Cotton Pest Management Programmes using Threshold-Based Interventions Developed by CIRAD and its Partners in Sub-Saharan African Countries

Silvie P.J.[1], Adegnika M.A.[2], Akantetou K.P.[3], Ayeva B.[3], Bonni G.[4], Brevault T.[5], Gautier C.[6], Héma O.[7], Houndete T.A.[8], Ochou G.[9], Prudent P.[6] Renou A.[10] and Togola M.[11]

[1]CIRAD, UPR Systèmes de culture annuels, Montpellier, France
[2]INRAB/CRA-CF, Cotonou, Benin, [3]ITRA/ CRA-SH, Anie, Togo
[4]INRAB/CRA-CF, Parakou, Benin, [5]CIRAD, UPR Systèmes de culture annuels, Montpellier, France
[6]CIRAD, UPR Systèmes de culture annuels, Maroua, Cameroon
[7]INERA, Bobo-Dioulasso, Burkina Faso, [8]INRAB/CRA-CF, Bohicon, Benin
[9]CNRA, Abidjan, Côte D'Ivoire, [6]CIRAD, UPR Systèmes de culture annuels, Maroua, Cameroon
[10]CIRAD, UPR Systèmes de culture annuels, Bamako, Mali, [11]IER, Sikasso, Mali

Abstract—*In the late 1980s, after a long period during which insecticides were sprayed at preset dates to control cotton pests and their damage, some French-speaking countries in sub-Saharan areas decided to disseminate a more sustainable crop protection approach among smallholders: targeted staggered control (LEC, for Lutte étagée ciblée). According to this approach, decisions on some insecticide sprays were made on the basis of infestation levels or the extent of crop damage induced by major pests: Aphis gossypii aphids, Haritalodes (= Syllepte) derogata leaf-eating caterpillars, and more generally Helicoverpa armigera, Diparopsis watersi, Earias insulana and E. biplaga bollworms. Polyphagotarsonemus latus mites were sometimes included on this list. Due to changes in cotton production conditions over the past 10 years, especially the development of pyrethroid resistance in H. armigera, and depending on the country, this programme has been abandoned, preserved or replaced by other programmes. The strict use of thresholds in Mali was thus taken to be a logical follow-up to LEC, which is still widely implemented. A targeted 'threshold-based' programme was developed in Togo. Cameroon abandoned LEC and opted for a 'sequential plan for individual decision' (SPID) programme (LOIC, for Lutte après observation individuelle des chenilles), based on control after sequential sampling of bollworms. In Benin, LEC has been presented in two forms, i.e. 'complete' and 'partial', tailored to two regions delineated according to the extent of damage of some bollworms that live inside cotton bolls, i.e. Pectinophora gossypiella, Thaumatotibia (= Cryptophlebia) leucotreta. In Ivory Coast, where these Lepidopteran pests are also present, the use of treatment thresholds is limited to the beginning of the cotton crop cycle. On the contrary, in Burkina Faso, thresholds are used after the first two calendar sprayings. The present article fully describes these new crop protection programmes, sampling methods and associated intervention thresholds, in addition to the advantages and constraints associated with their adoption.*

INTRODUCTION

The concept of Integrated Pest Management remains widely recommended in crop protection programmes against pests. Before any decision is taken to apply a toxic product, the use of action thresholds is an essential step (Stern *et al.*, 1959). In cotton production, the use of action thresholds (called 'thresholds' in the rest of this article), linked to the level of pests or damage, has been adopted in numerous countries where the growth of this crop is conducted in a mechanical way over large acreages, with the aim of reducing the quantity of pesticide use (the undesirable effects of pesticides are known) and, as a result, reducing production costs.

