B A
S E
Biotechnol. Agron. Soc. Environ. 2011 **15**(4), 545-552

Gone with transgenic cotton cropping in the USA. A perception of the presentations and interactions at the Beltwide Cotton Conferences, New Orleans (Louisiana, USA), 4-7/01/2010

Michel FOK

CIRAD. UR SCA. TA B102/02. Avenue Agropolis. F-34398 Montpellier Cedex 5 (France). E-mail: michel.fok@cirad.fr

Received on June 28, 2010; accepted on January 18, 2011.

This paper is a revised translation of Fok, 2000, with the permission of the Publisher.

The 2010 Beltwide Cotton Conferences provided a new vision of the consequences of about 15 years of widespread and uncoordinated cropping of transgenic cotton in the United States. Insect-resistant and/or herbicide-tolerant cotton varieties modified parasite complexes, namely those of insects and weeds damaging cotton crops. The Conferences have revealed that the adaptation solutions so far proposed make illusory the expectations at the launch of transgenic cotton, in terms of effective pest control, cost reduction, and antagonism between chemical and biotech methods. The USA case points out that the technical and economic sustainability of transgenic varieties must lie in a systemic and coordinated approach.
Keywords. Cotton, *Gossypium*, transgenic plants, resistance to injurious factors, resistance to herbicides, diffusion of research, USA.

Autant en emporte le coton transgénique aux États-Unis. Une perception des présentations et des échanges aux Beltwide Cotton Conferences, Nouvelle-Orléans (Louisiane, États-Unis), 4-7/01/2010. Les conférences 2010 du Beltwide Cotton ont apporté une vision nouvelle sur les conséquences de 15 années d'utilisation massive des variétés de coton transgénique aux États-Unis. Cette utilisation de variétés résistantes aux ravageurs et/ou tolérantes aux herbicides a conduit à l'observation des changements dans les complexes d'ennemis des cultures de cotonnier, à savoir les insectes et les plantes adventices responsables des dégâts sur les cultures cotonnières. Les solutions envisagées actuellement, comme le révèlent les travaux de recherche présentés, montrent que les effets positifs, proclamés au début de l'utilisation de ces variétés, se sont évanouis en termes d'efficacité du contrôle des ennemis des cultures, de réduction du cout et d'antagonisme entre voie chimique et voie biotechnologique de ce contrôle. Le cas des États-Unis indique que la durabilité technique et économique des variétés transgéniques doit reposer sur une approche systémique et coordonnée de leur utilisation.
Mots-clés. Coton, *Gossypium*, plante transgénique, résistance aux facteurs nuisibles, résistance aux herbicides, diffusion de la recherche, États-Unis.

1. INTRODUCTION

The Beltwide Cotton Conferences have been organized annually since 1983 in the United States by the National Cotton Council (NCC), an organization that has assumed a lobbying role to influence American cotton policy. The multidisciplinary conferences (**Table 1**) are highly technical, but they devote ample time to the political and economic issues of cotton production (Fok, 2010).

In 2010, the Beltwide Conferences focused on transgenic cotton, almost fifteen years after the first transgenic varieties of major crops (maize, soybean, cotton) were marketed. Initially, these incorporated one or more *Bacillus thuringiensis* genes for resistance to certain pests (Bt varieties), or a gene affording tolerance of a herbicide-active ingredient (particularly glyphosate), or both types of genes.

For cotton-related conferences held in the southern United States, it is tempting to paraphrase the title of the novel by Margaret Mitchell, *Gone with the wind*, to indicate how certain illusions have vanished. Indeed, while transgenic cotton varieties currently occupy 88% of American cotton growing areas (**Table 2**), a harmful

Table 1. Topics at the 2010 Beltwide Conferences (New Orleans) — *Thèmes des résultats de recherche présentés aux conférences du Beltwide 2010 (Nouvelle-Orléans)*.

Presentations	Economics	Agronomy[1]	Diseases	Pests	Weeds	Varietal improvement	Processing technologies[2]	Total
Papers	26	93	23	59	22	43	72	338
Posters	11	46	17	39	19	20	4	156
Total	**37**	**139**	**40**	**98**	**41**	**63**	**76**	**494**

[1] agronomy, physiology, soil and nutrition management, and engineering systems (relative to precision agriculture) — *agronomie, physiologie, gestion des sols et de la nutrition des plantes, systèmes d'ingénierie (relatifs à l'agriculture de précision)*; [2] ginning, cotton fibre metrology, textile use — *égrenage, mesure des caractéristiques des fibres de coton, utilisation des textiles*.

