Cotton in Benin:
governance and pest management

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Cotton in Benin: governance and pest management

Codjo Euloge Togbé

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To my spouse Brigitte

&

My daughter Couronnée

Abstract

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Pests are one of the main factors limiting cotton production worldwide. Most of the pest control strategies in cotton production rely heavily on the application of synthetic pesticides. The recurrent use of synthetic pesticides has large consequences for the environment (air, water, fauna, and flora) and human health. In cotton growing areas in Benin, targeted pests develop resistance, and this resistance is extended to malaria mosquitos. Other negative impacts are pest resurgence and secondary pest outbreaks due to the effects on the beneficial insect fauna. This dissertation addresses the technical and institutional constraints hindering the wide-scale use of staggered targeted control, 'Lutte étagée ciblée' (LEC, in French) for cotton production.

Wider adoption of LEC can only be achieved if some institutional changes were to occur, such as in the role of input suppliers in order to improve the procurement of LEC pesticides. This can only happen if farmers would be empowered and better organised. Locally available phytochemicals and biopesticides can be used to address problems related to the difficulty in obtaining synthetic pesticides, as well as their negative environmental impact. Neem oil (*Azadirachta indica*) and *Beauveria bassiana* are good candidates to be used in an integrated pest management approach, as their impact on the beneficial fauna is minimal. We tested whether the efficacy could be enhanced by using mixed formulations of neem oil and bio-insecticides, but yields obtained with neem oil used alone and mixed with biopesticides were not different. This suggests an absence of a synergistic effect between neem oil and *B. bassiana* (Bb11) and between neem oil and *B. thuringiensis.* The combination of biopesticides increased the cost of production more than that of the conventional treatments, compromising the profitability of such formulations. Participation in the research process increased farmers' knowledge on pest and natural enemy recognition. The increase in knowledge did not lead to any modification in farmer practices with respect to the use of neem oil and *Beauveria*, but it led to a significant change towards threshold-based pesticide applications. Policy implications for successfully changing farming practices are discussed.

Key words: cotton, synthetic pesticides, neem oil (*Azadirachta indica*), *Beauveria bassiana, Bacillus thuringiensis,* field experiment, farmers' participation

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Chapter 1

General Introduction

Codjo Euloge Togbé

Importance of cotton production

This research on improving the cotton pest management system in Benin was done within the framework of the Convergence of Sciences-Strengthening Innovation Systems (CoS-SIS) programme. The programme focuses on alleviating institutional constraints; this could potentially allow African farmers to double or even treble their production (Hounkonnou et al., 2012; Röling et al., 2012). The link between technology and institutional constraints has been reported in many studies conducted in the course of the first phase of CoS-SIS (Adjei-Nsiah, 2006; Ayenor, 2006; Dormon, 2006; Kudadjie, 2006; Nederlof, 2006; Saïdou, 2006; Sinzogan, 2006a; Vissoh, 2006; Zannou, 2006) and was also shown in the recent work by Mapfumo et al. (2013). By “institution” is meant the ensemble of deeply embedded norms and values, legal and regulatory frameworks, policies, governance, and negotiated agreements that are inherent to structures, networks, and value chains determining individual behaviours (Williamson, 2000).

In Benin, working groups of high-level experts (Röling et al., 2012) selected three priority areas representing national and smallholders’ interests, to participate in the CoS-SIS programme (see for details of IS in the section on theoretical background). Cotton production is one of these three areas, as this crop is of multidimensional importance in the country.

From an economic point of view, cotton is the most important cash crop in Benin, grown by 325,000 farmers and involving much commercial activity. It generates 45% of the national tax revenue, 80% of export revenues (AIC, 2006; Aprobes-Bénin, 2007; Midingoyi, 2008), and constitutes 13% of the Gross Domestic Product (GDP) and 60% of the industrial base (Performances, 2008) of the country. Approximately 35% of farming households are involved in growing this crop. It constitutes a source of revenue for three million people and represents about 2/3 to 3/4 of Benin’s agricultural income (Glin et al., 2006; Ton et al., 2000). Cotton farming therefore receives special attention and attracts funding from the government. Due to an increase in the cost of inputs driven by the international market, the cotton sector is subsidized, in order to permit farmers to access inputs at an affordable and uniform price across the country. Moreover, all farmers have access to inputs on a credit basis. The cotton produced is bought at a predetermined price agreed upon by ginners and farmers. At the beginning of each season, government representatives participate in price negotiations between all parties.

The contribution of cotton to the social development of the country is evident. In the cotton growing areas, production of this crop has contributed to the improvement of physical and social infrastructures and facilities such as rural roads, schools, warehouses for input storage, water supply systems and hospitals. At the household and individual level, cotton provides a living for over 50% of the population (EFJ, 2007; Glin et al., 2006), allowing farmers to acquire motorbikes, build houses, and pay school and healthcare fees (OBEPAB, 2002), as well as for social events such as weddings and ceremonies. Producing this crop is very labour intensive and involves both male and female workers. Bordering countries such as Burkina Faso and Togo also supply labour for cotton production in northern Benin. These migrants work under contract during the cropping season, and local authorities are sometimes involved in these arrangements.

Cotton production also plays a major role in sustaining food security in the country because it serves as a means through which fertilizers are provided to other food crops such as maize, sorghum and rice. This relationship between cotton and food crop production is sustained by the input supply system, which allows farmers who accept to grow cotton to receive an additional amount of fertilizers for food crops. Because this additional fertilizer received by farmers as a bonus for their commitment to growing cotton is generally considered to be insufficient, a certain amount of fertilizers intended for cotton production is deviated to food crops. Furthermore, the maize, which comes to maturity before cotton, is sold and the revenues are used to hire labour to harvest cotton.

From a political perspective, cotton production is integrated in a vertical structure linking farmers, input suppliers and ginners in an interdependent network (Association Interprofessionnelle du Coton, AIC), which is controlled by a handful of people appointed at the national level. The governance and management of this organization are often subjected to criticism, protests and reforms that seem not to address the real problems faced by the sector. Research is led by the Cotton Research Centre (CRA-CF), whose autonomy has become increasingly limited by the growing power of the AIC. The extension is the responsibility of the Ministry of Agriculture (MAEP). AIC and MAEP govern the whole sector, but their collaboration is not without conflict and sometimes generates crises that undermine the performance of the cotton sector. Farmers also take advantage of the poor organization of the cotton sector and bypass the institutions established to control the input supply system. Ginners and input suppliers are very powerful and politically integrated and they tend to exert control over the other parties involved, especially farmers and their organizations. This results in an information asymmetry and lack of transparency which are the root cause of the current crisis now facing the entire sector (Chapter 3).

The current government has had a pivotal role in decision-making for cotton production since 2006. Cotton has shifted from a marketable commodity to a political one, because many farmer leaders are involved in municipal governments and compete for power and wealth at the municipality level. Once these farmer leaders are elected, they have connections with the central government, which considers cotton growers as an important source of political support.

Cotton production in Benin

The environmental conditions prevailing in each region influence the contribution of cotton production to the total output of the country. In this regard, Benin is divided into four zones (Figure 1): North (Alibori and Atacora), North Central (Borgou and Donga), South Central (Zou and Collines), and South (Ouémé, Plateau, Couffo and Mono). These four zones differ in soil quality, rainfall, temperature and farming practices (Table 1). As a result of this variation, the occurrence and abundance of pests also varies (Youdeowei, 2001).

Table 1: Growth conditions of cotton plants and characteristics of agro-ecological zones in Benin

Agro-ecological factors	Cotton plant requirements	Prevailing conditions			
		North	North Central	South Central	South
Average temperatures (°C)	26-28	24.9-32.5	24.9-32.5	25-30	25-28
Rainfall (mm)	>700	900-1100	1100-1300	851-1491	900-1200
Dry season	Well-marked dry season	One dry season	One dry season	Two unequal dry seasons	Two unequal dry seasons
Soil	Sandy clay loam or sandy clay	Sandy clay	Sandy clay	Leached sandy clay	Sandy clay scrap
Sunshine in hours per day	>12	>12	>12	>12	>12
Land preparation	Deep plowing	Flat plowed field	Flat plowed field	Ridge	Ridge
Planting calendar	-	1-20 June	10 June-5 July	25 June-10 July	25 June-10 July

Adapted from Matthess et al. (2005) and Sinzogan (2006a)

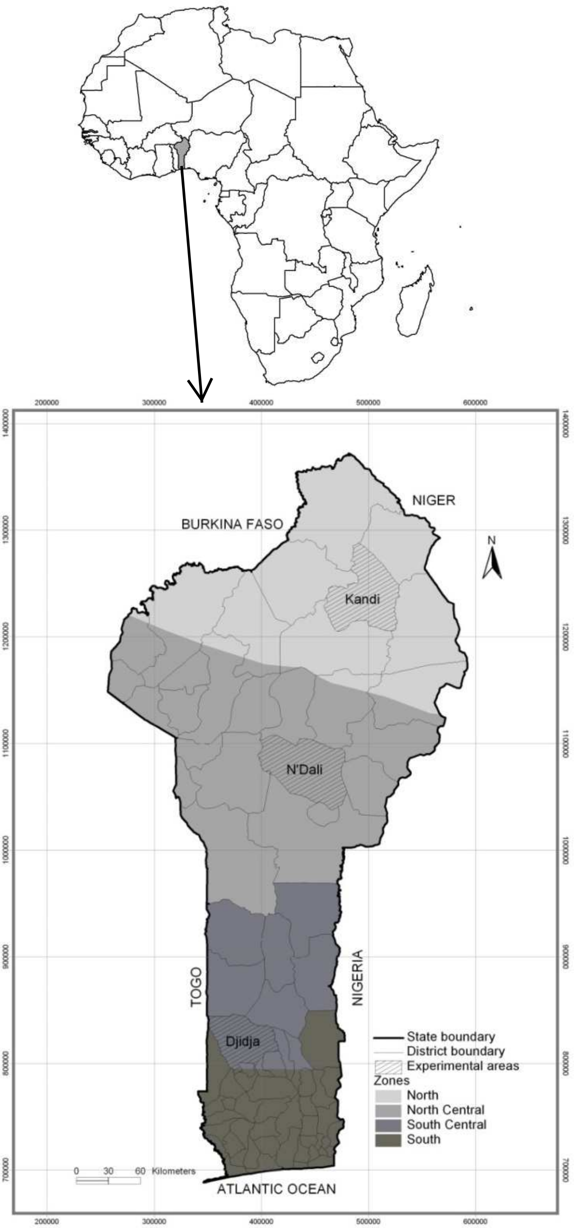

Figure 1: Cotton production zones and experimental sites in Benin

In general, the level of cotton production in Benin runs parallel to the quantity of acreage cultivated. The average production level of the five years before (1996-2000) and after the liberalisation of the cotton sector (2001-2005) is similar, or 348,363 and 340,293 tonnes, respectively (Midingoyi, 2008). The highest production level ever was reached during the 2004-2005 season (427,000 tonnes). Since then, the production has hardly exceeded 200,000 tonnes and there has been an overall downward trend since 2000. The lowest production level was recorded in 2006, when the production fell to 190,000, indicating a decrease of 56% compared with 2005. This decline in production was due to decreased acreage (29%), a reduced number of cotton growers, and lower yields (27%) (Aprobes-Bénin, 2007). This decrease in production weakened Benin's position on the world cotton market and reduced the export revenues of the country, thereby decreasing its contribution to the social economy of Benin.

From the 1960s to the early1980s, the average yield for cotton was approximately 1500 kg/ha. At that time, extension services played an important role in cotton farming and large amounts of inputs in the form of fertilizers and pesticides were provided. The effect of these measures did not last, as yields had fallen to below 1000 kg/ha by 1989. Schemes to counter this downfall were implemented and yields raised to 1250 kg/ha in 1994. But since then and until now, the downward trend has continued, and since 1998 the average yield has ranged between 1000 and 1100 kg per hectare. The potential yield on-station is 3,000 kg/ha and on-farm 1,800 to 2,500 kg/ha, for the recommended variety H279-1, which is predominantly used by farmers (Fadoegnon and Midingoyi, 2006). Therefore, it is necessary to create a conducive institutional environment to improve cotton production. The Innovation System (IS) approach is one such approach.

Background and statement of the problem

The recurrent crisis in the cotton sector is illustrated by fluctuations in production levels, which are the results of technical, socio-economic and institutional factors. Among the technical factors affecting cotton yields, pest and disease attacks have been ranked highest for many reasons. Pests and diseases have a devastating effect on the crop. Moreover, pest management has been associated with the misuse of pesticides, the development of resistance, pest resurgence and secondary pest outbreaks, and health problems.

Cotton is subject to attacks by a wide range of pests from the seedling stage up to the harvest (Matthews and Tunstall, 1994; Vaissayre et al., 1997). The susceptibility of the cotton plant to pest attack is mainly due to the introduction and adoption of high-yielding varieties and hybrids (Mancini, 2006). As a consequence, the use of synthetic pesticides has increased exponentially. Pesticide treatments constitute 30-40% of production costs in Benin (Abate et al., 2000; Akogbeto et al., 2005; Sinzogan, 2006b; Sinzogan et al., 2006). The nationwide pest control strategy is calendar-based, which consists of six fortnightly applications of synthetic pesticides starting from day 45 after seedling emergence. In most cases, the number of applications is higher than that because farmers erroneously expect a yield increase by spraying more than recommended. Synthetic pesticides continue to be widely used in view of their ease of application and quick effect (Dhaliwal and Arora, 2001). This strong dependency of cotton production on external inputs makes production costs high. Those costs have increased and for that reason profits have decreased, in particular for resource-poor farmers (Akogbeto et al., 2005).

The history of pest management strategies in Benin, as in other cotton growing countries in West Africa, is closely linked to the control of *Helicoverpa armigera*. This major cotton pest occurs in varying levels of abundance in the four agro-ecological zones (Table 2). The synthetic pesticides used to control the pest complex in cotton are acutely toxic to humans, and there is a high likelihood of adverse effects on human health and the environment, as well as development of pest resistance. In the late of 1990s, insecticide resistance in *H. armigera* emerged as a result of the widespread and continuous use of pyrethroid pesticides (Martin et al., 2002; Martin et al., 2000; Ochou et al., 1998). Resistance of *H. armigera* to pyrethroids had appeared in many other cotton-growing countries in the world before being noticed in West Africa (Afrique Agriculture, 1999; Martin et al., 2000; Martin et al., 1997; Ochou et al., 1998; Sawicki, 1986; Vaissayre, 1996). It became essential to device a new strategy of pest control, with focus on the management of resistance of *H. armigera* to pesticides. Thus, endosulfan was reintroduced for the first two applications of the season. Endosulfan is an organochlorine belonging to the same family as DDT and Dieldrin. It was used in the past for controlling cotton pests, but was removed from the West African Cotton system because of its high toxicity. Though less persistent, it was classified by the US Environmental Protection as Class I, or pesticides with high acute toxicity. The World Health Organization (WHO) classified endosulfan as moderately hazardous (class II).

The effects of this organochlorine insecticide were immediately noticed after the first season it was applied. Serious pesticide poisoning problems emerged, especially in the Borgou and Atacora departments in northern Benin. The extension service in Parakou (Borgou department) reported at least 37 deaths and 73 cases of serious illness due to pesticide poisoning. Following these reports, the non-governmental organization OBEPAB conducted an independent investigation in the Borgou area, recording 137 cases of serious poisoning and 10 confirmed deaths. Endosulfan was responsible for 60% of these cases, affecting mostly young people, with 80% of the victims being less than 40 years old (Ton et al., 2000).

Table 2 : Pests attacking leaves, flowers, and bolls of cotton plants

Zones and experimental districts	Plant parts	Pests	Abundance
North (Kandi)	Leaves	*Syllepta derogata*	+++
		Aphis gossypii	+++
		Nisotra sp, Podagrica sp.	+++
		Spodoptera littoralis	+•
	Squares, flowers and bolls	*Helicoverpa armigera*	+++
		Earias sp.	+•
North-Centre (N'Dali)	Leaves	*Polyphagotarsonemus latus*	++
		Syllepta derogata	+++
		Aphis gossypii	+•
		Nisotra sp *&* *Podagrica* sp.	+++
		Spodoptera littoralis	+•
	Squares, flowers and bolls	*Helicoverpa armigera*	+•
		Cryptophlebia leucotreta, Pectinophora gossypiella	+•
		Diparopsis watersi	+•
Centre (Djidja)	Leaves	*Polyphagotarsonemus latus*	+++
		Syllepta derogata	+
		Aphis gossypii	+
		Syllepta littoralis	+•
	Squares, flowers and bolls	*Cryptophlebia leucotreta,*	+++
		Pectinophora gossypiella	++
		Diparopsis watersi, *Earias* sp., *Helicoverpa armigera*	+
South	Leaves	*Polyphagotarsonemus latus*	+++
		Syllepta derogate	+ +
		Aphis gossypii	+•
		Spodoptera littoralis	+•
	Squares, flowers and bolls	*Cryptophlebia leucotreta*	+++
		Pectinophora gossypiella	+•
		Diparopsis watersi, *Earias* sp., *Helicoverpa armigera*	+

\+ = Low infestations   +• = Low to average infestations
++ = Average infestations   +++ = High infestations
Source : Adapted from MAEP/AIC (2009)

Despite important awareness campaigns and extensive reports made on radio, 241 cases of poisoning and 24 deaths were also recorded the following season, 2000-2001 (Tovignan et al., 2001). The causes of endosulfan poisoning and deaths are attributable to gross misuse of pesticides by cotton farmers, who disregard information received during training on the safe handling of pesticides. Instances of endosulfan misuse ranged from voluntary suicide attempts by directly drinking pesticides, consumption of food items that were contaminated with pesticides during storage in homes, consumption of food crops grown within sprayed cotton fields, consumption of stored grain treated with endosulfan, and use of empty pesticide containers for storing drinking water, soft drinks, cooking oil, or other consumables (Glin et al., 2006; Ton et al., 2000; Tovignan et al., 2001). Throughout the country, many adverse effects of endosulfan were also reported on snakes, rodents, birds, frogs, and earthworms. The scale of such threats to the environment, especially to the food web, can be appreciated through these two following statements by farmers, reported by Ton et al. (2000): '*Earthworms emerged from the soil, and subsequently died. Then, birds came to eat the earthworms and they died as well;*' and '*This year the product is very effective. It kills everything–even snakes. Earthworms appeared from the soil in large numbers immediately after spraying, and subsequently died. Even the leaves of the cashew nut trees I planted next to my cotton field turned brown due to the new product.*'

In 1988, concurrent with the use of endosulfan for the management of resistance of *H. armigera*, the Cotton Research Centre (CRA-CF), started experimenting with a new method, known in French as 'Lutte Étagée Ciblée' (LEC), in collaboration with researchers from the 'Centre de Coopération Internationale en Recherche Agronomique pour le Développement' (CIRAD). This method involves a basic protection of the cotton plant using half the dose of synthetic pesticides applied on a calendar-basis. This protection security, as it was termed by Silvie et al. (2013), has been maintained in order to reduce the risk introduced by the change from a pre-set date spraying to threshold-based interventions. This basic protection is followed by the monitoring of the cotton field to detect the threshold level of pests such as bollworms (*H. armigera*, *D. watersi*, *Earias* spp.), leaf-eating caterpillars (*S. derogata*, *A. flava*, *S. littoralis*) and aphids *A. gossypii*. The scouting begins 31 DAE and is carried out every week until 122 DAE. When a pest threshold is reached, additional treatments are then carried out with half the recommended doses of specific pesticides. The choice of the active ingredient and the quantity applied depends on the pest density observed in the field (Silvie et al., 2001). The scouting procedures are facilitated by a decision-making chart supplied to farmers. This device, also called peg-board, gives information about the targeted pests, their thresholds, and the appropriate pesticides to control them. Pyrethroids are used against various species of bollworms, and organophosphates against aphids, leaf-eating caterpillars, and also mites (see Chapter 2). Each specific pesticide is meant to target only one pest species, because it contents one active ingredient.

The exploratory study conducted in 2009 (Adjei-Nsiah et al., 2013) identified the LEC strategy as a promising technology. This method was considered the entry point of this thesis. The many strong points of LEC include improvement of cotton yields by providing effective protection to the cotton crop and increase of farmer profits by reducing production costs, as LEC often requires fewer pesticide inputs than the conventional strategy (Kpadé et al., 2008; Silvie et al., 2001). However, two major technical and institutional constraints hinder its large scale adoption: 1) the lack of competence among farmers in monitoring pests and diseases in the field, and 2) problems in obtaining the LEC-recommended pesticides. The issue of field monitoring falls into two categories. The first one is the inability of some farmers to carry out the scouting because of the intense knowledge and time required. The second related category is the lack of capacity to provide the necessary training to a huge number of farmers at grass root levels.

Problems in obtaining the specific pesticides needed is due to the economic-threshold principle in LEC, which makes it impossible to accurately know beforehand the exact quantity of specific pesticides that will be needed by farmers. As a result, some amounts of certain pesticides are not used, because the economic threshold of targeted pests is not always reached. After two years, leftover pesticides cannot longer be used, and this can trigger conflicts of interest between farmers and input suppliers.

The search for sustainable solutions to alleviate these constraints calls for interactions among a wide range of stakeholders, including natural and social scientists from various backgrounds. During the last decade, there has been a growing interest in building networks, platforms, alliances, and so-called innovation systems (Scoones and Thompson, 2009). All these tools are derived from participatory approaches which intend to achieve sustainable outcomes through multi-stakeholders processes.

Some NGOs and development projects have championed innovations by using one of the participatory approaches taking into account farmers' needs. They co-generated, with farmers, knowledge in a people-centred Innovation and Learning process (Chambers, 2009). In such a context, farmers are considered as partners, collaborators, and innovators, and are empowered to set a demand-driven research and development (R&D) agenda with their development partners (Scoones and Thompson, 2009). In Benin, the R&D approach currently used resembles the Transfer of Technology (ToT) system, using demonstration plots. At most, farmers are considered as end-users and are involved in certain experiments. This pipeline approach using technological packages is more adapted to the uniform and controlled conditions of industrial and green revolution agriculture than most of the sub-Saharan African agriculture, which has very diverse features (Chambers, 2009). The LEC strategy is a ToT approach, but needs some adaptations in order to be workable and acceptable to farmers (Nederlof and Odonkor, 2006; Röling et al., 2004; Röling, 2002; Scoones and Thompson, 2009). This requires a paradigm shift in which the roles of scientists, extension officers, and other non-farming professionals are redefined from that of being innovators to becoming technology intermediaries, translators, negotiators, and facilitators. This also requires attitudes and aptitudes beyond their traditional roles (Scoones and Thompson, 2009).

Overall research objectives

The aim of this research was to identify and test solutions for overcoming the barriers to wider adoption of LEC and Integrated Pest Management (IPM), through technical and institutional innovations. The research attempted to develop in a collaborative way with farmers an ecologically well-grounded IPM with alternatives to synthetic pesticides. These alternatives should not only be effective but also easy to access by farmers and at affordable prices. By creating a conducive environment for the supply of these alternative products, farmers could become less dependent on imported pesticides. As a result, the adverse effects on human health and the environment could be reduced considerably, while improving returns to farmers. Specifically, this thesis explores and analyses

- opportunities to address or bypass the constraints that limit large scale adoption of LEC;
- the rapid changes that occurred under the reform initiated in 2009 in order to identify the opportunities for alleviating the constraints of LEC;
- the effectiveness of a pest management strategy that is completely need-based and using only biopesticides or botanicals, from a biological and socio-economic point of view
- the contribution of participatory research in changes occurring in farmers’ knowledge and farming practices in integrated pest management.

Theoretical background

Integrated Pest Management: Concept and principles

According to Dhaliwal et al. (2004), the first definition of IPM was proposed in 1956 by Stern and co-workers (Stern et al., 1959). Since then more than 67 IPM definitions have been suggested (Bajwa and Kogan, 2002). A broad definition was adopted by an FAO Panel of Experts (FAO, 1967) : ''*Integrated pest control is a pest management system that, in the context of associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury*".

Taking into account the large variability in IPM practices, Benbrook (2002) proposed a new term: the IPM continuum. According to the author, IPM systems exist in almost limitless varieties along an IPM continuum. It includes four major zones/levels: no, low, medium and high or biointensive IPM. Farmers in the 'no-IPM' zone manage pests with routine pesticide applications. Low-level IPM depends on basic field sanitation, scouting and pesticide applications linked to thresholds. Medium- level IPM shifts a portion of the control burden to largely preventive measures and requires farmers to bypass most applications of pesticides because of the greater degree of reliance on beneficial organisms. High-level IPM systems manage pests largely through multi-tactic prevention-based interventions. Biointensive IPM (or Bio IPM) lessens pest pressure through management of ecological and biological processes and interactions. Despite the variation in the definitions proposed, the core element that always remains is the judicious use of pesticides based on economic threshold levels (ETL) (van Huis, 2009).

More recently, societal and economic considerations were added to the technical and environmental dimensions of IPM. The definition of Kogan (1998) encompasses these emerging aspects and provides an overall picture of IPM: "*IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment.*" This definition suggests to address pest management issues in an interdisciplinary way, from various perspectives. One thing that all IPM promoters should keep in mind is the pivotal role of farmers as end-users of IPM. The success of IPM depends on them, so they should be central to IPM program implementation. Hence the need for empowerment of farmers (van Huis, 2009), which constitutes the core motive of this study.

What is economic threshold level?

The concept of economic injury economic threshold level (ETL) was developed to help farmers identify when the benefits of applying a pest management practice (a pesticide) exceed the costs, so that it pays to apply it (Cousens, 1987; Pedigo et al., 1986). In other words, the ETL is the pest population level that warrants control. Economic thresholds are usually considered as a critical component of IPM systems (Bottrell, 1979). The concept is employed in regulating most key insect pests. The concept has been applied not only to insects but also to weeds (Marra and Carlson, 1983).

In practice, the application of economic thresholds in pest management involves identifying when incremental pest damage is equal to the cost of preventing it (Norton, 2007). Thus, the success of this method depends mainly on the reliability of the established threshold and the sampling procedure.

Some authors have expressed concerns about certain key points when using the threshold. Horne and Page (2008) indicated that the thresholds elude many variables that can influence the ability of pests to cause actual economic damage. They embedded this reflection in a question: '*given a number of pests (n) how much damage would they cause with (x, y or z) beneficial species present, at different planting dates (and so different growth rates), with different planting rates, different weather conditions, different value of crops at different times and in different years with the crop worth different amounts?*' That is why Hutchins (1995) suggested dynamic thresholds that account for changing economic or biological variables, in preference to traditional, static thresholds. Concerning the sampling procedure, it is important to seek the best option that will reduce the workload of the farmers while remaining accurate. But prior to the application of thresholds, the farmers' knowledge about the biology of pests and their natural enemies is of crucial importance.

What about the sampling?

Whatever the accuracy of the established threshold is, its success also depends on the adequacy of the sampling procedure and the eagerness of the farmers to apply it. Failure to accurately estimate arthropod abundance can lead to inappropriate selection and timing of management tactics, such as insecticide applications (Wade et al., 2006). Two important factors need to be taken into account with regards to the sampling: the sample size and the sample procedure. For the LEC and IPM strategies in Benin, the established sample size is 40 plants selected at regular intervals along the two diagonals of the field measuring between 0.5 and 1 hectare. This implies a heavy workload for farmers, resulting in a number of them refraining from applying it. However, Dhawan et al. (2009) assessed the jassid and whitefly population correctly by observing the number of nymphs and adults on three fully formed leaves in the upper plant canopy from 12 randomly selected plants (three plants/quarter) in an 1-acre field (0.40 hectare). This shows the possibility of reducing sampling size without losing accuracy in estimation of pest populations.

Various methods have been used to sample arthropods, such as the beat bucket, beat sheet, fumigation cage, pitfall trap, sweep-net, suction or D-Vac, visual examination, and whole plant bagging (Wade et al., 2006). The choice of the method is dependent on several interrelated variables, such as plant species, plant phenology and condition, target species, accuracy, ease of use, speed, and cost. In general, the 'best' method should detect all key arthropods and be suitable for use over the whole growing season. Although no single sampling method has been unanimously identified as the 'best', the beat sheet has often ranked highly (Deighan et al., 1985; Hillhouse and Pitre, 1974; Shepard et al., 1974; Studebaker et al., 1991; Turnipseed, 1974; Wade et al., 2006). The beat sheet involves beating or shaking a plant, or group of plants, to dislodge the arthropods in the foliage onto a sheet spread on the ground, where they can be quickly counted. The beat sheet is considered fast, inexpensive, easy to use, and accurate compared with visual inspection. However, it is limited to dry conditions, upright plants grown in rows, and for sampling arthropods that are easily dislodged, slow moving, and rapidly distinguishable (Bechinski and Pedigo, 1982; Kharboutli and Allen, 2000; Pyke et al., 1980; Shepard et al., 1974; Wade et al., 2006). Visual inspection was felt to be preferred on cotton plants in West Africa for the LEC implementation (Silvie et al., 2001; Silvie et al., 2013).

Technology, innovation and interface with IPM

Technology can be defined as knowledge or science conveyed in a ready-made product, a practical way of ''doing things'' or in the form of applied knowledge or service to be delivered to the community. Economic growth has been the aim of many technologies (Hekkert et al., 2007; Rangnekar, 1999). As such, technologies can be successful in the short run, but may fail to deliver convincing results in the long term (Smits, 2002) because of the negative side effects that may accompany their use (Hekkert et al., 2007). The use of DDT after the World War II is illustrative of the threats that a technology can represent to the environment and society in the long term. Smits (2002) indicates that scientific or technological constraints are rarely the main barriers in developmental issues. Most of the time, the constraints are ethical, social, managerial, organizational and institutional. On the other hand, the development of a sustainable technology can be beneficial to the environment and society as a whole. In that sense, management of technological change is necessary (Hekkert et al., 2007). This technological change calls for a process in which stakeholders from various backgrounds interact to reshape and re-adapt the existing technology to match the societal needs. This also implies changes in social dimensions such as user practices, regulation, and networks (Geels, 2002). The socio-organizational arrangement emerging as the outcome of such an interaction is what is called innovation.

Innovation is thus a "*successful combination of hardware, software and orgware, viewed from a societal and/or economic point of view*" (Smits, 2002). Hardware refers to the technical artefact (material and equipment), whereas software relates to the skills, knowledge and capacity that accompany the technology. Orgware relates to the organizational and institutional context that enables or constrains the innovation process. In a dynamic process, the technological innovation co-evolves with the orgware dimension so that the outcome is better aligned with other components of the system.

The cotton sector in Benin is subject to continuous changes and reforms that transform its organizational and institutional conditions. As such, it offers a dynamic environment to define changes that could be supportive to LEC and IPM. As stated above, the LEC strategy can be classified as low-end IPM because it involves a combination of calendar-based and threshold-based applications and some amount of synthetic pesticides. As such, this pest control strategy embodies the software dimension of the technology. The other two dimensions - hardware (required pesticides) and orgware (socio-organisational arrangements) - are missing for this pest management strategy to become a successful innovation. In this thesis we are looking for an effective combination of these three dimensions to support LEC in becoming a widely used innovation in the cotton sector in Benin.

Innovation System (IS) approach

Emerging through policy debates in developed countries in the 1970s and 1980s, the innovation systems concept (World Bank, 2006) is distinguished from the *'linear'* or *'transfer of technology'* model by recognizing innovation as an interactive process. An innovation system (IS) can be defined as a network of organizations, enterprises, and individuals that focuses on bringing new products, new processes, and new forms of organization into economic and social use, together with the institutions and policies that affect their behaviour and performance (Rajalahti et al., 2005).

The IS approach has been mentioned as a tool for enhancing knowledge and skills for problem solving (Ortiz et al., 2009) as well as for co-production of technology (Ashby, 2009). For instance, this approach has been found to elicit a more rapid uptake and wider spread of new varieties of potato and rice, suited to local needs (Ashby, 2009) and could be expected to bring about a rapid adaptation of LEC to suit farmer demands. This presupposes that farmers are empowered to make valuable contributions in adapting and innovating technologies (Rasheed Soulaiman, 2009) to suit their needs. IS not only helps to create knowledge; it provides access to knowledge, shares knowledge, and fosters learning (Agwu et al., 2008; Hall et al., 2005). This was the reason why the CoS-SIS programme put much emphasis on such an approach to the benefit of farmers.