At the end of the 1980s in the French-speaking sub-Saharan Africa region, cotton producing countries developed various forms of integrated protection programmes for cotton which were called 'Lutte étagée ciblée' (LEC) or 'targeted staggered control' (TSC). A basic programme, sometimes seen as a 'protection or safety net', is recommended according to a calendar preset in the conventional standard protection programme (usually five or six sprays at fortnightly intervals), with the application of insecticide doses reduced by half. Additional treatments or doses are carried out when the action thresholds are reached. Amongst the diversified fauna of Arthropods which are present on this crop (Vaissayre, 1994) certain groups of pests have been taken into account more specifically for the application of these thresholds. Therefore observation has mainly focused on aphids (*Aphis gossypii*), leaf-eating caterpillars such as *Haritalodes* (= *Syllepte*) *derogata*, *Anomis flava*, or *Spodoptera littoralis* and caterpillars described as ‘carpophagous’ such as *Helicoverpa armigera*, *Diparopsis watersi*, *Earias insulana* and *E.biplaga*, which feed on fruiting organs and are visible on the outside of them (i.e. ‘exocarpic’). In some countries, such as Togo and Benin for example, the presence of carpophagous caterpillars which live inside green bolls (‘endocarpic’) has led to the definition of two phytosanitary regions (a northern zone and a southern zone). In fact, populations of these species are higher in the southern regions where they cause significant damage to cotton and maize. The species concerned are *Thaumatotibia (= Cryptophlebia) leucotreta*, which is also present in Ivory Coast (Ochou *et al.*, 1998a,b), and the Lepidoptera *Mussidia nigrivenella*, a pest best known in maize but sometimes reported in significant numbers in southern Togo (Silvie, 1990).

A first summary detailing protection programmes using thresholds was published by Silvie *et al.* (2001). Since this time, the context in which cotton is produced in sub-Saharan Africa has changed. Major events have occurred locally, such as the privatization of cotton networks, leading to the division of operations and reorganisation of the production chain. In Burkina Faso, for example, the production zones have been consigned to three different entities, of which Faso Coton is part. In the Côte d’Ivoire, the Ivoire Coton group manages the north-west of the country. This geographical carving up of cotton production has led to a fragmentation which does not always make it easy to interpret production at the national scale, particularly when it comes to agricultural statistics. There is also a possible threat to pest management, caused by the definition of different phytosanitary protection strategies from one geographical zone to another within the same country. Regarding pest management, the ways cotton crops are protected have changed since the evolution of resistance to pyrethroids in the cotton bollworm *H. armigera* was highlighted in countries such as the Côte d’Ivoire (Martin *et al.*, 2002, 2005; Vaissayre *et al.*, 1998), Benin (Djihinto *et al.*, 2009) and, later, Cameroon (Achaleke & Brévault, 2010 ; Brévault *et al.*, 2008). On the other hand, the recent highlighting of resistance in *Bemisia tabaci* (Houndété *et al.*, 2010) does not appear to have changed the pest management programmes applied. Finally, another recent change has been the introduction of genetically modified cotton varieties carrying the *cry1Ac* and *cry2Ab* genes, which come from the bacterium *Bacillus thuringiensis* (Bt). Thanks to the production of insecticidal proteins, these cotton plants, known as ‘Bt cotton’, are resistant to the major Lepidopteran pests (Héma *et al.*, 2008; Traore *et al.*, 2008). Following these changes and according to the country, LEC programmes have been abandoned, modified or replaced by other types of protection programme which still use thresholds to decide when to apply insecticides.

The recently published summaries on cotton pest management (Peshin *et al.*, 2009 ; Kranthi & Kranthi, 2010) rarely mention the experiences of French-speaking Africa in this area (van Huis, 2009 ; Kranthi & Russell, 2009). It seems useful therefore, 10 years on, to update our knowledge on the use of thresholds in cotton pest management programmes in French-speaking sub-Saharan Africa.

Published knowledge on the current status of cotton protection programmes varies according to the country. As an example, the latest information on the protection of cotton crops in Chad and Central African Republic dates back to data published by Nibouche *et al.* (2003a). For these authors, the existence of various protection programmes, offered simultaneously to farmers, and changes in application techniques (from one to 10 liters of water plus insecticide applied per hectare), appear to be the cause for withdrawing the LEC programmes in these countries.

