NJAS - Wageningen Journal of Life Sciences 60–63 (2012) 67–78

Contents lists available at SciVerse ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Technical and institutional constraints of a cotton pest management strategy in Benin

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ARTICLE INFO

Article history:
Received 13 September 2011
Accepted 5 June 2012
Available online 19 August 2012

Keywords:
Pesticides
Cost reduction
Socio-organizational innovation
Farmers' empowerment
Benin

ABSTRACT

A pest management strategy entitled Staggered Targeted Control (in French Lutte Étagée Ciblée, known as LEC) has been promoted in Benin since 1988 as an alternative to the conventional spraying strategy in order to reduce production costs and improve cotton yield and quality. Many cotton growers are eager to use LEC and many projects are promoting it but the strategy is not widely applied in cotton growing areas. This study identifies the main reasons that hinder the adoption of LEC. Results show that LEC in its current form could not be considered a viable innovation because of a lack of alignment among key elements within the cotton sector. Socio-organizational arrangements for the management of pesticide leftovers and the setting up of a mechanism for farmers' empowerment are key institutional changes that could shift crop protection towards wider adoption of LEC. Actors in the cotton sector have furthermore suggested a transition towards a participatory approach in extension to improve farmers' expertise in LEC implementation, bypassing existing channels for delivery of LEC pesticides, and promoting alternatives like botanicals and biopesticides.

1. Introduction

The cotton chain in Benin has experienced a significant crisis over the last five years, which has resulted in a drastic decline in production. A peak production of 427,709 metric tons of cotton (lint and seed taken together) was achieved during 2004–2005 [1], mainly as the result of an increase in acreage [2–4]. The average yield per hectare was above 1500 kg in the 1980s but thereafter decreased steadily, settling currently around 1100–1200 kg. Yield is about 25–75% of the optimum [5]. Research station yields of the recommended variety H279-1 are around 3000 kg ha^{-1} but on farm the maximum yield varies from 1800 to 2500 kg ha^{-1} [6]. Since 2004–2005 an increasing number of farmers have left the sector, leading to a reduction in area grown and contributing to a steady decrease in overall production. The decline is related also to falling world market prices, falling farmers' income, high pest occurrence, soil fertility depletion, low and erratic rainfall, and non-application by farmers of the recommendations of the Benin cotton research centre (Centre de Recherche Agricole Coton et Fibre, CRA-CF).

Cotton production in Benin depends on large amounts of external inputs, leading to high production costs. The input costs have increased and so profits have decreased, in particular for resource-poor farmers [7]. The low world market price for cotton, when added to the increase in input prices, has affected the performance of the entire cotton sector. Pesticide prices are predicted to increase further because they are strongly related to the international price of fossil fuels. In this context, reducing pesticide costs, improving cotton yields, and ensuring higher profitability of cotton production for resource-poor farmers is a challenge.

Many studies [8–13] have been conducted on how to reduce production costs in order to improve farmers' profits. Conventional pest control practices rely on calendar-based spraying, using highly toxic chemicals for the purpose of both prevention and treatment of infestation. Two alternatives to the conventional spraying practices have been introduced for cotton protection in Benin: organic cotton, which does not allow any use of synthetic pesticides, and Staggered Targeted Control (Lutte Étagée Ciblée), known by the French acronym LEC, which is partly based on estimating the economic threshold of targeted pests [14]. The economic threshold is the pest population level that warrants control [15–17]. An exploratory study conducted from March to September 2009 [18] indicated that LEC remains a technically promising strategy that could boost cotton production in Benin, both quantitatively and

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http://dx.doi.org/10.1016/j.njas.2012.06.005

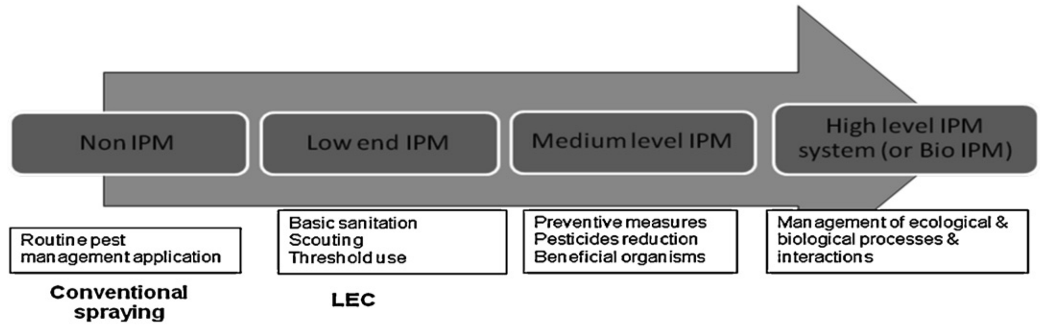

Fig. 1. Location of LEC on the IPM continuum.

Source: Benbrook [20].

qualitatively. Farmers in central to northern Benin, where many farmers have left the sector, have indicated that if conditions would allow the implementation of LEC they would return to cotton production [18]. The LEC strategy consists in cautiously applying full or half the recommended dose of a pyrethroid (Cypermethrin) applied on a calendar basis, followed by the use of specific pesticides applied only when the economic threshold is reached [14]. The LEC calendar in practice, and as recommended by research, involves the use of Tihan 175 O-Teq (Flubendiamid 100–Spirotetramate 75 g l^{-1}) for the first two treatments (exactly as in the conventional crop protection strategy); the four remaining treatments use Sherphos 370 EC (Cypermethrin 70 g l^{-1}–Triazophos 300 g l^{-1}) in northern Benin, and Sherphos 320 EC (Cypermethrin 70 g l^{-1}–Triazophos 250 g l^{-1}) in central and southern Benin. Monitoring the presence and incidence of targeted pests in the cotton fields is carried out on a weekly basis from the 31st day after planting (DAP) until the 122nd DAP. A specific pesticide is applied to lower the population of a targeted pest when the threshold is reached. Calendar spraying has been retained in the LEC to ensure minimum cotton protection in order to avoid significant losses when farmers move from the conventional calendar-based spraying strategy to threshold-based intervention [19]. The threshold is determined by scouting 20 plants along two diagonals of a field (i.e., 40 plants in total). These plants are selected at regular intervals along each diagonal. LEC can be applied to plots of 0.5–5 ha where plants are at the same growth stage [14].

The LEC strategy is an intermediate step between the conventional and an Integrated Pest Management (IPM) strategy. It shares with IPM some common practices, such as the use of an economic threshold [15], but LEC would be located at the lower end of the IPM continuum [20] because it still relies heavily on chemical treatments and uses an established threshold for specific pests (Fig. 1).