We started with a broad multi-stakeholder consultation process that led to the selection of some relevant learning needs that offered opportunities for research. After having identified the learning needs, a multi-stakeholder platform, the Consultation and Innovation Group (CIG), was set up and field experiments were carried out at the local (village) level. The platform and the experimental communities enabled us to identify, develop and test innovative solutions to address constraints and help elicit changes in policies based on the findings emerging from this IS network (Figure 2). Moreover this ‘new way of doing things’ would hopefully inspire members of the CIG platform to raise some funding in order to support farmer-to-farmer diffusion of tested options.

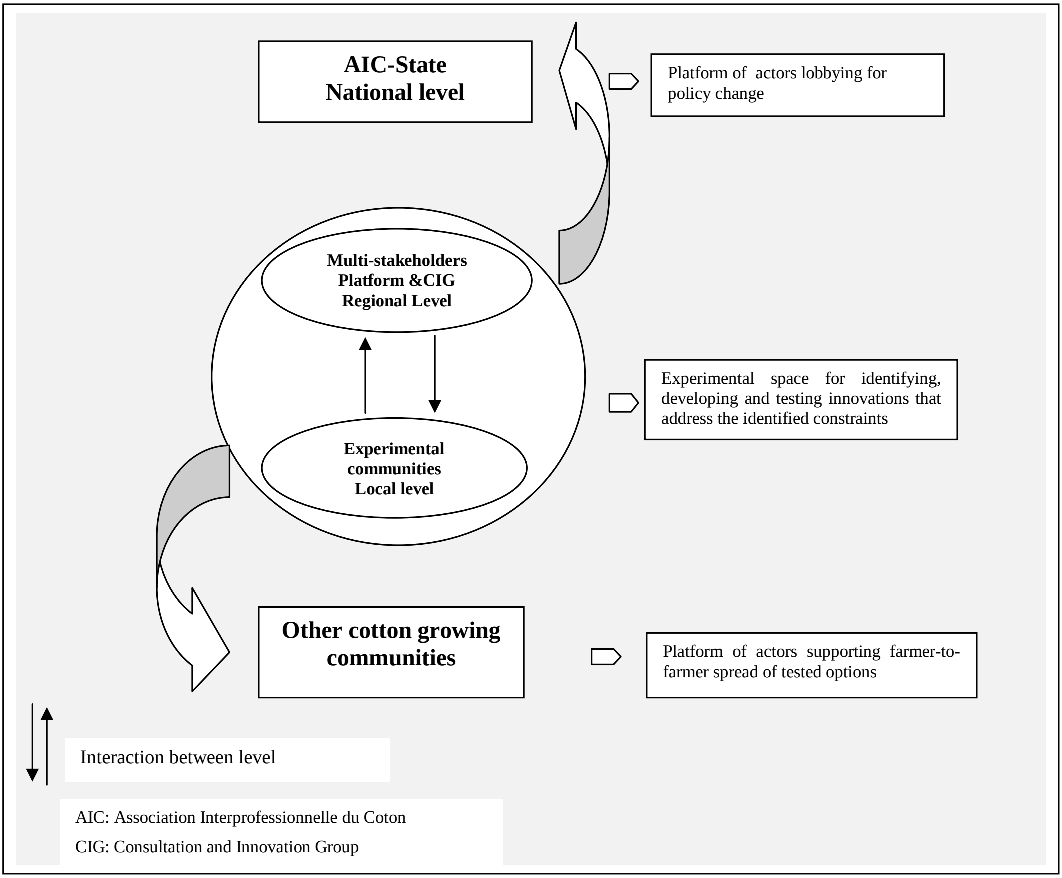

Figure 2: The overall innovation pathway

Research design and methodology

The research started with an exploratory study conducted in 2009 in all cotton growing areas in Benin (Figure 3). To validate the findings of the exploratory study, a workshop was organised in which farmers, extension agents, researchers, and representatives of donor agencies participated. After discussing at length the constraints and opportunities that emerged from this study, the LEC approach came out as a promising technology that could be used to decrease production costs and improve farmers' incomes, and as such was selected as a starting point for this research. A diagnostic study followed, aimed at identifying constraints in the large-scale adoption of LEC and IPM, as well as the practical issues to be addressed in order to make the LEC approach operational. Another workshop was organised after this diagnostic study to discuss the findings with farmers and extension agents in Benin, which resulted in a request to test phytochemicals and biopesticides as alternatives to synthetic pesticides. This experiment was carried out in a collaborative way with farmers and extension agents. The results were discussed and new suggestions were made for the second-year experiment.

In order to assess the contribution of farmers' involvement in such an experiment on their own learning process, a baseline study was conducted with two groups of farmers: (1) those who were involved in the experiment, called 'participating farmers' and (2) those who were not involved, as a control group. At the end of the study, another evaluation was made and the Difference-in-Differences (DiD) methodology was used to assess the effect of the farmer participatory research on the farmers' own knowledge and practices.

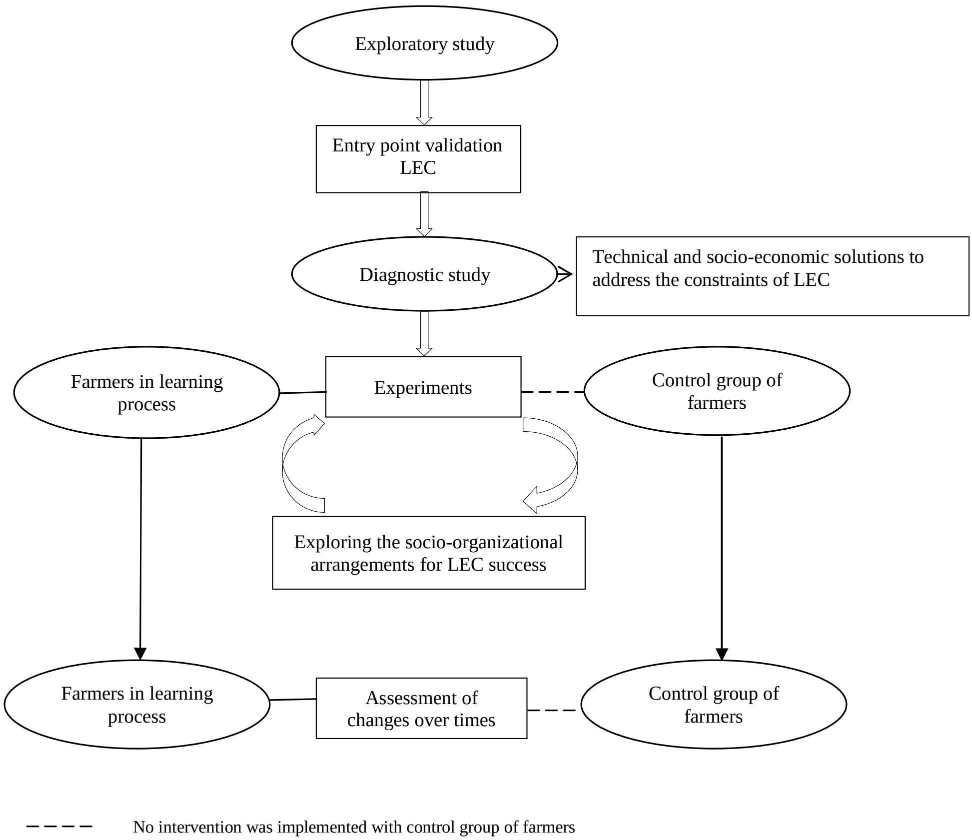

Figure 3: Overall research design

Outline of the thesis

The core of this thesis is formed by five empirical chapters (Chapters 2-6). These chapters report research on the constraints affecting the large-scale adoption of LEC. The last chapter (Chapter 7) contains a synthesis.

Chapter 2 identifies the technical and institutional constraints hindering the wide-scale use of the LEC strategy in Benin as well as how these constraints can be addressed. Arrangements between input suppliers and farmers for the management of LEC pesticides and setting up a mechanism for empowerment of farmers are key institutional changes that could lead to a wider adoption of LEC. Locally available phytochemicals and biopesticides can be used to address problems relating to the use of synthetic pesticides, such as the difficulties in obtaining them and their negative environmental impact.

Chapter 3 analyses how the various actors have responded to the 2009-2012 reform in the cotton sector. The so-called policy arrangement approach was used to understand the impact of the reform on farmers at the grassroots level. There was a transformation in the management of inputs (fertilizers, pesticides) and the protection of cotton. In this chapter, is shown that policy arrangements emerging from the reform may still need adjustment to be able to solve the crisis generated by the reform.

Chapter 4 evaluates the effectiveness of some locally available alternatives to conventional practices and the LEC method for controlling targeted pests. In this chapter, neem oil (*Azadirachta indica*) alone and in combination with the entomopathogenic fungus *Beauveria bassiana* (isolate Bb11) are compared with synthetic pesticides, applied either in a conventional calendar-based setting or in the LEC strategy. Bio-insecticides were not as effective as conventional and LEC methods. The LEC treatment provided better protection to the squares, flowers and bolls and delivered better yields than the conventional approach. However, neem oil and *B. bassiana* can be used in an IPM strategy to maintain a high population of natural enemies. The efficacy of bio-insecticides can be enhanced by testing a mixed formulation of neem oil and other bio-insecticides.

Chapter 5 explores the synergistic effect of a mixed formulation of neem oil and *B. bassiana*, and neem oil and *Bacillus thuringiensis* (Bt). The chapter indicates that the yield obtained with the mixed formulation and neem oil used alone and separately with *B. bassiana* were not different, suggesting an absence of synergistic effects between neem oil and *B. bassiana* (Bb11) and between neem oil and *B. thuringiensis*. The combination of biopesticides increased the cost of production more than that of the conventional treatments, compromising the profitability of such formulations, especially when there is no synergistic effect. The study of the compatibility of plant-based products and biopesticides is essential for a successful application of their combination in the IPM strategy.

Chapter 6 describes the learning process in which farmers were involved in 2011-2012 and assesses the effect of such a participatory research on IPM knowledge and farming practices. Difference-in-Differences methodology was used to document the changes in farmers' knowledge and practices during the following season. Participation in the research increased the knowledge of farmers on pest and natural enemy recognition and the knowledge on threshold use and biopesticide application. The increase in knowledge did not lead to any modification in farmer practices with respect to the use of neem oil and Beauveria, but it led to a significant change towards threshold-based pesticide applications. Policy implications for successfully changing farming practices are discussed.

Chapter 7 discusses the advantages and challenges of using the economic threshold level concept for pest management in agriculture and in cotton production. It also discusses the importance of and the constraints associated with the use of phytochemicals and biological agents in agriculture, either alone or in combination. Finally, in this chapter are some reflections on how to make the cotton sector in Benin innovation-prone and how to make collaborative research with farmers a success.

Chapter 2

Alleviating technical and institutional constraints of a cotton pest management strategy in Benin

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Abstract

A pest management strategy entitled Staggered Targeted Control (in French, Lutte Étagée Ciblée or LEC) has been promoted in Benin since 1988 as an alternative to the conventional spraying strategy, in order to reduce the cost of production and improve cotton yield and quality. Many cotton growers are eager to use LEC, and although many projects have been promoting it, the strategy is not yet widely applied in cotton growing areas. This study identifies the main factors hindering the adoption of LEC. It appears that LEC cannot be considered a viable innovation in its current form because certain key factors within the cotton sector are not well aligned. Better management of pesticide leftovers and empowering farmers are key institutional changes that could shift crop protection towards a wider adoption of LEC. Actors involved in the cotton sector have suggested that a transition towards a participatory approach would improve farmers' expertise in LEC implementation, at the same time bypassing existing sources of LEC pesticides and promoting alternatives such as botanicals and biopesticides.

Key words: Pesticides, cost reduction, socio-organisational innovation, farmers' empowerment, Benin

Introduction

The cotton sector 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 tonnes of cotton (lint and seed taken together) was achieved during 2004-2005 (AIC, 2009), mainly as a result of an increase in acreage (Midingoyi, 2008; Sinzogan et al., 2006a; Sinzogan et al., 2004). The average yield per hectare was greater than 1500 kg in the 1980s but decreased steadily thereafter, reaching approximately 1100-1200 kg at present. This yield is about 25-75% of the optimum obtainable (Matthess et al., 2005). Research station yields of the recommended variety H279-1 are about 3000 kg/ha^{-1}, but the maximum yield on farm varies from 1800 to 2500 kgha^{-1} (Fadoegnon and Midingoyi, 2006). Since 2004-2005, an increasing number of farmers have left the sector, leading to a reduction in areas growing cotton and thereby contributing to a steady decrease in overall production. The decline is related to falling world market prices as well and, as a consequence, causes a decrease in farmers' incomes; moreover, the decline is attributed to high pest occurrence, depletion of soil fertility, low and erratic rainfall, and disregard 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 high 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 (Akogbeto et al., 2005). 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 (Budak and Budak, 2006; Hofs et al., 2006; Mancini et al., 2007; Prudent et al., 2007; Swezey et al., 2007; Zalucki et al., 2009) have been conducted into 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 infestations. Two alternatives to conventional spraying practices have been introduced for cotton production in Benin: organic cotton, which does not allow the use of any 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 (CRA-CF, 2009). The economic threshold is the pest population level at which control is warranted (Bottrell, 1979; Cousens, 1987; Pedigo et al., 1986).

An exploratory study conducted from March to September 2009 (Adjei-Nsiah et al., 2013) indicated that LEC remains a technically promising strategy that could boost cotton production in Benin, both quantitatively and qualitatively. Farmers in Central to Northern Benin, where many farmers have dropped out of the sector, have indicated that if conditions would allow the implementation of LEC, they would return to cotton production (Adjei-Nsiah et al., 2013). The LEC strategy consists of cautiously applying full or half the recommended dose of a pyrethroid (Cypermethrin) on a calendar basis, followed by the use of specific pesticides applied only when the economic threshold is reached (CRA-CF, 2009). The LEC calendar in practice, as recommended following research, involves the use of Tihan 175 O-Teq (Flubendiamid 100 - Spirotetramate 75gl^{-1}) for the first two treatments (exactly as in the conventional crop protection strategy); the four remaining treatments use Sherphos 370 EC (Cypermethrin 70gl^{-1} - Triazophos 300gl^{-1}) in northern Benin, and Sherphos 320 EC (Cypermethrin 70gl^{-1}- Triazophos 250gl^{-1}) in central and southern Benin. Monitoring for the incidence of targeted pests in the cotton field 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 (Silvie et al., 2001). 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 in which plants are at the same growth stage (CRA-CF, 2009).

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 (Bottrell, 1979), but LEC would be located at the lower end of the IPM continuum (Benbrook, 2002) because it remains heavily reliant on chemical treatments and uses an established threshold for specific pests (Figure 1). A shift from conventional crop protection to the LEC strategy would entail a change in many practices and relationships, as shown in Figure 2.

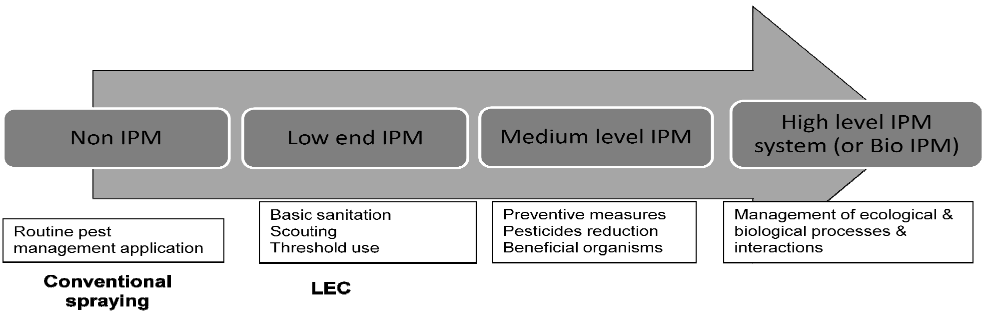

Figure 1: Location of LEC on the IPM continuum

Source: Adapted from Benbrook (2002)

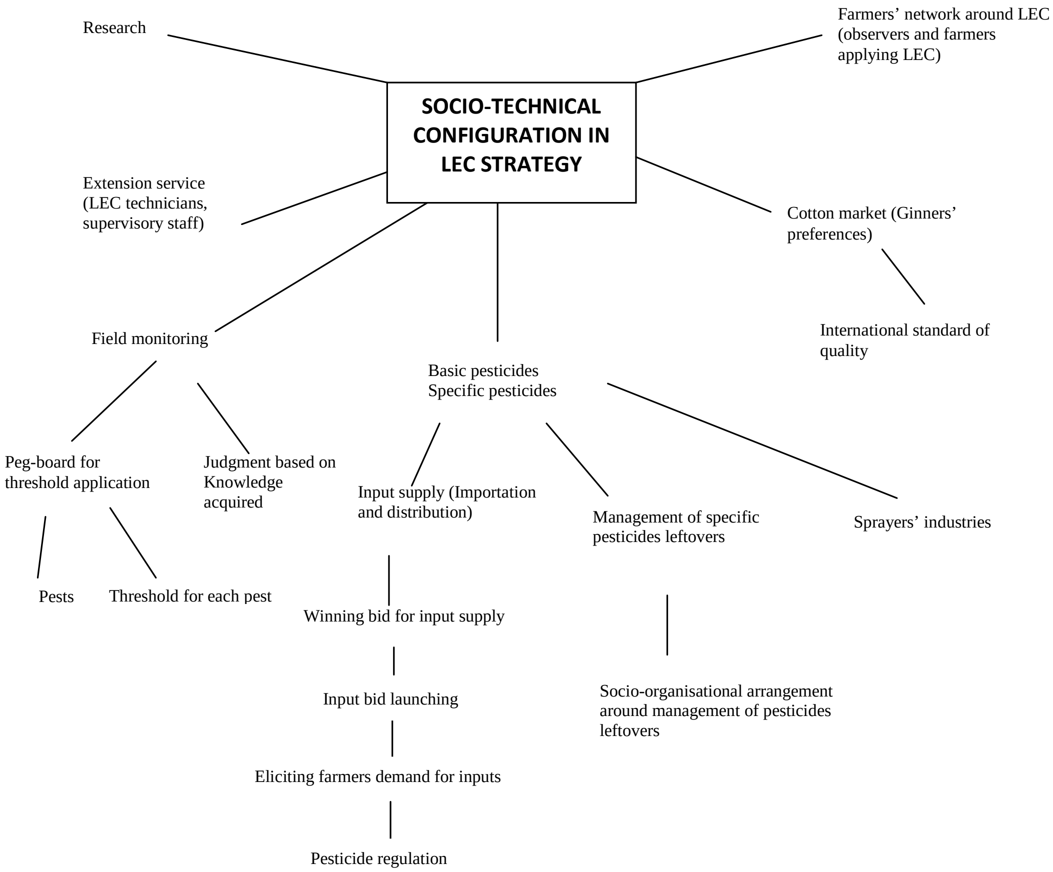

Figure 2: Linkage diagram of the socio-technical configuration of the LEC strategy
Source: Adapted from Geels (2002)

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 (Smits, 2002). 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 targeted pest is reached or not. The peg-board is a didactic tool that helps farmers to identify the various targeted pests, the threshold level, and the pesticides to be used when the threshold level is reached, i.e., Gazelle 200 SL (Acetamiprid 200gl^{-1}) for *Aphis gossypii*, Hostathion 400 EC (Triazophos 400gl^{-1}) for mites, *Polyphagotarsonemus latus*, and Cypercal 85.7 EC (Cypermethrin 85.7 gl^{-1}) for bollworms (*Diparopsis watersi*, *Earias* spp., *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 amount 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 for both farmers and extensionists. The challenge to the farmer is the time needed for scouting and recording, activities not performed in conventional cotton management. The challenge may be greater for extensionists because it is they who have to train the farmers 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 needs deliberate efforts to create effective links between technologies, people, and socio-organisational activities (indicated in Figure 2). The process of building coherent links and networks around a novel idea or technical device such as LEC has been called a process of alignment (Rip, 1995), meaning that the various aspects and dimensions of an innovation are brought in line with each other. Leeuwis (2004) suggests that innovations that are effective at local levels may fail to spread because of an insufficient, partial or unbalanced alignment at higher levels. We examine this proposition in this paper.

This study analyses the overall cotton value chain to identify 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 conditions in place for the LEC technology to become a viable innovation? If not, how can the constraints be addressed in order to make this technology a viable innovation? And what are possible alternatives?

Methodology

Study area

The district of N'Dali lies in the north-eastern part of Benin. It was selected for the diagnostic study partly because it is a transition zone between the highest and a medium cotton growing areas in terms of their contribution to national production, and partly because between 1998 and 2003, farmer based organizations (FBOs) have been actively involved in LEC promotion and implementation on three occasions. Furthermore, they gained experience through the multi-organizational platform set up by Sinzogan et al. during an earlier phase of the COS-SIS programme (Sinzogan et al., 2006b).

N'Dali is located in zone II among the four zones distinguished in Benin in relation to pest pressure. In the hot dry northern zone (I) the following pests are predominant: *H. armigera* (Lepidoptera: Noctuidae), *Syllepta derogata* Fabr. (Lepidoptera: Pyralidae), *Dysdercus völkeri* Schmidt (Heteroptera: Pyrrhocoridae), and *Aphis gossypii* Glover (Homoptera: Aphididae). Mites, *Polyphagotarsonemus latus* Banks (Arachnida: Acari: Tarsonemidae) are generally absent from this zone. *Helicoverpa armigera*, mites, *S. derogata*, and *D. völkeri* are prevalent in the north-central zone (II), while in the south-central 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 (IV) are *S. derogata*, *H. armigera*, and *C. leucotreta*. This pattern of distribution confirms that the cotton bollworm *H. armigera* attacks cotton throughout the country and is recognized as the major pest (Youdeowei, 2001).

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 the 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 (April-September 2010).

First, an inventory was made of the local FBOs, the so-called Groupement Villageois de Producteurs de Coton (GVPC) that have been involved in LEC, which generated 15 GVPCs in the 11 villages. Two or three key informants were identified in each of these LEC villages to identify all the 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.

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

GVPC	PADSE[1] (2000-2004)	AIC[2] (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

[1] Projet d'Amélioration et de Diversification des Systèmes d'Exploitation
[2]Association Interprofessionnelle du Coton
x=villages involved in the LEC program
Source: Diagnostic study, 2010

Focus group discussion and individual interviews

Focus group (FG) discussions (Krueger and Casey, 2009; Stewart et al., 2007) were organised with 10 willing farmers (male and female) in each of the 11 villages. Emphasis was placed on 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 FGs were held at the date and time preferred by the farmers and observers. The discussions focussed on farmers' and observers' enrolment in the LEC process, the reasons underpinning their acceptance of LEC, and the reasons for abandoning the strategy. The organisation of training in support of LEC implementation also was discussed. Finally, LEC constraints were analysed by the FG participants in four of the villages, randomly selected from among the 11.

Individual in-depth interviews (Creswell, 1997; Kvale and Brinkmann, 2008; Seidman, 2006) were conducted with the LEC farmers and observers who were still growing cotton in the 11 villages. The interviews focussed 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 is about what farmers say that they do and think, not what they actually do and think. Farmers may base their responses and arguments on what was said during earlier discussions or on the opinions of the leaders of their group. We used a skilled moderator to keep the discussion as naturally free and flowing as possible and to ensure that participants were contributing equally.

Regarding the individual interviews, we found that some farmers were uncomfortable discussing sensitive topics. Despite assurances of confidentiality given to them at the beginning, they refrained from talking about 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 possible biases.

Results

Process of LEC development and implementation

LEC was initiated in 1988 to deal with development of resistance by *H. armigera* against the insecticides used, which had resulted from over-reliance and on misuse of pesticides by farmers. The process of LEC implementation flowed down to farmers from the national research service via the public extension service (Figure 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) in 1988. During the second stage, the technology was refined by carrying out on-farm experiments led by 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 exocarpic feeders are abundant, a half dose of pyrethroid was recommended and in the central and southern part, where the endocarpic feeders are abundant, the full dosage of pyrethroid was recommended.

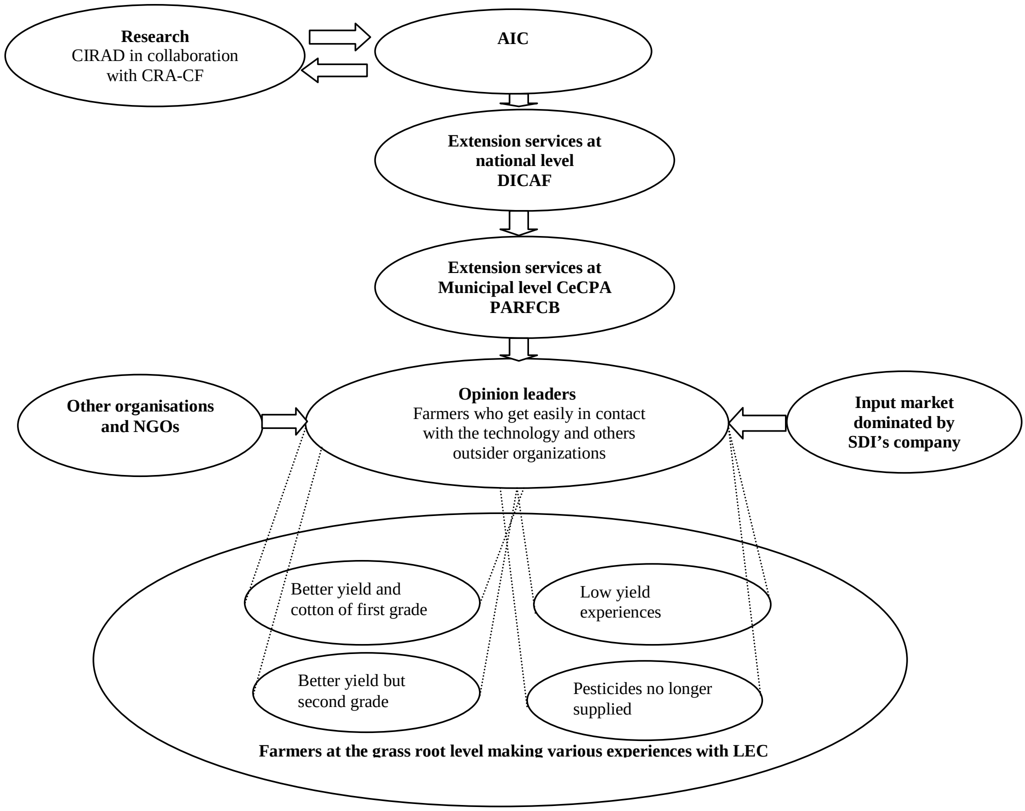

Figure 3: Process of LEC implementation from national to farmers' level
Source: Diagnostic study, 2010

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 1500 FCFA (2.29 Euros) for this service, which covered the increase in the price of one litre of Sherphos that year. The selection of the observers was based on their ability to speak and write in French. They were provided with a peg-board and training in LEC over two or three cotton seasons. Eleven LEC technicians were initially trained by CRA-CF; they were hired by the extension service to train the LEC observers. By 2007, a total of 1193 observers had been trained in Benin (DICAF, 2007).

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

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 specific pesticides and calculation of 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 targeted pest and threshold level Ability to determine the dose of specific pesticide

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

Farmers' motivations and opinions about LEC

During interviews, the LEC technicians listed numerous reasons why farmers were motivated to implement the LEC strategy, such as input cost reduction, effectiveness in controlling pests, environmental protection, and improvements in yield and cotton quality. These benefits were also listed 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, compared 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 is 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 with the technology, it is the presence of extension agents and LEC technicians in the field that makes it possible for farmers to use the strategy. The focus group discussions made it clear that in the absence of such support and guidance many farmers lacked trust in LEC, and did not completely abandon the conventional treatments - they stayed in contact with producers from non-LEC villages to obtain conventional pesticides. This has created a negative feedback, resulting in 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 half of the farmers interviewed indicated that the LEC strategy was more effective than the conventional. Nevertheless, all the farmers interviewed were supportive of LEC's contribution to input cost reduction, cotton quality, environmental protection, and to knowledge improvement.

Table 3: Farmers' motivations and opinions after LEC implementation in percentage of respondents

LEC properties	Modalities	Farmers motivations for LEC in percentage (n=155)	Farmers' opinions after LEC implementation in percentages (n=155)
Cost reduction	Agree	100 [97.0-100][1]	100 [97.0-100][1]
	Not agree	-	-
Cotton quality	Grade I	51 [42.9-59.03][1]	100 [97.0-100][1]
	Grade II	-	-
Yield compared to conventional	Higher yield	100 [97.0-100][1]	26 [19.3-33.6][1]
	Similar	-	49 [41.0-57.1][1]
	Lower yield	-	25 [18.7-32.9][1]
Pest management effectiveness	Agree	80 [72.7-85.8][1]	51 [42.7-59.0]1
	Not Agree	20 [14.2-27.34][1]	49 [41.3-56.8]1
Environmental protection	Better protection	20 [14.2-27.34][1]	100 [97.0-100][1]
Knowledge improvement	Improved	-	100 [97.0-100][1]
	Not improved	-	-

[1]values in brackets: 95% Confidence Interval
Source: Diagnostic study, 2010

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 could be distinguished (Table 4).

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 I 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

Category I: Villages that experienced low cotton yield. The low yields experienced by Kakara, Sinisson, and Yermarou were directly linked to poor application and/or abandonment 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 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). A misunderstanding of the technology was 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 was an insufficient number of observers in the village and this prevented 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 pack costs 41,000 FCFA (€62.54) and this cannot be afforded by any farmer. Thus the aphids were not controlled and the quality of cotton was compromised. The impact of aphid attack was only mentioned in this village because of the high losses incurred.

Category III*:* Villages that still produce 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 other pesticides. They tried to put maximum pressure on the local sales representative assigned by the SDI in N'Dali in order to acquire the appropriate pesticides in time. They also mentioned that they had not been supplied with sufficient quantities of Sherphos since 2008. 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 where farmers would still be 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 is 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.

Constraints

Tension around LEC: conflicts of interest

The tensions around LEC arose as soon as the strategy was launched because it threatens input suppliers with a loss of revenue because of the difficulties in managing the demand for specific pesticides, the lower overall cost price of LEC chemicals, and the decrease in the amount of pesticides used in LEC. Demand management is particularly difficult. According to the CRA-CF and the extension organisations (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 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, suppliers' revenues decreased because of the high concentration of specific pesticides meant little was required to control the targeted pest if it surpassed the threshold level. For instance, one litre of Gazelle is recommended for 25 ha but the cotton acreage per farm rarely exceeded 3 ha.

The unpredictable demand, in particular for the specific pesticides, is a big challenge for all stakeholders in the cotton value chain, and especially for farmers and input suppliers. The input suppliers have 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 depends crucially on solving the demand estimation problem and motivating the input suppliers to supply the appropriate inputs.

The monopolistic position of the SDI (Société de Distribution Intercontinental) within the cotton value chain may be responsible for the ongoing conflict of interest. It is the Talon Group of input suppliers, through the 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.

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 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 leftovers was mentioned by 61 to 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 result, the willing 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 2010-2011 season, Sherphos was unavailable in nearly all the municipalities selected for the implementation of the triennial plan. It is indeed remarkable that the rules established to regulate pesticide supplies were not respected. The lack of sanctions for poor performance will most likely perpetuate these conditions.

