, particularly around the edges of agricultural fields, weedy hosts also may be important sources of refuge for Bt cotton.

For IRM approaches based on alternative host plant species to be effective, several conditions should be examined: 1) the target pest species must utilize host plant species other than cotton that overlap in both space and time with cotton; 2) the performance on these other host plant species must be comparable to that on cotton to allow the different alternative hosts to produce sufficient susceptible insects at the right time to interbreed with any resistant insects emerging from the Bt cotton; 3) the spatial and temporal distribution of these different host plant species must overlap with that of cotton at a sufficiently fine scale and consistently enough to act as a functional refuge in all relevant areas; and 4) the pest insects must move freely between other host plant species and cotton.

On-Going Experimental Studies

These issues are being studied in a number of countries including China, India and South Africa. In India, studies of *Helicoverpa armigera* distribution in major cotton growing districts indicate that various crops are used by this species at the same time as cotton is infested, and that *H. armigera* actually performs better on many of these alternative hosts than on cotton. Studies conducted over two years in collaboration with agricultural universities demonstrated that cotton is routinely grown along with several other host crops of *H. armigera* in the cotton-belt of Central and South India, including pigeonpea, chickpea, tomato, okra, chili, corn, sorghum and sunflower. Pigeonpea is also commonly used as an intercrop with cotton in major cotton growing areas in India. Chickpea, pigeonpea, tomato and okra all typically support higher populations of *H. armigera* than cotton. Examples from one particular site are shown in Figures 1a and 1b. Furthermore, local agricultural practices encourage synchrony in bloom periods between pigeonpea and cotton, indicating that pigeonpea is a productive source of refuge for Bt cotton in many parts of India. Separate laboratory studies have demonstrated that insects from these different hosts are capable of successfully mating with each other. In addition, large-scale surveys of cropping patterns over the past three years in these same cotton-growing regions have shown that substantial areas of these alternative hosts are present in all years. Overall, these studies demonstrate that alternative hosts crops provide a substantial natural refuge for Bt cotton in central and South India. Comparable studies have reached similar conclusions in China (Wu *et al.* 2002); large acreages of alternative host crops form a natural refuge for Bt cotton in major growing regions of China. In the cases of both India and China, these alternative crop hosts are abundant enough to remove the need for farmer-planted refuges. Even in the

United States, alternative hosts of some of the target pest species of Bt cotton are undoubtedly supplementing the refuges planted by farmers (Gould *et al.* 2002).

In contrast with China and India, ongoing research in South Africa shows that natural weedy hosts and not crops are the predominant source of refuge in this case. This situation has been studied on a set of farms in a cotton-growing region in the north of South Africa. In this area, cotton is planted into a largely non-agricultural landscape with many potential weedy hosts (see Ismael *et al*. 2002 for a description of this cropping system and the role Bt cotton plays in this system). Eggs, larvae and adults of four species of bollworm were counted throughout the season for two years. The target pest species were African bollworm (*Helicoverpa armigera*), red bollworm (*Diparopsis castanea*), and spiny bollworms (*Earias biplaga* and *E. insulana*). Alternative weedy hosts were found to exist for all of these bollworm species (African bollworm - *Abutilon guineense*; red bollworm - *Cienfuegosia hildebrandtii* and *Abutilon austro-africanum*; spiny bollworms - *Hibiscus calyphyllus, A. guineense, A. austro-africanum* and *Corchorus trilocularis*), and the numbers of bollworms on these weedy species were comparable to or greater than those on cotton. Figure 2 illustrates these results in terms of larval bollworm populations.

In the same system in South Africa, an innovative IRM training program also has been initiated. This has involved government extension officers, representatives from a local cotton gin, a finance agent from the Landbank (financial training/budgets), and industry personnel. The training involves biotechnology and Bt cotton, with an emphasis on cotton production, refuge management, and the need for refuges. Overall, these studies highlight the need to look for original and creative solutions to IRM problems in different countries.

Conclusions

IRM practices can and must be adapted to local pest biology and agronomic practices, and must be integrated with existing agricultural practices. This requires adequate local knowledge to determine what sort of IRM practices will be appropriate in a particular region, and a recognition that ultimately the success of IRM will depend upon whether IRM practices can be both technically effective and logistically and economically feasible for farmers.

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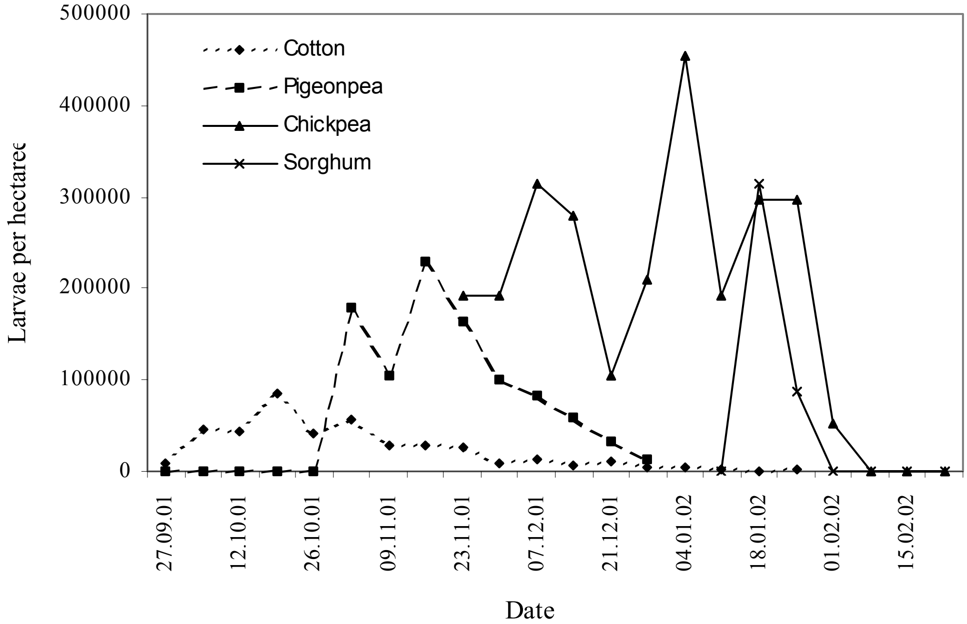