A shift from conventional crop protection to the LEC strategy would entail a change in many practices and relationships, as shown in Fig. 2. This figure indicates that LEC requires a socio-technical reconfiguration that would transform the existing cotton value chain, a reconfiguration that would involve both hardware and software [21]. For instance, LEC requires the use of hardware such as synthetic pesticides and a peg-board, which is a small drawing board used by farmers to assess whether the threshold of the targeted pest is reached or not. The peg-board is a didactic tool that assists farmers in identifying the various targeted pests, the threshold levels, and the pesticides to be used when the threshold level is reached, i.e., Gazelle 200 SL (Acetamiprid 200 g l^{-1}) for *Aphis gossypii*, Hostathion 400 EC (Triazophos 400 g l^{-1}) for mites (*Polyphagotarsonemus latus*), and Cypercal 85.7 EC (Cypermethrin 85.7 g l^{-1}) for other bollworms (*Diparopsis watersi*, *Earias* sp., *Pectinophora gossypiella* and *Cryptophlebia leucotreta*). Tihan is also used as specific pesticide for *Helicoverpa armigera*. The application of LEC also entails the acquisition of a certain kind of location-specific and generic knowledge (software). Farmers have to know how to scout their own fields in order to assess whether the threshold has been reached. The learning involved in LEC is a challenge to both farmers and extensionists. The challenge to the farmer is the time to devote to scouting and recording, activities not performed in conventional cotton management. The challenge may be greater for extensionists because they have to train the farmers in how to acquire this knowledge. The very success of LEC depends on the reliability of the scouting and – in the absence of a professional scouting service – this rests on the intrinsic performance of each farmer, i.e., on individual competence.

An innovation such as LEC clearly would need deliberate efforts to create effective linkages among technological arrangements, people, and socio-organizational arrangements (Fig. 2). The process of building coherent linkages and networks around a novel idea or technical device such as LEC has been called a process of alignment [22], meaning that the various aspects and dimensions of an innovation are brought in line with each other. Leeuwis [23] suggests that innovations that are effective at local levels may fail to spread because of an insufficient, partial or unbalanced alignment in higher-level arrangements and relationships. We examine this proposition in this paper.

This study analyses the overall cotton chain to identify the causal factors that prevent large-scale adoption of the LEC strategy and considers interventions that might remove or by-pass the identified constraints. Specifically, the following questions are addressed: are the conditions in place for the LEC technology to become a viable innovation? If not, how to address the constraints in order for this technology to become a viable innovation? And what are possible alternatives?

2. Methodology

2.1. Study area

The study was carried out in the district of N'Dali in the north-eastern part of Benin. It was selected for the diagnostic study partly because it is a transition zone between the largest and medium-sized cotton growing areas in terms of their contribution to national production, and partly because between 1998 and 2003 farmer-based organizations (FBOs) have been involved actively in LEC promotion and implementation on three occasions and they have gained experience through the multi-organizational platform set up by Sinzogan et al. during an earlier phase of the CoS–SIS programme [24].

N'Dali is located in zone II, one of the four zones distinguished in Benin in relation to pest pressure. In the hot dry northern zone (zone I) the following pests are predominant: *H. armigera* Hübner (Lepidoptera: Noctuidae), *Sylepta derogata* Fabr. (Lepidoptera: Pyralidae), *Dysdercus voelkeri* Schmidt (Heteroptera: Pyrrhocoridae), and *A. gossypii* Glover (Homoptera: Aphididae). Mites, *P. latus*

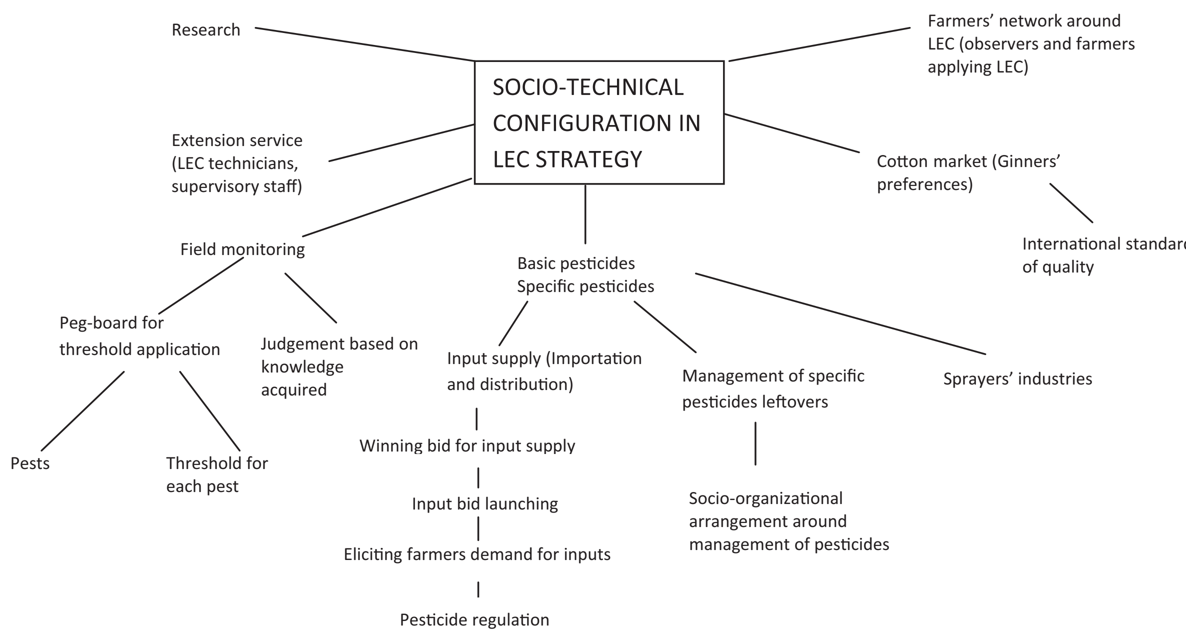

Fig. 2. Linkage diagram of the socio-technical configuration of the LEC strategy.

Source: Adapted from Geels [43].

Banks (Arachnida: Acari: Tarsonemidae) are generally absent from this zone. *H. armigera*, mites, *S. derogata*, and *D. voelkeri* are prevalent in the north-central zone (zone II), whereas in the south-central zone (zone III) the key pests are mites, *P. gossypiella* Saunders (Lepidoptera: Gelechiidae), *H. armigera*, and *C. leucotreta* Meyrick (Lepidoptera: Tortricidae). The most important cotton pests in the humid southern zone (zone IV) are *S. derogata*, *H. armigera*, and *C. leucotreta*. This pattern of distribution confirms that the cotton bollworm *H. armigera* attacks the cotton throughout the country and is recognized as the major cotton pest [25].