Table 5: Constraints to LEC as perceived by farmers in percentage of respondents (n=155)

Opinions	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	75	89	25	80	72	61	84
	[85.0-94.8][1]	[67.1-81.0][1]	[82.8-93.3][1]	[18.7-32.9][1]	[72.7-85.8][1]	[64.4-79.0][1]	[53.1-68.9][1]	[76.9-89.1][1]
Not Agree	5	16	8	70	17	20	30	11
	[2.4-10.3][1]	[10.9-23.1][1]	[4.2-13.4][1]	[61.7-76.7][1]	[11.4-23.8][1]	[14.2-27.3][1]	[22.8-37.7][1]	[6.7-17.2][1]
No opinion	4	9	3	5	3	8	9	5
	[1.6-8.6][1]	[5.2-14.9][1]	[1.2-7.8][1]	[2.4-10.3][1]	[1.2-7.8][1]	[4.2-13.4][1]	[5.2-15.0][1]	[2.4-10.3][1]

Source: Diagnostic study, 2010

[1]values in brackets: 95% Confidence Interval

Misapplication of the LEC strategy

Technical constraints related to the field scouting have led to the misapplication of LEC. This misapplication had to do with the expertise required by the technology and the extension model used for its large-scale adoption. Because the strategy is difficult, farmers at the grass-root level did not know much about the principles behind the application of LEC and they depended to a great extent on the observers to tell them what to do. Moreover, the number of observers was insufficient to cover the large area and numerous plots in the zone. It was impossible to guarantee that monitoring of pest thresholds was well performed for each plot and farm. The effect on cotton yield and quality was 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 (Figure 4).

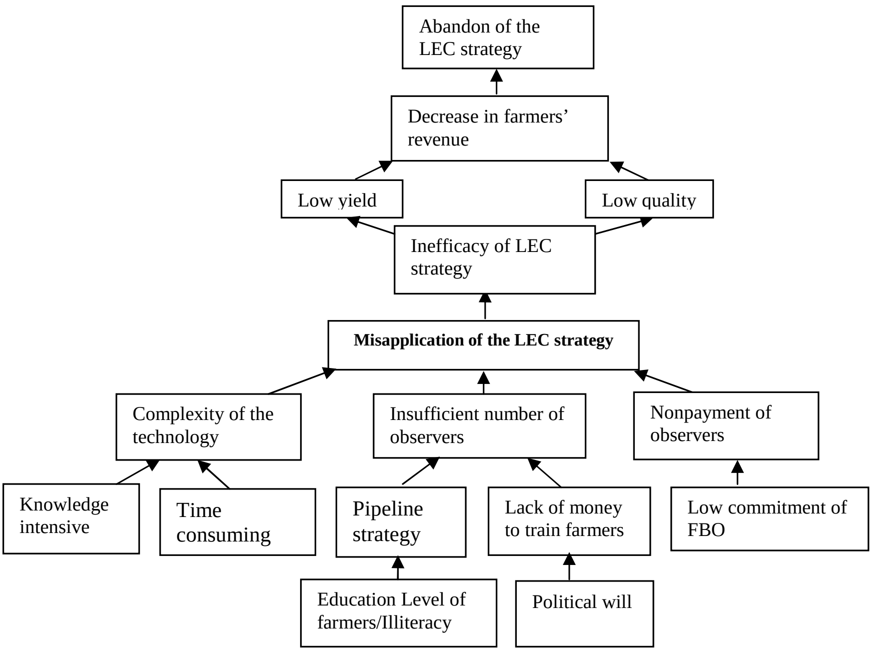

Figure 4: Analysis by farmers of the technical constraints leading to misapplication of LEC strategy
Source: Diagnostic study, 2010

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: notably, the input suppliers and to some extent also the government. Three reasons were identified in the survey and interviews as persistent causes of this constraint (Figure 5): the absence of political will, the weak FBOs, and the reluctance of input suppliers to overcome the challenges.

The absence of political will might be considered on the one hand as a strategic avoidance by government bodies to challenge the interests of input suppliers, and on the other hand, a reluctance to invest in LEC as a national strategy before knowing the benefit to the country. The FBOs' weakness was evidenced by their poor management performance and the influence of ginners and input suppliers on farmers' representatives within the AIC. The main reason for the reluctance of input suppliers to provide LEC pesticides, apart from potential loss of income, is difficult management of the stocks, which is a direct consequence of the unpredictable demand. Farmers try to return any unused LEC pesticides to the suppliers, but the latter demand payment for taking them back in order to cover stocking costs and the risk of the pesticides becoming obsolete. As the pesticides have not been used, the farmers and their organizations feel 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 supply chain, which makes it easy for the input suppliers to act only for their own benefit.

Options for alleviating the constraints

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: (i) payment by farmers themselves, and (ii) sharing the payment among various stakeholders, 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 that the price increase of Sherphos 370 EC imposed by the supplier could be used for the scouting service instead. 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 €8.69 to €10.98) to cover the costs of the services provided by the observers.

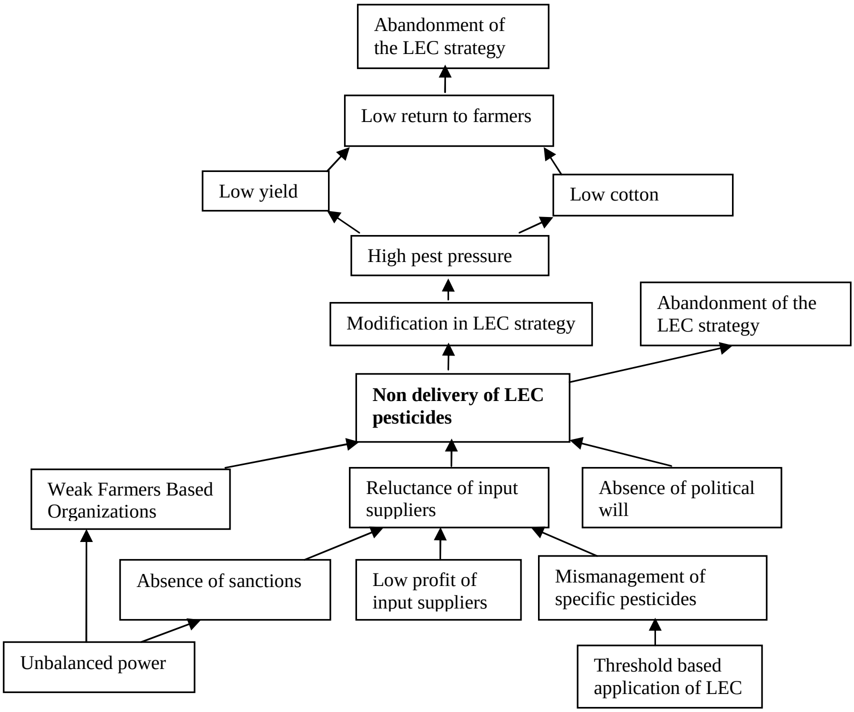

Figure 5: Analysis by farmers of the institutional constraints that cause the non-delivery of LEC pesticides by input suppliers.
Source: Diagnostic study, 2010

The extension agents and staff at the CRA-CF research centres at Parakou and Cotonou suggested that the best solution to the scouting issue is to train each farmer to become an expert in order to be able to monitor his or her 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 questionable, as it has been reported that even some extension agents (CPV) working in the field do not have the expertise to identify 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.

Specific pesticides. Our study indicates that the following options for managing the issue of leftovers would be welcomed by all the relevant players: (i) training farmers to estimate demand; (ii) packaging the specific pesticides in smaller containers affordable by farmers; (iii) finding other uses for the specific pesticides by introducing alternative crops; (iv) establishing aggregated blocks of land to allow farmers to apply the specific pesticides collectively; (vi) developing a mechanism for farmers to pay for the leftovers; and (vii) cost-sharing among key stakeholders (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 among actors such as the AIC, input suppliers, and farmers (vii). In the interviews, high scores were recorded for training farmer to better estimate their needs. However, training farmers was indicated by only 22% of the farmers themselves. According to the other 78%, even if farmers were well-trained they could never foresee the precise level of pest infestation. The proposal to introduce alternatives crops for using up any leftovers was favoured by 30% of the farmers. The other 70% thought that the development of this option would take too much time. The establishment of blocks to cluster farmers' fields together seemed unfeasible in the current context because of a lack of land owned at village level and the restriction this practice might impose on the rotation of crops. Only 20% of the farmers agreed with this option. Farmers strongly favoured the packaging of specific pesticides in small bottles (78%) and also the use of a rebate to cover the costs of the leftovers (74%).

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 of botanicals to the use of biopesticides. Botanicals are aqueous extracts obtained from leaves, seeds, fruits, and roots of various plants such as *Khaya senegalensis*, *Careca papaya*, *Hyptis suaveolens*, *Allium sativum*, *Capsicum* spp. and *Eucalyptus* spp. Sinzogan et al. (2006d) were able to reduce the number of treatments in cotton from 6 to 4 by applying the mixture of *Azadirachta indica* (Neem) plant extract with half the recommended dose of synthetic pesticides on a threshold basis.

Our interactions with farmers indicated that the preparation of botanicals is a time-consuming activity. It implies a lot of work for 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 control of pests on cotton (IITA, 2010). 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 too specific for *H. armigera* and cannot be used for other lepidopteran species damaging the cotton, while *B. bassiana* can target a wide range of species in this group.

Table 6: Actors' appreciations of the suggested options for dealing with the problems of the specific pesticides

Possible solutions	Actors' appreciation							Score[3]
						Farmers		
	AIC	Inputs suppliers	Researcher	Extension	Ginners	FBO[2]	Percentage of Farmers agree (n=155)	
Trainings for need expression	+	+	+	+	+	+	22 [15.9-29.4][1]	6
Packaging pesticides in the smaller containers	+	-	+	+	+	+	78 [70.6-84.1][1]	5
Seeking for alternatives crops for leftovers consumption	+	+	+	+	+	+	30 [23.3-38.3][1]	6
Blocks of parcels established with many farmers together	-	+	+	-	+	-	20 [14.2-27.3][1]	3
Payment of leftovers by farmers	+	+	+	+	+	-	5 [2.4-10.3][1]	5
Use of the rebate to pay the leftovers	+	+	+	+	+	+	74 [66.4-80.7][1]	6
Cost sharing by AIC, inputs suppliers and Farmers	-	-	-	-	-	+	80 [79.9;80.1][1]	1

Source: Diagnostic study, 2010
*values in brackets: 95% Confidence Interval
+ positive appreciation; - negative appreciation
[2]farmer based organisations
[3]score is the number of (+) reported for each option

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. (2006c). The ETL treatments proved to be less harmful for predators such as 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 (Deguine et al., 2008). 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.

Discussion

Many farmers have stopped using LEC because the intrinsic characteristics of the strategy render it too complicated to apply 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 there is an institutional problem. The prevailing extension strategy is probably 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 protected 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 (Sinzogan et al., 2006c). 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 (Ruthenberg and Jahnke, 1985). 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 excluded 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 a neglect of the field monitoring, on which the effectiveness of LEC depends. As a result, yields were low and the quality of cotton was affected due to poor control of pests such as aphids. Farmers' expectations that LEC would increase yield (Djihinto et al., Undated; IFDC, 2009; Kpadé et al., 2008; Michel et al., 2000; Nibouche et al., 1998; Silvie et al., 2001), improve quality (Djihinto et al., Undated), 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, as it requires fewer pesticides. The quantity of pesticides saved by LEC ranges from 44 to 54% compared with conventional spraying strategies (Djihinto et al., Undated; Michel et al., 2000; Nibouche et al., 1998). However, the IFDC (International Center for Soil Fertility and Agricultural Development) (IFDC, 2009) has indicated that the application of LEC as a 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 the case that the additional cost generated by the high pest pressure would be compensated for by the higher yield that result from effective LEC application than from the conventional regime (IFDC, 2009).

The decrease in the amount of pesticide used has been one of the important reasons that has shaped opinions about LEC as an environmentally friendly strategy (Kpadé et al., 2008). The specific nature of pesticides used on a threshold basis enables farmers to target the specific pests without affecting the rest of the entomofauna and in particular the beneficials. Floquet and Mongbo (2003) indicate that the higher the degree to which farmers master LEC, the lower the risk of poisoning, giving one very valid reason to promote the LEC strategy and thereby decrease the 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 many leftovers there may be at the end of a season because of unpredictability of local pest pressures and threshold applications, poses a serious problem for both cotton growers and input suppliers. The lack of competition in the pesticide market also hinders a resolution of this problem. The market is at present controlled by a single company, which is responsible for all pesticide imports. Furthermore, in many districts it has been assigned the exclusive right to deliver pesticides, representing in total 40% of the cotton growing area. This company in effect controls the ginners and the individual input suppliers and also holds power 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 value chain and between the chain and the socio-technical configuration. Among all the suggested solutions, only the packaging 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 participants in our study. However, with the decline of the cotton sector, no rebate has been returned to farmers and the packaging option still needs to be agreed upon by the input suppliers. Evidence of political will to bring the concerned actors together to deal with such institutional constraints may be required.

There is clearly a divergence of opinions and interests among the social groups involved in the LEC. In order for the strategy to become a viable innovation embedded in the higher-level rules of the game, a new socio-organisational arrangement would be required to put the LEC to work. Farmers would also need to be empowered to increase their influence vis-à-vis the other stakeholders in the cotton sector.

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, their lack of the expertise required by LEC, the labour costs 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 institutions 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 farmers' organizations are too weak at present to have sufficient power in any negotiations to bring about such changes. Moreover, the trends occurring in the cotton industry are not supportive of FBOs. The problems indicated in this study lie mostly beyond the farmers fields. 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 are not interested in being a part of any discussion related to LEC.

In such a context, the search for alternatives to LEC and its specific pesticides might be a better option. Given the promising results of experiments with alternatives, it seems technically possible to control cotton pests by using entomopathogenic formulations and botanicals only and 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 also could be addressed.

Chapter 3

Evaluation of the 2009 reform of the cotton sector in Benin: perspectives from the field

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C. E. Togbé, S. D. Vodouhê, G. Gbèhounou, R. Haagsma, E. T. Zannou, A. Guédénon, D. K. Kossou, A. van Huis. Evaluation of the 2009 reform of the cotton sector in Benin: perspectives from the field.

Abstract

The immediate consequences of the 2009 reform of the cotton sector in Benin are assessed from the farmers' perspective. Using a policy arrangements approach, we analyse how farmers experienced the transformations brought about by the reform and how it influenced their day-to-day activities. The new farmer cooperatives established after the reform were trusted by farmers. Many farmers returned to the sector, increasing cotton output. Nevertheless productivity remained low, around 900 kg per ha, probably because the reform addressed mainly institutional constraints. Technical constraints relating to varietal choice, improvement of soil fertility, and pest management were neglected. The policy arrangements emerging from the reform still generate discussion, in particular about the way actors and coalitions are organised. The top-down approach of the reform process has a limited capacity for problem solving, especially where the interests of the various parties collide. Adjustments made under the reform regarding FBOs and representatives of public services, the 'caution solidaire', and farmers' supervision proved to be inappropriate, thereby further undermining the cotton sector. A mix of technological and institutional reforms may offer a more effective option for the future.

Key words: Cooperatives, natural experiment, policy arrangements, coalitions, resources, discourses, institutions

Introduction

The cotton sector makes an important contribution to Benin's national economy, providing 70% to 80% of its export earnings, 35% of its tax revenues, and 13% of the Gross Domestic Product (AIC, 2006; Midingoyi, 2008). The cotton value chain is the most structured and organised of all commodities. Crops such as maize benefit from this commodity as well, because cotton growing opens farmers' access to subsidised fertiliser (Gergely, 2009; Kaminski et al., 2009). The health of the cotton sector is of prime concern to the government and the reason that it receives political and financial attention (Matthess et al., 2005).

Over the last five years, the cotton sector has been challenged by a series of crises leading to a decline in productivity and a retreat of farmers from cotton farming. National production of seed cotton decreased from 427,000 metric tonnes in 2004-2005 to about 200,000 metric tonnes in 2012. This low volume only satisfies approximately one-third of the ginning factories' capacity (Gergely, 2009). Analysis of the causes of this poor performance reveals two types of constraints that affect the entire cotton value chain: 1) technical constraints related to the production process; 2) organisational and institutional constraints related to the management of financial flows, the management of inputs, and the calculation of farm gate prices. The latter category also includes the group solidarity guarantee 'caution solidaire' (Togbé et al., 2012) that has been applied over the last 30 years. This guarantee allows micro-credit to be granted to small farmers without physical or material warranty, and they jointly commit themselves to repay the loan on the basis of mutual trust (Sinzogan et al., 2007). The disadvantage of this system is that everyone is responsible for all loans. If one farmer defaults, the whole group is held accountable.

In line with the national policy to revive the agricultural sector in Benin, the 'Projet d'Assainissement et de Relance de la Filière Coton au Bénin' (PARFCB) was launched in 2009, and this national reform is the focus of this study. This project aimed to improve the governance of farmer-based organisations (FBOs) in the cotton sector and build trust within these organisations, as well as to guarantee prompt payment to farmers on delivery of their seed cotton to the ginneries. It was expected that the measures proposed by the PARFCB would increase cotton production and lead to a better utilization of the capacity of the ginning factories.

This reform was an important external event during the time of our research, a natural experiment that opened an unexpected opportunity to study institutional transformation in action and understand the complexities of the cotton sector. We anticipated that the transformation initiated by the reform would lead to new interactions of the key actors in the sector, that may in turn have an effect on the outcome of the research conducted at the local level.

In this article we document and analyse by means of a policy arrangements approach (PAA) the dynamics that were initiated by the 2009 reform, taking into account technical, socio-economic and organisational dimensions.

Theoretical framework: a policy arrangements approach

The policy arrangements approach (PAA) was chosen because it is appropriate for short time frames. The framework suggested by this methodology is based on four interdependent and interwoven dimensions that are considered to be the most relevant for analysing any policy domain (Arts et al., 2006; Van Tatenhove and Leroy, 2000). These are (i) the actors and coalitions involved in the policy domain; (ii) their resources (money, knowledge, skills, competences, power); (iii) institutions, seen as the set of 'rules' (both formal and informal) currently in use, that guide and constrain the behaviour of individual actors; and (iv) the current policy discourses, which refer to the views and narratives of the actors involved in terms of norms and values, the definition of problems, and approaches to solutions (Arts and Van Tatenhove, 2006; Arts et al., 2000).

For Benin, coherent relationships between the four dimensions would be desirable. This is a challenge because the sector has been subject to misguided and uncoordinated transformations: policy incoherence as coined by Baffes (2003). Fok (2008) indicated that instability and uncertainty of the cotton sector frameworks in francophone African countries are translated into decreasing and fluctuating production. Actors and coalitions in the cotton sector are influenced by the prevailing discourses. They deploy their resources (especially political and financial power) and apply or by-pass existing rules to achieve their own goals. Thus changes in one area may have consequences for other areas, and even for the policy arrangements as a whole (Van Tatenhove and Leroy, 2003). The driving forces behind stability and change in policy arrangements are the essential points of the analysis (Arts et al., 2006). For instance, in some cases changes have been initiated by new coalitions; in other cases they are provoked by innovative discourses, or reinforced by rules and resources, setting off a chain reaction of change. This chain reaction may lead in turn to a change in the entire set of policy arrangements.

The reforms examined in this study were imposed by decisions taken at a high administrative level. The 'Association Interprofessionnelle du Coton' (AIC) then initiated further changes in the arrangements among the key actors and policy practices at lower levels.

We will apply a PAA approach to examine how interactions among actors instigated by the reforms led to a transformation of the cotton sector.

Methodology

Study area

This study was carried out in three villages in the district of N'Dali. The villages were randomly selected from a list of cotton growing villages based on the following criteria: whether there already existed a cooperative and if so, whether its level of indebtedness was high or low, or if there was a newly created cooperative. This resulted in three villages, each having a cooperative (CVPC) responding to the above-mentioned criteria, viz. Wobakarou, Kori, and Bouyérou (randomly selected from a list of 16, 11 and 6 villages):

Type I: cooperative derived from former Groupement Villageois de Producteurs de Coton (GVPC), with high level of indebtedness: Wobakarou

Type II: cooperative derived from the former GVPC, with low level of indebtedness: Kori

Type III: new cooperative that emerged after the reform: Bouyérou

The level of debt was taken as a criterion because the reform was prompted by the accumulating debts of the former GVPCs (caused mainly by the 'caution solidaire'). We chose to distinguish among the categories in this way because we hypothesised that the debt experience of the three categories of CVPCs would differ. One of the direct effects of the implementation of the reform was the emergence of new cooperatives, which motivated farmers to return to cotton production. Therefore, the nature of the cooperatives (former or new) was selected as the second criterion.

The district of N'Dali was selected for the following reasons. First, the district was highly affected by the pre-reform crisis, exemplified by the creation of unofficial farmers' networks for producing and selling cotton. Second, many farmers in the district were dissatisfied with the official cotton value chain framework (Sinzogan et al., 2007). Third, many farmers in the district had abandoned cotton growing (Totin, 2004). Fourth, and related to this, the district experienced an enormous output crash from 11,390 metric tonnes in 2004-2005 to 792 metric tonnes in 2009-2010 (Ganda, 2011). Consequently, N'Dali attracted particular attention of the decision makers and was one of the catalysts of the PARFCB reform.

Methods of data collection

Data were collected in two ways. First, semi-structured group interviews were held with the members of the Board and the steering committee of each CVPC. The interviews focused on how the decisions taken under the reform affected the internal governance of the cooperative in terms of input management, marketing procedures, and strategies to ensure prompt payment to each farmer. Second, a survey (n=158) was conducted with individual producers who had returned to the sector after the 2009-2010 season (in 2010-2011, and 2011-2012; see Table 3). The survey focused on the motives for their return to cotton production. Newly recruited extension officers working in the study area were also interviewed individually (n=9), as well as those actors working in higher-level organisations, such as representatives of the AIC, PARFCB, the input suppliers, and the ginners (n=4). These interviews focused on the responsibilities, roles, and coalitions emerging from the implementation of the reform. The interviews aimed at understanding how resources were released and deployed (e.g., power and money) and also at clarifying the changes in power relations among stakeholders (winners and losers), and how they pursued their own goals given the emerging policy arrangements.

Archival research and retrospective inquiries for the country as a whole were made, to investigate the initial situation in 2008. This, together with the collected data enabled us to make a ‛before and after’ comparison. Cause/effect relationships were established by real time monitoring (from 2009-2010 to 2011-2012) in order to trace the actual effects of the reform on FBOs in N’Dali. The monitoring started with the identification of causes (various measures taken under the reform), followed by recording the effects. This was done by non-participant observation (Kumar, 2005) which means that we only recorded what happened, without being further involved.

Findings

The reform was initiated in 2009, at a critical time when cotton output had fallen to historically low levels. Despite government support and significant public financial investments, the entire cotton sector was performing poorly, in particular with regard to the ‛caution solidaire’, supervision, input management, and marketing.

We present first the process of the reform initiation and implementation. Second, the core findings from our archival research and retrospective inquiries are presented along the four dimensions distinguished by the policy arrangement approach, as well as change that occurred in these four areas. Lastly, we report on the effects of this reform on cotton production, farmers' motivations for returning to cotton production and finally debt decrease.

The reform: perspectives and implementation

Any reform is a political process that comprises at least three steps (Crabbé and Leroy 2008): (i) agenda setting or problem definition; (ii) formulation of the policy or reform; and (iii) implementation of the policy or reform.

The first step, agenda setting, was carried out at the national level during encounters between the AIC and actors from the public services. According to the AIC and the government, the main reasons for the poor performance of the cotton value chain prior to the reform were

- lack of trust among farmers and between farmers and their representatives in various structures from district to national level;
- lack of competence by farmers to handle all the tasks assigned to them;
- corruption and embezzlement by their Board representatives;
- lack of an organised information flow from higher to lower hierarchical levels.

The second step was then taken: policies were formulated based on the various points identified as the causes of underperformance of the cotton sector. The dissolution of the farmers-based organisations (FBOs) at district and national was the core decision of this policy formulation that was expected to improve the internal governance of the FBOs. As a result, the AIC was to interact directly with farmers at the local level. Several other measures were taken to motivate farmers, such as supplying Tihan (a conventional pesticide, of which the import was controlled by a single supplier) free of charge, reducing overall input costs, increasing the cotton price, allowing for timely payments, and tightening the supervision of farmers by means of more regular extension support. Measures to improve internal governance of the FBOs ranged from transition to CVPC to enforcement of the rules (Table 1). Measures were also taken to improve the management of the input supply chain and the management of the group-based guarantee.

The third step, implementation, started at the beginning of March 2010. An information memo was widely disseminated, focusing on the rationale of the reform and its objectives. This was followed, in mid-March 2010, by the training of PARFCB employees and the extension service (CeCPA). This training related to the implications of the reform in terms of tasks, missions, and responsibilities, and was meant to pre-empt any local interpretation of the measures. Subsequently, the creation of farmers' cooperatives was initiated and this was completed by the end of March 2010. At the beginning of April 2010, general meetings of the new cooperatives were held, at which the members of the boards of directors were elected. Representatives and auditors were trained until the end of April. The training, information, and dissemination sessions were followed at the beginning of May 2010 by a second round of general meetings at which farmers affirmed the acreage they intended to plant that season and expressed their input requirements.

Table 1: The reform measures and the respondents' views of the degree of implementation (n=28)

Purpose of measures	Measures	Level of implementation
Change in governance	New eligibility criteria for members of CVPC	±
	Renewal of Board members by a third each year (during three years)	+
	Removal of FBO umbrella from district to national level	+
	Training of Board of Directors	±
	Organization by each CVPC of two general meetings with obligatory minutes	±
	Election of new representatives of CVPC	+
	Certificate issued by PARFCB to approve eligibility of farmers to become representatives	-
	Creation of new positions for representation at CVPC level	+
	New eligibility criteria for members of CVPC	±
Better management of inputs	Establishment of acreage using GPS to assess input demands	±
	Establishment of local committee for better input management	±
	Providing each warehouse with two padlocks	±
	Demand expression by farmers during general assembly	±
	Delivery of inputs according to demand	+
	New tools and documents for managing the CVPC	±
Improved management of ''Caution solidaire''	Establishment of the interdependent guarantee at CVPC level	+
	Establishment of small groups of solidarity within CVPC	±
Improved supervision of farmers	Strengthening the supervision of farmers by increasing the number of extension agents	+
Non-permanent measures directly linked to cotton production	Access to Tihan free of charge	+
	Increased cotton price	+
	Financial separation of the new CVPC from the debts accumulated by the GVPCs	+

Level of implementation: - none; ± partial; + full

Approximately 50% of these reform measures were completely implemented; the remaining ones were only partially implemented or not at all (Table 1). The measures were not applied in the same way in all zones and cooperatives. When implementation of the reforms required conditions that could not be met by the CVPC itself, or if the CVPC lacked sufficient internal capacity to implement them, the measures were dropped. Several reasons were given by the extension agents we interviewed to explain the discrepancies observed between the intention and the implementation of the measures. These included the high rate of illiteracy in the rural areas of N'Dali, the insufficient number of agents (e.g., for establishing the acreage by means of GPS), a lack of resources for implementing the measures (GPS, warehouses, printing certification forms), the excessive novelties introduced by the reform and, finally, the large number of tasks assigned to the extension agents with respect to farmer supervision.

Discourses

Before the reform

The central philosophy ruling discourses on cotton sector was liberalization. It implied the transfer of competencies from government to non-government actors (Ton and Wankpo, 2004; Tschirley et al., 2009). Liberalization was promoted and supported by the World Bank and other developmental institutions through a Structural Adjustment Programme (Minot and Daniels, 2005). The discourse assumed that the FBOs would be able to take over input management as well as cotton grading and cotton marketing. These tasks were formerly carried out by the public extension services and a quasi-autonomous agency called the 'Société Nationale de Promotion Agricole' (SONAPRA).

The liberalization discourse in the 2000s was followed gradually by the privatization of public enterprises (Baffes, 2005). This stimulated the entrance of private actors into input supply and ginneries, and allowed their coexistence with public actors. Nine companies began to supply inputs and eight companies started cotton ginneries. The total capacity of the ginneries grew to approximately 600,000 metric tonnes per year, i.e., higher than the levels of seed cotton production reached during the peak years.

The reform

Two important measures of the leading programme of the 2009 reform (PARFCB) give full understanding of the discourses behind the rationale of this political decision. The first is ''assainissement'' which literally means to improve the sanitary status of cotton sector.

Embedded in this is the idea of improving governance and management. Unfortunately, the focus was only directed towards FBOs. The second is "relance" which literally implies the revival of the cotton sector by increasing production. This objective was to be attained by improving the productivity and increasing the cotton acreage, which was at its lowest level since 2004 due to the withdrawal of many cotton growers. To improve governance, the concept of a new type of cooperative was introduced, emphasising the importance of solidarity as a guiding principle for farmers, and the importance of transparency of new procedures. The concept of participation was promoted to ensure transparency in the input-demand procedures. In addition, a view of cooperatives as commercial enterprises having responsibility for managing significant financial capital to which each farmer contributes, was emphasised. An awareness-raising campaign among farmers underlined the importance of paying membership fees and social contributions. Moreover, the role of solidarity groups within the cooperatives and the principle of mutual interest between and within these groups were emphasised. It was thought that solidarity would ensure mutual control among farmers, so that rules, procedures, and tasks encoded in the various measures would be followed.

The group-based guarantee established earlier at the district level was relocated to the cooperative level. As mentioned above, to become a member of a CVPC, a farmer was obliged to provide two passport photos and pay a membership fee. Only farmers belonging to the same solidarity group became responsible to each other for debt reimbursement.

Actors and coalitions

Before the reform

In line with the privatisation in the early 2000s, the FBOs, the input supply companies and the ginneries formed the AIC that was put in charge by the government of regulating the whole cotton sector. To facilitate financial flows among these three actors, the ‘Centrale de Sécurisation des Paiements et des Recouvrements’ (CSPR) was established. Farmers were organised from local to national levels into a ‘Fédération des Unions des Producteurs’ (FUPRO). This remained the only network among FBOs, until some farmers left the union and started dealing separately with dissident ginners and input suppliers (Sinzogan et al., 2007).

At this time (2001, 2002), no private company was allowed to perform the technical tasks of extension, research, and cotton grading. Extension was left to the government’s ‘Direction du Conseil Agricole et de la Formation Opérationnelle’ (DICAF) and its offices at departmental and district levels (Centre Régional/Communal pour la Promotion Agricole, CeRPA and CeCPA). DICAF was placed in charge of the training intended to strengthen the capacity of extension agents. DICAF operated under a contract with the AIC to identify the training needs of extension agents in response to farmers' concerns. The resulting mix of public and private organisations is illustrated in Figure 1.

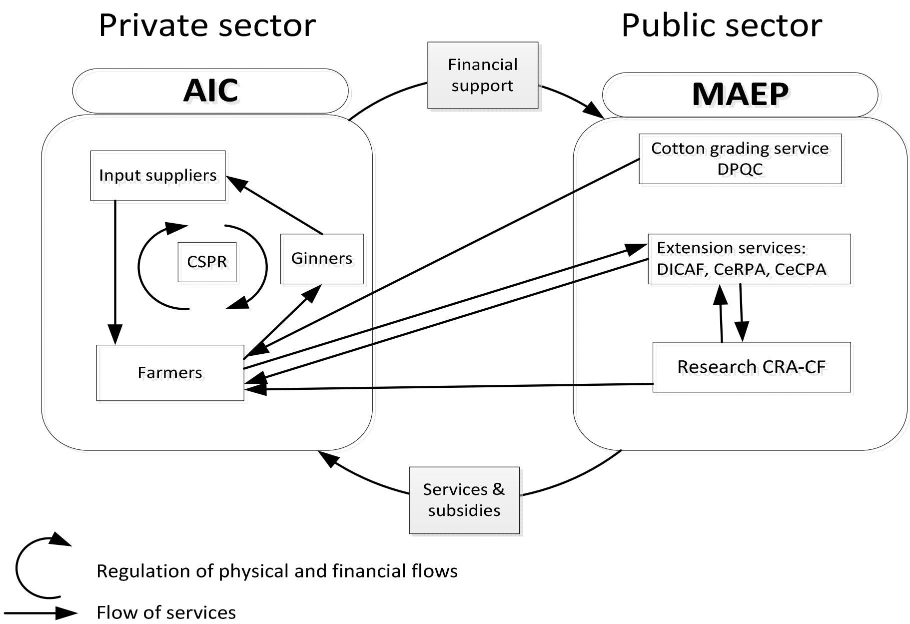

Figure 1: Arrangements among actors of the cotton sector in Benin before the reform
MAEP: Ministère de l'Agriculture de l'Elevage et de la Pêche
CeRPA: Centre Régional pour la Promotion Agricole
CeCPA: Centre Communal pour la Promotion Agricole
AIC : Association Interprofessionnelle du Coton
CRA-CF : Centre de Recherches Agricoles Coton et Fibres
DICAF : Direction du Conseil Agricole et de la Formation Opérationnelle
DPQC : Direction de la Promotion de la Qualité et du Conditionnement

Liberalization of the sector meant the separation of actors involved into two categories, private and public services. It has given power to private services to have control over the entire cotton sector but this power was given to them without ensuring that all the conditions were met to handle all the prerogatives assigned to them. Also, the risk of hijacking power by only one category of actors existed but was overlooked, as farmers did not have the same level of education, political anchorage, and financial power to influence further process of the liberalization. This had affected the resultant changes that occurred in the cotton sector from 2009. The disengagement of the State was also followed by a decrease in attention to extension services, leading to a decrease in the number of extension agents, as retiring employees were not replaced.