PAST AND CURRENT STATUS OF THRESHOLD-BASED PROGRAMMES IN WEST AFRICAN COUNTRIES

LEC programmes are based on a basic calendar programme. This calendar is the same as the conventional programme, comprising five or six sprays at fortnightly intervals starting from the 45th day after emergence (early squaring), but with insecticide doses reduced by half.

In 2001, two broad types of the LEC programmes were noted by Silvie *et al.* (2001). In the first type (called the 'D-1' programme), in Benin and Cameroon, scouting was performed the day before spraying in the calendar programme to adjust active ingredient and dosage the following day. In the second type (the 'D+7' programme), in Burkina Faso, Mali and Togo, insect sampling was performed six days after spraying with pesticides applied at a reduced dosage in the calendar programme. If pest density was above the threshold, spraying was performed the next day with the active ingredient depending on the target pest.

TABLE 1: CHARACTERIZATION OF THRESHOLD-BASED CONTROL PROGRAMMES IN WEST AFRICAN COUNTRIES

Country	Benin	Ivory Coast	Togo ('reinforced')	Burkina Faso	Mali (LEC[c] & SST[d])
Maximum sampled field area (ha)	0.5 to 5				5
Period of observation for introduction of thresholds	From 30 days after emergence	From 33 to 66 days after emergence	After first calendar treatment	30 days after emergence	From 30 days after seeding until boll maturing
Maximum number of counting	12		5 (North) 6 (Mid and South)		
Number of sampled plants/plot	40 (20/diagonal)	30	30/diagonal	25/diagonal (in 1998) 30 /diagonal (in 2010)	25/diagonal
Number of sampled leaves/plant	*Not considered*	*Not considered*	*Not considered*	*Not considered*	*Not considered*
Action thresholds					
Exocarpic bollworms (*H.armigera*, *D. watersi*, *Earias* spp.)	5 larvae *H. armigera* 10 larvae (other exocarpics)[a]	3 larvae (including endocarpic such as *P. gossypiella*)	3 larvae *H. armigera*	5 larvae	5 larvae
Endocarpic bollworms (*Pectinophora gossypiella*, *Thaumatotibia* (= *Cryptophlebia*) *leucotreta*)	*P. gossypiella* grouped with exocarpic/*others not considered*	*Grouped with exocarpic larvae*	*Not considered*	*Absent/Not considered*	*Absent/Not considered*
Leafworms (*Haritalodes* (= *Sylepte*) *derogata*, *Spodoptera littoralis*, *Anomis flava*)	plants infested by *H. derog*	3 infested plants	*Not considered*	8 infested plants by *H. derogata* 8 larvae (*S. littoralis*, *A. flava*)	5 infested plants
Aphids	33 infested plants	10 plants	*Not considered*	21 infested plants	20 infested plants
Whiteflies	*Not considered*	*Not considered*	*Not considered*	10 infested plants[b]	
Mites (*P. latus*)	3 infested plants	2 focus with damaged leaves	*Not considered*	*Not considered*	*Not considered*
Leafhoppers	*Not considered*	10 plants	*Not considered*	*Not considered*	*Not considered*

[a] If none of these thresholds is reached, use the threshold 'cumul. carpophagous' = 10 larvae (*H. armigera* + other exocarpics)
[b] Infested plant: presence of at least 3 adults or 1 larva
[c] LEC: Lutte étagée ciblée
[d] SST: *Sensu stricto threshold*

Today, Benin, Togo, Cameroon, Ivory Coast, Mali and Burkina Faso recommend weekly observations. Supplementary treatments, based on thresholds, can be applied seven days after the initial treatment. But new variations are also offered to producers (Tab. 1). Evidence of the resistance of *Helicoverpa armigera* to pyrethroids has, logically, led to temporal restrictions on the use of these active ingredients, to allow better control of bollworms and delay the evolution of resistance. Two or three 'protection windows' have been defined within the cropping season (Tab. 2) (Brévault *et al.*, 2009). Each window corresponds to two treatments in the 'conventional' programme.