Three out of N'Dali's five sub-districts have experience in applying LEC. The diagnostic study was carried out in 11 villages out of a total of 13 involved in LEC implementation in these three sub-districts; two were omitted because no LEC farmer was available for interview in these villages during the time of the study.

First, an inventory was made of the local farmer-based organizations (FBOs), the so-called Groupement Villageois de Producteurs de Coton (GVPC), that have been involved in LEC, generating 15 GVPCs in the 13 villages. Two or three key informants were identified in each of the 11 LEC villages to identify all farmers who still grew cotton and had been involved at least once in LEC implementation. In total, 155 farmers and 17 observers were identified (Table 1). By observers we mean farmers who were directly involved in giving LEC training to other farmers together with the technician appointed for the district.

2.2. Focus group discussions and individual interviews

Focus group discussions (FGD) [26,27] were organized with 10 willing farmers (male and female) in each of the 11 villages. Emphasis was given to the willingness to participate, because most farmers were not available in this period, having left the villages to settle temporarily in fields far away from their homes. The FGDs were held at the date and time preferred by the farmers and observers. The discussions focused on farmers' and observers' enrolment in the LEC process, the reasons underpinning their acceptance of LEC, and the reasons for abandoning the strategy. The organization of training in support of LEC implementation also was discussed. Lastly, LEC constraints were analysed by the FGD participants within four of the villages randomly selected from among the 11.

Individual in-depth interviews [28–30] were conducted with the LEC farmers and observers in the 11 villages who were still growing cotton. The interviews focused on their motivation for implementing LEC, their opinions after LEC implementation, the constraints experienced, and options for overcoming the LEC constraints.

There are some limitations to this approach. The information collected through focus group discussions are about what farmers say they do and think, and not what they actually do or think. Farmers may base their responses and arguments on what was said during the first interventions or on the opinions of the leaders of their group. We used a skilled moderator to keep the discussion free and flowing as naturally as possible and to ensure that participants were contributing equally.

Regarding the individual interviews, we found that some farmers were uncomfortable when the topic was very sensitive. Even despite the assurance given to them at the beginning, they refrained from talking on some specific issues. Other farmers, particularly those who were accustomed to individual interviews, used the opportunity to express the experiences that they had accumulated over a long time and even went beyond the actual topic. Our interviewer did some cross checking to detect the biases.

3. Results

3.1. Process of LEC development and implementation

LEC was initiated in 1988 to deal with the development of resistance of *H. armigera* to the insecticides used, which had resulted from over-reliance and misuse of pesticides by farmers. The process of LEC implementation flowed down to farmers from the national research service via the public extension service (Fig. 3). The development of the strategy unfolded in two stages. The first took place on-station under the entire control of CIRAD (Centre de Coopération International en Recherche Agronomique pour le Développement) and the Cotton Research Centre (CRA-CF)

Table 1
Farmers within GVPC involved in LEC implementation in N'Dali.

GVPC[a]	PADSE[b] (2000–2004)	AIC[c] (2005–2007)	AIC (2009–2012)	Number of LEC farmers	Number of observers
Warikpa		x	x	6	0
Suanin	x	x	x	6	1
Wobakarou	x	x	x	6	2
Kori		x		26	2
Sirarou I		x		14	5
Sirarou II		x		0	0
Gounin	x	x		32	1
Sakarou	x	x		8	2
Tamarou		x		26	2
Kakara		x		5	0
Sinisson		x	x	18	2
Yermarou		x		8	0
Gah Dèbou		x		0	0
Ouénou I	x	x		0	0
Ouénou II	x	x		0	0
				155	17

Source: Diagnostic study 2010.

[a] Groupement Villageois de Producteurs de Coton.
[b] Projet d'Amélioration et de Diversification des Systèmes d'Exploitation.
[c] Association Interprofessionnelle du Coton.
x = villages involved in the LEC programme.

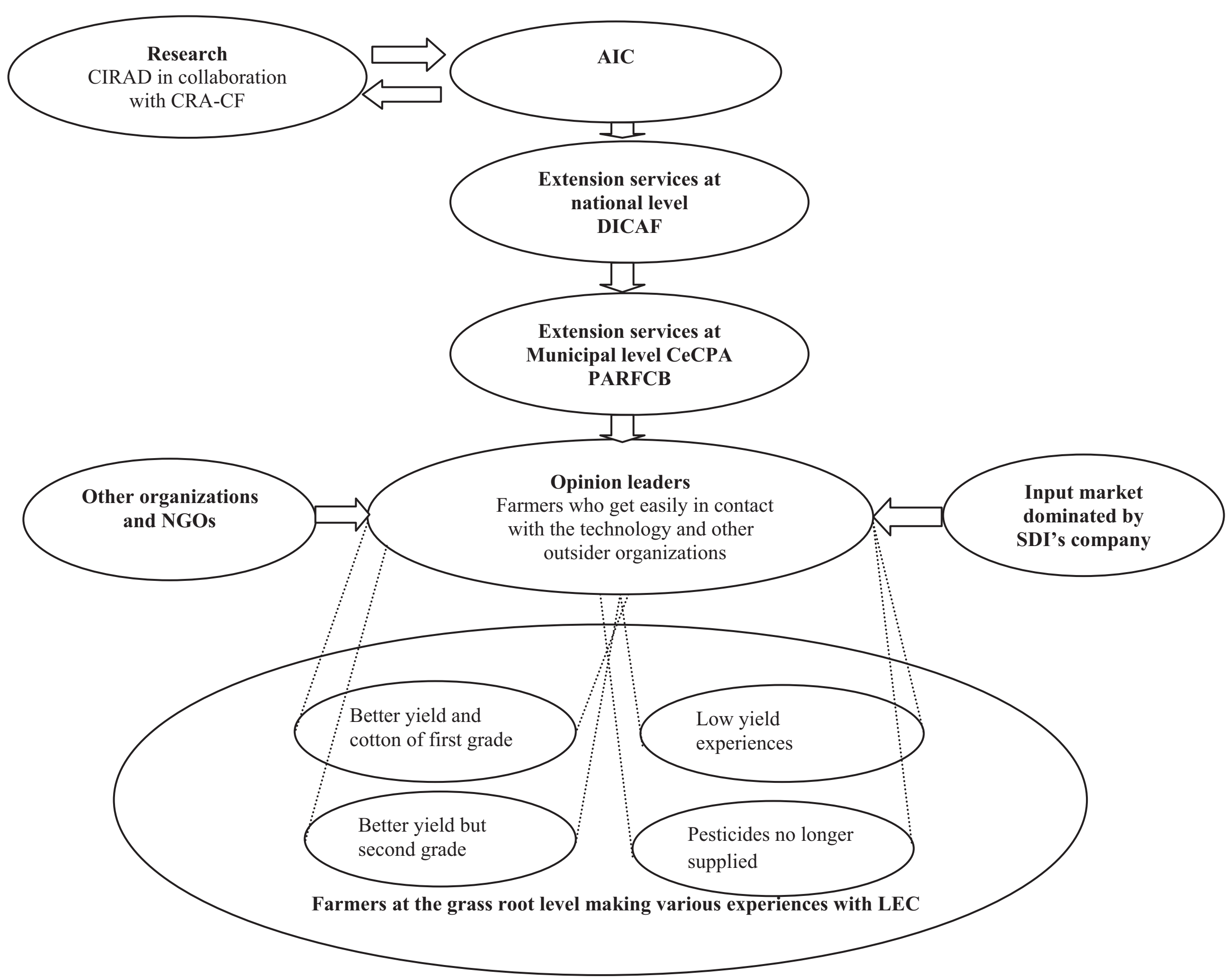

Fig. 3. Process of LEC implementation from national to farmers' level.