The reform

The new measures of the 2009 reform introduced new concerns and responsibilities that brought in new actors, but also excluded others (Table 2). Among the excluded actors were the previous representatives of the FBO organisational structure from district to national level, and the cotton grading officers. Among the new actors were the PARFCB agents, who were recruited to supplement those of the extension services.

The dismantling of the previous FBO organisations allowed the PARFCB agents to take over some of the tasks formerly carried out by the FBOs. Prior to the reform, CeCPA had carried out cotton extension. Under the reform, the scope of its mission was extended to include many aspects of governance such as controlling input delivery, establishing the level of debt, supervising primary marketing, and paying the farmers. For this purpose, new partnerships were set up between the AIC and CeCPA and between PARFCB and CeCPA to strengthen the capacity to supervise farmers and oversee the governance of the CVPCs. Cotton advisors drawn from both CeCPA and PARFCB began working closely with farmers under tight supervision of their directors. Farmers also could request assistance from the supervisory staff when needed.

Many of the newly recruited agents had management and accounting experience. The supervision of input delivery, carried out by the extension services through the new agents, encouraged the agents to work closely with input suppliers at district level. For instance, information related to pesticides and fertilizers was channeled to farmers through the extension services via the PARFCB agents. This path of dependency gave much power to the extension agents and opened the door to collusion between the agents and input suppliers, at the expense of farmers. In addition, feedback on management performance and on compliance with the defined rules was conveyed to the AIC by the same PARFCB-appointed agents.

Table 2: Actors' responsibilities in the cotton sector of Benin before and after the reform of 2009

Actors		Responsibilities before the reform	Extra responsibilities after the reform
Farmers	CVPC members	Produce cotton to feed a self-managed market	Mutual control of farmers belonging to the same sub-group of solidarity
	Board of Directors of CVPC	Financial and administrative management of GVPC (secretary took decisions)	Secretary no longer taking the decisions
	Former representatives ex- CCPC, CDPC and CNPC.	Farmers' representation at district level in the AIC. Supply of inputs to GVPC and coordination of cotton marketing	Withdrawn from cotton sector
Supervision staff	CeCPA-CeRPA	Supervision and extension	Acreage measured by GPS Coordination of input delivery and cotton marketing
	PARFCB Agents		Technical assistance via AAGC for better management and accountability of cooperatives' finances
Ginners		Purchase of seed cotton Payment of 40% before start of marketing Ginning and exporting of cotton fiber	Control of cotton quality
Inputs suppliers		Timely supply of good quality inputs to farmers	Same
Research CRA-CF		Alleviating technical constraints of cotton production Suggesting types and dosages of pesticides	With AIC: design research agenda and validate results
AIC		Providing services to GVPC : supervision, seed and inputs supply, credits for production	Providing assistance for administrative and financial management to CVPC Joint designing of research agenda and joint validation of results
CSPR		Repartition of cotton to ginning factories Recovery input credit Cotton payment to producers	Same
Quality control service (DPQC)		Cotton grading	Withdrawn from the cotton grading service

AAGC : Agent d'Appui à la Gestion Coopérative
AIC : Association Interprofessionnelle du Coton
CCPC: Conseil Communal des Producteurs de Coton
CDPC : Conseil Départemental des Producteurs de Coton
CNPC : Conseil National des Producteurs de Coton
CRA-CF : Centre de Recherches Agricoles Coton et Fibres
CSPR : Centrale de Sécurisation des Paiements et des Recouvrements
CVPC: Coopérative Villageoise des Producteurs de Coton
GVPC: Groupement Villageois des Producteurs de Coton
PARFCB : Projet d'Assainissement et Relance de la Filière Coton au Bénin

Resources

Before the reform

The vertical structuring of farmers was meant to ensure that their interests were defended within the AIC. This structure gives great power and some advantages to farmers appointed in the FBOs over their fellow farmers. Thus, those at the national level had power over those at departmental level, for example. Most farmers were illiterate but nevertheless responsible for appointing representatives to the AIC. Some level of education was required for these representatives to be able to handle the tasks assigned to them. As a result, many representatives were appointed who were not cotton growers, defeating the purpose of their appointment. The cotton setting is a political arena where power relationships play an important role, in particular within the AIC. Once representatives reached the national level, they were no longer accountable to the grass roots members. Moreover, the AIC became dominated by input suppliers and ginners, who often joined forces to overrule the farmers' representatives.

The market for inputs gradually lost its competitiveness. Among the nine companies that competed for a licence to supply inputs every season, the same company, the 'Société de Distribution Intercontinentale' (SDI), won the bid each time. In turn, it built a network of dependent distributors among the losing companies. The bidding process lacked transparency and SDI rapidly became a monopoly supplier. It acquired a number of ginneries whereby the ginning sector too, slowly fell under SDI's control. It began to influence the reform process and regulations to advance its own interests.

A part of the research activities were funded by the AIC. Consequently, research and extension had to comply with AIC's requirements before being carried out. The development of the cotton sector mostly came to serve the interests of the powerful groups represented in the AIC and largely neglected the broader interests of farmers. Farmers also complained about the variety they had to plant, arguing that it produced fewer and lighter seeds than the earlier one used (cotton seed is paid on weight basis).

The reform

Control of the AIC over only part of the extension cadre, coupled with the power accrued by other actors at various levels as their resources in terms of power and money increased, created two poles of authority in the extension structure (Figure 2). These centres of authority were meant to be complementary; the one under the ministry was meant to improve the supervision of farmers in terms of application of the recommendations for better cotton production, while the one under AIC was expected to keep the amount of debt lower than before the reform by watching over the governance of FBOs, especially their input management. Each pole of decision involved a set of actors hierarchically related to each other through a vertical network. The extension service CeCPA depended on the CeRPA and DICAF, both under the control of MAEP. The AIC-appointed technicians worked within the pre-reform extension framework, but were directly linked to PARFCB, and thus embedded in the AIC.

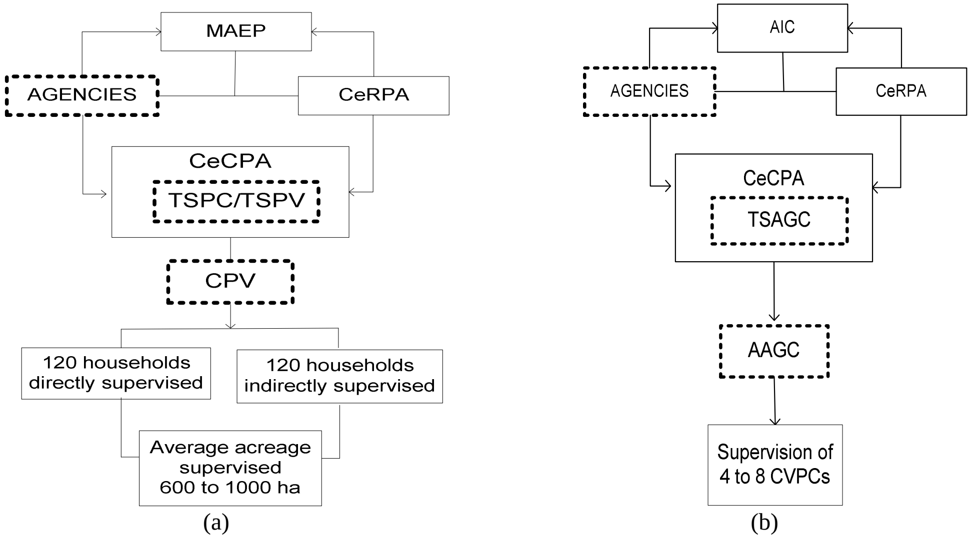

Figure 2 : Extension schemes that emerged after the reform
(a) under the ministry in charge of agriculture
(b) under the Association Interprofessionnelle du Coton
Note: Dashed rectangles include the new agents
Source: AIC, 2012

AAGC : Agent d'Appui à la Gestion Coopérative
AIC : Association Interprofessionnelle du Coton
CCPC: Conseil Communal des Producteurs de Coton
CDPC : Conseil Départemental des Producteurs de Coton
CeCPA: Centre Communal pour la Promotion Agricole
CeRPA: Centre Régional pour la Promotion Agricole
CNPC : Conseil National des Producteurs de Coton
CPV: Conseiller en Production Végétale
CRA-CF : Centre de Recherches Agricoles Coton et Fibres
CSPR : Centrale de Sécurisation des Paiements et des Recouvrements
CVPC: Coopérative Villageoise de Producteurs de Coton
GVPC : Groupement Villageois de Producteurs de Coton
MAEP: Ministère de l'Agriculture de l'Elevage et de la Pêche
PARFCB : Projet d'Assainissement et de Relance de la Filière Coton au Benin
TSAGC: Technicien Spécialisé en Appui à la Gestion Coopérative
TSPC: Technicien Spécialisé en Production Cotonnière
TSPV: Technicien Spécialisé en Production Végétale

The success of the cotton value chain came to depend on how activities and resources (subsidies, money, and knowledge) were coordinated and how power was exercised to support production at the local level. The PARFCB was given a pivotal role in coordinating the reform. Over time, it took over - together with the AIC - all the prerogatives of the FBOs and public services such as CeCPA and the cotton grading service. The specilist cotton quality grading officers were dismissed during the 2011-2012 season, and replaced by PARFCB agents and ginners, who were, however, not trained for this work. The PARFCB employees interviewed indicated that the decision was taken to avoid the corrupt behaviour of the former cotton grading officers. Respondents in our interviews indeed indicated that in order to have their cotton graded as grade I, farmers used to pay significant amounts of money to the grading officers, because grade II received about 50 FCFA (0.1 US$) less than grade I. The grading officers were not consulted before the decision was taken and vigourously expressed their disappointment to the government.

Overall, the AIC came to hold great power in the cotton chain, power that had been formerly shared by FBO organisations. The absence in the new arrangements of strong FBOs at departmental and district levels broke the communication flow and feedback channels to farmer members at local level. Despite the establishment by AIC of a national council 'Comité Consultatif National Transitoire' (CCNPC) to represent farmers at the national level, the committee failed to establish itself as a strong farmers' voice. This was because it was not a grass roots organisation. The farmers we interviewed were indeed not aware of the existence of this organisation. One of the main complaints expressed by them was the lack of a body that could represent their experience and views honestly and firmly at the national level.

Institutions

Before the reform

Three arrangements are important for successful cotton production: input management (from bid launching to input delivery to farmers via input bid winning), cotton allocation to supply ginning factories, and governance of FBOs at various levels. In all three domains, actors failed to comply with the rules and regulations that governed these domains, due to lack of enforcement.

Prior to launching the input tender, a commission with representatives of input suppliers, ginners, and farmers, together with agents from public services, had to decide on the input prices for the coming season and on the procedures for selecting input suppliers and distributors. This commission also had to ensure the delivery of inputs of good quality to farmers. Farmers had to express their input requirements by September of the on-going season in order to be able to get inputs in time for the following season, which generally starts in May. In practice, the expression of input demands for each season often came late. Farmers argued that they need to complete the growing season before talking about the next season. This was one of the reasons given by input suppliers to justify the delay of input delivery. Another procedure specified that, when it was difficult to agree on input prices, additional meetings would need to be held by the commission to reach consensus. Farmers indicated, however, that input suppliers deliberately delayed the moment of consensus. According to farmers, input suppliers were speculating that international input prices would increase if they waited long enough, which would enable them to sell the inputs, which they had acquired at lower prices earlier and stored, for a substantial profit. All these strategies increased the cost of production for farmers. Our diagnostic study revealed that input suppliers preferred to sell conventional pesticides, and ensured by various means that the pesticides needed for applying the recommended lower-dose LEC strategy did not arrive on time or in sufficient quantity (Togbé et al., 2012). Farmers further stated in our survey that even if the right chemicals were available in sufficient quantity and at official prices, they often turned out to be outdated. Fok (2008) also indicated the delay in cotton input delivery in Benin.

Cotton ginners had to comply with a number of rules specified by the CSPR, such as respecting the seed cotton allocation plan and the advance in currency of 40% of the value of the seed cotton allocated to them. The remaining 60% of the value of the seed cotton that ginners were to pay sometimes came into the hands of farmers only after great delay. The allocation plan defines the quantity and the provenance (villages and districts) of the seed cotton to which each ginning factory can lay a claim. In practice, when total cotton production decreased, the gap between the ginning capacity and the quantity produced and allocated to the ginnery became wider. Ginners responded by bypassing the rules. They hijacked the seed cotton attributed to other ginning factories and created confusion and embezzlement. This practice was also due to the long distance that sometimes separates the ginning factories and the cotton growing areas. Furthermore, cotton transporters were also involved in such manipulations.

A set of rules was also established for the better governance of FBOs. Each farmer had a mandate to participate in the election of FBO representatives. Once elected, farmers' representatives were to serve a term of two years, renewable only once. Insufficient numbers of farmers were willing to become representatives at various levels of the FBO structure. Thus politically ambitious people who were not cotton farmers were appointed as farmers' representatives to the Board of Directors, hijacking the prerogatives pertaining to farmers' representatives. The governance of the GVPC was characterized by (i) farmers' low awareness of existing regulations and their low compliance, allowing a handful of individuals to monopolize the key positions (President, Secretary and Treasurer) within the GVPC over the years; (ii) lack of control by external auditors, leading to embezzlement; and (iii) poor information flow because of farmers' lack of knowledge regarding the tasks ascribed to the positions occupied by the so-called farmers' representatives on the Board of Directors. The necessary documentation procedures were incorrectly handled by these individuals and as a result, farmers were deprived of much information.

These conditions created an environment for engendering debt. Debt increased when the value of farmers' seed cotton production was less than the amount of input credit received. It became one of the main reasons why farmers withdrew from the cotton sector. Not only did the acreage cultivated decrease, but also the yields per hectare. As already noted, the decline in production led to an under-utilization of the ginning capacity.

The reform

In line with the 2009 reform, several steps were taken to follow and monitor the management of inputs in order to reduce embezzlement. These steps were supposed to be based on the accurate expression of the types and quantities of the inputs needed, ahead of the next season, so as to allow effective monitoring and control over the inputs delivered to each FBO. Requirements were first expressed during a general meeting in the presence of all farmer members of the cooperatives (Sekloka, 2010). Each farmer was expected to declare the acreage he or she intended to cultivate in the coming season and other farmers were encouraged to add their comments on the claims made. The acreage was subsequently supposed to be verified by means of GPS by an extension agent. Several documents were then to be supplied to each cooperative: one to record the inputs ordered, another for inputs delivered and further receipts indicating the amount of inputs received by each farmer.

Immediate outcomes of the reform

The policy arrangements brought about by the reform had some immediate effects on the production volume, the motivation of farmers, and their debt ratio.

Cotton production

Production in N'Dali increased from approximately 34 metric tonnes during the 2009-2010 season to nearly 300 metric tonnes during the 2010-2011 season. This is a direct result of the increase in acreage planted, caused by the return of many cooperative members to cotton production (Figure 3). A strong increase in production was also observed for the country as a whole with a doubling of output over the same period (Figure 4).

Productivity (kg cotton per ha) remained low in the three CVPs included in this study, although it increased by about 12% over 2009-2011 (Figure 3). This is somewhat of a surprise, given the tight supervision of farmers by the CPV, the control exerted through the verification of acreage planted before delivering inputs, and the mutual control by farmers themselves.

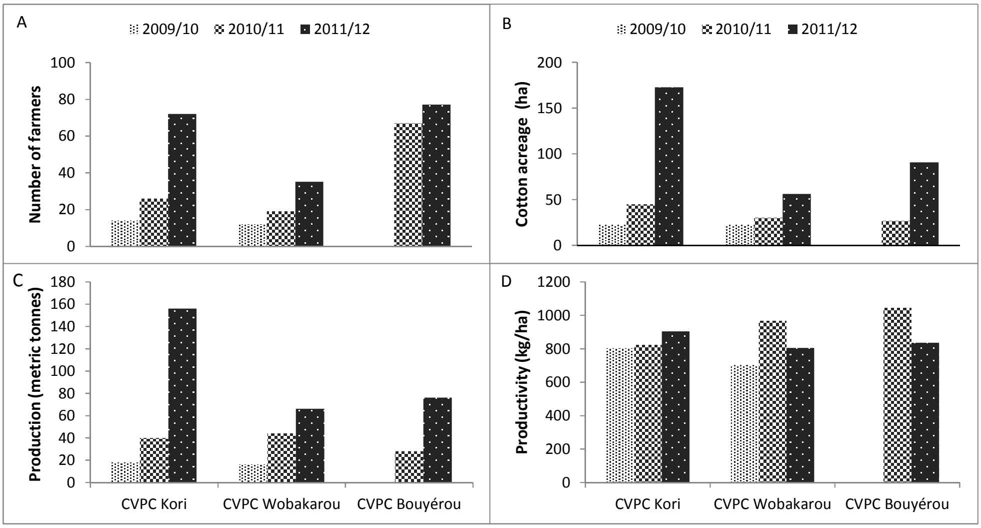

Figure 3: Effect of reform on (A) the size of the cotton cooperatives, (B) area cultivated, (C) output, and (D) productivity in the cooperatives of Kori, Wobakarou and Bouyérou from 2009-2010 to 2011-2012.
CVPC: Coopérative Villageaoise de Producteurs du Coton.

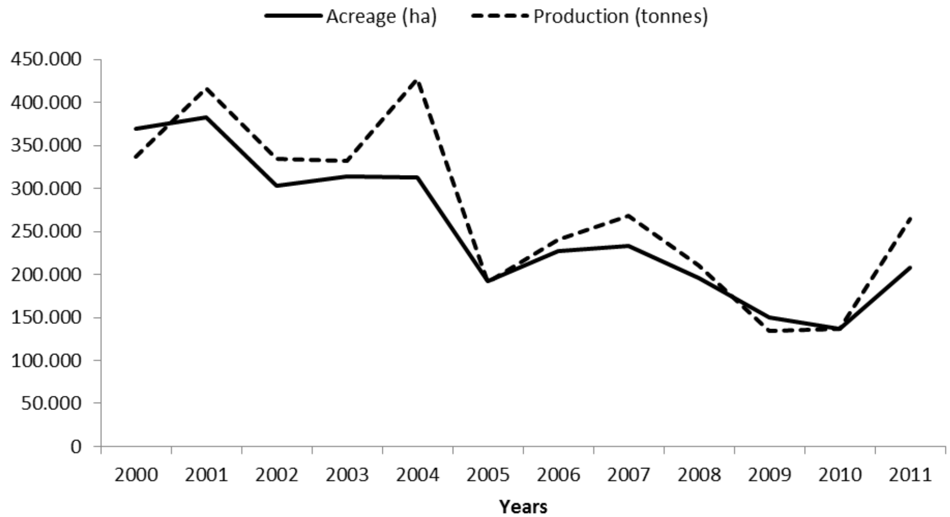

Figure 4: Evolution of cotton acreage (ha) and production (metric tonnes) from 2000 to 2011 in Benin
Source: AIC, 2012

Motivations of new cotton farmers

The shift from the GVPC to CVPC and the various measures initiated with regard to the governance of FBOs had a positive effect on the number of CVPCs, as farmers became motivated again and more confident that cotton could be a viable crop for them. In the three villages we identified 158 farmers (86% of the total number of farmers) who returned to cotton production along with the implementation of the reform. Table 3 lists various reasons for their return. About 36% mentioned the confidence brought by the new requirements for registering as a cotton farmer, and for eligibility to become farmers' representatives. About 26% indicated not having to pay for Tihan and experienced an increase in cotton farm gate prices. Note that these two benefits were only temporary measures, so the effect of these measures disappeared over time. Furthermore, almost 25% of the farmers were attracted by the timely and regular payment for their cotton harvest. About 13% mentioned the need to generate cash savings, perhaps indicating their failure of doing this through other cash crops such as soybeans and maize.

The 77 farmers belonging to the cooperative in Bouyérou, one of the six cooperatives established in N'Dali during the reform, were all experienced producers who had abandoned cotton production because of bad governance and performance of the cotton sector. In this CVPC, the farmers returned to cotton production because of the incentives brought about by the reform (27%) and the quick and regular payments (73%).

Table 3: Farmers' main reason (in percentages) for returning to cotton production in 2010-11 and 2011-12

Reasons	Kori n=58	Wobakarou n=23	Bouyérou n=77	Altogether n=158
Better revenue (Tihan free of charge and increased cotton price)	42	36	0	26
More stringent requirements for farmer to join CVPC, farmers being more accountable	38	46	27	36
Availability of cash	20	18	0	13
Quick and regular payment	0	0	73	25
Total	100	100	100	100

Debts among cotton farmers

To evaluate the effect of the reform on the management of inputs, we calculated the ratio of debt per CVPC, obtained by dividing the total amount of input credit by the total value of the production in the same season. In all three villages, the debt ratio fell strongly and by 2011 ranged between 48 and 60%. A similar trend in the decline of the debt ratio has been estimated for the whole country over 2009-2011 (Figure 5).

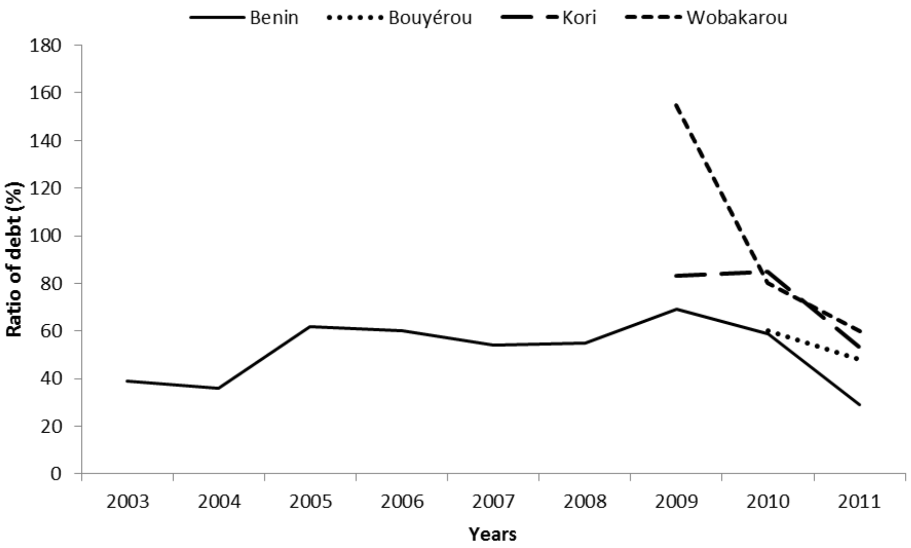

Figure 5: Evolution of the debt ratio from 2003 to 2011 in Benin and from 2009 to 2011 in Bouyérou, Kori and Wobakarou
(Source: CSPR, 2012)

The estimated decrease in the debt ratio in the three villages could be considered a positive consequence of the new procedures for input delivery and credit recovery. The assistance provided by the AIC-appointed agents, the tracking of areas cultivated by means of GPS for assessing the amount of inputs required, and the use of a warehouse with two padlocks (in two out of the three villages) led to transparency and better management of inputs, avoiding overestimation and embezzlement. The falling trend in the debt ratio can also be attributed to the 'caution solidaire', which was relocated to the cooperative level. Thus, unlike the period before the reform, when the cotton revenue of one village could be used to offset the debt incurred by farmers in another village, only farmers belonging to the same solidarity group within a cooperative, became responsible to each other for debt reimbursement.

Nevertheless, there is still work to do in order to achieve a debt ratio between 35 to 40%, the target set by the reform. An improvement in productivity seems to be the key for this. Matthess et al. (2005) indicate that yields were 25 to 75% below the optimum. This suggests that there is still potential for achieving the target of the reform through increasing productivity in the cotton sector.

Second-generation problems created by the reform

Apart from the positive effects that were noticed as outcomes of the reform, many unexpected problems emerged:

- Mistrust in production statistics communicated by the AIC. The statistical data collected through GPS were sent directly to the AIC. The RCPA did not receive the data of the 2011-2012 season, so the real acreage cultivated was not known by the extension services, but only by the AIC agents. Also, many farmers complained that their actual production was not recorded accurately and that the agents colluded to understate the amount and thus reduce payments made to them.

- Lack of transparency in the calculation of the rebate returned to farmers and in the effectiveness of all the money collected for performance of critical functions. This suspicion arose because of the exclusion of the grading agents by the AIC. The rebate is based on the weight of seed cotton delivered. The weights that were recorded raised some doubts about the accuracy of the weighing scales. As mentioned earlier, an amount of 30 FCFA was collected for each kg of seed cotton sold. This amount was paid by both ginners and farmers to finance road construction and maintenance (to provide easy access to cotton growing areas, seed supply and delivery), research activities, and other tasks the government were supposed to take care of. Our interviews indicate that, after four years of experience, many farmers thought that the money collected in this way had not led to any concrete improvement. For instance, the seed germination rate each year (40-50%) remained low (the percentage should be higher or equal to 75%), indicating poor quality of the planting seed. This was probably related in turn to ineffective pest management in the production and storage of the seed to be distributed for planting.

- Bad management of subsidies. The research, extension and cotton grading officers that were interviewed cited numerous instances of abuse and cheating by the AIC. The AIC has not reported data on the management of the subsidies and is widely suspected of misusing the funds (Nounagnon, 2012).

As the complaints and pressures from the field and from public services built up, the policy arrangements set up under the reform were brought to an abrupt halt. Increasing exposure of the inefficiencies and abuses at public meetings and in press, radio, and television led to intervention by the President. Before the 2012-2013 season opened, the AIC lost all responsibility for the sector and was abolished. The monopoly input supplier lost its licence, and the sector relied on the army to distribute inputs for the 2012-2013 season. Today, intensive and wide-ranging debate is ongoing over what policy arrangements would serve the sector best as a whole and sustain farmers' interest in growing cotton.

Discussion

Neglected areas of the reform

From an analysis of what has been the focus of the reform, it appears that the main problem was considered to be the capacity and behaviour of the farmers and their representatives. Indeed, little attention was paid to the constraints hampering farmers. This is always the case when the arrangements are imposed abruptly, by a dominant player, and without experimentation (Fok, 2008). The reform focused mainly on adjusting the relationship between the AIC and the FBOs and on the internal governance of FBOs. The behaviour of others, in particular of the input suppliers (dominant player), was neglected because of political power, whereby the difficult relation between farmers and input suppliers continued. Some other constraints neglected by the reform, which were mentioned by farmers, were:

- Light weight of the official variety of seed cotton in use. The ginneries buy the farmers' harvest of seed cotton by the weight of the bales. The AIC and other agents involved in seed improvement and promotion introduced a new variety that yielded much higher proportion of lint at a lower seed weight. At first farmers welcomed the new variety because it grew well, until they realised that they would have to deliver considerably more seed cotton in order to receive the same price as that of the earlier variety;
- Lack of nationwide soil fertility recommendations. Farmers suggested that fertilizer brands should be adapted to each region, as soil types are not the same everywhere;
- Ineffective pest control. Farmers suggested that the pesticide package should be adapted according to the pest regime in each zone and season. Pest damage was increasing and the crop was becoming unprofitable in many areas. Fok (2008) related farmers' complaints about pesticide quality to insect resistance.

Various measures taken for keeping farmers motivated to grow cotton were meant to mitigate the effect of the dissolution of FBOs. There were advantages and power attached to the position of farmers' representatives, which were hijacked by semi-illiterate or literate people who, in most cases, were not professional farmers. The cotton rebate meant for farmers at local levels transited through all the various representatives at national, departmental and district levels before farmers received them. The management of these rebates lacked transparency, as no accountability was given to farmers at the grass-roots level. Moreover, some meetings and training sessions were organised on behalf of farmers and only the representatives attended them before the fellow farmers had been informed. There was a financial compensation related to their attendance. Besides, the management of inputs gave the farmers' representatives opportunities to have the amount needed for cotton and food crop production. Following this decision, there was talk all over the country that these representatives were planning to cause cotton production to fail in order to claim their importance in the sector. But, these threats seemed not to decrease farmers' motivations, as AIC foresaw these reactions and countered them by giving some incentives such as providing Tihan free of charge and increasing the price of cotton. Many awareness campaigns were also organised to give explanations to farmers during the planting period. As a result, many farmers returned to cotton production definitely expecting to see their efforts being rewarded.

All the decisions taken under the reform were expected to be implemented, but the realities on the ground had limited the extent of the implementation of some of them. This suggests the importance of a pilot phase, which could have been conducted to refine the whole programme. Although a pilot phase would not have guaranteed complete success, it would have increased the likelihood of attaining the goals of the reform (van Teijlingen and Hundley, 2001). Also, the reform was too ambitious to the extent of the results it was meant to achieve. The implementation revealed its limitations in meeting all the required conditions for reaching the expectations.

The appointment of new recruited agents with accountant experience thus far has not solved completely the problem of corruption and mismanagement. It was reported in some districts that an important amount of cotton seed intended for planting was sold in Nigeria, a bordering country. Also, those agents planted their own cotton and maize, preventing farmers from receiving the required amount of fertilizers and pesticides for their production. This indicates that these agents did not understand the extent of the responsibilities attached to their appointment.

The short time frame from the launch to the establishment of the cooperatives: linear approach

The methodology underlying the reforms in Benin employed a linear approach with pre-written policies and procedures formulated and implemented at levels higher than the farmers' level. Some basic weaknesses and inadequacies of such an approach can be identified. First, the setting up of the CVPC was neither desired nor decided on by cotton farmers themselves, but was prompted by the PARFCB. There was indeed no awareness or positive desire among farmers to adopt a cooperative form of organisation. Second, the reform was brought to the attention of farmers as late as March 2010, and it was implemented immediately afterwards. The short time frame between informing the farmers about the reform and the establishment of the cooperatives (less than one month) shows that farmers were not prepared, nor were their representatives, to bear all the burdens associated with the reform. Thus, farmers did not participate in the design of new measures that could solve their problems. Despite the training and meeting sessions they were given in order to understand the reform, these awareness sessions appear to have been insufficient to bring them to the full knowledge of the intent of the reform. Overall, the formulation and implementation used a top-down approach conducted by a small elite group of self-interested parties that mainly ignored the interests and participation of farmers.

The imposition of the reform measures on the sector was possible because of the powerful position of the AIC. The AIC-farmer ‘‘partnership’’ largely reduced the autonomy of farmers, especially with the removal of the FBO umbrella. It is as if the proponents of the reform had stepped back in time to abandoned models of 'transfer' in which farmers were considered as passive receptors of other people's decisions. In order to benefit from the input credits and extension supervision, farmers were forced to comply with measures imposed unilaterally by the AIC. Such a change in behaviour could be interpreted as an 'accommodating acceptation' or 'conformism' (Tossou, 1995). According to these researchers, such changes in behaviour are not sustainable and will soon disappear if the source of pressure is withdrawn.

Sustainable cotton production through stable configuration

Critical for a successful and sustainable cotton production is the support by a socio-organisational arrangement of actors who have a real interest in cotton production. This implies that 'sustainability' cannot just be looked at in biophysical or ecological terms; the state of 'hard systems' depends crucially on interactions between people (the 'org system') (Berkes and Folke, 1998; Leeuwis, 2004; Röling and Wagemakers, 1998). In Benin, for example, sustainable cotton production is unlikely to be realized without fostering new agreements, new modes of coordination, and new forms of organisation among farmers themselves, and between them and other stakeholders. This requires a redistribution of resources (power) and may also call for a new discourse and approach. Stability of these new arrangements (the four dimensions distinguished by the PAA) subsequently is, in our view, a prerequisite for the sustainability of the cotton sector.