Table 2. Share of areas (%) planted in transgenic varieties in the United States in 2009 — *Parts des superficies (%) en variétés transgéniques aux États-Unis en 2009*.

Crop	Bt genes only	HT genes only	Stacked Bt + HT genes	Total
Maize	0	91	0	91
Cotton	17	23	48	88
Soybean	17	22	46	85

HT: herbicide tolerance — *tolérance à l'herbicide*; Bt: *B. thuringiensis* pest resistance gene — *gène* B. thuringiensis *de résistance à des ravageurs*. Source: USDA-ERS (http://www.ers.usda.gov/data/biotechCrops/).

side has emerged in pests that previously needed no control ("new" pests hereafter) and a growing number of weed plants have acquired resistance to glyphosate.

Although the Beltwide Conferences have regularly publicized works on "new" pests since 1999, the changes in pest complexes were glossed over in an overview by the US Department of Agriculture (Fernandez-Cornejo et al., 2006). However, for the first time in 2010, the Beltwide Conferences paid real attention to the observed changes and brought to light the concerns of cotton producers in the United States, as revealed by the following quotations:

"I'm happy that transgenic cotton exists, but that is not enough for me to sleep easy" (Bob Griffin, consultant[1]).

"Biotechnologies, a double-edged sword" (title of the presentation by David Hydrick, consultant[2]).

The purpose of this article is to comment on the 2010 Beltwide Conferences as regards changes in cotton crop parasite complexes. The first part presents observations of those changes, and the second part describes potential solutions as revealed by current works. The final section highlights the illusions.

2. PARASITE COMPLEXES AT THE MOMENT

2.1. Clear concern about changes in parasite complexes

Compared to past years, the 2010 Beltwide Conferences held more sessions on changes observed in cotton crop pest complexes. For instance, there was a specific workshop on weed plants that have acquired resistance to glyphosate, which is massively used in no-tillage systems. There was also a discussion panel on the contributions of transgenic varieties. These were the two events most followed by all the attendees, indicating that producers, consultants, and researchers have become aware of the changes in pest and weed complexes. The following quotations bear witness to their doubts about continuing with transgenic cotton varieties:

"the no-tillage technique reduces wind erosion and improves the water-holding capacity of soils, it is very well suited to Texas, and I wouldn't want to give it up because of glyphosate-resistant weeds" (Barry Evans, cotton producer in Texas[3]).

"I've heard said that we need to return to conventional cotton growing, but in what proportion and how can we be sure that a new major outbreak of bollworms won't come and destroy the crop?"

[1] Bob Griffin, taking part in the Consultants Perspective session. No audio record and no script of his oral presentation are available, but his point reported here is consistent with Norsworthy et al. (2007) who interviewed many consultants, including Mr. Griffin.

[2] David Hydrick, giving the consultants' perspective at the Value of Transgenics Panel of January 5. A record of his slideshow is freely available at http://ncc.confex.com/ncc/2010/webprogram/Session1883.html. His view, as well as those of all who took part in the above-mentioned panel, is reported in Smith (2010).

[3] Barry Evans, a cotton producer asked to give his perspective at the Value of Transgenics Panel of January 5. A record of his slideshow is freely available at http://ncc.confex.com/ncc/2010/webprogram/Session1883.html. His view is reported in Smith (2010).

(Roger Leonard, entomologist from Louisiana State University[4]).

"What we need is new chemicals" (conclusion of Stanley Culpepper, weed scientist from University of Georgia[5]).

2.2. Changes in pest complexes

Before Bt-cotton was adopted in the United States, the main pests were bollworms (*Helicoverpa zea*, *Heliothis virescens* and *Pectinophora gossypiella*) and the boll weevil *Anthonomus grandis*. The pests targeted by the first Bt-cotton varieties were bollworms. As those varieties came onto the market at the same time as the national weevil eradication programme was reaching the last cotton growing States, the main pest problems appeared to be solved.