Source: Diagnostic study 2010.

Table 2
Characteristics and knowledge of individual farmers interviewed with regard to the LEC ($n = 155$).

Characteristics of individual farmers		Percentages ($n = 155$)	Knowledge about the various aspects of LEC
Non-observers	Do not know how to write and speak French	74 [66.4–80.7][a]	Limited knowledge about targeted pest Lack of knowledge about the threshold Lack of knowledge about the specific pesticides and the calculation of the dose
	Know how to write and speak French	15 [9.8–21.7]	
Observers	Know how to write and speak French	11 [6.7–17.2]	Good knowledge on the targeted pest and the threshold level. Ability to determine the dose of specific pesticide

Source: Diagnostic study 2010.
[a] Values in brackets: 95% confidence interval.

in 1988. During the second stage the technology was refined by carrying out on-farm experiments under the control of researchers but in collaboration with the extensionists from CARDER (Centre d'Action Régionale pour le Développement Rural) and farmers.

In 2000–2001, a technically important change occurred in the LEC strategy: the first field monitoring was brought forward from the 45th day after planting (DAP) to the 31st DAP, thereby increasing the number of observations. Because the frequency of observations was increased, the sampling size was reduced from 60 to 40 plants. The dosage of pesticides was differentiated based on the frequency and abundance of bollworms with an external feeding regime (exocarpic) and bollworms with an internal feeding regime (endocarpic). In northern Benin where the exocarpics were abundant, half a dose of pyrethroid was recommended and in the central and southern part, where the endocarpics were abundant, the full dose of pyrethroid was recommended.

During the second stage, LEC technicians were trained and they in turn trained farmer-observers to monitor the fields of their fellow farmers; the observers received for this service 1500 FCFA (€2.29), which covered the increase that year in the price of a litre of Sherphos. The selection of the observers was based on their ability to speak and write French. They were provided with a peg-board and training in LEC over two or three cotton seasons. Eleven LEC technicians initially were trained by CRA-CF; they were engaged by the extension service to train the LEC observers. By 2007 a total of 1193 observers had been trained in Benin [31].

The farmers who first came into contact with LEC through the observers represent most of the LEC farmers in N'Dali (89% of our survey sample; $n = 155$). Information from the individual interviews indicated that most of these farmers (74%) were illiterate (Table 2) and thus did not themselves meet the criteria to become observers and they were not directly involved in the training process with technicians. For this reason, they were not provided with the didactic material (peg-board). So their understanding of the technology remained limited.

3.2. Farmers' motivations and opinions about LEC

During the interviews the LEC technicians listed numerous reasons why farmers might be motivated to implement the LEC strategy, such as input cost reduction, pest control effectiveness, environmental protection, and yield and cotton quality improvement. These benefits were listed also during the focus group discussions and the individual farmer interviews. The most important benefits mentioned by all farmers were input cost reduction and yield increase. The higher effectiveness of LEC pesticides, in comparison to those used under conventional spraying, were cited by 80% of the farmers. Farmers were less aware of the impact of the technology on the environment: this point was highlighted by only 20% of the farmers. Farmers also believed that the cotton quality was better under LEC, a benefit mentioned by 51% of respondents as one of the reasons why they accepted to be involved in LEC.

Besides these intrinsic factors directly associated to the technology, it was the presence of extension agents and LEC technicians in the field that made it possible for farmers to use the strategy. The focus group discussions made it clear that in the absence of such support and guidance, because of untrained farmers' lack of trust in the effectiveness of the LEC strategy, many did not abandon completely the conventional treatments and they stayed in contact with producers from non-LEC villages to obtain the conventional pesticides. This has created negative feedbacks resulting in the continuing misapplication of LEC and sustaining distrust in its effectiveness.

Moreover, farmers who had been involved in the LEC implementation reported that their opinions had changed concerning claims about its benefits, especially with regard to yield effects. About half the farmers interviewed (49%) had experienced little change in the yield and a quarter reported that their yield had decreased (Table 3). Overall, only 50% of the farmers interviewed indicated that the LEC strategy is more effective than the conventional one. Nevertheless, all farmers interviewed were supportive of LEC's contribution to input cost reduction, cotton quality, environmental protection, and to knowledge improvement.

3.3. Typology of LEC villages

The focus group discussions held in the villages revealed that while the experiences of farmers within a given village were similar, they varied across the 11 villages. Their experiences were influenced by the willingness of input suppliers to deliver LEC inputs to their villages. Four categories of LEC villages can be distinguished (Table 4).

Category I: Villages that experienced low cotton yield. The low yields experienced by Kakara, Sinisson, and Yermarou are directly linked to the poor application of the LEC strategy, especially the failure to apply economic pest thresholds, because of a total lack of training and observers. The farmers had resorted to calendar-based spraying of the LEC, using Endosulfan (banned for use in Benin and replaced in LEC by Tihan) and Sherphos. They did not monitor thresholds and did not apply the LEC pesticides at the right time. They had experienced severe pest outbreaks, and resultant crop damage and low yields.

Category II: A village that experienced poor cotton quality (grade II). Misunderstanding of the technology is at the root of the poor quality of the cotton harvest in Kori. According to the LEC farmers in this village, their LEC cotton is always classified as grade II because of the yellowish colour and stickiness of the lint. This was caused by the development of fungi on the honeydew produced by aphids. This grade lowered the revenue of the cotton growers enormously. According to the focus group discussions, there were an insufficient number of observers in the village and this prevented

Table 3
Farmers' motivations and opinions after LEC implementation.