Convenient arrangements among actors and coalitions can be created by applying the Innovation System (IS) approach, which is promoted by several developmental organisations (e.g., World Bank, CTA). An innovation system is an advanced participatory approach, defined as a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect their behaviour and performance (Hall et al., 2006; The World Bank, 2012). Innovation is no longer seen as a measurable output (e.g., a technology or product), but as a process through which knowledge emerges from various sources to achieve desired social or economic outcomes (Hall et al., 2001; Hall et al., 2007; Smits, 2002; Tesfaye, 2009). Mbétid-Bessane and Havard (2009) hold the same view point. Analysing cotton policies in Central Africa, these authors suggested technical (hard and soft systems) and organisational (org system) innovation in which farmers, extensionists and researchers are bound in alliance in searching for appropriate solutions to decrease farmers' vulnerability.

This alliance can also include those stakeholders such as input suppliers and ginners who play significant roles in policy agenda development and implementation in the cotton sector in West Africa (Fok, 2008). Many experiences using the IS approach for research and development are now conducted in Africa by many research programmes such as the 'Convergence of Sciences-Strengthening Innovation Systems' (CoS-SIS programme), the Forum for Agricultural Research in Africa (FARA), and Joint Learning in Innovation Systems in African Agriculture (JOLISSA). Their results should be capitalised upon by decision makers to help avoid making continuous mistakes.

Conclusions

The cotton sector in Benin, like in many countries in West Africa, is subject to multiple policy adjustments that hardly address the real problems faced by actors and stakeholders. The reform that took place in the cotton sector from 2009 until the crisis of 2012 can be credited for establishing some degree of trust within farmers' cooperatives. However, the policy arrangements that emerged from the reform created new frustrations and abuses. This has led to great tension, challenging the stability of the designed arrangements and thus the sustainability of the sector. We have suggested that the top-down nature of the policy process, from problem definition to implementation, is probably to a large extent responsible for the final breakdown. A wider consultation involving all stakeholders, such as used in an innovation approach, may be more appropriate. Also, a larger and more important role of farmer based organisations is also required to achieve a viable cotton sector in Benin.

Chapter 4

Evaluating alternatives to conventional cotton pest control in Benin

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Submission in preparation

Abstract

Neem oil (*Azadirachta indica*) alone and combined with the entomopathogenic fungus *Beauveria bassiana* (isolate Bb11) was applied to control cotton pests, based on surveys to determine pest thresholds. The efficacy of these treatments was compared with that of synthetic insecticides applied either in a calendar-based application or in the "Lutte Etagée Ciblée (LEC) strategy, consisting of using first calendar-based (half dose) followed by threshold-based applications. The experiment was carried out in collaborative research with farmers in three cotton agro-ecological zones differing in rainfall, pest prevalence, and farming practices. The neem oil and neem oil-Bb11 treatments required 2 to 6 applications, while conventional and LEC received 6 to 8 applications. The percentage of damaged bolls in plots treated with neem oil and neem oil plus Bb11 was higher than that recorded under conventional and LEC, resulting in yields being 25% and 39% lower, respectively. However, no significant difference was observed in yields measured in the agro-ecological zone with the highest rainfall. Yields in the biopesticide plots were 26-42% higher and in the conventional and LEC plots 44-59% higher than those in the control plots. Overall, the LEC regime scored best, both in yield and profitability. The incidence of natural enemies was highest in the control and in the plots treated with biopesticides. Although the use of entomopathogen Bb11 and neem oil avoids many problems associated with the application of synthetic insecticides, their efficacy needs to be enhanced by improved formulation or by combining them with other pesticides.

Key words: biopesticides; neem oil; synthetic pesticides; natural enemies; thresholds; Integrated Pest Management

Introduction

Pests are one of the main factors limiting cotton production in Benin. Despite pest management strategies, yield loss can reach 30% (Oerke and Dehne, 2004), resulting from the combined effects of arthropods (12%), pathogens (11%), and weeds (7%). In the absence of pest control, yield loss caused by arthropods alone can reach 62%, while the cotton quality may decrease by an estimated 40% (Gnimassou, 2005; Totin, 2003). Of the overall production costs including labour, between 25 and 45% are used for protection against pests. There is a large diversity of insect species attacking cotton; most species are cosmopolitan and polyphagous. Cotton damage is inflicted by lepidopteran, coleopteran, heteropteran, and acarian species at each growth stage. More than 1300 pest species have been identified on cotton, of which almost 500 in Africa (Matthews, 1996; Vaissayre and Cauquil, 2000; Vaissayre et al., 2006). In Benin, pest species are dominated by phyllophagous insects such as *Syllepta derogata* Fabr. (Lepidoptera: Pyralidae), *Aphis gossypii* Glover (Homoptera: Aphididae), *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), *Polyphagotarsonemus latus* Banks (Arachnida: Acari: Tarsonemidae), and carpophagous insects such as *Earias* spp. (Lepidoptera: Noctuidae), *Diparopsis watersi* Rotsch (Lepidoptera, Noctuidae), *Dysdercus volkeri* Schmidt (Heteroptera: Pyrrhocoridae), *Pectinophora gossypiella* Saunders (Lepidoptera: Gelechiidae), *Cryptophlebia leucotreta* Meyrick (Lepidoptera: Tortricidae) and *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae), the latter one being the most important (Youdeowei, 2001).

For a long time, synthetic pesticides have been and are still being sold using 'fast moving customer goods' marketing strategies in most developing countries (Islam et al., 2012). Their application has become a systematic and easy solution to control these pests. Almost a quarter of the synthetic pesticides produced globally per annum is used on cotton (Ferron et al., 2006), for a total of 30 billion US dollars (PAN, 2008). In Benin, the production of cotton has grown by 38.1% between 1993 and 2000 (from 272,371 to 376,141 tons), while the amount of pesticides used increased by 17.3% (from 1,972,764 litres to 2,314,127 litres) (OBEPAB, 2002).

The overreliance on synthetic pesticides for cotton production is associated with financial, human and environmental costs (OBEPAB, 2002; PAN, 2000; Reddy and Manjunatha, 2000). The nationwide cotton pest control regime in Benin is still the conventional treatment using calendar-based sprays. It consists of six fortnightly applications using synthetic pesticides, starting 45 days after seedling emergence (DAE). The number of applications is often higher because farmers erroneously expect that using extra pesticides can increase yields. The synthetic pesticides used to control the wide range of pest species in cotton are acutely toxic. The continuous use of synthetic pesticides has resulted in the development of pest resistance (Martin et al., 2000; Ochou and Martin, 2002) and has trapped farmers in a pesticide treadmill (Nicholls and Altieri, 1997). The higher amount of pesticides thus required results in increasing production costs. Furthermore, the subsequent use of other pesticides such as organochlorines, organophosphates, carbamates, and pyrethroids to circumvent the resistance has not been successful thus far (Castella et al., 1999; Grzywacz et al., 2010; Peshin et al., 2007; Pree et al., 2001).

Alternative pest management options are available, such as "targeted staggered control" (Lutte Etagée Ciblée - LEC). In 1988, this strategy was introduced in Benin by the Cotton Research Centre (CRA-CF) and is based on calendar spraying of certain pesticides using half the normal dose, complemented by threshold-based applications of specific pesticides. However, many constraints have hindered the large scale adoption of LEC, in particular the non-availability of the specific pesticides (Togbé et al., 2012). It has become necessary to find alternative pesticides in order to reduce dependency on input suppliers (PADSE, 2005; Togbé et al., 2012). Also, it was felt that these alternatives should be sustainable, economically viable, and less damaging to the environment than the pesticides used in LEC (Togbé et al., 2012).

Neem oil and *Beauveria bassiana* emerged as possible alternatives for farmers to compare with the conventional treatment and LEC. Neem oil was reported to be effective (as a repellent or insecticide) in controlling more than 400 pests (Erler et al., 2010) including armyworms, leafminers, aphids, and whiteflies (Isman, 1999; Schmutterer, 1990; Walter, 1999). The efficacy and profitability of neem-based products have been evaluated on several pest species of cotton, vegetables, rice, and maize (Acosta et al., 2009; Lima et al., 2010; Roobakkumar et al., 2010; Tang et al., 2002). The entomopathogenic fungus *Beauveria bassiana* is also a potentially effective candidate for a wide range of pests, and works by ingestion and contact (Inglis et al., 2001; Wraight et al., 2010). It proliferates in the host, and all growth stages (egg, larvae, and adult) of many pests are susceptible (Espinel et al., 2008; Gatarayiha et al., 2011; Pires et al., 2010; Poprawski et al., 1999). Prasad et al. (2010) recorded a mortality of 76% of fourth instars of *H. armigera* in a bioassay, starting 2-3 days after the treatment, mainly because of the rapid propagation of the infection within the host. The fact that *Beauveria* is not toxic to non-targeted organisms makes it a good candidate for use in an Integrated Pest Management (IPM) strategy.

Little research using neem oil and *B. bassiana* has been conducted on cotton in Benin, and most results are unpublished. This study aims at testing the efficacy of neem oil (*Azadirachta indica*) alone and combined with the entomopathogenic fungus *Beauveria bassiana* (isolate Bb11) for controlling major pests targeted by the LEC regime in cotton. These pests include *S. derogata*, *A. gossypii*, *P. latus* and carpophagous species such as *H. armigera, Earias* spp., *D. watersi*, *P. gossypiella*, and *C. leucotreta*. Furthermore, data were also collected on *B. tabaci* and *D. volkeri*.

Materials and methods

Experimental sites

The experiment was carried out in 2011 in three districts (Kandi, N'Dali, and Djidja) that are characterized by differences in rainfall, period of planting, and pest infestation. Kandi is located in the hot dry northern zone of Benin, with annual rainfall ranging between 900 and 1000 mm. Cotton is recommended to be planted from 1 to 20 June. The dominant pests are H. armigera, S. derogata, and A. gossypii. In N'Dali, annual rainfall ranges between 1000 and 1200 mm and planting is recommended from 20 June to 5 July. The prevailing pests are the same as those present in Kandi, but here the mite P. latus is most dominant. In Djidja, rainfall is the highest with 1200 to 1400 mm, and the recommended planting period is between 25 June and 10 July. Major pest species are mites, P. gossypiella, H. armigera, and C. leucotreta. The farming practices are similar in Kandi and N'Dali, but differ from those in Djidja. For example, land preparation is minimum tillage including ox-drawn plow in Kandi and N'Dali, whereas ridges are used in Djidja.

Experimental design

The experimental design was a randomised complete block design with 15 villages as blocks. Five villages were selected within each district and all five treatments (Table 1) were applied in each village, resulting in five replicates of each treatment in each of the three districts. The treatments were applied to plots of 600 m^2 (30 x 20 m). Plants were spaced 0.8 m between and 0.4 m within rows, resulting in a total of 3750 plants per plot.

The experiment was managed and conducted in a collaborative way with farmers, extension workers, and a researcher who facilitated the process. In each village, 10 farmers were randomly selected to participate. They met on a weekly basis at the experimental site for data collection and decision-making about treatment applications. The weekly scouting of the plots with threshold-based applications was carried out from 31 to 122 DAE.

The neem oil was obtained by cold-press-extraction. Its azadirachtin content was determined at 0.087µg/ml using High Performance Liquid Chromatography (HPLC).

In treatment T4, neem oil and *B. bassiana* (Bb11) were applied separately: neem oil for controlling aphids and mites and Bb11 for bollworms (Pires et al., 2010; Wraight et al., 2010). Bb11 is an oil-based formulation (see Table 1) which allows the suspension of conidia in water because they are hydrophobic (Gatarayiha et al., 2010). *Beauveria bassiana* was provided by the International Institute of Tropical Agriculture (IITA-Benin).

Table 1: The five treatments carried out in each of 15 experimental villages

Treatments	Calendar-based application	Threshold-based application
T0: Control	None	None
T1: Conventional spray method	Six fortnightly applications starting 45 DAE First & second application: Tihan (Flubendiamid 100 – spirotetramat 75 g/l Third & fourth: Nurelle (cypermethrin 36 - chlorpyriphos ethyl 200 g/l) Fifth & sixth: Thunder (Betacyfluthrin 45 - imidacloprid 100 g/l)	None
T2: LEC as recommended by research	Six fortnightly applications starting 45 DAE First & second application: Tihan (Flubendiamid 100- spirotetramat 75 g/l Third to sixth application: Sherphos 370 EC (Cypermethrin 70g/l - Triazophos 300g/l) in Kandi and N'Dali, and Sherphos 320 EC (Cypermethrin 70g/l - Triazophos 250g/l) in Djidja (Prudent et al., 2006)	Specific pesticides such as Gazelle 200 SL (Acetamiprid), Hostathion 400 EC, (Triazophos) and Cypercal 87,5 EC (Cypermethrin) (Silvie et al., 2001a; Silvie et al., 2013)
T3: Cotton treated with neem oil on threshold basis	None	Aqueous formulation of neem oil: (neem oil 10% and water 90%), applied at 10 l per ha
T4: Cotton treated with neem oil and *B. bassiana* (Bb11) on threshold basis	None	Oil-based formulation of *B. bassiana* 50 g/ha ($50x10^{11}$ conidia/ha), kerosene (70%) and peanut oil (30%) (Douro Kpindou et al., 2011)

[1]Days after emergence of cotton plants

Data collection

Weekly scouting involved counting the numbers of damaged squares, flowers, and bolls on 10 plants in each of the two diagonals of the plot. The whole plant was examined, from bottom to top and from leaves to bolls via the buds and flowers. Both sides of the leaves were inspected. The numbers of plants infested by *S. derogata*, *A. gossypii*, and *P. latus* were counted by checking for the presence of the pest on the leaves. The numbers of the bollworms *Earias* spp., *D. watersi,* and *H. armigera* were carefully counted on the pre-squares, squares, flowers, and bolls. The bracts of squares and bolls were opened and examined and the number of larvae and nymphs were recorded and pooled for each pest species. In order to assess whether the threshold had been reached (Silvie et al., 2001b; Silvie et al., 2013) (see Table 2), farmers were provided with a decision-making chart to facilitate the recognition of pests. The appropriate pesticide was applied when the threshold for a given pest was reached.

During the scouting, natural enemies such as spiders, ants, and coccinellids were counted and collected as well. Due to the high mobility driven by their vigorous prey searching behaviour (Islam et al., 2012), natural enemies were counted first, before sampling for pests.

Cotton was harvested in an area of 10 x 10m delineated in the middle of each plot. Yields were estimated in kg per ha and per treatment.

Table 2: Targeted pests and their thresholds

Targeted pests	Threshold for 20 plants scouted
Aphis gossypii	17 plants infested
Syllepta derogata	5 plants infested
Polyphagotarsonemus latus	2 plants infested
Helicoverpa armigera	3 bollworms
Diparopsis watersi and *Earias* sp.	5 bollworms
Cumul *Helicoverpa* and other bollworms[1]	5 bollworms

[1]Other bollworms: *Earias* sp., *D. watersi*, *C. leucotreta* , *P. gossypiella*
Source: adapted from (CRA-CF, 2002; Silvie et al., 2001a)

Statistical analysis and profitability assessment

Analysis of variance (ANOVA) was performed with SAS proc GLIMMIX procedure (SAS 9.2, SAS Institute, Cary, NC, USA). Cotton yield and the average number of insect pests, natural enemies, and damaged reproductive organs at the end of season were analyzed with treatments, districts and their interactions as main effects. Village nested within district was included as a random factor. Whenever the F-tests for fixed effects were found to be significant, a Tukey's test ($\alpha = 0.05$) was performed for multiple comparisons among treatments. Furthermore, temporal dynamics of cumulative phyllophagous, carpophagous, damaged organs and natural enemies were graphically represented.

To assess the profitability of each of the five protection treatments, a cost-benefit analysis was carried out (Table 7). Costs are related to expenditures on labour and inputs, and do not take into account the use of land. Costs of labour are those related to farming activities such as land clearing, tillage, planting, thinning, weeding, ridging, pesticide applications, and field monitoring. These costs were calculated using the number of man-days per ha required for each farming activity, multiplied by the daily wage rate. One man-day corresponds to 8 h of work by one person. The average daily wage rate was set at 3 US$, which is close to the government-mandated minimum wage of 31,625 CFA francs per month (2.88 US$ per day). Input costs consisted mainly of fertilizers and pesticides. Revenues were obtained by using a cotton price of 0.52 US$/kg. Profit per ha was calculated as revenue minus the costs of labour and inputs.

Farmers established their own criteria for the effectiveness of treatments. In the three districts, they considered yield to be the most important factor for comparison. They also made a visual assessment of the sanitary status of the plants in all plots.

Results

Impact of treatments on pest populations

The array of pests observed during the scouting varied from one district to another. Nine pests were recorded in total and all of them were observed in N'Dali, whereas eight were observed in Kandi and Djidja (Tables 3b & 3c). The effect of treatment on infestation by the targeted pests differed among the districts, as shown by the significant interaction of treatment by district (Table 3a), except for *C. leucotreta* and *D. volkeri*. There was a significant difference, however, in the level of infestation of *D. völkeri* among the districts. The highest population of this pest was recorded in Kandi (Table 3d).

There is no clear pattern of treatment effect on pest infestation. The infestation by *A. gossypii* was reduced significantly by conventional, LEC, neem oil, and neem oil-Bb11 in N'Dali, whereas it was only reduced significantly by conventional and LEC in Kandi and Djidja (Table 3b). Also the infestation by *A. gossypii* was significantly higher in N'Dali than in Djidja and Kandi for all five treatments tested.

Infestation by *S. derogata* was reduced significantly by all treatments in Kandi and N'Dali. In Djidja, the infestation by *S. derogata* was significantly reduced by LEC and neem-Bb11, but not significantly by conventional treatment and neem oil (Table 3b).

Table 3a: Analysis of variance of the effects of treatment and district on the infestation of pests

Source	df	*A. gossypii*	*H. armigera*	*S. derogata*	*Earias/Diparopsis*	*D. volkeri*	*P. latus*	*B. tabaci*	*C. leucotreta*	*P. gossypiella*
Treatment	4	55.12***	7.65***	52.77***	17.51***	4.20**	11.13***	6.60***	0.90ns	9.96***
Village(District)	12	2.05*	2.51**	3.28***	1.98*	2.93**	1.32ns	3.18**	0.74ns	2.72***
District	2	183.59***	3.26ns	343.47***	19.91**	34.93**	197.95***	805.75***	1.29ns	170.16***
District*treatment	8	22.63***	2.81*	6.48***	5.29***	2.05ns	5.65***	5.66***	0.90ns	9.96***

ns, *,**,*** non significant or significant at $P< 0.05$, 0.01, or 0.001, respectively.

Table 3b: Mean number of infested plants by phyllophagous along the season 2011-2012 based on 14 observations on 20 plants

Treatment	Phylophagous											
	A. gossypii			*S. derogata*			*P. latus*			*B. tabaci*		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	3.25 Ab	5.74 Aa	2.66 Bb	1.13 Ab	3.33 Aa	0.91 Ab	0.24 Ab	0.00 Ab	1.46 Aa	4.44 Aa	1.14 Ab	0.01 Ac
Conventional	2.04 Cb	2.93 Ca	2.57 Bab	0.01 Bb	1.19 Ca	0.20 ABb	0.00 Ab	0.00 Ab	0.52 Ca	4.50 Aa	0.21 Ab	0.17 Ab
LEC	2.33 BCb	3.70 Ba	2.66 Bb	0.00 Bb	2.14 Ba	0.16 Bb	0.00 Ab	0.00 Ab	0.69 BCa	3.79 ABa	0.26 Ab	0.07 Ab
Neem oil	2. 90 ABb	3.96 Ba	3.10 ABb	0.66 ABb	1.96 Ba	0.39 ABb	0.17 Ab	0.00 Ab	0.96 Ba	3.81 ABa	0.39 Ab	0.08 Ab
Neem oil- Bb11	2.80 ABb	3.66 Ba	3.27 Aab	0.34 Bb	1.90 BCa	0.19 Bb	0.09 Ab	0.01Ab	0.87 BCa	3.06 Ba	0.50 Ab	0.15 Ab

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and pest are not significantly different at $P<0.05$ according to Tukey's test.

Table 3c: Mean number of carpophagous pests observed along the season 2011-2012 based on 14 observations on 20 plants

Treatment	Carpophagous								
	H. armigera			*Earias spp./D. watersi*			*P. gossypiella*		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	0.20 Ab	0.80 Aa	0.51 Aab	0.36 ABb	0.80 Aa	0.30 Ab	0.00 Ab	1.43 Aa	0.00 Ab
Conventional	0.16 Aa	0.20 Ba	0.13 Aa	0.01 Ba	0.26 Ba	0.00 Aa	0.00 Ab	0.63 BCa	0.00 Ab
LEC	0.08 Aa	0.24 ABa	0.01 Aa	0.07 Ba	0.33 Ba	0.03 Aa	0.00 Ab	0.93 Ba	0.00 Ab
Neem oil	0.33 Aa	0.19 Ba	0.06 Aa	0.54 Aa	0.27 Bab	0.16 Ab	0.00 Ab	0.56BCa	0.00 Ab
Neem oil- Bb11	0.31 Aa	0.13 Ba	0.04 Aa	0.33 Aa	0.21 Ba	0.09 Aa	0.00 Ab	0.34Ca	0.00 Ab

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and pests are not significantly different at $P<0.05$ according to Tukey's test.

The total average of infestation by *S. derogata* in N'Dali was significantly higher for each treatment compared to that of the same treatment in Kandi and Djidja.

The infestation by *P. latus* was quite low in the season 2010-2011 (Table 3b). Under the various treatments, the infestation by this mite species was not significantly different in Kandi and N'Dali, but in Djidja its infestation was significantly reduced by all treatments, compared to the control (Table 3b). The total average of infestation by *P. latus* under each of the various treatments was significantly higher in Djidja than that of the same treatments in Kandi and N'Dali.

The infestation by *B. tabaci* under the various treatments was not significantly different in the three districts except for neem oil-Bb11 which shows significant efficacy in Kandi, compared to the control (Table 3b). The infestation by *B. tabaci* under the various treatments across districts was higher in Kandi than in the other districts.

The infestation by *H. armigera* under the various treatments was not significantly different within Kandi and Djidja (Table 3c). In N'Dali, the infestation by *H. armigera* was significantly reduced by the conventional treatment, neem oil and neem oil-Bb11. The infestation by *H. armigera* under each treatment was not significantly different across the districts, except for the control in which the highest infestation was recorded in N'Dali and the lowest in Kandi.

The infestation by *Earias* spp. & *D. watersi* was significantly reduced by the conventional treatment and LEC compared to neem oil and neem oil-Bb11 in Kandi, and by the conventional treatment, LEC, neem oil and neem oil-Bb11 in N'Dali (Table 3c). There is no clear pattern for the infestation by *Earias* spp. & *D. watersi* under the various treatments across districts. *Pectinophora gossypiella* was absent in Kandi and Djidja. In N'Dali, its infestation was significantly reduced by all treatments (Table 3c).

The fluctuation observed in pest infestation during the season has led to a variation in the number of thresholds reached per treatment and per district, and has also affected the number of spray applications (Figure 1). The number of thresholds reached was considered only for the targeted pests of LEC. No threshold was reached for *Earias* spp. & *D. watersi* and these species were taken into account in the threshold of the other pooled carpophagous (bollworms) (Table 4). The mite *P. latus* and *H. armigera* did not reach the threshold in Kandi. In N'Dali and Djidja, the threshold was not reached by aphids. Thresholds for *Syllepta derogata* and other bollworms were mainly reached in Kandi, while those for *S. derogata* and *P. latus* mainly in N'Dali and Djidja.

Table 3d: Main effects of treatment and district on the infestation by *C. leucotreta*, *D. volkeri* and population of ants in the field experiment during the season 2011-2012

Main factor	*C. leucotreta*	*D. volkeri*
Treatment		
Control	0.03 a	2.31 a
Conventional	0.00 a	1.95 a
LEC	0.00 a	1.86 a
Neem oil	0.00 a	3.19 a
Neem oil- Bb11	0.00 a	3.05 a
District		
Kandi	0.00 a	4.04 a
N'Dali	0.00 a	1.46 b
Djidja	0.00 a	1.92 b

Means followed by the same letter within a column are not significantly different at P>0.05 according to Tukey's test

Table 4: Number of times thresholds were reached per treatment in each district.

District	Treatment	*A. gossypii*	*S. derogata*	*P. latus*	*H. armigera*	*Helicoverpa* & other bollworms[1]	Total number of threshold applications	Number of calendar based applications	Total Number of applications
Kandi	Control	1	2	0	0	1	4	0	-
	Conventional	0	0	0	0	0	0	6	6
	LEC	0	0	0	0	0	0	6	6
	Neem oil	0	1	0	0	2	3	0	3
	Neem oil- Bb11	0	1	0	0	1	2	0	2
N'Dali	Control	0	6	4	1	2	13	0	-
	Conventional	0	0	1	0	0	1*	6	6
	LEC	0	1	1	0	0	2	6	8
	Neem oil	0	1	1	0	0	2	0	2
	Neem oil- Bb11	0	2	1	0	0	3	0	3
Djidja	Control	0	2	6	2	2	12	0	-
	Conventional	0	0	3	0	0	3*	6	6
	LEC	0	0	2	0	0	2	6	8
	Neem oil	0	1	3	0	0	4	0	4
	Neem oil- Bb11	0	2	4	0	0	6	0	6

[1]Other bollworms: *Earias* sp., *D. watersi*, *C. leucotreta*, *P. gossypiella*

*No pesticide was applied when the threshold was reached in conventional treatment

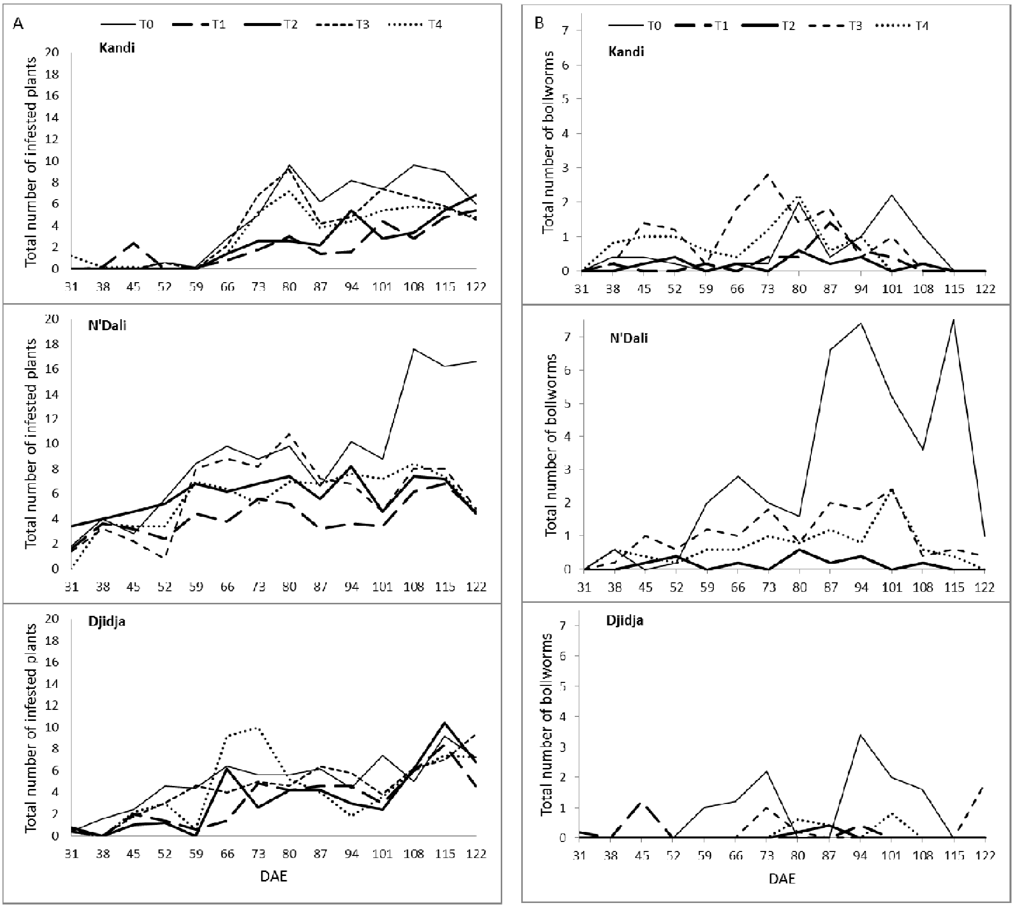

Figure 1: Temporal dynamics of total number of infested plants by phyllophagous (A) and total number of bollworms (carpophagous) (B) observed on 20 plants during 2011-2012, starting from day 31 after seedling emergence (DAE) in Kandi, N'Dali and Djidja.

The number of times the thresholds were reached varied from 0 to 3 for the conventional treatment and from 0 to 2 for LEC, while it varied from 3 to 4 for neem oil and from 2 to 6 for neem oil-Bb11. The lowest number of thresholds was observed in Kandi while the highest number was recorded in Djidja. The total number of applications made on a calendar and threshold basis varied from 2 to 6 for neem oil and neem oil-Bb11, and from 6 to 8 for conventional and LEC treatments (Table 4).

Impact of treatments on cotton reproductive organs

The dynamics of damage to reproductive organs resulting from pest infestation during the 2011-2012 season differed from one district to another (Figure 2). Damage started earlier in

Kandi and Djidja than in N'Dali. The number of damaged reproductive organs in the control plots was higher during the entire season in the three districts. Furthermore, the dynamics of the damage in plots treated with the calendar-based treatments and LEC were similar, as well as those observed under neem oil and neem-Bb11.

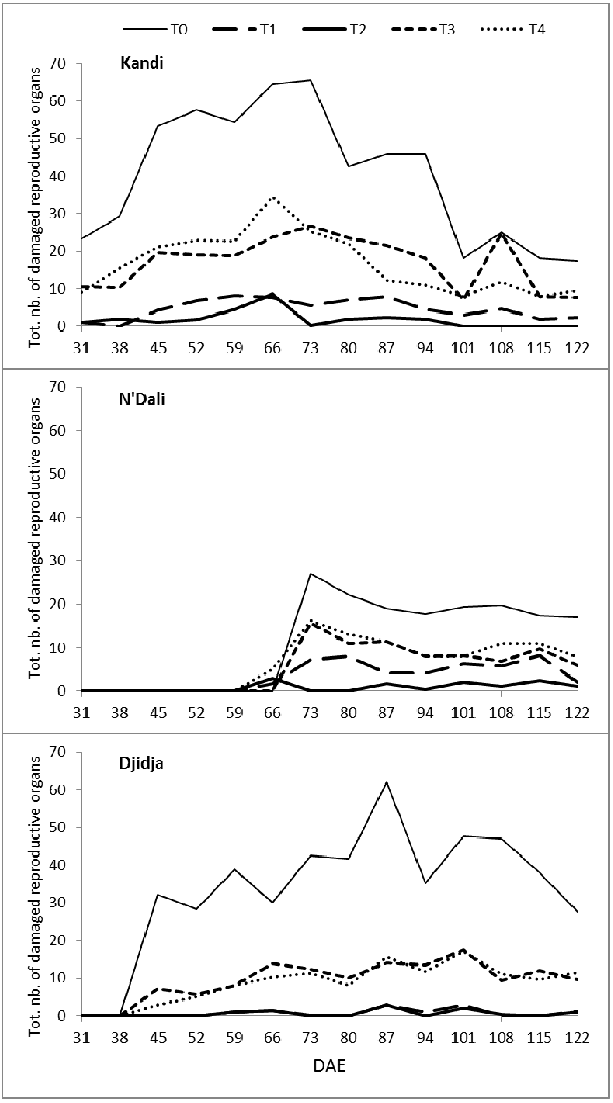

Figure 2: Temporal dynamics of the total of damaged reproductive organs observed on 20 plants during 2011-2012, from day 31 after seedling emergence (DAE) in Kandi, N'Dali and Djidja. T0= control, T1=conventional treatment, T2=LEC; T3=neem oil; T4=neem oil-Bb11.