TABLE 2: USE OF ACTIVE IN GRADIENT RELATIVELY TO WINDOWS OF SPRAYING (W1,W2, W3)

Country	Benin		Ivory Coast	Togo		Burkina Faso	Mali	Cameroon
Region	Northern	Southern		Northern	Southern			
Type of programme	complete LEC	partial LEC		reinforced*			LEC, SST	LOIC
W1	No pyrethroid/ indoxacarb	No pyrethroid/ indoxacarb	Use of thresholds (38 and 66 dae[1] only)	No pyrethroid/ 2 first treatments with indoxacarb 25g/ha or profenofos 720g/ha	3 treatments with binary association against mites and Lepidoptera	Calendar treatment/no pyrethroid	No pyrethroid/ indoxacarb	Indoxacarb 25g/ha
W2	2 treatments with binary association against mites and Lepidoptera (Sherphos® 370 EC)	2 treatments with binary association against mites and Lepidoptera (Sherphos® 320 EC)	Calendar treatment	1 treatment with binary association against mites and Lepidoptera	3 treatments with binary association against aphids and Lepidoptera	Binary association (pyrethroid + OP[2]) against mites)	Binary or ternary association against aphids or whiteflies	Cypermethrin 36g/ha + profenofos 150g/ha
W3	2 treatments with binary association against mites and Lepidoptera (Sherphos® 370 EC)	2 treatments with binary association against mites and Lepidoptera (Sherphos® 320 EC)	Calendar treatment	2 last treatments with binary association against aphids and Lepidoptera		Binary association (pyrethroid + neonicotinoide against aphids, jassids and whiteflies)	Indoxacarb if necessary	Indoxacarb 25g/ha

TABLE 3: COMPARISON OF MARGINS (IN CFA (1)/HA) CALCULATED FOR VARIOUS COTTON PROTECTION PROGRAMMES IN FRENCH-SPEAKING SUB-SAHARAN AFRICA

Margin and Country	Conventional' Programme	Programmes using Thresholds (LEC - LOIC)	Reference
MARI[2]			
Burkina Faso	41 243	68 206	COMPACI *et al.*, 2010
Cameroon	51 340	79 630	
Ivory Coast	33 300	107 300	
Net margin			
Benin	Weak guidance	LEC	Mathess *et al.*, 2005
North	33 682	46 391	
North-central	-11 431	20 468	
Centre	-64 384	14 026	
South	-91 806		
[1]cfa = Franc of the African Financial Community (€1 = 655.96 cfa)			
[2]MARI = Margin After Repayment of Inputs			

Faced with the importance of resistance, Togo, that abandoned the LEC programme in 2000, adopted a ‘reinforced programme’. Special scouting for *H. armigera* is systematically conducted six days after the five treatments (northern region) or six treatments (southern region) of the conventional calendar programme.

Between 2000 and 2002 in Ivory Coast, the Ivoire Coton company adopted a programme that used thresholds only during the first protection window (Tab. 2). From 2009, the same company has been using this strategy within the scope of the ‘COMPACI’ project (Ochou and Amon, 2010). The programme uses thresholds only This covers the first two application dates in the calendar programme (‘conventional’). Following this, the calendar programme is followed. The explanation for this is the presence of endocarpic caterpillars, which are difficult to control with insecticide applications.

In contrast, for its crops grown in Burkina Faso, the Faso Coton company has decided to employ a programme based on thresholds but only after two first treatments in a predefined calendar programme (Leynaert, 2010).

Mali followed the logic set in motion through its adoption of an initial LEC programme and by 2008 had implemented a programme of treatments decided on *sensu stricto* thresholds (SST). With this programme, there is no longer a ‘basic programme’ of insecticide applications. The decision to spray is taken only after the passing of defined thresholds, which remain the same as those in the LEC programme (Tab. 1). However, it is clearly defined for economic reasons that the interval between two consecutive treatments must be no less than 14 days. In 2008, Mali implemented 14,000 hectares of cotton land with LEC programme, 52,000 hectares with the SST programme, while the preset calendar or ‘conventional’ programme was performed on 112,000 hectares. Therefore, programmes using thresholds represented 37% of the area devoted to cotton production.