It is undeniable that Bt-cotton was effective against the target pests. Massive use of Bt-cotton gradually led to a drop in their populations, to such a point that their chemical control called for only a half treatment per year on average. But since 2003, Bt-cotton no longer reduces the number of treatments against these pests; there are almost as many treatments as for conventional cotton. In that respect, it is surprising not to find any analysis of the technical and economic merits of substantially reducing the extent of Bt-cotton use in the communications presented to the Beltwide conferences.

Bt-cotton is no longer effective enough and the current situation has become complicated. Today, pest control has to be tuned with this change in pest complexes, probably due to the very high selectivity of Bt toxins against the target pests. Yet that selectivity was promoted as an advantage of Bt-cotton. Indeed, when Bt-cotton was launched, fears were expressed about target pest resistance to Bt toxins and damage to untargeted fauna (Hardee et al., 2001), but nobody, to my knowledge, gave a thought to changes in the noxious status of untargeted pests.

Three findings highlight this change in pest complexes. Firstly, the pink bollworm *P. gossypiella* is imperfectly controlled, at least when first generation of Bt-cotton was used (Tabashnik et al., 2002) as it is recently acknowledged by Monsanto in India (Mahyco Monsanto Biotech, 2010). Secondly, there have been some serious outbreaks of phylophagous armyworms of the genus *Spodoptera* (*S. exigua* and *S. frugiperda*), which have also occurred in other countries using Bt-cotton: notably in China with the species *S. litura* (Fok et al., 2005). Before Bt-cotton no chemical treatment was needed against phylophagous caterpillars, but it has become necessary today as they also damage cotton bolls. Lastly, sucking insects have become preponderant pests, whereas they were not systematically so before. This involves two bugs, *Lygus lineolaris* and *Lygus hesperus*, mites (*Tetranychus* spp.), whiteflies (*Bemisia* spp.), and aphids (*Aphis* spp.). Pest complexes that have overstepped economic damage thresholds vary with the cotton-growing zones, but the greatest fears are being expressed for bugs and aphids, which occur on numerous other plant species (Greene, 2010). For instance, 300 host species have been inventoried for the bug *L. lineolaris*. For aphids, infestation levels have increased since 2006, reaching an unprecedented level in 2009 (500 to 1,000 aphid larvae per terminal leaf).

These new pest outbreaks mean greater use of chemical insecticides. Seed producers have increased seed treatments; a dozen pesticides are thus used. One researcher expressed surprise, with some irony, that seeds can still germinate under such conditions. In 2009, field control of "new" pests called for 6.5 treatments, on average, throughout the American cotton States, but there had been little need for such treatments before. Yield losses have also been estimated in the absence of chemical treatments, or where such treatments are not effective enough. The speakers agreed that the chemicals used are less efficient, in line with the recent increase in new pest pressure. That loss in efficiency concerns organophosphate, carbamate, and neonicotinoid compounds for seed and leaf treatments.

Lastly, in the opposite of what was announced, the cost of cotton pest control has increased since transgenic varieties were introduced. The total cost including seeds and pesticides has increased from US$ 125/acre to 160/acre in the last fifteen years (Hydrick, 2010). One of the factors behind the rising price of Bt-cotton seeds is the sophistication of seed treatment. Further costs involve the multiple insecticides necessary to control pests not targeted by Bt-cotton.

The price trend for pesticides also needs to be considered in relation to changes in market structure. On the one hand, the number of European or American phytopharmacology companies has fallen drastically: there were 42 firms in 1962, then 33 in 1980, and finally 7 in 2009. On the other hand, many new products have come onto the market. Those products have novel modes of action, but each is represented by few commercial products. The competition between products is thus only virtual, as they are not truly substitutable.

---

[4] Taking part in the Consultants' Perspective session (http://ncc.confex.com/ncc/2010/webprogram/Paper11231.html). No audio record and no script of his oral presentation are available, but his point reported here is consistent with his statement one year earlier as reported by Golden (2009).

[5] Taking part in the Consultants' Perspective session. A record of his slideshow is freely available at http://ncc.confex.com/ncc/2010/webprogram/Session1883.html. Culpeppers' point – which we indicate here - has also been reported by Haire (2010).

Given this overall situation, some proposed returning to conventional cotton growing, to a non-specified degree. This is already a reality: in 2009, there were apparently 400,000 acres (out of a total cotton area of 8.9 million acres) and an area of 1.5 million acres is predicted for 2010. The question was still eluded to by researchers specializing in pest control, pointing out the risk of a possible return to heavy infestation by the target pests of Bt-cotton.