As reflected by the significant interactions, the effect of treatments on the number of damaged squares, flowers, and bolls varied from one district to another (Table 5a). The number of damaged squares was significantly reduced by the four treatments compared to the control, the decrease being higher under the conventional and LEC treatments than under neem oil and neem oil-Bb11 (Table 5b). The same pattern was observed with the average number of damaged flowers in Kandi. In N'Dali, there was no significant difference between the mean number of damaged flowers, while in Djidja the mean number of flowers was significantly reduced only by the conventional and LEC treatments. In the three districts, these two treatments significantly reduced the number of damaged bolls, more so than neem oil and neem oil-Bb11. There is no clear pattern for the effects of treatment on the damaged reproductive organs across districts.

The effect of the treatments on yields also varied per district (Table 5a &5b). The decrease in the average number of bolls observed under the conventional and LEC treatments was followed with the yields being higher than those obtained under the neem oil and neem oil-Bb11 in N'Dali. In Kandi, LEC resulted in the highest yield, although not significantly different from the conventional, while the yields obtained under the conventional treatment and neem oil and neem oil-Bb11 were not significantly different. Overall, the yields in the biopesticide plots were 26-42% higher and in the conventional and LEC plots 44-59% higher than in the control plots. Yields obtained with neem oil and neem oil-Bb11 were 25% and 39% lower than those of LEC and conventional in Kandi and N'Dali. In Djidja no significant difference was observed in the yields of the treated plots. Across districts, the yield of a specific treatment was not significantly different, except in the case of LEC in N'Dali and Djidja.

Table 5a: Analysis of variance of the effect of treatment on the damaged squares, flowers, bolls and yields during 2011-2012

Source	df	Squares	Flowers	Bolls	Yields
Treatment	4	7012.02***	375.84***	676.95***	53.89***
Village (district)	12	0.80ns	1.16ns	0.59ns	2.39*
District	2	2822.38***	556.91***	334.12***	7.03**
District*treatment	8	1332.49***	310.65***	59.03***	3.10**

ns, *,**,*** non significant or significant at $P< 0.05$, 0.01, or 0.001, respectively.

Table 5b: Mean numbers of damaged squares, flowers, bolls and yields during 2011-2012, based on 14 observations on 20 plants

Treatments	Damaged squares			Damaged flowers			Damaged Bolls			Seed cotton yields ($kgha^{-1}$)[z]		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	16.61 Ab	3.69 Ac	22.89Aa	4.60 Aa	0.03 Ac	0.96 Ab	18.80 Aa	7.69 Ac	9.77 Ab	900 Ca	714 Ba	675 Ba
Conventional	0.64 Ca	0.34 Ca	0.14 Da	0.24 Cb	0.00 Ab	0.63 BCa	3.76 Ca	3.02 Ca	0.00 Cb	1,585 ABa	1,668 Aa	1,300 Aa
LEC	0.90 Ca	0.38 Cab	0.07 Db	0.29 Cab	0.09 Ab	0.53 Ca	0.61 Da	0.34 Da	0.03 Ca	1,645 Aab	1,794 Aa	1,340 Ab
Neem oil	7.32 Ba	1.29 Bc	4.11 Bb	0.54 BCa	0.01 Ab	0.79 ABCa	9.21 Ba	4.17 Bb	4.63 BCb	1,217 BCa	1,010 Ba	1,180 Aa
Neem oil- Bb11	7.57 Ba	1.76 Bb	3.18 Cc	0.71 Ba	0.01 Ab	0.86 ABa	8.34 Ba	4.75 Bb	4.69 Bb	1,219 BCa	1,104 Ba	1,160 Aa

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and pests are not significantly different at $P<0.05$ according to Tukey's test.
[z]Yields were measured at the end of the season.

Impact of treatments on populations of natural enemies

Both predators and parasitoids were observed in the experimental plots. Predators belonged to the families Coccinellidae, Pentatomidae, Chrysopidae, Reduviidae, Lygaeidae, Salticidae, Formicidae, and Araneidae. Data were recorded only for three families: Coccinelidae, Formicidae, and Araneidae, because they were present in large enough numbers to allow comparison between treatments. Five Coccinellids were identified: *Cheilomenes vicinia* (Mulsant), *C. propinqua* (Mulsant), *C. lunata* (Fabricius), *C. sulphurea* (Olivier), and *Exochomus troberti* (Mulsant), and five Formicidae species were also identified: *Camponotus maculatus* (Fabricius), *C. sericeus* (Fabricius), *C. acvapimensis* Mayr, *C. flavomarginatus* (Mayr), and *Dorylus burmeisteri* (Shukckard).

The conventional treatment and LEC had a similar effect on natural enemies, and neem oil, neem oil-Bb11, and the control were also similar (Figure 3). The influence of the treatments on ant populations was similar from one district to another (Table 6a), while the populations of spiders and coccinellids differed between districts (Table 6a). The conventional and LEC treatments reduced the population of ants, while the population of ants under neem oil and neem oil-Bb11 and control were not affected. The highest number of ants was observed in Djidja, while the lowest was recorded in Kandi (Table 6c).

In the three districts, the conventional and the LEC treatments significantly reduced the populations of spiders and coccinelids. In general, populations of spiders and coccinelids recorded in the plots treated with neem oil and neem oil-Bb11 and the control were not different (Table 6a & 6b).

Table 6a: Analysis of variance of the effect of treatment on spiders, ants and coccinellids

Effect	df	Spiders	Ants	Coccinellids
Treatment	4	981.05***	11.56***	27.86***
Village(District)	12	2.71**	0.76ns	1.58ns
District	2	8.51***	4.93*	7.99**
District*treatment	8	2.76*	0.91ns	2.78*

ns, *, **, *** non significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 6b: Mean numbers of spiders and coccinellids during 2011-2012 based on 14 observations on 20 plants

Treatment	Spiders			Coccinellid		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	11.00 Aa	10.48 Aa	11.30 Aa	7.13 Aa	13.70 Aa	8.94 ABa
Conventional	0.06 Ba	0.46 Ba	0.23 Ba	0.59 Aa	0.40 Ba	0.91 Ba
LEC	0.72 Ba	0.83 Ba	0.74 Ba	0.94 Aa	0.74 Ba	1.58 Ba
Neem oil	10.18 Aa	9.86 Aa	11.66 Aa	6.39 Aa	10.30 Aa	11.63 Aa
Neem oil- Bb11	10.71 Aa	9.60 Aa	11.27 Aa	7.03 Aa	19.20 Ab	10.06 ABab

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and natural enemy are not significantly different at P<0.05 according to Tukey's test.

Table 6c: Main effects of treatment and district on the population of ants in the field experiment during 2011-2012

Main factors	Ants
Treatment	
Control	32.58 A
Conventional	11.64 B
LEC	4.66 B
Neem oil	28.91 A
Neem oil-Bb11	33.66 A
District	
Kandi	16.41 B
N'Dali	20.86 AB
Djidja	29.60 A

Means followed by the same letter within a column are not significantly different at P>0.05 according to Tukey's test.

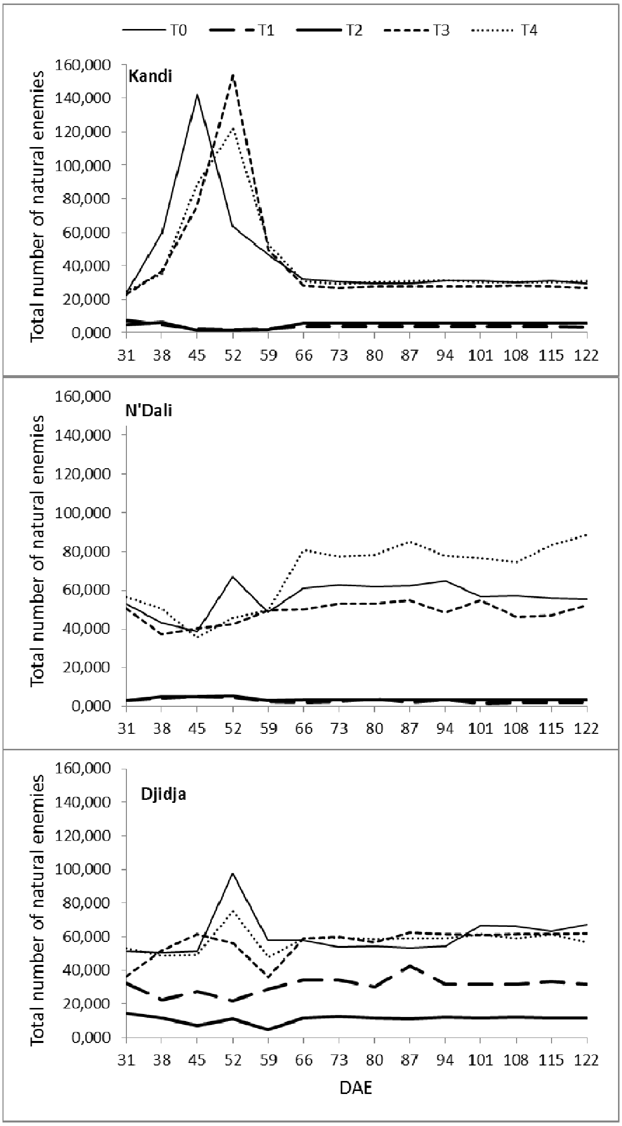

Figure 3: Dynamics of natural enemies during 2011-2012 starting from day 31 after seedling emergence (DAE) in Kandi, N'Dali and Djidja. T0= control, T1=conventional treatment, T2=LEC; T3=neem oil; T4=neem oil-Bb11

Profitability of the protection systems

The costs of labour in the application of LEC, neem oil, and neem oil-Bb11 were the same (Table 7). These costs were slightly higher than the labour costs in the control and conventional treatments because of the scouting and spraying activities. The costs of inputs also differed, and these were highest under the conventional treatment. The difference in input costs between LEC and bio-insecticide treatments resulted from the variation in the amount of insecticides used, which depended on the number of times the threshold was reached.

Profits per ha of the five cotton protection strategies were very different. The highest profit was obtained with LEC, followed by the conventional treatment. Profitability of neem oil is higher than that of neem-oil-Bb11 in Kandi and Djidja, but in N'Dali it was the other way around. The control had a positive profit in Kandi, but not in N'Dali and Djidja.

Table 7: Profitability of the five cotton protection strategies

District	Treatment	Seed cotton yields (kg/ha^{-1})	Average revenue (US $ per ha)[1]	Cost of labour (US $ per ha)[2]	Total pesticides and fertilizers costs (US $ per ha)	Profit (US $ per ha)
Kandi	Control	900	451	228	96	126
	Conventional	1,585	794	236	168	389
	LEC	1,645	824	242	132	450
	Neem oil	1,217	610	242	126	241
	Neem oil-Bb11	1,219	611	242	136	233
N'Dali	Control	714	358	238	118	1
	Conventional	1,668	836	248	190	397
	LEC	1,794	899	254	156	489
	Neem oil	1,010	506	254	138	114
	Neem oil-Bb11	1,104	553	254	168	131
Djidja	Control	675	338	220	118	-0.5
	Conventional	1,300	651	238	190	222
	LEC	1,340	671	244	172	255
	Neem oil	1,180	591	244	158	189
	Neem oil-Bb11	1,160	581	244	198	139

The costs indicated above are the actual costs incurred by farmers in the experiment for the 2011 season.
[1]Average revenue is obtained by using a seed cotton price of 0.5US $ per kg.
1US $=499 FCFA during the cotton harvest in December 2011.
FCFA : ''Franc de la Communauté Française d'Afrique''.
[2]Scouting and spraying included.

Farmer appreciation

In all three districts, farmers preferred the LEC, followed by the conventional, neem oil, and neem oil-Bb11 (Table 8) treatments. Farmers rated the sanitary state of the control plots as poor, that of the LEC and conventional plots as very good, and that of the neem oil and neem oil-Bb11 plots as good. Farmers reported that the inputs used for LEC treatments and Bb11 were less available in Kandi and N'Dali, and not available in Djidja.

Table 8: Ranking (by consensus) of treatments according to farmers' appreciation

District	Treatments	Sanitary state of plots	Availability of input	Rank
Kandi	Control	Bad	n.a.	5
	Conventional	Very good	Yes	2
	LEC	Very good	Moderate	1
	Neem oil	Good	Yes	3
	Neem oil- Bb11	Good	Moderate	4
N'Dali	Control	Bad	n.a.	5
	Conventional	Very good	Yes	2
	LEC	Very good	Moderate	1
	Neem oil	Good	Yes	3
	Neem oil- Bb11	Good	Moderate	4
Djidja	Control	Bad	n.a.	5
	Conventional	Very good	Yes	2
	LEC	Very good	Not	1
	Neem oil	Good	Yes	3
	Neem oil- Bb11	Good	Not	4

Bb11: Isolate of *B. bassiana*
n.a. not applicable

Discussion and conclusion

This field experiment evaluated the efficacy of conventional treatment, LEC, neem oil, and neem oil-Bb11 in controlling cotton pests. The ability of such treatments to protect cotton reproductive organs was assessed. This study also underlined the importance of economic thresholds in managing pests while safeguarding natural enemies. Finally, the yield and the profitability of cotton production were evaluated.

Efficacy of treatments regarding pest control

Differences in the composition of pest species whose threshold were mostly reached indicated that discrepancies exist between the three agroecological zones considered in this study. The number of times the threshold of *S. derogata* was reached was higher than in case of other carpophagous pests. *Syllepta derogata* attacks leaves, but its presence may not affect the productivity of the plants because it occurrs early during the vegetative stage. Cotton plants have considerable ability to compensate for early damage and loss of foliage and early squares (Matthew, 1996).

Even if the threshold is not reached, pest insects may occur and inflict some level of damages. The threshold of *H. armigera* is set at three bollworms per 20 plants. But the number of *H. armigera* was often two or lower, and no pesticides were applied. Damage may have occurred when the infestation did not quite reach the threshold level, but remained just below it long enough to cause economic damage (Matthews, 1996). Also, the work by (Nibouche et al., 2003) indicated that there is 10% error in determining economic thresholds. The multiple losses that may occur in cotton production suggest that it may be wise to reconsider the scouting method used and which pest instar to consider. The eggs of *H. armigera* hatch in 2-3 days and larvae can emerge several times within the same week (Wilson, 1993; Matthew, 1996). Scouting only once a week would allow some larvae to enter the squares and bolls, where they would be less exposed to the action of spray deposits, and a larger dose of insecticide would be required to control them (Matthews, 1996). Scouting should thus target the pest eggs in order to prevent the damage caused by the larvae, especially when bioinsecticides are used. The detection of the mite *P. latus* in Djidja and N'Dali occurred before 20 weeks after cotton seedling emergence. This was crucial and required a quick treatment because early infestations by mites have a great effect on the yield. However, after 20 weeks, the effect of mite infestations becomes beneficial as it can aid defoliation which makes harvesting easier (Wilson, 1993).

The diversity of treatment effects from one district to another shows that the specific climatic conditions and pest species abundance in each agro-ecological zone can alter the efficacy of control actions. The number of calendar-based applications recommended in the conventional treatments is 6; but the number of applications on plots treated with LEC was higher or equal to 6. Moreover, under the conventional spraying method, the threshold was reached a certain number of times in N'Dali and Djidja, without affecting the number of applications as under this regime, pest abundance is not considered. This result indicates that calendar-based sprayings may not be applied at the right time, and that a certain amount of pesticides has probably been released into the environment without having had an effect on the pests targeted. Besides, these sprays may not be economically profitable and can be harmful to natural enemies, causing pest resurgence or secondary pest outbreaks (Vaissayre et al., 2006). Using synthetic pesticides on a threshold basis would increase the efficiency of the conventional treatment and may probably improve the productivity of cotton.

The number of sprays varied from 2 to 6 for the bioinsecticides (neem oil and neem oil-Bb11). Application of the economic threshold allowed a decrease in the number of treatments to an average of three applications on the plots treated with neem oil and four applications in the plots treated with neem oil-Bb11. Similar results were also found by Silvie et al. (2001b) Naranjo et al. (2002). The work by Sinzogan (2006) in northern Benin tested the bio-efficacy of the entomopathogenic formulations of *Bacillus thuringiensis* (Bt) and *Saccaropolyspora spinosa* (Spinosad), and a mixture of *Azadirachta indica* (neem) plant extract with half the recommended dose of synthetic pesticides. By using economic thresholds, the number of applications was reduced from 6 to 4. This provides evidence for considering the threshold-based applications of entomopathogenic fungi and botanicals for an IPM strategy.

The applications of synthetic pesticides in LEC and the conventional treatment were more effective in protecting the reproductive organs than were the bio-insecticides. These results are similar to those found by many other authors (Patel and Vyas, 2000; Verghese et al., 2005) who highlighted the poor efficacy of neem extracts compared with synthetic pesticides. Lipa (1985) demonstrated that foliar applications of entomopathogenic fungi provided slow and inadequate control of high-density larval populations and of late-instars and adults of Colorado beetle (*Leptinotarsa decemlineata*). Also, Inglis et al. (2001) indicated that the application of entomopathogenic fungi alone, under field conditions, does not always provide adequate control of pests. As indicated by Gouli et al. (2009), biological pesticides require more time to act, and, within the time between application to when the insect is killed, serious plant damage may occur. However, various other biological effects of the microbial pesticides, such as repellency, may compensate for this delay (Gouli et al., 2009). Further research (Faria and Wraight, 2007; Godonou et al., 2009) revealed that bio-insecticides in their wild-type form are seldom as effective as chemicals. To overcome this drawback, many studies have been conducted to seek for compatibility, synergism, efficacy of entomopathogenic fungi with botanicals, plants oils and synthetic pesticides used sometimes at a sub-lethal dose. The combination of *B. bassiana* with synthetic insecticides increased the toxicity more than the effect obtained by using the insecticides alone (Huang et al., 2013). Islam et al. (2010) indicated that biological control agent (*B. bassiana*) or botanical insecticide (neem) used alone were moderately effective against *B. tabaci*. But adding neem to a *B. bassiana* treatment increased mortality of *B. tabaci*. Also, using azadirachtine (an important component of neem oil) on lepidopterous pests was demonstrated to be beneficial for IPM strategies (Leskovar and Boales, 1996). The combined formulation or application of a fungal entomopathogen and a botanical insecticide may enhance the efficacy of mycopesticides beyond their individual effects (Feng et al., 2004). In such cases, the slow action of mycopesticides may be efficiently compensated for, resulting in good protection of bolls, and subsequent good yield. Therefore, the search for appropriate formulations to reach this goal is pivotal (Cazorla and Morales Moreno, 2010).

Effect of treatments on the population of natural enemies

Populations of spiders, ants, and coccinelids were significantly higher in the plots treated with neem oil and neem oil–Bb11. The decrease of the natural enemies in LEC shows that LEC is less environmentally friendly than the bioinsecticides, suggesting that bioinsecticides have the ability to safeguard natural enemies. This is in line with results from many other studies (Hohmann et al., 2010; Mancini et al., 2008) . The high mobility of the foraging natural enemies make them more susceptible to pesticides than pests, in particular when pests have a cryptic behaviour, like bollworms. Neem extract reaches mainly pests but not natural enemies, because the active ingredients in the extracts reacts only after ingestion. Guertin et al. (2004) showed hat *B. bassiana* is highly pathogenic on sucking bugs (*Lygus lineolaris* L.), but does not harm certain natural enemies such as coccinelids. The work by Polanczyk et al. (2010) demonstrated that biopesticides did not affect *Trichogramma atopovirili* as far as the following parameters are concerned: longevity, adult mortality, total parasitism, progeny emergency, number of individuals per egg, and sex ratio. This work concluded that the entomopathogenic fungi *B. bassiana* and *M. anisopliae* can be used with *Trichogramma atopovirili* in an IPM strategy.

Effect of treatments on the yield and profitability

The total production cost (including that of labour) per hectare did not vary much across treatments. The input costs of the conventional and neem oil-Bb11 were similar and higher than those of LEC and neem oil. The input costs of LEC and neem oil were also the same. The profitability of LEC and that of the conventional treatment were higher than those of neem oil and neem oil-Bb11. The pattern of profitability is similar to that of the yields, indicating that yields are the major determinant of profitability. The profitability of the control without pesticide was positive in Kandi. In N’Dali and Djidja, the control did not give a profit, meaning that under such conditions farmers should provide a minimum protection for cotton.

As stated above, the efficacy of bio-insecticides was lower compared to that of synthetic insecticides used in conventional and LEC. This difference in yield can foster the reluctance of farmers to adopt the bio-insecticides. However, the return to farmers who adopt them could be compensated if the real value of the bio-insecticides on the preservation of the environment were to be estimated, giving farmers a price incentive to grow organic cotton.

It is well-known that yield obtained from organic cotton is far lower than that using conventional treatments (Mensah et al., 2012). Farmers in northern Benin continue to produce this type of cotton because they receive 50 FCFA (0.1US$) more for each kg than for conventional cotton. Without such an incentive, farmers may not be motivated to adopt the bio-insecticides despite their relative advantages for the preservation of the environment compared to conventional cotton.

In the three districts, farmer groups ranked LEC as the most cost-effective system, followed by the conventional treatment. Given the positive performance of LEC, the difficulty for farmers to obtain LEC pesticides is an important issue to address. As long as this problem is not solved, it can compromise the use of LEC (Togbé et al., 2012). Neem oil and *B. bassiana* are available, but their impact was smaller than LEC. Farmers suggested to use these products on a calendar basis in order to be able to make a better comparison with LEC and conventional treatments. Such a suggestion should be taken into account, considering the reluctance of the farmers to conduct the scouting before each application. Sinzogan (2006) emphasized this point by acknowledging that IPM strategy is more labour-intensive, requiring investment by farmers in learning to recognise the pest complex and scouting while also monitoring for the presence of natural enemies. This may be by far the main reason why farmers always revert very easily to conventional spraying methods, despite the advantages of an IPM strategy.

Chapter 5

Field evaluation of synergistic effects of *Beauveria bassiana* and *Bacillus thuringiensis* with neem oil

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Abstract

The synergistic effect of *Beauveria bassiana* and *Bacillus thuringiensis* with neem oil was evaluated in three agroecological zones in Benin. These zones differ in rainfall, pest abundance and farming practices. Five treatments were compared with a control with no insecticide: a calendar-based treatment using synthetic insecticides and four bioinsecticide treatments on a threshold basis. The bioinsecticide treatments were: neem oil; neem oil and Beauveria used separately for different target pests; neem oil mixed with *B. bassiana*; and neem oil mixed with *B. thuringiensis*. In the three districts, the number of damaged bolls and cotton yields did not differ under the four bioinsecticide formulations, suggesting an absence of synergy between neem oil and *B. bassiana* (Bb11) and neem oil and *B. thuringiensis* (Bt). Also, the number of natural enemies in all bioinsecticide treatment plots was similar and not different from that in the control plot. The cost of combining the biopesticides was higher than that of the conventional treatments. Overall, the highest yield and profitability were obtained with the conventional treatment. Screening the compatibility of both plant-based products and biopesticides through bioassays is essential for a successful application of their combination in any IPM strategy.

Key words: biopesticides; neem oil; synthetic pesticides; natural enemies; thresholds; Integrated Pest Management

Introduction

In agriculture, pest control remains a matter of priority to ensure the productivity of various crops (Wahab, 2009). The use of bioinsecticides to control pests has increased over recent decades due to the detrimental effects of chemical pesticides on humans and the environment. The widespread and continuous use of chemical pesticides causes environmental problems (pest resurgence and secondary pest outbreaks) and leads to the development of insect resistance (Dhaliwal and Arora, 2001; Vijayarani et al., 2009). Many studies have been conducted to find natural alternatives to synthetic chemicals (Casida and Quistad, 1998; Devanand and Rani, 2008; Gahukar, 2000; Kelm et al., 1997). As such, plant derivatives commonly used in the tropics (Casida and Quistad, 1998; Salako et al., 2008; Schmutterer, 1990) are promising. Nearly 2000 to 2400 plant species of various families have been identified as possessing insecticidal properties (Baskaran and Narayanasamy, 1995; Klocke, 1987) and are successfully used to control over 100 insects belonging to 10 different orders, as well as 100 non-insect pests (Gahukar, 2010). Plants are rich sources of bioactive organic chemicals and offer an advantage over synthetic pesticides because they are less toxic, less prone to cause resistance and easily biodegradable (Dhaliwal and Arora, 2001; Parmar and Walia, 2000; Ravensberg, 2011; Smirle et al., 2000).

Essential oils are one category of plant-derived products that are readily biodegradable and less detrimental to non-target organisms than synthetic pesticides (Dubey et al., 2008). This property of essential oils is ascribed to bioactive organic chemicals. Most of these active compounds are specific to particular insect groups and not to mammals (Isman, 2000). Among plant-based products, neem is most commonly used. Neem products have been identified as better alternatives to toxic pesticides (Sateesh, 1998), and are effective in controlling a wide range of insect species of different families (Isman, 2000; Schmutterer and Singh, 1995). The mode of action can be repellency due to odour and bitterness, antifeedant action, growth inhibition, delay in oviposition, and chemosterilisation (Ananthakrishnan, 2000; Parmar and Walia, 2000).

Microbial insecticides such as entomopathogenic fungi represent another alternative having less environmental impact than synthetic pesticides. The fungus *Beauveria bassiana* (Bals.) Vuill. has been reported as a promising biological control agent that can be used to maintain a variety of insect pests under the economic threshold level (Coates et al., 2002; McGuire et al., 2005; Rehner and Buckley, 2005).

However, limitations in the efficacy of bioinsecticides have also been demonstrated. The efficacy of bioinsecticides can be lower than that of synthetic pesticides (Ahmed et al., 2002; Faria and Wraight, 2007; Gouli et al., 2009; Wraight et al., 2001) and this has been shown for neem extracts (Patel and Vyas, 2000; Rawale et al., 2002; Sarode et al., 2000; Sinzogan, 2006). We confirmed this in an experiment conducted in 2011-2012, which showed that the percentage of damaged buds, flowers and bolls was higher in plots receiving neem oil and neem oil-Bb11 than plots in which synthetic pesticides were used (conventional treatment consisting of calendar-based spraying and the Lutte Étagé Ciblée (LEC) treatment consisting of calendar-based spraying followed by threshold applications of specific pesticides), yields being 25 and 39% lower, respectively (Togbé et al., Chapter 4). Under field conditions, the application of entomopathogenic fungi alone does not always provide effective pest control (Inglis et al., 2001), probably because control of high-density larval populations and of late-instar larvae and adults is slow and inadequate (Lipa, 1985). Bio-insecticides in their wild-type form were seldom considered as effective as synthetic pesticides (Ahmed et al., 2002; Faria and Wraight, 2007; Wraight et al., 2001). Biological pesticides require more time to act, and, within the time between application and the death of the insect, serious plant damage may have occurred (Gouli et al., 2009). However, various other biological effects of the plant derivatives, such as repellency, may compensate for this delay (Gouli et al., 2009). Islam et al. (2010) indicated that the biological control agent (*B. bassiana*) and the botanical insecticide (neem) used alone were moderately effective against *Bemisia tabaci* (Gennadius). But the biological formulation of neem and *B. bassiana* together increased mortality of *B. tabaci*. Azadirachtine (an important component of neem oil) used against lepidopterous pests has been demonstrated to be beneficial for IPM strategies (Leskovar and Boales, 1996). We then assumed that the combined effect of entomopathogenic fungi and the botanical insecticide would have a larger effect than using the products separately.

In this study, we evaluated the synergistic effect of neem oil with either *B. bassiana* or *Baccilus thuringiensis* var. kurstaki (Berliner) in the field. Our research questions were: Do combinations of neem oil with either *B. bassiana* or *B. thuringiensis* decrease pest occurrence, thereby providing better protection to buds, flowers and bolls, and have less effect on natural enemies than neem oil applied alone or neem oil and *B. bassiana* applied to specific insects? and how profitable is each treatment within each district?

Material and methods

The experiment was carried out during the 2012-2013 season in three districts (Kandi, N'Dali, Djidja). These districts differed in terms of rainfall, pest diversity, pest abundance and farming practices. The experiment involved farmers, extension agents and researcher scientists in a participatory manner.

Experimental design

Three villages (see Table 1) were selected within each of three districts. Within each village, experimental units were arranged using a randomized complete block design with four blocks. A control without pesticides was compared to five treatments, a conventional treatment of calendar-based spraying with synthetic pesticides, and four treatments applied on a threshold basis as follows: neem oil, neem oil and Beauveria used separately for different target pests,and neem oil mixed with either *Beauveria* or *B. thuringiensis* (Table 2). An experimental plot of 12 × 10 m (120 m^2) was allocated to each replicate. Plants were spaced 0.8 m between rows and 0.4 m within rows. A buffer distance of 10 m was established between plots and blocks to limit contamination by pesticide drift.

Table 1: Villages selected for the experiment

Districts	Villages
Kandi	Sonsoro, Kpede, Fafa,
N'Dali	Bori, Yermarou, Suanin,
Djidja	Zinkanme, Lakpo, Slovegni

Data collection

Working with farmers, 40 plants were scouted for pests for each treatment in each village on a weekly basis, viz, 10 plants per plot, from 31 until 122 days after plant emergence (DAE). The whole plant was screened starting from the bottom: upper and lower side of leaves, buds, flowers, and bolls.

The numbers of plants infested by *Syllepte derogata* (Fabricius), *Aphis gossypii* (Glover) and *Polyphagotarsonemus latus* (Banks) were counted by checking for the presence of the pest on the leaves. For the bollworms, *Earias* spp., *Diparopsis watersi* (Rothschild), *Helicoverpa armigera* (Hübner), the buds, flowers and bolls were examined and the number of larvae recorded. The aim of these observations was to verify whether thresholds were surpassed (Table 3).

Monitoring of plant damage started from flowering onwards and included the number of damaged squares, flowers and bolls. While scouting, natural enemies such as ants, ladybirds and spiders were counted as well. The observations were made before spraying and

7 days after spraying. Cotton yield per hectare was estimated by harvesting each plot twice, excluding the border lines. At each experimental site, the labour and input costs were calculated for each farming activity.

Table 2: Description of the six treatments used in the nine experimental villages

Treatment	Calendar -based application	Threshold-based application
T0: Control	No calendar-based application	None
T1: Conventional spray method	Six fortnightly applications starting 45 DAE First & second applications: Phoenix (cypermethrin 72 - acetamiprid 16 g/l); Third & fourth applications: Califos (Profenofos 500 g/l) Fift & sixth applications: Emamectine super (Emamectinebenzoate 24 – acetamiprid 32 g/l)	None
T2: Cotton treated with neem oil[1] on a threshold basis	No calendar-based application	Aqueous formulation of neem oil: (neem oil 10% and water 90%) supplemented with a small quantity of soap detergent, applied at 10 l per ha
T3: Cotton treated with neem oil and *B. bassiana* (Bb11) on a threshold basis[2]	None	Oil-based formulation of *B. bassiana* 50 g/ha ($50x10^{11}$ conidia/ha), kerosene (70%) and peanut oil (30%) (Douro et al., 2011)
T4: Cotton treated with the mixture of neem oil and *B. bassiana* (Bb11) on a threshold basis	None	Mixture of neem oil and Bb11 50 g/ha ($50x10^{11}$ conidia/ha), kerosene (70%) and neem oil (30%)
T5: Cotton treated with mixture of neem oil and *B. thuringiensis* on a threshold basis	None	Mixture of neem oil and *B. thuringiensis*: 20 g of Bt added to neem oil 10% and water 90% supplemented with small quantity of soap detergent, applied at 10 l per ha

[1]Neem oil was obtained by cold-press-extraction. The azadirachtin-content was detected by HPLC at 0.087µg/ml.
[2]Neem oil and Bb11 were applied separately; neem oil was applied when pests other than bollworms reached the threshold level, and Bb11 only when the bollworms reached the threshold level.
DAE: Day After Emergence

Table 3: Threshold of targeted pests

Targeted pests	Thresholds for 40 plants observed
Aphis gossypii	33 plants infested
Syllepte derogata	10 plants infested
Polyphagotarsonemus latus	3 plants infested
Helicoverpa armigera	5 bollworms
Diparopsis watersi. and *Earias* spp.	10 bollworms
Accumulation of *H. armigera* and other bollworms[1]	10 bollworms

[1]Other bollworms: *Earias* spp., *D. watersi, Cryptophlebia leucotreta, Pectinophora. gossypiella*
Source: adapted from CRA-CF (2002)

Statistical analysis and profitability assessment

Analysis of variance (ANOVA) was performed with SAS proc GLIMMIX procedure (SAS 9.2, SAS Institute, Cary, NC, USA). The analysis of variance (ANOVA) of the different response variables was conducted with a model including district, treatment, and their interaction treatment-district as fixed factors. Also, blocks nested within villages by districts, and villages nested within districts were considered as random factors. Whenever the F-tests for the interaction were found significant, the Tukey's test ($\alpha = 0.05$) was performed for multiple comparison among treatments.