LEC properties	Modalities	Farmers' motivations for LEC in percentages (n = 155)	Farmers' opinions after LEC implementation in percentages (n = 155)
Cost reduction	Agree	100 [97.0–100.0][a]	100 [97.0–100.0][a]
	Not agree	–	–
Cotton quality	Grade I	51 [42.9–59.0]	100 [97.0–100.0]
	Grade II	–	–
Yield compared with conventional	Higher yield	100 [97.0–100.0]	26 [19.3–33.6]
	Similar	–	49 [41.0–57.1]
	Lower yield	–	25 [18.7–32.9]
Pest management effectiveness	Agree	80 [72.7–85.8]	51 [42.9–59.0]
	Not Agree	20 [14.2–27.3]	49 [41.3–56.8]
Environmental protection	Better protection	20 [14.2–27.3]	100 [97.0–100.0]
Knowledge improvement	Improved	–	100 [97.0–100.0]
	Not improved	–	–

Source: Diagnostic study 2010.
[a] Values in brackets: 95% confidence interval.

Table 4
Typology of villages involved in the LEC implementation in N'Dali.

Categories	Villages	Criteria
I	Kakara Sinisson Yermarou	Villages that experienced a low cotton yield
II	Kori	A village that experienced poor cotton quality (grade II)
III	Warikpa Suanin Wobakarou	Villages that still produce cotton with LEC based on positive experiences with respect to yield and quality
IV	Sirarou Gounin Sakarou Tamarou	Villages that were still motivated to produce cotton with LEC (based on positive experiences with respect to yield and quality) but were not adequately supplied with LEC pesticides by input suppliers

Source: Diagnostic study 2010.

regular monitoring of the fields. Moreover, the observers had not been paid and this did not stimulate them to do the scouting well for their peers. In addition, Gazelle (which is used for controlling aphids) is sold in packages of 1 l and the recommended application rate is 1 l for 25 ha. Each package costs 41,000 FCFA (€62.60) and this cannot be afforded by a single farmer. So the aphids were not controlled and the quality of cotton was compromised.

Category III: Villages that still produced cotton with LEC. LEC farmers in Warikpa, Suanin and Wobakarou were all motivated to apply the strategy and agreed that LEC should be widely applied. However, they experienced delays in the delivery of Sherphos and non-availability of the specific pesticides. They tried to put maximum pressure on the local sales representative assigned by SDI (Société de Distribution Intercontinentale) in N'Dali in order to acquire the appropriate pesticides, and in time. They also mentioned that since 2008 they had not been supplied with sufficient quantities of Sherphos. Although they belong to the group of villages selected for implementation of the triennial LEC plan (2009–2012) they still had not been adequately supplied with the required chemicals.

Category IV: Villages that still were motivated to produce cotton with LEC. These four villages (Sirarou, Gounin, Sakarou and Tamarou) had obtained a good yield and good quality cotton when using the LEC strategy. Yet their experience was limited to the lifespan of a project that implemented the LEC together with the farmers. The farmers indicated that once the project had ended they were no longer supplied with the LEC pesticides and for this reason had returned to conventional treatments to control pests.

3.4. Constraints

3.4.1. Tension around LEC: conflicts of interest

The tensions around LEC arose as soon as the strategy was launched because it threatened input suppliers with a loss of revenue, related to the difficulties of managing the demand for the specific pesticides, the lower overall cost price of the LEC chemicals, and the decrease in the amount of pesticides used in LEC. Demand management was particularly difficult. According to the CRA-CF and the extension organizations (CeCPA and DICAF), it is the threshold application in LEC that leads to fluctuations in the amount of the specific pesticides required for each season, because it is related to the unpredictability of pest abundance from year to year and across regions. Thus the exact quantity of specific pesticides cannot be established with certainty in advance before the start of the cropping season. In a calendar-based strategy the needs are calculated in advance based on the predicted acreage for the cropping season ahead. Moreover, because of the high concentration of the specific pesticides, little is required to control the targeted pest if it surpasses the threshold level. For instance, 1 l of Gazelle is recommended for 25 ha but the cotton acreage per farm rarely exceeds 3 ha.

The unpredictable demand, particularly for the specific pesticides, is a big challenge for all the stakeholders in the cotton chain, and especially for farmers and input suppliers. The input suppliers expressed their dissatisfaction by first increasing the price of LEC pesticides and ultimately ceasing to supply them; since 2007, no LEC specific pesticides have been imported into Benin. Farmers in turn have responded to this situation first by applying the LEC strategy without using the specific pesticides and finally returning to the conventional strategy. The success and wider adoption of the LEC strategy crucially depends on solving the demand estimation problem and motivating the input suppliers to supply the appropriate inputs.

The monopolistic position of SDI within the cotton chain may be responsible for the continuation of the conflict of interest. It is the Talon Group of input suppliers, through SDI, that should deliver the pesticides to the main cotton production area comprising the communes of Banikoara, Kandi, Bembereke, Sinende, N'dali, Pehunco and Kouande. This area is the major LEC production area and accounts for about 40% of all inputs needed by cotton farmers in Benin.

3.4.2. *Constraints to LEC adoption, as perceived by farmers*

Farmers identified three main constraints: field monitoring, availability of Sherphos, and availability of the specific pesticides (Table 5). The constraints associated with field monitoring (75–91% of the respondents) were perceived to be lack of training, the difficulty to pay for the field scouting service, and the amount of knowledge required for scouting. The delay in the supply and the insufficient quantity of Sherphos were seen as major obstacles by 72–80% of the respondents. The non-availability of the specific pesticides and the management of the leftover was mentioned by 61–84% of the respondents.

The problems related to Sherphos have emerged very recently and they have enlarged the scope of the LEC constraints. The triennial plan for disseminating LEC made by the Interprofession (AIC) aimed to reach 50,000 farmers by 2012. However, in 2009, the first year of plan implementation, an insufficient amount of Sherphos was supplied. As a consequence, the willing villages and farmers selected for the implementation of the plan were discouraged and forced to decrease the LEC acreage, and to use conventional pesticides instead for controlling cotton pests. In the season 2010–2011, Sherphos was not available in nearly any of the municipalities selected for the implementation of the triennial plan. It is indeed remarkable that the rules established to regulate pesticide supply are not respected. It can be expected that the lack of sanctions for poor performance will perpetuate these conditions.

3.4.3. *Misapplication of the LEC strategy*

The technical constraints related to the field scouting have led to the misapplication of LEC. This misapplication has to do with the expertise required by the technology and the extension model used for its large-scale adoption. Because the strategy is difficult and relies on the role of observers, farmers at the grass root level do not know much themselves about the principles behind the application of LEC and they depend to a great extent on the observers to tell them what to do. Moreover, the number of observers is insufficient to cover the large area and numerous plots in the zone. It has been impossible to guarantee that monitoring of pest thresholds is well performed for each plot and farm. The effect on cotton yield and quality is noticeable: low yield within GVPCs belonging to category I, and poor quality in those belonging to category II. Farmers' experiences in these villages – quite reasonably – have led them to abandon the strategy (Fig. 4).