2.3. Changes in weed plant complexes

Transgenic cotton varieties that are tolerant of the active ingredient of herbicide, glyphosate, occupy 71% of the total cotton growing areas in the United States today (**Table 2**), and that share continues to increase. Yet, since 2003, glyphosate resistance seen in weed plants has gradually spread to all cotton producing States for all major crops (cotton, maize, soybean, etc.). This phenomenon reflects a shift in the weed flora, directly linked to using herbicides for weed destruction in no-tillage systems, notably glyphosate-based Roundup® from Monsanto.

The most frequently mentioned glyphosate-resistant weed species[6] are primarily *Conyza canadensis* (horseweed) and *Amaranthus palmeri* (pigweed), which are of greatest concern to American producers, then *Lolium multiflorum* and *rigidum* (Italian and rigid ryegrasses), *Sorghum halepense* (Johnsongrass) and *Ambrosia artemisiifolia* (ragweed). The resistance of *Amaranthus rudis* (common waterhemp) has just been confirmed in Texas after being reported in four other States (Light et al., 2010).

Plots can be totally invaded by several species of resistant weeds. A 2009 survey indicated that the number of herbicide-resistant species varied from 2 to 18 depending on the cotton States (among which 12 were glyphosate-resistant); that 75% of fields had been affected in certain counties of those States; and that 45% of producers had resorted to manual eradication. What a paradox in the country of motorization where, with the expansion of precision agriculture, the new revolution is proclaimed to be agricultural machinery packed with ever more electronic wizardry!

Another unexpected phenomenon has come to light. Cultivating glyphosate-tolerant transgenic varieties of soybean, cotton, and maize has led to transforming those cultivated plants themselves into weeds. For example, in cotton fields, soybean or maize plants arising from seeds left after harvest are the most difficult weeds to control, since glyphosate does not kill them due to their tolerance. Similarly, glyphosate-tolerant transgenic cotton is also a weed in soybean and maize.

2.4. Changes in parasite complexes in relation to no-tillage

Glyphosate-tolerant transgenic varieties have made it possible to expand no-tillage practices. In no-tillage systems, the main crop is sown without tilling the soil in a plant cover that has been controlled beforehand with herbicides. With the permanent plant cover, the crop is sown at a lower soil temperature than in bare soil cultivation, and higher humidity. Consequently, fungal diseases develop on seedlings (damping off), along with leaf fungal diseases after the seedling stage. Consultants therefore recommend greater fungicide use. Despite this recommendation, researchers and consultants admit that much yet remains to be done to optimize fungicide treatment techniques.

Interaction between transgenic varieties and no-tillage cultural techniques has effects that go beyond the fungus disease complex. Pest pressure is also influenced by the plant cover. An increase in sucking pest pressure, notably thrips, aphids, mites and bugs, is frequently reported at the start of the season, to the point that consultants already recommend destroying the vegetation a few weeks before sowing, including around the plots to be sown, until researchers can find new solutions. Griffin et al. (2010) presented some interesting results on cotton relay intercropping, by sowing cotton before the harvest of a winter cereal, so as to avoid attacks of thrips at the beginning of the cotton cycle.

3. ONGOING RESEARCH ON PARASITE COMPLEX MANAGEMENT

Papers on controlling parasite complexes indicated that research is counting on chemistry and biotechnologies to protect cotton crops, whilst attempts at a more systemic approach remain lukewarm.

3.1. More work to vouch for the efficiency of Bt-cotton

Although Bt-cotton has now been grown on a large scale for almost 15 years, work is still being undertaken to determine its efficiency. Bollworms, targeted by Bt genes, are still present, sometimes to a large degree in States of the Mississippi delta, which is notably different from what is found in China (Wu et al., 2008). Speakers indicated that bollworms must not be overlooked, even though they are no longer the pests that threaten cotton the most.

[6] Year of confirmed resistance in at least one State: as of 2000 for horseweed, 2005 for pigweed, 2004 for ragweed and Italian ryegrass, 2007 for Johnsongrass (http://www.weedscience.org/Summary/UspeciesMOA.asp?lstMOAID=12).

In recent years, the gain in Bt-cotton profitability is no better on average than that with chemically protected conventional cotton. One major cause is the sharp increase in the cost of using Bt technology (seeds and royalties). A return to conventional cotton may seem legitimate, but that was not explicitly brought up in the papers presented.