Figure 1a. Abundance of *Helicoverpa armigera* larvae found over the course of the season on different crop hosts at a location in the central cotton-growing region of India. Numbers are expressed on a per hectare basis.

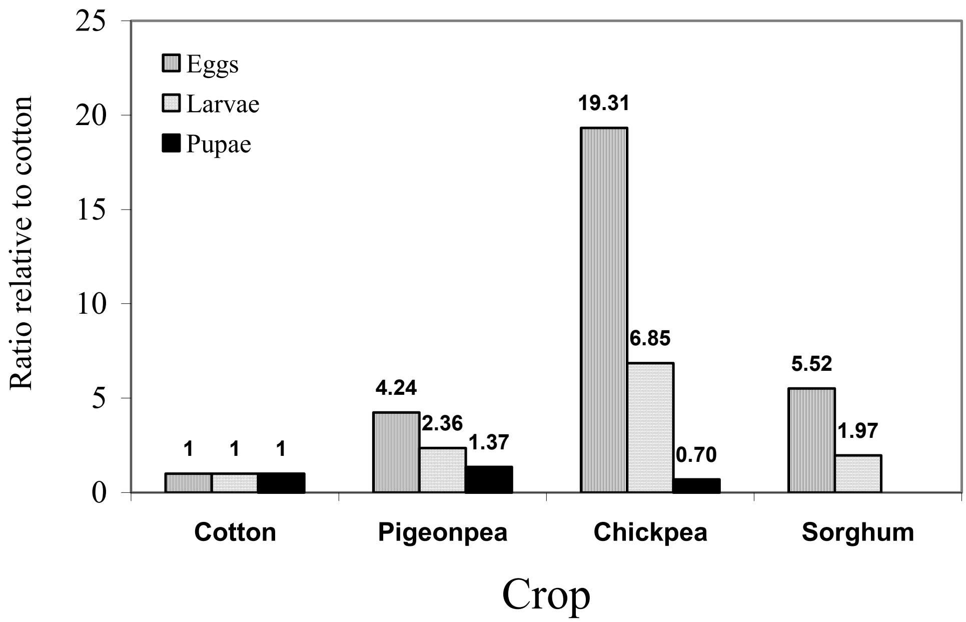

Figure 1b. Abundance of different life stages of *Helicoverpa armigera* found on different crop hosts at a location in the central cotton-growing region of India. Numbers are expressed relative to the abundance on cotton.

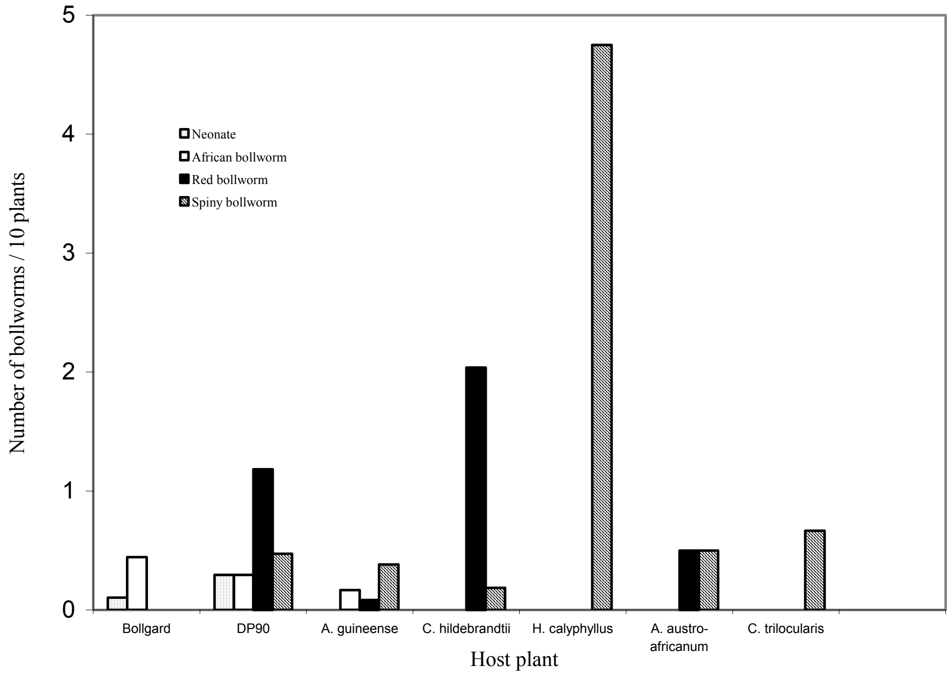

Figure 2. Abundance of different bollworm species found on conventional and Bt cotton (Bollgard®), and on common weedy plant species, on and around cotton farms in the Makhathini Flats, South Africa. Numbers are expressed per 10 plants of the relevant species.