In Benin, two forms of the programme adapted to the two regions, ‘LEC complete’ (north) and ‘LEC partial’ (south), have evolved during the development of the Projet d’Amélioration et de Diversification des Systèmes d’Exploitation (improvement and diversification of growing systems project) (Prudent *et al.*. 2006). A total area of 17,000 hectares was managed under LEC in 2009, representing nearly 12% of Benin’s total cotton area.

In 2006, after studies by Nibouche *et al.* (2003b) and Beyo *et al.* (2004), Cameroon opted for a protection programme called ‘LOIC’ (Lutte après Observation Individuelle des Chenilles) or ‘SPID’ (Sequential Plan for Individual Decision). This programme uses sequential sampling on individual bollworms. It therefore does not include the counting of leaf-eating caterpillars and aphids or their damage. This simplified observation method for pests was adopted by 2,195 growers in 2009, representing 1,170 hectares of cotton crops (less than 1% of the total surface area).

There has been a marked diversification in the cotton protection programmes using thresholds over the past 10 years. They are more fully detailed below.

Sampling of Plants, Pests and Decision-Making Procedures

The sampling procedures are very similar in each country, with the exception of Cameroon which has opted for sequential sampling.

For all the countries, observation field by field and the decision to spray (or not to spray) concern only the field under observation. Treatment by crop 'block', which used to be conducted in Cameroon, is no longer possible everywhere because of the presence of other crops in these 'blocks'.

The number of plants observed in Cameroon varies according to the results obtained as scouting in the field continues. A maximum of 25 plants is analyzed per area of 0.25 hectares. For the other countries, between 25 and 40 plants are observed. They are chosen individually at random (therefore not next to each other in the same row), in general following one or two diagonals. Their observation is completed and damage or pest presence is noted, at a minimum, for bollworms (*H. armigera*, *D. watersi*, *Earias* spp.), leaf-eating caterpillars (*H. derogata*, *A. flava*, *S. littoralis*) and the aphid *A. gossypii*. The threshold levels leading to the decision to spray vary according to the country (Tab. 1 and 2). For example, the threshold of three caterpillars of *H. armigera* per 30 observed cotton plants is used in Togo to decide if treatment is needed against this pest (Tab. 1). This threshold is 5 larvae for 40 observed plants in Benin. In other countries, all the exocarpic larvae are considered together. Mite (*Polyphagotarsonemus latus*) damage is also taken into account in Ivory Coast and Benin (Tab. 1). Leafhoppers (Cicadellidae) are taken into account only in the Côte d'Ivoire and the *Bemisia tabaci* whitefly in Burkina Faso (Tab.2). In the latter country, following the introduction of Bt cotton plants, there are no specific thresholds used for bugs (Pentatomidae, Pyrrhocoridae or Miridae) which represent an important group in West African growing systems (Poutouli *et al.*, 2011).

For easier record keeping in the field, various types of pegboards have been created for LEC programmes in each country. An original pegboard was specially created for the LOIC programme in Cameroon, which uses the sequential sampling technique (Beyo *et al.*, 2004).

Active Ingredients, Dosage and Spraying Technique

The first protection window (W1) no longer includes pyrethroids. The two treatments in the first window (Tab. 2) are designed to control the first caterpillars of *H. armigera.* The active ingredients are used in 'conventional' programme doses, sometimes described as 'full doses'. In some countries, such as Cameroon and Mali, this family of insecticides is not recommended in the third protection window either (Tab. 2). Following this, in Burkina Faso, there is no reduction in the dose and the products used are binary associations of pyrethroids (against caterpillars) and organophosphorous insecticides aimed at aphids, whiteflies and mites (Leynaert, comm. pers.) or neocicotinoid. In Mali's LEC programme, from the second protection window products based on the binary association of pyrethroids-organophosphorous insecticides are applied in half doses (compared to the 'full dose'). Similarly, in Benin, the doses of the last four applications are reduced. They are conducted using a combination of cypermethrin and triazophos (SHERPHOS® 370 or 320 EC depending on the region, north or south). For additional applications, based on thresholds, and according to the country, simple or combined products are used. In Benin, if the mite threshold is exceeded, triazophos (HOSTATHION® 400) should be applied at the rate of 200ml/ha (in the north) or 300ml/ha (in the south). For bollworms, aphid and *H. armigera* thresholds, the products used can be respectively CYPERCAL® 87.5 EC (cypermethrin) at 200ml/ha, GAZELLE ® 200 SL (acetamiprid) at 40ml/ha and LASER ® 480 SC (spinosad) at 100ml/ha.