Pest resistance to Bt toxins was covered in only two papers by researchers from Monsanto. The first was an overview of published results (**Table 3**) and concluded that field resistance would be proven for only *H. zea* against the toxin induced by the *Cry1Ac* gene (Dennehy et al., 2010). However, it is considered that such resistance would not be troublesome because varieties carrying that gene alone will be taken off the market in 2011. The authors of the second paper explained why pest resistance found in the laboratory is not confirmed in the field. In the process, they criticized the scare tactics of researchers working to identify resistance in the laboratory.

3.2. Persistence of the chemical pathway to control Bt-cotton target pests

First of all, it is important to remember that the emergence of bollworm resistance to pyrethroid-based insecticides was one of the reasons for proposing transgenic cotton. Musser et al. (2010) reported on the monitoring of bollworm resistance to pyrethroid insecticides in nine cotton States – Texas, Mississippi, Georgia, Tennessee, South Carolina, Louisiana, Arizona, Missouri and Virginia. Resistance is monitored by the Vial-test, which consists in collecting target pests, enclosing them in a tube impregnated with 5 μg of pyrethroid, and recording the survival rate. For the 2007-2009 period, the bollworm survival rate reached 10 to 30% in seven of the nine States, showing persisting resistance to pyrethroids, even though the insecticides have been used much less since Bt-cotton has been grown. Although they could not give any reasons for this, the authors of the paper pointed out that the rate was even greater than that measured in 1998. This work is therefore truly relevant at a time when a return to conventional cotton growing is being mooted.

The current limitations of Bt-cotton in controlling all Lepidoptera pests even seem to be reviving the search for new families of chemicals. One new commercial product (the Anthranilic Diamide family) was presented for its effectiveness on a wide spectrum of Lepidoptera in major crops (cotton, maize, soybean, etc.). Apparently, this product has already received approval for most crops, but not yet for soybean. The results indicate that two applications of the product lead to the same protection as Bt-cotton use, but information about the cost remain vague.

The proposed use of chemicals with a wide spectrum of action is a major strategy change on the part of phytopharmacology companies, compared to the "targeted strike" option against precise pests. The possible effect of this strategy on changes in pest complexes was not discussed.

3.3. Chemical control of pests not targeted by Bt-cotton

Twenty-one of the 59 papers dealing with pest control evaluated harvest losses caused by "new" pests – mainly sucking insects and to a lesser degree leaf-eating caterpillars – and assessed the effectiveness of new insecticide molecules.

Five papers focused on the proven lower susceptibility of sucking insects (bugs, aphids) to the insecticides used since 2000 to cope with a recrudescence of their attacks. No loss of susceptibility to organophosphorus insecticides was found in 2004 but it became obvious in 2007, as for the bug *L. lineonaris* in relation to acephate (Snodgrass et al., 2009). During the 2010 Beltwide Conferences, it was therefore explicitly recommended to stop using acephate insecticide. This might be also the case for other insecticides, because a *L. lineonaris* population was found, as early as 2007, to be simultaneously resistant to carbamates, organophosphates, and pyrethroids. This observation warrants the call for new families of insecticides.

New insecticide products are currently being assessed by phytopharmacology companies and researchers from universities; the results were reported by one or the other. A commercial product of the

Table 3. Research results on the appearance of resistance in pests targeted by two Bt genes: overview by Dennehy et al., 2010 — *Les resultats de recherche sur l'apparition de la résistance des ravageurs cibles de deux gènes Bt : une synthèse par Dennehy et al., 2010.*

Pests	Resistance to *Cry1Ac*		Resistance to *Cry2Ab*	
	in the laboratory	in the field	in the laboratory	in the field
Pectinophora gossypiella	yes	no	yes	no
Helicoverpa virescens	perhaps	no	no	no
Helicoverpa zea	yes	perhaps	no	no

Sulphilimines family seems to be favored, notably against two species of bugs and aphids, but also whiteflies and other sucking insects. This product against aphids is so promising that one speaker went as far as to state that chemical control of aphids would thereby be solved. Due to hit the market in 2012, it is effective at a dose of 25 $g \cdot ha^{-1}$ of active ingredient, as opposed to a double dose of rival products currently being tested, and doses ten to fifty times higher for former products of the organophosphorus family. The residual effect is observed up to 14 days after application. Two treatments of 25 $g \cdot ha^{-1}$ of active ingredient were more effective against the bug *L. lineonaris* than almost a kilo (two pounds) of acephate.