Cost and margin analysis was performed per district. We considered one-man-day as a unit of labour which corresponds to the work accomplished by a man in 8 hours. These data were pooled together and the mean was calculated per district. The profitability of each system was assessed in each district by using the average value of the yields per treatment.

Results

Effectiveness of treatments on pest infestation

The effect of the treatments on infestations by *A. gossypii*, *S. derogata*, *H. armigera*, *Earias* spp., *D. watersi*, *D. völkeri* and *P. gossypiella* was dependent on the districts where the experiment was conducted, as reflected by the significant interaction of treatment with district (Table 4a).

Infestation by *A. gossypii* was significantly reduced by conventional treatments and neem oil in Kandi; and by the five treatments in Djidja (Table 4b). In N'Dali, there was no significant difference in the infestation by *A. gossypii* under the various treatments, including the control. Moreover, the infestation by *A. gossypii* recorded under the various treatments was the lowest in N'Dali, whereas the highest infestation was found in Kandi. Infestation by

S. derogata was significantly reduced by all the treatments except neem oil*Bt in Kandi; in N'Dali, the infestation by this lepidopterous pest was significantly reduced by the conventional treatment and neem oil*Bb11, whereas in Djidja its infestation was reduced by the conventional, neem oil-Bb11 and neem oil*Bb11 treatments. The infestation by *S. derogata* under the various treatments across districts was not significantly different in Kandi and N'Dali except for the conventional and neem oil*Bt. In Djidja, infestations by *S. derogata* were lower than in Kandi, except under the conventional treatment. Infestations by *P. latus* were the same under the various treatments in Kandi and N'Dali; in Djidja, the infestation by this mite was only reduced by the conventional treatment. Across the districts, infestation by this mite was higher in Djidja, except under the conventional, neem oil and neem oil*Bt treatments.

Infestation by *H. armigera* was significantly reduced by the conventional treatment and neem oil*Bb11 in Kandi (Table 4c), by the bioinsecticides except neem oil in N'Dali; and by the conventional, neem oil*Bb11 and neem oil*Bt in Djidja. Infestation of *H. armigera* under the various treatments was lower in Djidja than in Kandi and N'Dali. The infestation by *Earias* spp. & *D. watersi* under the various treatments was significantly reduced in N'Dali and only by neem oil*Bt in Djidja. The infestation by these carpophagous pests was generally higher in N'Dali than in the other districts. There was no significant difference in the infestation by *P. gossypiella* under the various treatments in Kandi and N'Dali. The same is true with regard to the infestation of *D. völkeri*, except in Djidja under neem oil-Bb11, neem oil*Bb11, and neem oil*Bt where a reduction in the infestation by this pest was noticed. The extent of the infestation was the same across the districts, except under neem oil-Bb11, neem oil*Bb11 and neem oil*Bt where a significant reduction was noticed in Djidja compared to N'Dali.

Table4a: ANOVA of treatment effects on pest infestation

Source	df	*A. gossypii*	*S. derogata*	*H. armigera*	*Earias/Diparopsis*	*D. volkeri*	*P. latus*	*B. tabaci*	*C. leucotreta*	*P. gossypiella*
Treatment	5	23.27***	34.11***	23.11***	17.18***	5.49***	0.72ns	8.41***	1.00ns	3.00*
Block (Village (District))	27	5.30***	1.87*	1.99**	2.16**	3.72***	3.68***	0.85 ns	0.90ns	0.90 ns
Village (District)	6	11.11***	22.46***	27.67***	7.60***	25.29***	11.89***	26.55***	1.00ns	3.00**
District	2	1378.21***	104.26***	253.44***	117.73***	47.70***	50.41***	193.02***	1.00ns	3.00ns
District*treatment	10	16.30***	9.71***	2.40*	5.14***	5.25***	2.08*	0.35 ns	1.00ns	3.00**

ns = non-significant, * P<0.05,** P<0.01, and *** P< 0.001.

Table 4b: Mean number of plants infested by phyllophagous pests during the 2012-2013 season based on the mean of 14 observations on 10 plants

Treatments	Phylophagous								
	A. gossypii			*S. derogata*			*P. latus*		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	2.32 Aa	0.08 Ac	1.41 Ab	1.07 Aa	0.71Aa	0.43 Ab	0.00 Ab	0.00Ab	0.18 Aa
Conventional	1.48 Ba	0.04 Ac	0.63 Bb	0.00 Db	0.40 Ba	0.08 Bb	0.00 Aa	0.05 Aa	0.05 Ba
Neem oil	1.77 Ba	0.05 Ac	0.76 Bb	0.73 BCa	0.50 ABab	0.24 ABb	0.00 Aa	0.00 Aa	0.11 Aa
Neem oil-Bb11	2.31 Aa	0.08 Ac	0.64 Bb	0.61 Ca	0.45 ABa	0.13 Bb	0.00 Ab	0.01Ab	0.17 Aa
Neem oil*Bb11	2.39 Aa	0.07 Ac	0.80 Bb	0.61 Ca	0.42 Bab	0.18 ABb	0.00 Ab	0.00 Ab	0.14 ABa
Neem oil*Bt	2.54 Aa	0.06 Ac	0.60 Bb	0.93 ABa	0.46 ABb	0.12 Bc	0.00 Aa	0.02 Aa	0.11 ABa

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and natural enemy are not significantly different at P<0.05 according to Tukey's test.

Table 4c: Mean number of infested plants by carpophagous pests during the 2012-2013 season based on the mean of 14 observations on 10 plants

Treatments	Carpophagous pests											
	H. armigera			*Earias spp./D. watersi*			*P. gossypiella*			*D. völkeri*		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	0.67 Aa	0.75 Aa	0.39 Ab	0.17 Ab	0.64 Aa	0.22 Ab	0.00 Aa	0.00 Ba	0.00 Aa	0.63 Ab	1.09 Aa	1.03 Aa
Conventional	0.41 Ca	0.64 ABa	0.25 Bb	0.01 Ab	0.27 Ba	0.05 ABb	0.00 Aa	0.00 Ba	0.00 Aa	0.40 Ab	0.81 Aa	0.72 ABab
Neem oil	0.61 ABa	0.62 ABCa	0.32 ABb	0.01 Ab	0.30 Ba	0.11 ABab	0.00 Aa	0.00 Ba	0.00 Aa	0.64 Aa	0.87 Aa	0.72 ABa
Neem oil-Bb11	0.57 ABa	0.56 BCa	0.26 ABb	0.04 Ab	0.27 Ba	0.21 Aab	0.00 Ab	0.02 Aa	0.00 Ab	0.71 Aab	0.87 Aa	0.46 Bb
Neem oil*Bb11	0.52 BCa	0.54 BCa	0.22 Bb	0.09 Ab	0.32 Ba	0.09 ABb	0.00 Aa	0.00 Ba	0.00 Aa	0.62 Ab	1.15 Aa	0.58 Bb
Neem oil*Bt	0.59 ABa	0.49 Ca	0.21 Bb	0.17 Ab	0.36 Ba	0.03 Bb	0.00 Aa	0.00 Ba	0.00 Aa	0.72 Ab	1.13 Aa	0.48 Bb

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and natural enemy are not significantly different at P<0.05 according to Tukey's test.

The population of *B. tabaci* was not significantly different under the control, neem oil, neem oil-Bb11 and neem oil*Bt; whereas the conventional and neem oil*Bb11 reduced significantly its population (Table 4d). The highest number of *B. tabaci* was recorded in Kandi and the lowest in Djidja. The infestation by *C. leucotreta* was not significantly different under the various treatment and also across district.

The thresholds for various pests were reached from 66 DAE in Kandi and from 73 DAE in N'Dali and Djidja (Table 5, values in brackets). This period corresponds to the flowering and fructification phases, when the highest number of buds, flowers and bolls are present on the cotton plants. The number of thresholds decreased noticeably at 122 DAE, when most of the bolls were already open, indicating that food availability for many pests attacking cotton had decreased. The highest number of thresholds was recorded in plots that received no treatment. No threshold was recorded in the plots treated with the conventional treatments in Kandi and Djidja. Likewise, the lowest number of thresholds was recorded with the conventional treatment in Djidja.

In Kandi and N'Dali, *H. armigera*, *S. derogata* and other carpophagous species such as *Earias* spp. and *D. watersi* were the main pests that reached the threshold in contrast to the mites *P. latus* in Djidja (Table 5). The number of times that threshold levels for various pests were reached was higher in Kandi than in N'Dali; and in N'Dali higher than in Djidja. In the three districts, the number of applications using the bioinsecticide treatments was lower than in conventional treatments. Likewise, the number of applications on the plots treated with bio-insecticides was lower in N'Dali than in Kandi, and in Djidja lower than in N'Dali.

Table 4d: Main effects of treatments and district on the infestation by *B. tabaci*, *C. leucotreta*, damaged flowers and coccinellids during the 2012-2013 season based on the mean of 14 observations on 10 plants

Main factors	Phyllophagous	Carpophagous	Organs	Natural enemies
	B. tabaci	*C. leucotreta*	Damaged flowers	Coccinellids
Treatments				
Control	1.84 ab	0.00 a	0.09 a	0.12 ab
Conventional	1.33 c	0.00 a	0.07 a	0.05 b
Neem oil	1.92 a	0.00 a	0.08 a	0.15 a
Neem oil-Bb11	1.53 bc	0.00 a	0.08 a	0.12 ab
Neem oil*Bb11	1.30 c	0.00 a	0.05 a	0.10 ab
Neem oil*Bt	1.60 abc	0.00 a	0.08 a	0.12 ab
Districts				
Kandi	2.38 a	0.00 a	0.01 b	0.17 a
N'Dali	1.71 b	0.00 a	0.10 a	0.09 b
Djidja	0.67 c	0.00 a	0.11 a	0.06 b

Means followed by the same letter within a column are not significantly different at P>0.05 according to Tukey's test.

Table 5: Number of times the threshold is reached and number of sprayings per treatments

District	Treatment	*A. gossypii*	*S. derogata*	*P. latus*	*H. armigera*	*Earias* spp. + *D. watersi*	Helicoverpa & other bollworms[1]	Number of times the thresholds were reached	Number of calendar-based applications	Total number of applications
Kandi	Control	0	4 (66, 87, 101, 108)	0	1 (87)	0	1 (101)	6	0	0
	Conventional	0	0	0	0	0	0	0	6	6
	Neem oil	0	3 (66, 101, 108)	0	1 (87)	0	0	4	0	4
	Neem oil-Bb11	0	2 (87, 108)	0	1 (101)	0	0	3	0	3
	Neem oil*Bb11	0	2 (66, 101)	0	1 (87)	0	1 (108)	4	0	4
	Neem oil*Bt	0	4 (87, 101, 108, 115)	0	0	0	1 (87)	5	0	5
N'Dali	Control	0	0	0	5 (73,80,87, 101, 108)	1 (73)	0	6	0	0
	Conventional	0	1 (73)	0	1 (101)	0	0	2	6	6
	Neem oil	0	1 (73)	0	2 (80, 94)	1 (101)	0	4	0	4
	Neem oil-Bb11	0	1 (80)	0	2 (80, 94)	0	0	3	0	3
	Neem oil* Bb11	0	0	0	3 (80, 94, 108)	0	0	3	0	3
	Neem oil*Bt	0	1 (80)	0	2 (87, 101)	0	0	3	0	3
Djidja	Control	1 (73)	0	1 (87)	1 (94)	1 (115)	0	4	0	0
	Conventional	0	0	0	0	0	0	0	6	6
	Neem oil	0	0	0	0	1 (101)	0	1	0	1
	Neem oil-Bb11	0	0	2 (80, 94)	0	0	0	2	0	2
	Neem oil* Bb11	0	0	1 (80)	0	0	0	1	0	1
	Neem oil*Bt	0	0	1 (80)	0	0	0	1	0	1

Values in brackets represent the DAE at which the thresholds were reached.
DAE: Day After Emergence.
[1]Other bollworms: *Earias* sp., *D. watersi*, *C. leucotreta* , *P. gossypiella.*

Effects of treatments on the protection of squares, flowers and bolls

The effect of the treatments on the average number of damaged squares, bolls and yields was different per district, as indicated by the significant treatment-district interaction, except for damaged flowers (Table 6a). The number of damaged flowers in Kandi was lower than in N'Dali and Djidja (Table 4d).

The number of damaged squares under the various treatments was not significantly different in N'Dali (Table 6b). In Kandi and Djidja, only the conventional treatment reduced the number of damaged squares. The number of damaged squares recorded under each treatment was significantly higher in Kandi than in Djidja and N'Dali where similar effects were obtained under each treatment (Table 6b). In Djidja, the number of damaged bolls was significantly reduced by the various treatments compared to the control; while in Kandi it was reduced significantly only under conventional, neem oil and neem oil*Bb11 treatments, and in N'Dali by conventional and neem oil*Bb11 treatments. Moreover, the number of damaged bolls under each treatment across the district was higher in Kandi than in N'Dali and Djidja.

As shown by the interaction of treatment with district (Table 6a), the effect of the treatments on the yields was different per district. In the three districts, the yield was significantly increased under the five treatments compared to the control. Moreover, the yield obtained under the conventional treatment was significantly higher than that obtained from the four bioinsecticide treatments in Kandi and N'Dali. In Djidja, the yields obtained from neem oil, neem oil-Bb11 and neem oil*Bb11 were not significantly different, nor were those obtained under conventional treatment and neem oil*Bt. A comparison across the district with regard to each treatment indicates that the yield obtained by the control and neem oil*Bb11 was not significant different from one district to another one. The pattern of the yield with regard to other treatments across the districts was the same, with Kandi and/or N'Dali having the highest yields.

Table 6a: ANOVA of treatment effect on the number of damaged squares, flowers, bolls and yields

Source	df	Squares	Flowers	Bolls	Yields
Treatment	5	19.23***	1.09ns	46.56***	260.25***
Block (Village (District))	27	2.31***	0.89ns	2.73***	1.15ns
Village (District)	6	169.19***	9.07***	170.24***	68.19***
District	2	503.81***	24.69***	763.00***	42.92***
District*treatment	10	8.25***	0.60ns	9.08***	15.35***

ns = non-significant, * P<0.05,** P<0.01, and *** P< 0.001.

Table 6b: Mean number of damaged squares, bolls and yields during the 2012-2013 season based on the mean of 14 observations on 10 plants

Treatments	Damaged squares			Damaged Bolls			Seed cotton yields (kg/ha^{-1})[1]		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	3.96 Ba	1.86 Ab	2.07 Ab	1.18 Aa	0.74 Ab	0.70 Ab	787 Da	726 Ca	752 Da
Conventional	2.66 Ca	1.53 Ab	1.19 Bb	0.75 Ca	0.53 Bb	0.39 Cb	1589 Aa	1582 Aa	1207 ABb
Neem oil	4.18 ABa	1.76 Ab	2.32 Ab	1.04 Ba	0.61 ABb	0.54 Bb	1217 BCa	1118 Bab	1043 Cb
Neem oil-Bb11	4.73 Aa	1.60 Ab	1.85 ABb	1.09 ABa	0.55 ABb	0.43 BCb	1258 Ba	1084 Bb	1081 Cb
Neem oil*Bb11	4.69 ABa	1.42 Ab	1.69 ABb	1.05 Ba	0.53 Bb	0.43 BCb	1125 Ca	1122 Ba	1089 BCa
Neem oil*bt	4.27 ABa	1.93 Ab	2.01 Ab	1.14 ABa	0.62 ABb	0.41 Cc	1278 Bab	1161 Bb	1296 Aa

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and pests are not significantly different at P<0.05 according to Tukey's test.
[1]Yield were measured at the end of the season.

Effects of treatments on activity of natural enemies

Many natural enemies (predators and parasitoids) were observed in the experimental plots. Predator families such as Coccinellidae, Pentatomidae, Chrysopidae, Reduviidae, Lygaeidae, Salticidae, Formicidae and Araneidae were seen. Data were recorded only for three families, viz., Coccinellidae, Formicidae and Araneidae because they were present in large enough numbers to allow comparison between treatments.

The coccinellids were more abundant in Kandi than in the other districts (Table 4d). The average number of coccinellids was not significantly different under the control and the bioinsecticide treatments. Moreover, the population of coccinellids decreased significantly under the conventional treatment compared to that observed under the three bioinsecticide combinations (Table 4d).

The effect of the treatments on the population of spiders and ants was different per district (Table 7a). The number of spiders under the various treatments was not significantly different in N'Dali (Table 7b). In Djidja, the population of spiders in the bioinsecticide and the control plots was not significantly different. The conventional treatments reduced the population of spiders significantly. In Kandi, there is no clear pattern of the effect of the treatments on the population of the spiders. Similarly, no significant treatment effect was observed on ant populations in N'Dali, while in Djidja, the conventional treatment showed a significant difference. No clear pattern of the effect of the treatments was noticed on ant populations in Kandi.

Profitability of the treatments

The total cost of labour remained the same in each district for each treatment, as well as the cost of scouting for the bioinsecticide treatments (Table 8). However, the costs of insecticides were different, even when only bioinsecticide treatments were considered, and this was due to variations in the number of times the pest thresholds were reached. The costs of bioinsecticide mixtures Neem oil*Bb11 and Neem oil*Bt were higher than that of the conventional treatment, especially in Kandi and N'Dali. In Djidja, the cost of insecticides was lower than that of the conventional treatments.

Table 7a: ANOVA of the effect of treatment on the population of spiders, ants and coccinellids

Effect	df	Spiders	Ants	Coccinellids
Treatment	5	15.07***	16.00***	2.97*
Block (Village (District))	27	0.96ns	0.64ns	2.67***
Village (District)	6	7.28***	9.74***	0.57ns
District	2	80.12***	123.33***	14.21***
District*treatment	10	6.51***	6.95***	1.39ns

ns, *,**,*** non significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 7b: Mean number of spiders and ants during the 2012-2013 season, based on the mean of 14 observations on 10 plants

Treatments	Spiders			Ants		
	Kandi	N'Dali	Djidja	Kandi	N'Dali	Djidja
Control	1.11 ABCab	0.68 Ab	1.54 Aa	1.81 ABCb	1.04 Ab	2.82 Aa
Conventional	0.80 Ca	0.72 Aa	0.53 Ba	1.40 Ca	1.05 Aa	0.93 Ba
Neem oil	1.32 ABa	0.78 Ab	1.50 Aa	2.22 ABa	1.12 Ab	2.73 Aa
Neem oil-Bb11	1.52 Aa	0.68 Ab	1.48 Aa	2.47 Aa	1.06 Ab	2.66 Aa
Neem oil*Bb11	0.98 BCab	0.64 Ab	1.40 Aa	1.64 BCb	0.94 Ab	2.55 Aa
Neem oil*bt	1.18 ABCb	0.72 Ab	1.66 Aa	2.09 ABCb	1.10 Ac	2.92 Aa

Means followed by the same uppercase letter within a column are not significantly different and means followed by the same lowercase letter within a row and pests are not significantly different at P<0.05 according to Tukey's test.

The profitability of the various systems varied across treatments and across districts. The highest profit was obtained with the conventional treatments in Kandi and N'dali while in Djidja the highest profitability was obtained with the bioinsecticide mixture neem oil*Bt.

Moreover, the profits of neem oil*Bb11 and mixture neem oil*Bt were 42% lower than that of the neem oil and neem oil-Bb11 in Kandi. In N'Dali, the profit obtained from the untreated plots was negative and very low in Djidja.

Table 8: Costs and profits of various pest control systems in cotton production in three districts of Benin

District	Treatment	Yield (kg/ha^{-1})	Average revenue ha^{-1}(US$)	Cost input (US$)		Labor (man days ha^{-1})		Total cost (US$)			Profit (US$)
				Fertilizer & herbicide	Insecti-cide	Farming activities	Scouting	Farming activities	Scouting	Inputs	
Kandi	Control	788	424	105	0	115.29		265		105	53
	Conventional	1,589	855	105	75	116.29		274		180	401
	Neem oil	1,217	655	105	41	116.29	3.33	274	14	146	234
	Neem oil-Bb11	1,258	677	105	41	116.29	3.33	274	14	146	256
	Neem oil*Bb11	1,125	605	105	123	116.29	3.33	274	14	228	103
	Neem oil*Bt	1,278	688	105	129	116.29	3.33	274	14	234	178
N'Dali	Control	726	391	128	0	134.38		275		128	-12
	Conventional	1,582	851	128	75	135.65		289		203	360
	Neem oil	1,118	602	128	41	135.65	2.5	289	7	169	143
	Neem oil-Bb11	1,084	583	128	51	135.65	2.5	289	7	179	115
	Neem oil*Bb11	1,122	604	128	92	135.65	2.5	289	7	220	95
	Neem oil*Bt	1,161	625	128	93	135.65	2.5	289	7	221	115
Djidja	Control	752	405	128	0	104.66		267		128	9
	Conventional	1,207	650	128	75	105.66		279		203	168
	Neem oil	1,043	561	128	10	105.66	2	279	10	138	144
	Neem oil-Bb11	1,081	582	128	31	105.66	2	279	10	159	144
	Neem oil*Bb11	1,090	586	128	31	105.66	2	279	10	159	148
	Neem oil*Bt	1,297	698	128	62	105.66	2	279	10	190	228

Purchase price paid to producer for 1 kg of cotton was 0.54 US$ for the 2012-2013 season.
1 man day corresponds to the labour performed by one man in 8 hours. It costs an average 2.36$US in Kandi; 2.13 US$ in N'Dali and 2.64 US$ in Djidja; scouting not included.
1US$ = 483 FCFA in the period of cotton harvest (January 2013).

Discussion and conclusions

Effect of treatments on the thresholds and number of sprayings

The threshold level of various pests was reached from the 66-73 DAE in the three districts regardless the pest species. This period coincides with the blooming and fruiting stages of cotton, when availability of food was largest for the carpophagous pests. This period is critical for the productivity of the crop and requires special attention from farmers to prevent pest attack on squares, flowers and bolls. Moreover, the peak of *H. armigera* occurs at early fruiting stage (90-120 DAE) (Achaleke et al., 2009). Decision-making regarding treatment application is largely based on the insect larvae (CRA-CF, 2002; Nibouche et al., 2003; Silvie et al., 2001) which are visible because of their size. But at this stage, most of the damage has already occurred. It would perhaps be more useful to scout for the pest eggs in order to prevent the damage caused by the larvae, especially when bioinsecticides are used. Farmers need to be trained to monitor and control pests effectively. Especially *Earias spp*., *D. watersi* and *H. armigera* should be targeted, as they cause much damage to flowers and bolls in Kandi and N'Dali. Special attention should be given to *H. armigera*, the most harmful species, which is able to infest farmers' fields at the squaring and blooming stage (45-90 DAE). The high mobility and voracious feeding habit of *H. armigera* larvae (Nibouche et al., 2007) make it difficult to control effectively. Moreover, its eggs hatch in 2-3 days and the larvae can emerge several times the same week. For this reason, it has been recommended to increase the frequency of scouting (twice weekly), at least during the flowering period of the crop - namely from weeks 8 to 16 after plants emergence (Matthews, 1996; Wilson, 1993). Scouting only once a week would allow the eggs to hatch, and once the larvae are inside the squares or bolls, they are less vulnerable to the spray deposits, and a larger dose of insecticide would be required to control them (Matthews, 1996).

In general, the protective effect of the conventional treatments on squares, flowers and bolls was similar to that obtained with the bioinsecticides. This result is different from those obtained from the experiment carried out during the 2011-2012 season (Togbé et al., Chapter 4) in which the lowest number of damaged squares, flowers and bolls were recorded with conventional treatments throughout the three districts. This change in the efficacy response can be explained by the modification that occurred in the composition of the conventional treatment in 2012-2013. Protection of the bolls is mainly required during the third and fourth treatments and a binary (pesticide with two active ingredients) is often recommended to tackle pests in this period. This was done in the 2011 2012 season by using Nurelle (cypermethrin

36 - chlorpyriphos ethyl 200 g/l), while in the 2012 2013 season in the official prescription for the whole country this was replaced by Califos with only one active ingredient (Profenofos 500 g/l) (Table1). Although Califos was recommended for controlling *H. armigera*, the active ingredient may not have provided protection to the reproductive organs as much as the Nurelle did. Throughout the country, the low performance recorded in this season may have been an evidence of this effect.

The protection of reproductive organs provided by the four treatments using bioinsecticides, neem oil alone, neem oil-Bb11, neem oil*Bb11 and neem oil*Bt did not show a clear difference in the effectiveness of the treatment. This suggests the absence of a synergistic effect between neem oil and *B. bassiana*, and between neem oil and *B. thuringiensis*. The combination of entomopathogens with other pesticides may not always lead to an enhanced effect (Ravensberg, 2011). Several research studies show that, at a given temperature, certain concentrations of neem oil have been found compatible and synergistic when combined with an entomopathogenic fungi such as *B. bassiana* and *Metharizium. spp*. However, beyond such concentrations, spore viability or colony growth is delayed and sometimes suppressed. showing that neem oil can cause loss of potency or inhibition of the entomopathogenic agents (Araujo Júnior et al., 2009; Depieri et al., 2005; Haroon et al., 2011; Mohan et al., 2007; Shah et al., 2008). For this reason, a trade-off should be sought between the concentration of phytochemicals that would optimize the activities of the enthomopathogens (Shah et al., 2008). On the other hand, the quality of the entomopathogenic agents needs to be investigated. The quality parameters of entomopathogenic agents are related to the number of infective propagules (viability and virulence), physical and chemical properties (physical stability, chemical stability, shelf-life) and microbial purity (microbial contaminants and safety) (Ravensberg, 2011). Even when these conditions are met, the efficacy of such products is not always guaranteed. The efficacy is related to the product’s field performance (Ravensberg, 2011) which depends on a number of factors such as environmental and agronomic factors: temperature, humidity, sunlight, soil type, rainfall, and interactions among these environmental factors (Inglis et al., 2001). The case of Bt might be a bit different because this microbial product behaves almost like a chemical and is less influenced by the crop and environmental parameters. Ravensberg (2011) explained that ingestion of Bt by a pest usually follows quickly after application and therefore environmental factors influencing survival of Bt are less critical than with fungi. As neem oil has an anti-feedent effect (Devi and Prasad, 1996; Koul et al., 1990; Mayabini, 2005; Mondal et al., 1995) this may have prevented the ingestion of Bt by pests and affected its impact

(Elzen and James, 2002). For this reason, the combination of neem oil with any microbial agents acting by ingestion may not be recommendable (Ravensberg, 2011). These results indicate that, prior to the combination of a microbial pest control product with other crop protection components, the compatibility of both materials has to be established. If possible, this should be taken into account with regard to the timing of the treatments. The mixed formulation may not be appropriate in this case.

Effects of treatments on the population of natural enemies

The diversity of natural enemies existing in the various systems tested gives evidence that beneficial arthropods offer possibilities that can be used in a cotton IPM strategy. Therefore, understanding the role and compatibility of these natural enemies with biopesticides can play a determinant role in managing the cotton pest complex. Srinivasan (2012) indicated that biopesticides are very compatible with other pest management techniques such as natural enemies and resistant varieties. He also reported that the application of *B. thuringiensis*-based biopesticides enabled parasitoids such as *Diadegma semiclausum*, *Cotesia plutellae* and *Diadromus collaris* to establish in several countries, and provided significant control of the diamondback moth (*Plutella xylostella*) on brassicas in South and Southeast Asia. Also, enhanced effects were found on the mortality of diamondback moth when entomopathogenic fungi were combined with the parasitoid, *Oomyzus sokolowskii* (dos Santos et al., 2006). Further research assessing the effects of these biopesticides in cotton production can allow a decrease in the amount of synthetic pesticides used, while relying on the potential found in the environment.

In general, the number of ants, coccinellids and spiders in the control plots and in the plots treated with bioinsecticides were not different, suggesting that neem oil and the bioinsecticides *B. bassiana* and *B. thuringiensis* did not harm natural enemies. This safeguarding property of neem oil and biopesticides with regard to the natural enemies has already been demonstrated in previous studies. Neem products were reported far safer than chemicals for predatory coccinellids (Sakthivel and Qadri, 2010; Tavares et al., 2010) and spiders (Joseph et al., 2010) and both predatory arthropods (Sakthivel et al., 2012). Neem oil was also found safer for ants (Mancini et al., 2008; Sinzogan, 2006). Moreover, its efficacy against a broad spectrum of pests, minimal mammalian toxicity, minimal impact on pollinators and rapid disappearance from the environment are important attributes that can favour the adoption and success of neem-based products in IPM strategies (Isman, 2000).

Effect of treatments on the yield and profitability

The effects of the treatments on the protection of the reproductive organs of cotton plants have been shown through the yield of the crop. Even in Kandi and Djidja, where significant difference in the yields was obtained with the bioinsecticides, this difference does not provide clues to rank the effectiveness of the treatments with regard to the yield. Overall, the conventional treatment provided the highest yields in Kandi and N'Dali, suggesting that bioinsecticides are not as effective as the synthetic pesticides (Ahmed et al., 2002; Faria and Wraight, 2007; Gouli et al., 2009; Wraight et al., 2001). This result also confirms that the combination of entomopathogenic fungi with phytochemicals such as neem oil does not always lead to a synergistic effect. Knowing this, bio-assays related to the compatibility of such treatments need to be conducted before field application of such mixtures takes place.

The cost of labour did not vary across treatments, and or within each district. However, in Kandi and N'Dali, the input costs of combined treatments are higher than that of conventional treatments and neem oil applied alone (T2) and separately with *B. bassiana* (T3: neem oil-Bb). This was due to the fact that the threshold of pests was reached many times, increasing the number of treatments and hence the cost of bioinsecticides. The increase in the cost of input of combined treatments (T4: neem oil*Bb; T5: neem oil*Bt) affected their profitability negatively. These results show that the cost of biopesticides can play a determinant role in the adoption to use a bioinsecticide. Knowing the high value that farmers place on the financial return of their cotton production, special attention should be given to input costs. In Djidja, the highest profitability was realised by the combined treatment of neem oil*Bt because in the 2012-2013 season, the number of thresholds was decreased, greatly lowering the cost of insecticides and other related costs.

The threshold-based applications of bioinsecticides and their combinations did not perform as effectively as the calendar-based conventional treatment. However, the large differences in pest incidence between districts indicate that the use of economic thresholds is justified. Several questions remain, such as whether the farmers were sufficiently trained to do the scouting, and whether outsourcing to professionals should be considered. The other question is whether the methodology of scouting was accurate enough and whether sufficient parameters (such as frequency of scouting, expected yields, price of inputs, etc.) have been taken into account.

Chapter 6

Effect of participatory research on farmers' knowledge and practice of IPM: the case of cotton in Benin

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Abstract

This study assesses the effect of participatory research on farmers' knowledge and practice of Integrated Pest Management (IPM) in Benin. Of the 180 cotton growers sampled, 150 took part in the research, while 30 served as control. The participatory field experiments were carried out during the 2011-2012 cotton growing season, and focused on the development and application of pest management knowledge. A 'Difference-in-Differences' methodology was used to document the changes in farmers' knowledge and practices across the following season, 2012-2013. Participation in the research increased farmers' ability to recognise pests and natural enemies and how to use thresholds and apply biopesticides. Increase in knowledge did not lead to any modification in the farmers' use of neem oil and the entomopathogen *Beauveria*, but it did lead to a significant change in threshold-based pesticide applications. Farmers seemed to want to reduce pest management costs, whatever the type of pesticide recommended (conventional or bio-based). The related policy implications are discussed.