In Togo, the principle of alternating active ingredients is followed. In the northern area, for example, the active ingredient used for the 'reinforced' treatment against *H. armigera* is different to that used for the first two treatments in the calendar. However, the choice of active ingredients beyond pyrethroids remains limited. Endosulfan, which was originally used, was prohibited in 2009 for toxicological reasons. Spinosad, an active ingredient recognized as being efficient for the control of *H. armigera*, is not generally used because of its cost. Products such as indoxacarb (AVAUNT® 150 SC) or organophosphorous ingredients such as profenofos (CALFOS® 720 EC) are available and used alone (Tab. 3). In Burkina Faso, profenofos has been used at only 500g/ha rather than 720g/ha (used in Togo). Emamectin benzoate could also be used on its own at 9.5g/ha in the next future (Leynaert, comm. pers.). In the case of Cameroon (Prudent, comm.. pers.), there are no thresholds used to control aphids or whiteflies. The treatment decision is taken by the producer and the agent who supports him when they judge that the infestation is too large. A neonicotinoid, acetamiprid, is applied at 10g/ha against aphids or 20g/ha against whiteflies.

The widespread spraying technique is to use a volume of 10 litres of fluid per hectare (Very Low Volume). The operator passes through every third row (0.80m between rows) with a sprayer which has a rotary disc from, for example, the Berthoud company (model C5-10®, equipped with a green nozzle, in Togo) or MicronSprayer (from MicroUlva® with a black nozzle, in Togo, or Ulva Plus®, in Mali and Cameroon). These devices have a reservoir which is carried on the back of sufficient capacity (10 litres). This technique uses the wind to help spread the toxic mixture (water plus insecticide) which always carries an increased risk of contamination for the operator, especially when the wind changes direction during spraying.

ADVANTAGES OF THRESHOLD-BASED PROGRAMMES

In French sub-Saharan Africa the main advantages expected for protection programmes using thresholds (‘threshold programmes’) are economic, combining a reduction in the insecticide use, number of applications or quantity and increase of yields.

Insecticide Reduction

When pest pressure is low, programmes using *sensu stricto* thresholds, such as in Mali and Cameroon, lead to a reduction in the number of treatments. For example, in Cameroon the LOIC programme, tested over 2,000 hectares in 2006 and 2007, led to a reduction in the number of sprays in five of the 17 villages that were monitored (Brévault *et al.*, 2009). In 2008, the farmers who adopted this programme carried out less insecticide treatments than other growers and their average cottonseed yields were no lower (Bertrand *et al.*, 2010).

But the application of thresholds does not always lead to a reduction of all insecticide used. In Togo in 1995, before the implementation of the current ‘reinforced’ programme, 50% savings in cypermethrin were noted by Ayeva and Agossou (2000) with, however, additional use of chlorpyrifos-ethyl to control infestations of the leaf-eating caterpillar *H. derogata*.

Yield Increase

When reducing the number of applications and the volume of insecticides used, there is often an increase in average yields in fields which are protected by threshold programmes. This increase in yield, which could in part be due to closer monitoring in the fields, is dependant on the weather and agronomic conditions. In Mali in 2010, an average yield of 833kg of seed cotton per hectare was achieved with the application of s*ensu stricto* application thresholds, whereas it was 1,051kg two years earlier. In Cameroon in 2009, a comparison of the ‘conventional’ and ‘LOIC’ programmes on 266 producers’ fields showed a gain of 259kg/ha of cottonseed in favour of the latter programme (Gautier *et al.*, 2010).