Table 5
Constraints to LEC as perceived by farmers.

Opinions	Percentage of respondents ($n = 155$)							
	Field scouting				Sherphos supply		Specific pesticides	
	Lack of training	Difficulty to pay for field scouting services	Hardness of field scouting	Reluctance for field to be scouted by observers	Delay in Sherphos delivery	Insufficient quantity	Non-availability	Leftovers management
Agree	91 [85.0–94.8][a]	75 [67.1–81.0][a]	89 [82.8–93.3][a]	25 [18.7–32.9][a]	80 [72.7–85.8][a]	72 [64.4–79.0][a]	61 [53.1–68.9][a]	84 [76.9–89.1][a]
Not agree	5 [2.4–10.3]	16 [10.9–23.1]	8 [4.2–13.4]	70 [61.7–76.7]	17 [11.4–23.8]	20 [14.2–27.3]	30 [22.8–37.6]	11 [6.7–17.2]
No opinion	4 [1.6–8.6]	9 [5.2–14.9]	3 [1.2–7.8]	5 [2.4–10.3]	3 [1.2–7.8]	8 [4.2–13.4]	9 [5.2–15.0]	5 [2.4–10.3]

Source: Diagnostic study 2010.
[a] Values in brackets: 95% confidence interval.

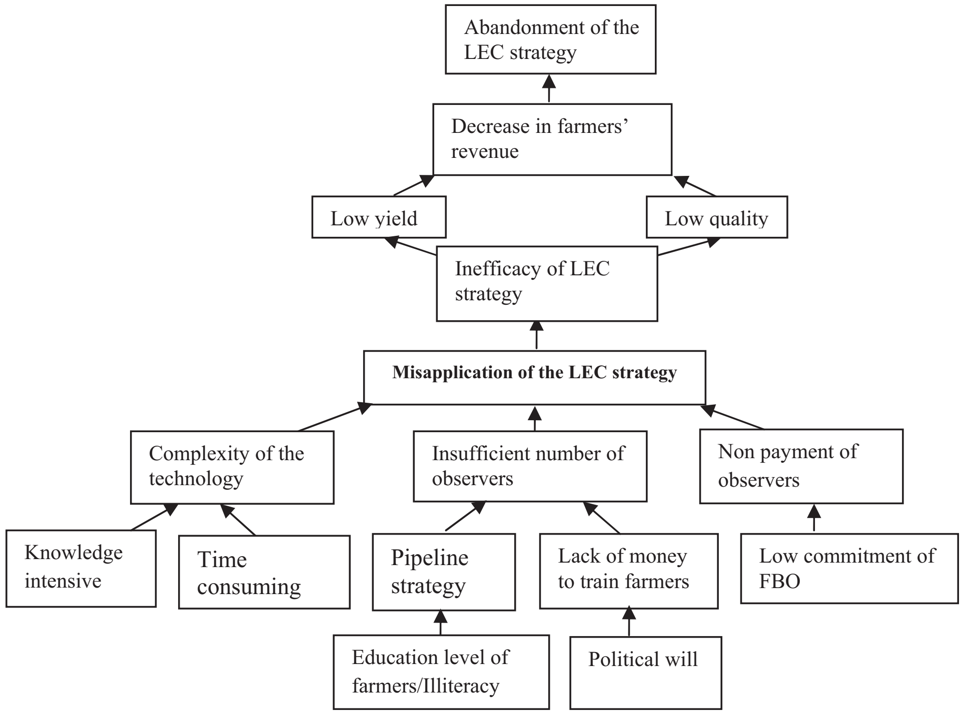

Fig. 4. Analysis by farmers of the technical constraints leading to misapplication of LEC strategy.
Source: Diagnostic study 2010.

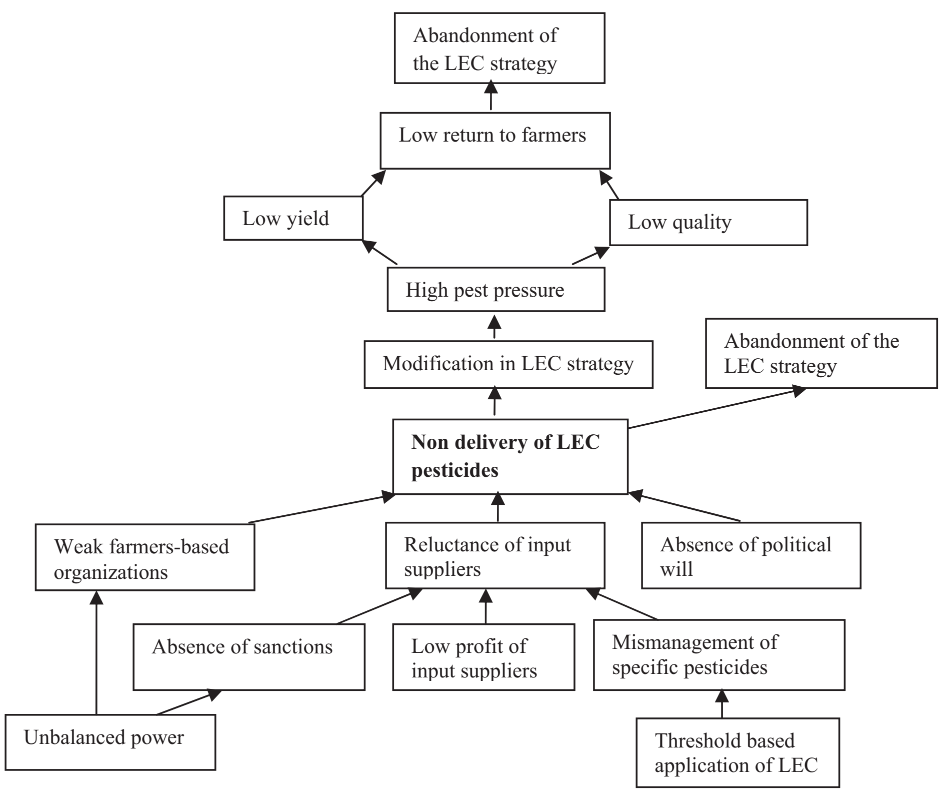

Fig. 5. Analysis by farmers of the institutional constraints that cause the non-delivery of LEC pesticides by input suppliers.
Source: Diagnostic study 2010.

3.4.4. Non-delivery of appropriate pesticides by input suppliers

The non-delivery of an adequate type and quantity of pesticides to implement LEC remains probably the biggest institutional issue to be overcome for LEC to work, because it involves actors other than farmers, especially the input suppliers and, to some extent, also the government. In the survey and the interviews, three reasons were identified as persistent causes of this constraint (Fig. 5): the absence of political will, the weak FBOs,

Table 6
Actors' appreciation[a] of the suggested options for dealing with the problems of the specific pesticides.