In general, the companies did not seek to show that their products were better than those of their rivals. They emphasized equivalent efficiency and the contribution made towards a broader range of usable products, so as to offer flexibility of choice and make it possible to alternate use of available products. The work includes measuring effects on a wide spectrum of pests, but using different doses. The wide spectrum is now presented as an advantage. Likewise, variation in doses depending on pests is promoted as an asset of flexibility and compatibility when implementing an Integrated Pest Management (IPM) programme.

3.4. Pest control by a new generation of transgenic varieties

For their part, the biotechnology companies are pursuing the transgenic cotton pathway, proposing new types of varieties incorporating new genes. Such is the case with the Bayer company, with TwinLink cotton due on the market in 2012, a new dual Bt cotton with the two Bt genes *cry1Ab* and *cry2Ae*, which control Lepidoptera pests. The commercial release will follow shortly for a new set of transgenic cottons with staked genes, from the combination of pest-resistance Twinlink genes and herbicide-tolerant LibertyLink gene (from Bayer as well), which provides tolerance of a glufosinate ammonium-based herbicide. Compared to Monsanto's existing varieties, the new transgenic cotton is apparently most effective against *P. gossypiella* (pink bollworm), out of the three pests targeted by Bt genes, and also seems to have some effect against two leaf-eating caterpillars of the genus *Spodoptera*. In addition, Bayer has inserted its own glyphosate-tolerance gene (GlyTol™ gene) to create varieties of the TwinLink/GlyTol™ type, which will have the particularity of tolerating two different herbicides.

Syngenta, another phytopharmacology and biotechnology multinational, is working for its part on resistance to pests by studying a combination of the Bt *cry1Ab* gene and the *VIP3A* gene, which has been approved but is not yet proposed for marketing.

Other solutions envisage a more complex association of three genes. A researcher from Monsanto announced the impending market launch of the Bollgard III variety, derived from a combination of two Bt genes used in Bollgard2 (*cry1Ac* and *cry2Ab*) and the *VIP3A* gene from Syngenta. It was surprising to hear a researcher from Monsanto praising the Syngenta gene in terms of a wider spectrum against Lepidoptera pests.

Monsanto was the only firm to indicate results for a new Bt gene in controlling a bug species, though in theory Bt toxins do not appear to be adapted to the ingestion system of bugs. The results are promising, but marketing is still a long way off.

3.5. Exploration of new avenues to control new pests

One agronomic approach involves studying new pest population dynamics. A negative effect of neighbouring maize has been discovered on bug infestation in cotton fields, leading to the recommendation to treat against bugs in maize adjacent to cotton fields.

New work has begun on understanding the determinism of the olfactory system of a bug species, which would appear to be decisive in seeking food; such an understanding might pave the way for control by disrupting the pest's feeding habits.

Other research work is based on exploiting high definition video to continually film the movements and feeding habits of a bug species, depending on the age and sex of the insects. The idea is to find out which, of males and females, cause the greatest damage to cotton, and at what stage of their development.

3.6. Management of glyphosate-resistant weeds

The chemical solutions proposed at the moment are not really effective. Residual or contact herbicides have been used, though without long-lasting success, that tap into existing molecules, some of which are already old like Paraquat. Some positive results were mentioned for the combination of Paraquat and Diuron, but only against one resistant weed species (horseweed) in Arkansas (a minor cotton producing State). Residual herbicides against pigweed in several cotton States of the Centre-South help to control 47 to 97% of weed cover, up to 14 days after sowing, depending on the herbicide used and soil moisture conditions. But that remains inadequate, because the weed continues to germinate well beyond that time and its high prolificacy (200,000 to 600,000 seeds per female plant) requires total elimination to prevent rapid invasion of the plot.

On the whole, the new control methods entail extra cost, notably because several products have to be combined to cope with the large number of glyphosate-resistant weed species.

Researchers highlighted the need for new chemicals, whilst considering that we should not just count on herbicides. When phenomena develop and new products are proposed, new control programmes are tested that combine several products, be they new or old. Adjustments in herbicide programmes may call for changes in cultivation techniques. In Texas, to prevent the appearance of pigweed resistance, the herbicide programme is based on applying residual products when the soil is prepared, then in the pre-sowing and post-emergence periods. However, such a programme is not compatible with no-tillage techniques. Where pigweed resistance has already occurred, as in the South-Central States, deep tillage is being tested, combined or not with the establishment of a thick plant cover. Such a technique does not seem to be compatible with no-tillage either and is not enough against other resistant weed species.