Economic Balance

Reducing the quantity of insecticides sprayed leads to economic savings. Ayeva and Agossou (2000), in a comparison of the same 20 fields in Togo in 1995, identified a monetary saving of 30% in the costs when using LEC programmes compared to the ‘conventional’ programme. In Cameroon, Gauthier *et al.* (2010) identified an additional cost of 1335cfa/ha (= €2.0) with the ‘conventional’ spray programme.

Calculating margins is an analysis tool often used for comparing crop protection programmes. Thus COMPACI *et al.* (2010) have calculated the margins after repayment of inputs (MARI) in the case of calendar-based (‘conventional’), threshold and LEC programmes (Tab. 4).

In Benin, the Matthess *et al.* (2005) study concerned three programmes actually used in the country, ‘conventional’, organic cotton and LEC, and two programmes defined by ‘extrapolation’, Bt cotton and fair trade cotton. As in the case of MARI, the net margin determined by these authors was in favour of LEC programmes. The profitability of the LEC programmes in Benin is also confirmed by Prudent *et al.* (2006).

Ecological Impact and Human Health

Lower pollution of watercourses and air and greater conservation of the fauna which regulates pest populations are ecological advantages which have not been measured in a quantitative way. The use of indicators of environmental quality is an aspect which merits further investigation. The risk of contamination to the person applying the treatment has not generally been measured. With the possible increase in the number of passages when a threshold is reached at the end of seven days, it could be thought that the risk of contact with insecticides would increase.

MAJOR CONSTRAINTS

Transfer of Knowledge

The first constraints met are those linked to the dissemination of any innovation among smallholders. Communicating in local languages concepts such as the management of insecticide resistance and thresholds may present translation problems (Tourneux, 2003). The coexistence of several protection programmes within the same country, or a new parameter to consider, and several production chains (organic cotton, fair trade cotton) can further complicate the task of disseminating these programmes to small growers.

The major constraint is the lack of knowledge of observers on the biology and ecology of Arthropods (Sinzongan *et al.*, 2004), on sampling techniques and on spotting and identifying problems associated to pests and their damage, plant diseases and mineral deficiencies. Besides field diagnostic tools such as pegboards, audio-visual tools and booklets identifying problems are generally available to personnel who are trained. Beneficial insects (natural enemies of damage-causing insect pests) are also detailed. Observers are members of farmers’ associations. Some, such as those in Mali, are qualified ‘neo-literates’ and are part of a programme to eliminate illiteracy.

Knowledge about pesticides and spraying equipment is sometimes deficient (Sougnabe *et al.*, 2010), including the risks relating to their use and guidelines for protecting the user, linked with the problem of interpreting symbolic messages such as the warning pictograms on bottles (Tourneux, 1993). The option of creating rural schools, proposed by Ochou *et al.* (1998a,c), or Champs-Ecoles des Producteurs (CEP), equivalent to Farmer Field Schools (FFS), offering participative training, have been developed in the sub-regional GIPD programme (Gestion Intégrée de la Production et des Déprédateurs, integrated management of production and pests) in Mali, Benin, Burkina Faso and Senegal (COS-Coton, 2011). But this approach is considered as too expensive (Treen & Burgstaller, 2003).

Compliance with Threshold Principles

Independent of the adoption of threshold protection programmes, the economic crisis of the cotton chains in cotton-producing countries have led to a reduction in the acreages dedicated to cotton growing over the past few years. Investigations carried out within farmers' associations have shown that official recommendations are not strictly applied, with frequent under-dosing of plant protection products for economic reasons (Sinzongan *et al.*, 2004) or the inappropriate use of insecticides on other crops such as cowpea (*Vigna unguiculata*) and tomato (Sougnabe *et al.*, 2010). Given this context, the increase in the number of treatments reported in Benin by Williamson *et al.* (2008) appears difficult to interpret.

Strict compliance with recommendations is difficult to obtain for several reasons. Prudent *et al.* (2007) have shown, for example, in Benin that planters who have learned LEC techniques find it difficult to remember the methods a few years after training. The complexity of the observations which have to be carried out have been mentioned by Sinzogan *et al.* (2004). Another constraint is the necessity of conducting weekly observations. Finally, instances of under-dosage, or non-application of insecticide, despite a threshold being reached, are sometimes seen. The opposite is true too, with cases reported of treatments being carried out even if the defined threshold has not been reached.