Possible solutions	AIC	Input suppliers	Researchers	Extensionists	Ginners	Farmers		Score[c]
						FBO[b]	Percentage of farmers agree (n = 155)	
Training for need expression	+	+	+	+	+	+	22 [15.9–29.4][d]	6
Packing pesticides in smaller containers	+	–	+	+	+	+	78 [70.6–84.1]	5
Seeking alternative crops for use of leftovers	+	+	+	+	+	+	30 [23.3–38.3]	6
Blocks of parcels established with many farmers together	–	+	+	–	+	–	20 [14.2–27.3]	3
Payment of leftovers by farmers	+	+	+	+	+	–	5 [2.4–10.3]	5
Use of the rebate to pay the leftovers	+	+	+	+	+	+	74 [66.4–80.7]	6
Cost sharing by AIC, inputs suppliers and farmers	–	–	–	–	–	+	80 [79.9–80.1]	1

Source: Diagnostic study 2010.
[a] + = positive appreciation; – = negative appreciation.
[b] Farmer-based organizations.
[c] Score is the number of (+) reported for each option.
[d] Values in brackets: 95% confidence interval.

and the reluctance of input suppliers to overcome the challenges.

The absence of political will might be considered a strategic avoidance by state actors to challenge the interests of input suppliers. On the other hand, not investing in LEC could be a national strategy as long as the returns to the state are unknown. The FBOs' weakness is evidenced by their poor management performance and by the influence of ginners and input suppliers on the representatives of farmers within the AIC. The main reason for the reluctance of input suppliers to deal in LEC, apart from potential loss of income, is the management of the specific pesticide stocks, which is a direct consequence of the unpredictable demand for these pesticides. Farmers try to return any unused LEC pesticides to the suppliers, but these demand payment for taking them back in order to cover stocking costs and the risk of the pesticides becoming obsolete. Since the pesticides have not been used, the farmers and their organizations for their part think that this is unfair. The difficulty of managing pesticide leftovers no doubt could explain in part the reluctance of the input suppliers, although they themselves tend to focus more on the problem of demand estimation. The farmers interpret the suppliers' behaviour more cynically, citing the decrease in profit for input suppliers and the power imbalance within the cotton chain that makes it easy for the input suppliers to act only for their own benefit.

3.5. Options for alleviating the constraints

3.5.1. Field monitoring

Among the options to ensure payment for the scouting service provided by the farmer-observers that have emerged from our diagnostic study are: (1) payment by the farmers themselves, and (2) sharing the payment amongst actors, including input suppliers, ginners, government, and the AIC. Our study suggests that farmers are not willing to pay directly for this activity. The LEC farmer-observers we interviewed suggested instead an increase in the price of Sherphos 370 EC and deduction of a percentage of the price increase in order to pay for the scouting service. There is a precedent: during the pre-extension of the LEC by PADSE: the price of Sherphos 370 EC was increased from 5700 to 7200 FCFA (from €8.70 to €10.99) to cover the costs of the services provided by the observers.

The extension agents and staff at the CRA-CF research centres at Parakou and Cotonou suggested that the best solution to the scouting issue was to train each farmer to become an expert in order to be able to monitor his own field. They argued that the illiteracy of some of the farmers would not be a hindrance in developing such expertise among farmers. This solution is worth questioning, since it has been reported that even some extension agents (CPV) close to farmers do not have the expertise in identifying all pests in order to monitor the field as recommended. Some farmers complain that they do not benefit from these agents' advice when the need arises.

3.5.2. Specific pesticides

Our study indicates that the following options for managing the issue of leftovers would be welcomed by all relevant actors: (1) training farmers to estimate demand; (2) packing the specific pesticides in small bottles affordable by farmers; (3) finding other uses for the specific pesticides by introducing alternative crops; (4) establishing aggregated blocks of land to allow farmers to apply the specific pesticides collectively; (5) developing a mechanism for farmers to pay for the leftovers; and (6) using rebates to cover the cost of the leftovers (Table 6). The appreciation of actors for each of these options varies according to their position in the chain. The least favoured option was cost-sharing amongst actors such as the AIC, input suppliers, and farmers. High scores were recorded for training for better expression of demand. However, training farmers for better need expression was indicated only by 22% of the farmers themselves. According to the remaining 78%, even if farmers were well-trained they could never foretell the precise level of pest infestation. The proposal to introduce alternative crops for using up any leftovers was favoured by 30% of the farmers. The remaining 70% thought that the development of this option would take too much time. The establishment of blocks to cluster farmers' fields seemed unfeasible in the current context because of lack of land at village level and the restriction this practice might impose on crop rotation. Only 20% of the farmers agreed with this option. Farmers strongly favoured the packing of specific pesticides in small bottles (78%) and also the use of a rebate to cover the costs of the leftovers (74%).

3.6. Seeking alternative options

During the last two decades, new arenas have been explored by various projects and organizations for the implementation of Integrated Pest Management, ranging from the search for botanicals to the use of biopesticides. Botanicals are aqueous extracts obtained from leaves, seeds, fruits, or roots of various plants such as *Khaya senegalensis*, *Carica papaya*, *Hyptis suaveolens*, *Allium sativum*, *Capsicum* spp. and *Eucalyptus* spp. Sinzogan et al. [3] were able to reduce the number of treatments in cotton from 6 to 4 by applying on a threshold basis the mixture of *Azadirachta indica* (neem) plant extract with half the recommended dose of synthetic pesticides.

Our interactions with farmers indicated that the preparation of botanicals is a time-consuming activity. It implies a lot of work for the farmers, who are already overwhelmed by other farming activities in cotton and food crop production. Thus the search of ready-made products has received attention and has led to a neem oil that is locally produced and available around the 'cotton growing belt'.

The effectiveness of neem oil has been explored over the last four years by the International Institute of Tropical Agriculture (IITA), yielding meaningful results for pest control in cotton [32]. IITA also has been engaged in many experiments on the use of the biopesticides *Metharizium anisopliae* and *Beauveria bassiana*. It is reported that *M. anisopliae* is specific to *H. armigera* and cannot be used for other lepidopteran species damaging cotton, whereas *B. bassiana* can target a wide range of species in this group.

Other experiments based on the bio-efficacy of the entomopathogenic formulations of *Bacillus thuringiensis* (Bt) and *Saccaropolyspora spinosa* (Spinosad) applied on a threshold basis were conducted by Sinzogan et al. [33]. The economic threshold level (ETL) treatments proved to be less harmful for predators like ants, spiders and coccinellids. It should be taken into account that each agro-ecosystem has the ability to self-regulate pest abundance through the action of natural enemies [34]. An interesting avenue for future research is to develop an Integrated Pest Management (IPM) strategy combining the use of ETL with botanicals or entomopathogens, and refraining from the use of synthetic pesticides.