In addition, it was suggested that new control techniques should also be adapted to the specific biology of glyphosate-resistant weeds. Knowledge of that biology is also becoming a paramount factor in future control methods, given that some species such as *A. artemisiifolia* have developed biological selection with delayed germination, thereby avoiding the herbicide application period.

Another solution may be the upcoming market launch of new transgenic varieties tolerant of 2.4 D-based herbicide. The survey conducted in real time[7] during a workshop with consultants revealed some mistrust of these new varieties, due to the risks of herbicide drift outside the treated fields.

Faced with doubts about the sustainability of using glyphosate-tolerant varieties, six universities have launched a research initiative funded by Monsanto, the Benchmark Study (http://www.weeds.iastate.edu/mgmt/Benchmarkstudy.htm). Two presentations[8] reported on the Benchmark Study since 2005-2006, indicating that the use of Roundup Ready varieties is possible and profitable, despite the appearance of resistant weeds, provided producers are effectively advised on their use. In addition, this initiative acknowledges the need for stewardship (training and information) for sustainable use of Roundup Ready varieties.

4. CONCLUSION

The 2010 Beltwide Conferences provided a new vision of the consequences of using transgenic cotton varieties in the United States. With the hindsight of almost 15 years of cultivation, the changes in cotton pest complexes and the solutions sought to cope with them show that the proclaimed positive effects of using these varieties look like lost illusions today, in the following four fields:

– The transgenic cotton varieties currently being grown do not definitively solve the crop's pest problems, since new enemies have appeared (insect pests and weed plants). Consequently, their use has not made it possible to durably reduce chemical pesticides, which have become necessary again. Today, this is expensive and demands a high degree of technical command, because the effectiveness of the new pesticide molecules depends on the conditions of use;
– Controlling the crop's enemies by transgenic varieties has become more expensive overall, be it through the continual rise in seed prices or through the additional pesticides needed. Thus, the feeling of comfort that prevailed at the start of their use has been replaced by a feeling of uncertainty about the efficiency and cost-effectiveness of such control;
– Biotechnological solutions, like any technical solution, call for users to be informed and trained, to ensure sustainability and effectiveness. In addition, a coordination system is required, but its implementation in a context of private interests can be difficult, or even impossible;
– Control solutions by chemistry or biotechnologies prove to be complementary. In addition, competition between firms in each of the two branches is only virtual, either because new chemical pesticides are not substitutable, or because of possible complicity between biotechnology companies.

However, the phenomena observed in the United States cannot be generalized, as they refer to an extreme case of massive, simultaneous, and uncoordinated use of transgenic varieties of soybean, maize and cotton, and which have followed on from each other in the same plots or in the same environments. It is therefore risky to extrapolate these phenomena to other regions of the world, even though "new" pests have appeared in China (Lu et al., 2010), and maybe in Australia (Robinson et al., 2010), as have glyphosate-resistant

[7] The organisers of the Beltwide Conferences, always on the leading edge of technologies, conducted a real time survey using products from the eInstruction company (http://www.einstruction.com/products/index.html).

[8] Owen M.K.D. et al. Benchmark Study: perspective on glyphosate-resistant crops and the sustainability of chemical weed management; Jordan D. L. et al. Benchmark Study: comparison of weed management programs, yield, and economic return to glyphosate-based herbicide programs in a continuous cotton rotation. Both oral presentations are freely available at http://ncc.confex.com/ncc/2010/webprogram/Session1876.html.

weed plants in Argentina and Brazil (Vila-Aiub et al., 2008). Faced with this situation, one consultant concluded on the merits of a systemic and coordinated approach to transgenic variety use. This proposed novel approach seems to be of paramount importance for understanding the scope and limitations of using these varieties and for offering new prospects in the debate about transgenic cultivated plants.

Acknowledgements

The author thanks Mrs Cécile Fovet-Rabot for revising the article, MM. Peter Biggins and Gary Burkhart for English editing and, the journal Cahiers Agricultures in which a French version has been published (Fok, 2010). This English version does not touch upon cotton policy aspects, but takes a more in-depth look at certain technical aspects with more literature references.