Economic Benefits

At the producer level, the job of observation in the field may be given to paid observers. In Togo, for example, where an observer carried out the job in 10 fields in 1995, the payment was 100 cfa (= €0.15) per observation and per field. The payment for this service, when carried out by a third party like this, is a limitation very often mentioned by owner-producers. Another cost mentioned by producers is for the management of the insecticides that have not been used for threshold treatments. This cost has sometimes been included in the purchase price of products destined for producers wanting to apply LEC programmes, but this 'discriminatory' policy has triggered complaints from the producers involved. Packaging in 15 litre containers is a handicap in Cameroon because each drum opened and not completely used must still be paid for.

There are also economic constraints to be considered at the organisational level. The cost of 'cascade' or 'stepped' training is never mentioned. In the programme offered in the Côte d'Ivoire, for example, National Research (CNRA) has to train 205 extension officers, who in turn train 500 'producer-instructors' who in turn train 1,500 producers. As a result of this, by 2012 it is forecast that in three years 1,500 'producer-instructors' and 500 LEC producers will have been trained (Ochou and Amon, 2010). And yet this training represents a major effort and investment for a number of extension staff (Bertrand *et al.*, 2010).

CONCLUSION

In French-speaking sub-Saharan Africa, the current situation for cotton protection programmes using action thresholds reveals a great variation from one country to another. All the same, their development over significant acreages in some countries provides a measure of the interest shown in this type of programme by both producers and the organisations which provide them with technical and financial assistance. The multiplicity of the programmes offered is sometimes, but not always, linked to an ecological reality. For example, in those regions with endocarpic Lepidopteran species (southern Benin, Togo and the Côte d'Ivoire) it is more difficult to envisage the application of thresholds. For cost reasons, there is no general monitoring of adult populations of *Thaumatotibia leucotreta* or *Pectinophora gossypiella* with sexual pheromones, and producers are reluctant to destroy green cotton bolls to evaluate the presence of these pests. Furthermore, the 'rosetted bloom' damage caused by *P. gossypiella* does not allow an action threshold to be established. The situation for these pests therefore remains unchanged since the studies presented by Vaissayre (1994).

An increase in this diversity of protection programmes is a reasonable perspective, linked with new projects under development financed by external institutions (for example, COMPACI, Cotton made in Africa, Better Cotton Initiative). The GIPD programme, which is under development in Mali, is the only project until now which seeks to take natural enemies into consideration through the calculation of target pest/natural enemy ratios, such as those offered in Australia, albeit in a very different context. Producers' knowledge of these beneficial aids to crop production is often limited (Prudent *et al.*, 2007) and a special effort will have to be made in terms of training.

A simplification of the numerous existing threshold-based protection programmes, logically oriented by an ecological and a regional analysis would probably be more satisfactory for a better diffusion among smallholders, and consequently, for a reduction of costs. It will need the development of a network involving researchers, growers, and all the actors of the production chain. For a large scale monitoring of the impact of these new programmes, the contribution of producers will be essential.

A future challenge will be posed to pest management in countries which adopt or will adopt transgenic resistant cotton to Lepidoptera. Until now, only Burkina Faso has very recently grown genetically modified (GM) cotton over large acreages. According to the available information (Leynaert, 2010, COS-Coton, 2011), the first four treatments in the 'conventional' programme were eliminated, while the two applications at the end of the cycle were maintained, to control biting and sucking insects. Research is continuing to evaluate the impact on non-targeted fauna, particularly bugs, and, with National Research, adjustments are being made to the protection programme. In this context, definition of thresholds for likely-emerging pests, as Mirids or Pentatomids bugs observed in other countries for example, will be very useful.

Thus, the challenge is to develop a more theoretical approach for a better definition of threshold - than the empirical one applied in many cases – and at the same time, to succeed by a participative way of extension and field application of the threshold, with a clear message, a good management of inputs and a collective evaluation of the economical benefits of threshold-based programmes.

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