4. Discussion

Many farmers have stopped using LEC because the intrinsic characteristics of the strategy render it too complicated to be applied without the support of farmer-observers. However, because the selection criteria for the observers have been so stringent, many farmers did not qualify for training and the number of observers has remained insufficient to support the large-scale adoption of the strategy.

The fact that most observers have never received payment indicates that there is an institutional problem. The prevailing extension strategy probably is responsible. This is based on a Transfer of Technology (ToT) approach that embodies the view that knowledge emerges from research activities carried out in a protective space, and reaches the users through a pipeline as a ready-made product. The research institute at the beginning of the pipeline is seen as the exclusive source of innovation [33]. The job of extension workers is not to co-develop the innovation to fit institutional conditions in an actual context but only to spread a finished product [35,36]. This top-down strategy has not worked in the case of LEC because it implied that while some farmers were to become experts, others were locked out unless they bought the expertise from the former. The illiteracy of the majority of farmers was used by researchers and extensionists to justify this choice of strategy. However, in the villages studied, the farmers did not accept this as a justifiable reason for excluding them.

The insufficient number of observers gave rise to the neglect of the field monitoring, on which depends the effectiveness of LEC. As a result, yields were low and the quality of cotton was affected due to poor control of pests like aphids. Farmers' expectations that LEC would increase yield [19,37–41], improve quality [39], and protect the environment were compromised. Involving farmers more closely in field testing LEC under their own conditions may be required in order to make the strategy effective.

All farmers in this study agreed that LEC could decrease production costs, since it requires fewer pesticides. The quantity of pesticides saved by LEC ranges from 44% to 54% in comparison to the conventional spraying strategy [37–39]. However, the IFDC (International Center for Soil Fertility and Agricultural Development) [40] has indicated that the application of LEC as cotton pest control strategy does not automatically lead to a reduction in the amount of insecticides and therefore also the costs. When the pest pressure is high, the application of LEC may cost more than conventional pest control. However, it would still be that the additional cost caused by the high pest pressure would be compensated by the higher yields resulting from effective LEC application, compared with the conventional spraying regime [40].

The decrease in the amount of pesticide used has been one of the important reasons that have shaped opinions about LEC as an environmentally friendly strategy [41]. The specific nature of pesticides used on a threshold basis enables farmers to target the specific pests without affecting the rest of the entomofauna, in particular the beneficial insects. Floquet and Mongbo [42] indicated that the higher the degree to which farmers master LEC, the lower the risk of poisoning and affecting human health. This implies more vigorously that the LEC strategy could be promoted for decreasing injudicious use of pesticides by farmers.

The uncertainties associated with the effectiveness of LEC have made many farmers suspicious with regard to its application. Some of these farmers continue to seek conventional pesticides in order to reduce the perceived risks related to LEC. As a result, many adaptations have occurred during LEC implementation, ranging from abandoning the use of economic thresholds to using conventional as well as specific pesticides. An Innovation System (IS) approach, which from the beginning assumes that all key actors need to work together to make systemic change happen, favours the quick and wide uptake of an innovation first developed in a niche at local level because all actors have contributed to the process. However, for this to happen, extension officers would have to shift from their traditional routine towards a new role as facilitators, negotiators or co-developers of LEC.

Even if LEC is well applied and farmers are well trained, adequate quantities and types of pesticide need to be supplied in order for LEC to work. The reluctance of input suppliers to deliver the appropriate pesticides for LEC is based on the difficulty of managing the stocks of the specific pesticides. Indeed, the unpredictability of how much leftovers there might be at the end of a season, because of unpredictability of local pest pressures and the threshold application, poses a serious problem to both cotton growers and input suppliers. The lack of competition in the pesticide market also hinders solving this problem. At present, the market is controlled by a single firm, which is responsible for all pesticide imports. Furthermore, this firm has been assigned the exclusive right to deliver pesticides in many districts, representing in total 40% of the cotton growing area. This company in effect controls the ginners and the individual input suppliers and holds power also over other actors in the cotton sector.

The resilience of the constraints that hinder the application of LEC is proof of a lack of alignment among the actors in the cotton chain and between the chain and the socio-technical configuration. Amongst all suggested solutions only the packing of the specific pesticides in quantities affordable by a single farmer, and the use of a rebate to pay the observers, received high scores from both farmers and other actors in our study. However, with the decline of the cotton sector, no rebate has been returned to farmers and the packing option needs to be agreed by the input suppliers. Bringing the concerned actors together to deal with such institutional constraints may be required but probably would need prior evidence of political will to drive co-ordinated efforts.

There is clearly a divergence of opinions and interests among the social groups involved in LEC. In order for the strategy to become a viable innovation embedded in the higher-level rules of the game, a new socio-organizational arrangement would be required to put the LEC to work. It would be likely to require also the empowerment of farmers to increase their countervailing influence vis-à-vis the other actors in the chain.

5. Conclusions

The intrinsic characteristics of LEC are not sufficient to allow or drive a shift from the conventional treatment to threshold-based spraying. Many constraints still exist and would need to be alleviated to create the conditions that would favour the large-scale adoption of the strategy. Such barriers are related to the illiteracy of farmers, the lack of expertise required by LEC, the time cost of the strategy, the involvement of a large range of pesticides, the management of the leftovers of specific pesticides and, to a large extent, the reluctance of input suppliers to deliver the specific pesticides. The input suppliers hold great financial and political power over the whole cotton industry, which enables them to bypass the institutional set up for the regulation of the cotton sector and thwart the intentions of the LEC strategy.

Given the nature of the barriers identified, it is clearly a big challenge to remove all the constraints simultaneously in order to create optimal conditions for LEC to work. Farmers could play key roles in the process through their organizations but farmer organizations at present are too weak to have sufficient countervailing power in negotiations to bring about such a restructuring. Moreover, the trends occurring in the cotton industry are not supportive of FBOs. The problems indicated in this study lie mostly beyond the farm gate. It seems they would be most likely to be resolved by using an Innovation System (IS) approach in which all actors come together to reflect on and seek solutions for the common problem they are facing; such an approach at present lacks any compelling driver. The input suppliers in particular do not accept to be part of any discussion related to LEC.

In such a context, the search for alternatives to LEC and to its specific pesticides might be a better option to explore. Given the promising results of experiments with alternatives, it seems that it is technically possible to control cotton pests by using entomopathogenic formulations and botanicals only, at the same time avoiding further development of resistance, while safeguarding the natural enemies. An ecologically well-grounded IPM strategy in cotton should therefore be possible provided the socio-institutional issues elucidated in this study would also be addressed.

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