Bibliography

Dennehy T.J., Head G.P., Anilkumar K.J. & Price P.A., 2010. Update on susceptibility of key cotton pests to Bt toxins Cry1Ac and Cry2Ab. *In: Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*. Audio presentation at http://ncc.confex.com/ncc/2010/webprogram/Paper10949.html, (01/04/2011).

Fernandez-Cornejo J. & Caswell M., 2006. *The first decade of genetically engineered crops in the United States*. Economic Information Bulletin, 11. Washington, DC, USA: USDA Economic Research Service.

Fok M., 2010. Autant en emporte la culture du coton transgénique aux États-Unis... *Cah. Agric.*, **19**(4), 292-298.

Fok M., Liang W., Wang G. & Wu Y., 2005. Diffusion du coton génétiquement modifié en Chine : leçons sur les facteurs et limites d'un succès. *Econ. Rurale*, **285**, 5-32.

Golden P., 2009. Can cotton be grown cheap? *California Farmer*, January 6, http://californiafarmer.com/story.aspx/can/cotton/be/grown/cheap/21156, (14/01/2011).

Greene J.K., 2010. The bug problem in cotton – Can we manage bugs and boll-rotting pathogens without a crystal ball? *In: Proceedings of the 2010 Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*, 242.

Griffin J.D. et al., 2010. Reduction of thrips populations with tillage and winter cover crops. *In: Proceedings of the 2010 Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*, 905

Haire B., 2010. Pigweed threatens Georgia cotton industry. *Southeast Farm Press*, July 8, http://www.gmwatch.org/latest-listing/1-news-items/12342-volunteers-and-resistant-weeds-hitting-us-farming, (14/01/2011).

Hardee D.D., Van Duyn J.W., Layton M.B. & Bagwell R.D., 2001. *Bt cotton management of the tobacco budworm-bollworm complex*. Washington, DC, USA: USDA Agricultural Research Service.

Hydrick D., 2010. Transgenic: a double edge sword. *In: Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*. Audio presentation at http://ncc.confex.com/ncc/2010/webprogram/Paper11013.html, (01/04/2011).

Light G.G. et al., 2010. Glyphosate-resistant common waterhemp confirmed in Texas. *In: Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*, 1539-1544.

Lu Y. et al., 2010. Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. *Science*, **328**(5982), 1151-1154.

Mahyco Monsanto Biotech, 2010. *Press releases: cotton in India*, http://www.monsantoindia.com/monsanto/layout/pressreleases/mmb_pressrelease.asp, (23/6/2010).

Musser F.R. et al., 2010. Pyrethroid resistance monitoring of bollworms. *In: Cotton Beltwide Conferences, 4-7/01/2010, New Orleans, Louisiana, USA, NCC*, 1259-1264.

Norsworthy J.K., Smith K.L., Scott R.C. & Gbur E.E., 2007. Consultant perspectives on weed management needs in Arkansas cotton. *Weed Technol.*, **21**(3), 825-831.

Robinson P. & Tapim F., 2010. New mealybug in Queensland cotton. *ABC News*, February 5, http://www.abc.net.au/news/stories/2010/02/05/2811656.htm, (12/02/2010).

Smith J.T., 2010. What's bugging cotton growers nowadays? Weevils and worms may be gone but producers encounter brand-new problems. *Mid-South Farmer*, January 5, at http://midsouthfarmer.com/story.aspx/whats/bugging/cotton/growers/nowadays/34405, (14/01/2011).

Snodgrass G.L., Gore J., Abel C.A. & Jackson R., 2009. Acephate resistance in populations of the tarnished plant bug (Heteroptera: Miridae) from the Mississippi river delta. *J. Econ. Entomol.*, **102**(2), 699-707.

Tabashnik B.E. et al., 2002. Control of resistant pink bollworm (*Pectinophora gossypiella*) by transgenic cotton that produces *Bacillus thuringiensis* toxin Cry2Ab. *Appl. Environ. Microbiol.*, **68**(8), 3790-3794.

Vila-Aiub M.M. et al., 2008. Glyphosate-resistant weeds of South American cropping systems: an overview. *Pest Manage. Sci.*, **64**, 366-371.

Wu K.-M. et al., 2008. Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin-containing cotton. *Science*, **321**, 1676-1678.

(21 ref.)