Key words: field experiment, farmer learning, pest management costs, biopesticides, neem oil.

Introduction

We assessed the effect of farmer participatory research on the knowledge and practice of Integrated Pest Management (IPM) in cotton farming in Benin. During the last few decades, farmer participatory research has been conducted in various agricultural domains such as plant breeding, plant production, crop protection, and soil fertility (Ashby, 2009; Dawson et al., 2011; Joshi et al., 2012; Nederlof et al., 2007; Rannestad et al., 2013; Williams et al., 2012). By now it is widely accepted that farmers can play an important role in agricultural research, development, and extension (R&D&E). According to Gonsalves (2005), farmers can help R&D&E to respond to their specific problems, needs and opportunities; to identify and evaluate technology options that build on local knowledge and resources; to ensure that technical innovations are appropriate for local socio-economic, cultural and political contexts and desirable given farmers' goals; and to promote wider sharing and use of agricultural innovations.

This study reports on a project during which farmers collaborated with researchers to investigate alternatives to conventional cotton pest management. We evaluated the joint learning process that took place during the production season of 2011-2012, and assessed the immediate outcome on farmers' knowledge of pest management at the onset of the 2012-2013 season, against baseline data collected at the beginning of the 2011-2012 season. During 2012-2013, we also recorded changes in the practices of the participating farmers in their own fields. The outcomes of the field experiment conducted with farmers in 2011-2012 was reported in separate paper (Togbé et al., Chapter 4).

The methodological challenge for assessing the impact of participatory research in the context of Farmer Field Schools in Integrated Pest Management has been discussed by Van den Berg and Jiggins (2007). Two types of methods of comparison can be distinguished: the latitudinal (with-and-without) design and the longitudinal (before-and-after) design. The latitudinal method consists of comparing a treated and a control group, on the assumption that groups are the same in every relevant aspect except for the treatment (Tripp et al., 2005; Van den Berg and Jiggins, 2007; Van Duuren, 2003). In practice, it is advisable to ensure the similarity of the groups before the experiment starts, instead of trying to make an ex-post statistical correction (Van den Berg and Jiggins, 2007). A major drawback of the latitudinal design is the danger of 'contamination' of the control group. For this reason, many studies have preferred a longitudinal design (FAO, 1993; Le Toan, 2002; Pincus, 2002). This method has the merit of being able to assess any changes induced by the treatment over time, but cannot control for other factors that might contribute to the same achievement. The

Difference-in-Differences (DiD) or Double Delta design corrects this shortcoming. Being a combination of latitudinal and longitudinal design, DiD has been considered the most robust (Feder et al., 2004a, b; Khan et al., 2005; Mancini et al., 2006; NAESC, 2003; Praneetvatakul and Waibel, 2002). In the current study, we used the DiD design to evaluate the immediate effects of the participation of farmers on their knowledge and farming practices.

Background

Agricultural research continues to face the challenge of helping to feed a growing and increasingly demanding world population. Initially, this challenge was met by creating effective input services and introducing high-yelding varieties, leading to the Green Revolution of the 1960s and 1970s. Many areas of human society were impacted by the Green Revolution as a result of only technological changes. The other dimensions of agricultural innovation such as socio-economic, cultural, institutional and political were neglected (Biggs, 2007; Gonsalves, 2005). Along with dramatic improvements in agricultural production, new problems emerged in terms of pests, diseases, nutrients, and water management (Price, 2001).

The technology transfer paradigm proved to be inappropriate for dealing with new problems affecting many aspects of human existence, such as the environment, human health, rural community economy and livelihood and the sustainability of crop productivity. With hindsight, the principal weakness of the technology transfer paradigm is the lack of interaction between researchers and farmers. In Sub-Saharan Africa, the Green Revolution has failed to take off (Djurfeldt, 2005). Unlike Asian countries, African countries failed to create the supportive institutions, including input services, extension, and pricing policies that would have created realistic opportunities for smallholder farmers. Van Huis et al. (2007) concluded from a comparison of eight experiments with participatory technology development with West African farmers that, given the small windows of opportunity faced by those farmers, approaches that rely on technology transfer alone have marginal impact. The adoption of technologies produced by agricultural research stations has been disappointing. Farmers need reasons and incentives to innovate. In Benin, for example, cotton farmers often do not follow the recommendations of the Cotton Research Centre (CRA-CF, 2002) because of the accompanying constraints.

As a result, innovation pathways have started to move away from generating and transferring science-based technologies to passive end users, and have begun to embrace a learning process that includes activities for generating, sharing, and utilizing knowledge. This learning process draws upon various sources of knowledge, from community based-systems to formal science, and yields a wide range of knowledge products, from technological to socio-institutional innovations. It implies a shift in the role of farmers from being merely recipients and beneficiaries to actors who are sufficiently empowered to play a major role in determining the direction of the process (Gonsalves, 2005; Röling, 2010).

Giving an active role to farmers is not undisputed. It has been reported that some scientists are sceptical about the innovative capacity of farmers, considering it sub-optimal and unscientific (Eshuis and Stuiver, 2005; Gupta, 1989; Gupta, 1995). The consensus today, however, is that the strengths of farmers and the limitations of researchers have been generally overlooked (Chambers, 2010; Hoffmann et al., 2007; Richards, 1989). Selener (2005) indicated that by working in isolation, scientists at research stations tend to generate inappropriate technologies, thereby wasting money and time. Farmers' inputs are needed in research because they have knowledge and skills that are complementary to those of professional researchers (Hall, 2005; Lyon, 1996; Richards, 1989; Roling, 1990; Sumberg and Okali, 1997). By working together, the two groups may have more impact on innovation than by working separately (Ashby and Pretty, 2006).

In cotton farming in Benin, the key problems faced by farmers since 2005 are high input costs, decline in yields, and low quality of the lint produced. Most prominent among the proposed solutions are the application of good agricultural practices (as recommended by the Cotton Research Centre) and an improved pest management strategy (Togbé et al., 2011). Implementing an integrated pest management strategy requires considerable knowledge on the part of farmers (Orr, 2003).

We organized a participatory research experiment during which farmers were trained in good agricultural practices, including the recognition of pests and natural enemies, determining thresholds, and adequate application of appropriate pesticides. This experiment was designed to enable interaction between farmers, the researcher and extensionists, concerning the knowledge and skills that are needed to better manage cotton production. During each working session, farmers were requested to contribute freely in their local language. The involvement of farmers in the learning process allowed them to interact with fellow farmers in their aim to improve cotton quality and yield. The researcher helped to create space for interaction and to facilitate the whole process.

The learning process

Overall set up

The learning experiment was carried out in the 2011-2012 season in three cotton-growing districts of the country: Kandi, N'Dali and Djidja. These districts are located in three agro-ecological zones differing in cotton pest infestation, rainfall, acreage cultivated, and cotton production (high, medium and low cotton-growing areas). In each of these three districts, five villages were selected for treatment and one village for control. In each village, 10 farmers were randomly selected. Hence, the experiment comprised 15 experimental villages and three control villages; 150 farmers participated, while 30 farmers served as control.

The field experiment was designed as follows. The size of each experimental plot was 600 m^2 (30 x 20 m). A buffer distance of 10 m was created between plots to limit contamination by pesticide drift. According to this design, the space occupied by the buffers was 70 % of the 1 ha allocated to the field experiment. Most of the weeds growing in this space were annuals, which dried at the end of the season and could have constituted a source of contamination for the seed cotton. We therefore decided to weed this space. At first, the farmers disagreed and refused to spend their time cleaning a non-planted space, but they were convinced by the arguments of the extension agents. For reasons of comparison, the same field experimental design was applied to all 15 villages.

Developing trusting relationships with farmers

In each district, we randomly selected five cotton-growing cooperatives in different villages to host the experiment. Before establishing contact with farmers, a number of steps were followed in order to build a trusting relationship with them, as suggested by Haagmann et al. (2003). First, meetings were arranged with extension agents in charge of each cotton growing area to share with them the findings from the diagnostic study (Togbé et al., 2012) and to obtain their agreement on carrying out experiments with farmers in the selected villages. These meetings included farmers' representatives who were contacted by extension staff. Second, other meetings were arranged with farmers' representatives of selected cooperatives to introduce the "Convergence of Sciences: Strengthening Innovation Systems" (CoS-SIS) programme to farmers, as well as informing them of the objectives of the experiments (http://cos-sis.org/; Röling et al. (2012)). Farmers' representatives agreed to host the experiments in their respective villages, and negotiated with farmers in their communities to dedicate 1 ha of land to the experiment. Feedback was provided to the public extension officer at district level, the so-called ''Responsable Communal pour la Promotion Agricole''

(RCPA). Third, meetings were held with the farmers willing to participate. Among these farmers, 10 were randomly selected to be directly involved in the experiment (with no financial compensation). These 10 farmers agreed to make contribute labour for farming activities such as planting, thinning, weeding, applying fertilizers, spraying and harvesting. All necessary inputs (fertilizers and pesticides) were provided by the CoS-SIS program. Their acquisition was facilitated by the Extension Service (Table 1).

Table 1: Expected contributions of the members of a learning group to the learning process and the resulting expected outputs

Members of a learning group	Contributions to the learning process	Direct benefits
Farmers	- Perform farming activities - Perform weekly observations - Decide to spray when pest threshold is reached	- Knowledge - Cotton harvested
Extension agents	- Facilitate provision of inputs - Provide farmers with the decision-support charts - Appoint one agent per village	- Reports about the experiment
Researchers	- Provide the required inputs - Facilitate the learning process - Report and document on the learning process	- Data collected - Reports - Publication

In each village, a learning group was established composed of farmers, extension service agents, and the researcher. This group was linked to the relevant Consultation and Innovation Group (CIG) initiated by the CoS-SIS programme. The aim of CIGs is to address institutional constraints at a high level (Hounkonnou et al., 2012; Nederlof and Pyburn, 2012). The cotton CIG encompasses input suppliers, ginners, researchers, extension services, private organizations and farmers' representatives located at district and national levels.

Selection of pest control strategies

The pest control strategies were derived from an earlier diagnostic study (Togbé et al., 2012), which aimed at alleviating the technical and institutional constraints of a pest management strategy entitled LEC. One major constraint was the non-delivery of the specific pesticides required for LEC by input suppliers, and this probably prevented the strategy from being applied nationwide. As a possible solution, the study suggested the use of botanicals and biopesticides. Moreover, as biopesticides and botanicals are less harmful to the environment and health than are conventional pesticides, they could replace the latter.

Farmers suggested using neem oil as an alternative to synthetic pesticides. Their awareness of the potentials of neem oil was raised by many documentaries on television. Farmers were already familiar with the application of aqueous extract of neem leaves on cowpea. The extract is made by grinding the leaves and soaking them for 24 h in water before filtering. The preparation of this extract is labour intensive, and comes on top of the effort of growing food crops, which explains why neem extract is not used for cotton despite its proven effectiveness (Sinzogan et al., 2006).

Therefore, learning experiment also included a pest control strategy that makes use of neem oil. For this we investigated where we could buy the large amounts of neem oil needed for large-scale applications. Although there are women's associations and some private enterprises that produce neem oil in the country, we chose to buy the neem oil from only one company (Cobeneem/Benin) to be sure of a uniform product quality. The entomopathogenic fungal pesticides *Metarhizium anisopliae* and *Beauveria bassiana* have been produced and tested with farmers in northern Benin by the International Institute of Tropical Agriculture (IITA, 2010). Through our interaction with IITA, both biopesticides were suggested as alternatives because of their low toxicity for humans and low impact on the environment. These naturally occurring entomopathogenic fungi germinate within the insect body, proliferate rapidly and kill the host (Acosta et al., 2009; Er et al., 2007; Espinel et al., 2008; Pires et al., 2010; Prasad et al., 2010; Wraight et al., 2010). The mode of action of these biopesticides would allow farmers to conserve the conidia by collecting and storing the dead bollworms, and applying them to their crops the following year.

Finally, the application of neem oil, *Beauveria* and *Metarhizium* was expected to decrease production costs and thereby increase farmers' revenues. *Beauveria* has a wide spectrum and is known to be effective in controling bollworms in cotton. Unlike *Beauveria*, the isolate of *Metarhizium* suggested was too specific and was therefore discarded by farmers during meetings (Table 2).

Table 2: Summary of criteria used for treatment validation

Treatments suggested during diagnosis	Criteria	Validation for being tested in the field
Neem aqueous extract	Self-made	Discarded
Neem oil	Ready-made products Effective on many pests Locally available	Accepted
Beauveria	Effective on many cotton caterpillars Locally available Self-production by collecting dead bollworms	Accepted
Metarhizium	Self-production by collecting dead bollworms Very specific	Discarded
LEC	Reference for comparison	Accepted
Conventional treatments	Reference for comparison	Accepted

Organisation of the learning process

The first author served as facilitator for the whole process. Farmers met one day a week. During each training session, farmers shared their knowledge about pests and practices. We emphasised the major pests that damage cotton. Through interaction, farmers themselves learned to recognize each pest and the damage it caused. Farmers were provided with pegboards (Brévault et al., 2009; Silvie et al., 2001) and decision-support charts to facilitate training on pest recognition and threshold determination. Additional information was given to them concerning thresholds, the scouting method and appropriate pesticides. During such trainings, we raised the farmers' awareness on the role of natural enemies and the waste incurred by spraying pesticides on a calendar basis, irrespective of whether spraying thresholds were reached.

Regular field monitoring by farmers started on day 31 after plant emergence. Before the first observation, farmers agreed to count the number of healthy and damaged bolls on 20 plants to evaluate the effectiveness of the treatments. They also agreed to conduct a visual inspection. Finally, farmers considered the yield to be the most important factor that would enable comparison with regard to the efficacy of the treatments.

Regarding the farmers' autonomy, decision making for spraying was always based on the farmers' own observations. In practice, decisions were always based on consensus and made during the weekly meetings. The first author was involved as facilitator in this process; his main role consisted in reminding the group of the threshold for the various pests, when asked. The weekly meetings were held in the farmers' local language. For this purpose, we used the common language of Batonou (in Kandi and N'Dali) and Fon (in Djidja) to refer to the targeted pests and plant parts (Table 3).

Table 3: Pests and plant parts in Batonou (Kandi, N'Dali) and Fon (Djidja)

Item	Name in local language	
	Batonou	Fon
Pests		
Aphis gossypii	Gaaniku	Chêkê
Sylepta derogata	Naareku	Wanfou amanwoloto
Mites (*Polyphargotarsenemus latus*)	Kparoru	Yêyê
Helicoverpa armigera	Birerudi	Tongloe houewenon
Earias spp.	Koko sansu	Tongloe ounon
Diparopsis watersi	Koko bakaru	Sanmian
Dysdercus volkeri	Direkokonu	Lissebossu
Bemisia tabaci	Sonsu kpika	*Not present*
Plant parts		
Leaves	Wurussu	Ma
Buds	Binu	Kpater
Flowers	Wiinsu	Se
Boll	Bireru	Gloe

Evaluation of the participatory research and learning process

Data collection

Various data were collected about the joint-learning process, and before and after the experiment.

Variables measured before the learning process: Prior to the participatory experiment in the 2011-2012 season, baseline data were collected with the 150 farmers selected to join the experiment and the 30 farmers selected as control. The baseline study gathered general information regarding level of education, past experience, and farming practices, with special attention paid to pest management practices. Farmers were asked to take a specific-knowledge test about pests and natural enemies, pest thresholds, LEC pesticides in general, specific pesticides in particular, and the harvest procedure needed to obtain good quality cotton. A scale ranging from 0 (lack of knowledge) to 3 (full knowledge) was used: 0 = no knowledge about the pest; 1 = recognizes the pest by the damage it causes; 2 = can describe the pest and the damage; 3 = knows about the pest, the damage caused, and how to deal with it. The remaining questions were treated as follows: 1 for right response; 0 otherwise. The number of right answers relative to the total number of questions defined the knowledge score for each farmer.

Variables measured during the learning process: During the learning process, group dynamics were monitored and evaluated, taking into account (1) the level of commitment to the work as reflected in the presence of the farmers at the experimental site each week, and (2) the involvement of farmers in the decision making for spraying.

Variables measured after the learning process: The same questions asked before the learning experiment were answered again by farmers after the experiment. Changes in farming practices that occurred after the experiment were monitored by independent researchers, who followed participating and control farmers through field visits during the following season (2012-2013). The aim of this monitoring was to identify any innovation introduced in the pest management techniques by farmers. The following pest management methods were considered as innovative: 1) use of neem oil; 2) use of Beauveria; 3) use of threshold-based decisions on spraying. If no innovation was introduced, farmers were questioned why not.

Analytical methods

Assessment of changes in farmers' knowledge

Following Liebenehm et al. (2009), the impact of the participatory research on farmers' knowledge was measured by grouping the outcome variables into categories:

- knowledge on pests and their natural enemies (maximum score: 30);
- knowledge on thresholds and bio-pesticides, including neem oil and Beauveria (maximum score: 20);
- knowledge on harvest conditions needed to obtain good quality cotton (maximum score: 4).
- total score was the sum of the points from these three categories (maximum score: 54).

Difference-in-Differences (DiD) procedures were used to estimate the impact on farmers' knowledge scores. With this approach, the impact of a policy on a variable can be estimated by computing a double difference, one over time (before-after) and one across subjects (e.g., between beneficiaries and non-beneficiaries, see Bertrand et al. (2004)) . This approach, also referred to as the ‘‘natural-experiment approach”, ensures that any unobserved variable that remains constant over time but is correlated with the selection decision and the outcome variable will not bias the estimated effect (Buckley and Shang, 2003).

The knowledge gained by farmer i after participating in the experiment is modelled by the following regression equation:

$$K_{i,1} - K_{i,0} = \delta + \beta X_i + \gamma T_i + \varepsilon_i \qquad (1)$$

$K_{i,1} - K_{i,0}$ is the difference in the knowledge of farmer *i* before and after the treatment. X_i is a set of farmer *i*'s personal characteristics, including gender, age, education level, household size, farm acreage, and earlier involvement in LEC (past experience). T_i is a dummy variable for treatment; it equals 1 if farmer *i* took part in the learning process and 0 otherwise. Parameter γ captures the effect of participation on knowledge. We test the null hypothesis that $\gamma = 0$. That is, involvement in the participatory research does not improve farmer knowledge. (The regression analysis was done with SPSS 16.0.)

Assessment of changes in farmers' practices

Difference-in-Differences (DiD) procedures were also employed to assess the impact of the learning experiment on changes in pest management practices. The latter were measured by whether or not a farmer adopted an innovative pest management strategy as learned during the participatory research, namely the use of neem oil, Beauveria and pest thresholds. The null hypothesis is that involvement of farmers in the participatory research did not affect their practices about cotton pest management in the following season.

Results

Farmers' socio-demographic characteristics and participation rate

Farmers' characteristics are summarised in Table 4. The experimental group was dominated by males, and there was no significant difference between participating and control farmers with respect to the gender balance ($\chi^2 = 0.012$; $p>0.05$). Women are highly involved in farming activities in cotton, but mostly in their husband's field. The average age of farmers was between 36 and 37 years; household size averaged 5.5-5.9 persons; and the farm acreage ranged between 6.2 and 6.5 ha. These three variables showed no consistent difference between participants and control farmers. The overwhelming majority of farmers were involved in agricultural production as principal activity (98.7% of participants and 96.7% of the control group). Education background showed no consistent difference between participants and control farmers (Table 4).

The participation rate of farmers in the experiment was 60.1%, 58.4%, and 55.3% in Kandi, N'Dali, and Djidja, respectively. A farmer was considered to have participated in the experiment if he had attended at least 50% of the weekly meetings. Various reasons were stated by farmers to justify their absence from group work. These included social matters such as illness and funerals of close relatives or community leaders. Involvement in their own farm, or other associative activities, such as meetings of the board of farmer organisations, was also reported as a reason for not attending the weekly group work.

Table 4: Farmers characteristics

Variable (Parameter)	Participating farmers (n = 150)	Control farmers (n = 30)	Test statistic and p value
Gender			
Male	92.7%	93.3%	$\chi^2 = 0.02$; $p = 0.898$
Female	7.3%	6.7%	
Age (years)	36.3	37.2	$t = -0.039$; $p = 0.969$
Household size (number)	5.9	5.5	$t = 0.31$; $p = 0.759$
Farm acreage (ha)	6.5	6.2	$t = 0.42$; $p = 0.675$
Education			
Illiterate	49.3%	53.3%	$\chi^2= 7.50$; $p = 0.058$
Alphabetised	16.7%	33.3%	
Primary	16.0%	3.3%	
Secondary	18.0%	10.0%	
Principal activity			
Agriculture	98.7%	96.7%	
Other	1.3%	3.3%	

Farmers' knowledge acquisition through the learning process

Before the experiment, participating and control farmers had a comparable level of knowledge on cotton pests and their natural enemies, pest thresholds and bio-pesticides and on harvest conditions to obtain good quality cotton (Table 5).

Participation in the learning process led to a significant increase in farmers' knowledge on cotton pests and their natural enemies (Tables 5 and 6). Being male positively affected the amount of knowledge gained, while education background (number of years of schooling) had a negative effect (Table 6). The other variables of the model (age, household size, involvement in LEC, and farm acreage) did not affect the increase in farmers' knowledge.

The involvement of farmers in the learning process increased their knowledge about cotton pest thresholds and bio-pesticides (Tables 5). Male gender and previous involvement in LEC also contributed to more knowledge, while larger farm acreage decreased farmers' knowledge score on thresholds and bio-pesticides (Table 7).

Farmers' involvement in the learning process did not have significant effect on the knowledge regarding harvest conditions to obtain good quality cotton (Table 5). This knowledge was positively influenced by farm acreage and past involvement of farmers in

LEC programmes. However, the explanatory power of the model is weak given the very low value of R-square (Table 8).

Table 5: Difference-in-differences estimates of the effect of participation in the learning process on farmers' knowledge

Knowledge categories	Difference between categories		Difference-in-differences
	Before the learning experiment	After the learning experiment	
Knowledge of pests and their natural enemies (max. score=30)	0.1	9.2**	DiD = 9.1**
Knowledge on thresholds of pests and bio-pesticides (max. score = 20)	0.4	10.1**	DiD = 9.6**
Knowledge on harvest conditions to obtain good quality cotton (max score =4)	0.1	0.24*	DiD = 0.2
Total knowledge score (max. score is 54)	0.6	19.5**	DiD=18.9**

*: Denotes statistical significance at 5% level (Student's t test).
**: Denotes statistical significance at 1% level (Student's t test).

Table 6: Regression of changes in farmers' knowledge on pests and their natural enemies on participation in the learning process and farmer characteristics

Variable (Parameter)	Coefficient	t value	P
Constant time effect (δ)	1.298	0.831	0.407
Participation (γ)	9.663**	13.499	0.000
Gender (β_1)	2.675*	2.238	0.027
Age (β_2)	-0.039	-1.336	0.183
Education (β_3)	-.253**	-3.150	0.002
Household size (β_4)	-0.091	-1.366	0.174
Involvement in LEC (β_5)	-0.775	-0.729	0.467
Farm acreage (β_6)	-0.023	-0.539	0.590
Regression model summary	R^2 = 0.544, F = 28.133**		

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

Overall, the involvement of farmers in the learning process contributed substantially to the increase in their total knowledge score (Table 5). Gender (being male) resulted in an increase of knowledge, while more education and a larger farm acreage resulted in a decrease of knowledge (Table 9).

Table 7: Regression of changes in farmers' knowledge on thresholds of pests and bio-pesticides on participation in the learning process and farmer characteristics

Variable (Parameter)	Coefficient	t value	P
Constant time effect (δ)	-1.732	-1.002	0.318
Participation (γ)	10.090**	12.722	0.000
Gender (β_1)	4.300**	3.247	0.001
Age (β_2)	0.007	0.227	0.821
Education (β_3)	-0.100	-1.118	0.265
Household size (β_4)	-0.080	-1.089	0.278
Involvement in LEC (β_5)	2.557*	2.171	0.031
Farm acreage (β_6)	-0.171**	-3.591	0.000
Regression model summary	R^2 = 0.534, F = 27.064**		

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

Table 8: Regression of changes in farmers' knowledge on the harvest conditions to obtain good quality cotton on participation in the learning process and farmer characteristics

Variable (Parameter)	Coefficient	t value	P
Constant time effect (δ)	0.045	0.186	0.853
Participation (γ)	0.199	1.813	0.072
Gender (β_1)	0.257	1.404	0.162
Age (β_2)	-0.003	-0.699	0.485
Education (β_3)	-0.012	-1.002	0.318
Household size (β_4)	0.018	1.796	0.074
Involvement in LEC (β_5)	-0.402*	-2.466	0.015
Farm acreage (β_6)	-0.017**	-2.589	0.010
Regression model summary	R^2 = 0.102, F = 2.677*		

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

Table 9: Regression of changes in farmers' total knowledge score on participation in the learning process and farmer characteristics

Variable (Parameter)	Coefficient	t value	P
Constant time effect (δ)	-0.390	-0.137	0.891
Participation (γ)	19.952**	15.327	0.000
Gender (β_1)	7.233**	3.328	0.001
Age (β_2)	-0.034	-0.655	0.513
Education (β_3)	-0.365*	-2.498	0.013
Household size (β_4)	-0.152	-1.263	0.208
Involvement in LEC (β_5)	1.379	0.714	0.477
Farm acreage (β_6)	-0.211**	-2.703	0.008
Regression model Summary	R^2 = 0.607, F = 36.365**		

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

4.4. Change in farmers' practices

We investigated whether in 2012/2013, the year after the learning experiment, farmers applied the practices they had learned during the collaborative research on their own plots. Although the use of Beauveria was one of the pest management methods implemented during the experiment, it was not applied by farmers (both participating and control farmers) on their own plots in the following year. Lack of time was the main reason for not using Beauveria (about two-thirds of the respondents) (Figure 1). This was followed by farmers' perception of this method as being complex and ineffective (21-27% of respondents). Other reasons included high cost and farmers' having more trust in conventional pesticides (Figure 1).

Neem oil was not used by control farmers on their own plots. Among participating farmers, the proportion of cotton farms using neem oil on their plots did not significantly increase. Only 4.6% of them used neem oil in cotton protection in their own fields during the season 2012-2013. The main reasons for not adopting neem oil by was the unavailability of the product (more than three-quarters of respondents), followed by farmers' trust in conventional pesticides (one-fifth of respondents). Only few respondents mentioned complexity (1.4%), poor effectiveness (3.5%), and high cost of this product (2.8%) (Figure 1).

Using thresholds of various pests to make a spraying decision was encountered among both participating and control farmers. Before the experiment, the proportion of cotton farmers using thresholds on their own fields was similar (3%) among experimental and control farmers.

After the learning process, 56.4% of the experimental farmers effectively used thresholds on their own fields during the 2012-2013 season (Table 10a). The involvement of farmers in the experiment contributed significantly to an increase in the proportion of cotton farmers using threshold methods (Tables 10b). Being male and farm acreage also had a positive effect on using thresholds.

Among the participating farmers who did not use thresholds to make spraying decisions in the 2012-2013 season, the main reason mentioned was time constraints (almost two thirds of the respondents). About 35% of them had forgotten how to use the thresholds, 11% of them complained about the complexity of the method, and 20% of them perceived it as irrelevant.

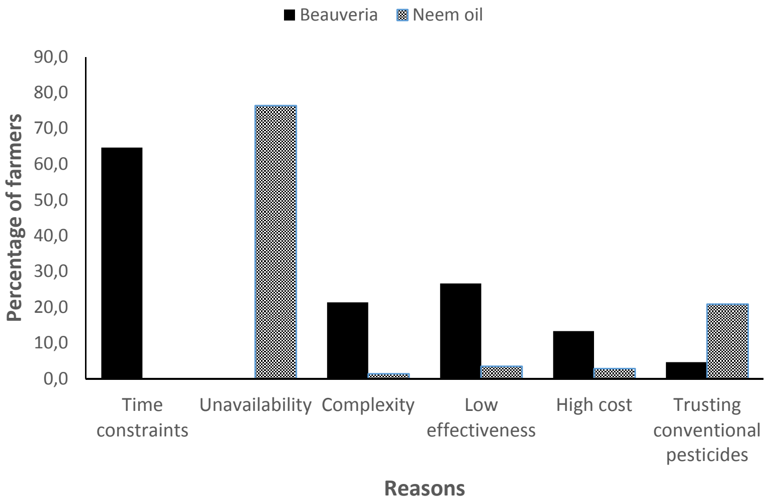


Figure 1: Reasons underlying the non-use of Beauveria and neem oil by participating farmers on their own plots.

Table 10a: Difference-in-differences estimate of the effect of participation in the learning process on the proportion of cotton farms using threshold methods

Category of farmer	Before the experiment	After the experiment	Difference
Participating farmers	3.6%	56.4%	52.8%
Control farmers	2.7%	4.7%	2.0%
Difference between groups	0.9%	51.8%**	DiD = 50.8%**

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

Table 10b: Regression of changes in the proportion of cotton farms using threshold methods on participation in the learning process and farmer characteristics

Variable (Parameter)	Coefficient	t value	P
Constant time effect (δ)	-0.406*	-2.459	0.015
Participation (γ)	0.510**	6.741	0.000
Gender (β_1)	0.435**	3.440	0.001
Age (β_2)	0.005	1.485	0.139
Education (β_3)	-0.003	-0.349	0.728
Household size (β_4)	0.008	1.097	0.274
Involvement in LEC (β_5)	0.182	1.616	0.108
Farm acreage (β_6)	-0.031**	-6.878	0.000
Regression model Summary	R^2 = 0.334, F = 11.801**		

*: Denotes statistical significance at 5% level, and ** statistical significance at 1% level.

Discussion

Farmers' characteristics and participation in the experiment

Before the learning process took place, participating farmers and control farmers had statistically equal knowledge scores. When looking at the main socio-demographic characteristics (age, gender, education, household size, and principal activity), no significant differences between participating farmers and control farmers could be found.

Between 40 and 45% of the farmers who were selected for the experiment did not participate fully in it, attending less than half of the weekly group meetings. Individuals missed group sessions because they had to work on their own farm, or were engaged in hiring workers or in off-farm activities. This is consistent with the reluctance of farmers to weed the experimental fields without any remuneration, as mentioned above, although they agreed to participate in the learning experiment without any financial compensation. This suggests that before the experiment, farmers underestimated the amount of work involved in taking part in it. Opportunity costs of farmers will be especially high during the cropping season.

In the literature, sub-optimal participation is also reported for farmer field school sessions, which take half a day. For most farmers, the time devoted to these sessions depended on the time left after household activities (Godtland et al., 2004; Tripp et al., 2005). Likewise, Hoffmann et al. (2007) found that when farmers are engaged in research or extension programmes, there is a tendency to interrupt the contract when the return on investment is not as promising as expected.

This raises the issue of what could motivate farmers to engage in participatory research. Ortiz et al. (2011) argued that the viability of participatory research methods depends greatly on the potential benefits farmers can gain, i.e., their expected increase in financial, human and social capital. However, insofar as these expected gains in production knowledge are spread among farmers, including those who did not participate, this poses a free-rider problem. Farmers know that even if they do not take part in the learning, they still can benefit from it. Financial compensation might then be required to get farmers on-board. In our initial discussions with farmers, they brought up the idea of financial compensation, arguing that when they attend meetings in other projects, they receive a daily amount as a compensation for their time. Financial compensation would raise the costs of participatory research programmes. More importantly, it could bias the results: one does not come for the schooling but for the money. This point needs further investigation.

Farmers' knowledge acquisition through the participatory research

Farmers who took part in the learning process increased their knowledge about cotton pests and their natural enemies, pest thresholds and bio-pesticides. There was no effect, however, on the knowledge dealing with the relation between harvesting practices and cotton quality. This is probably because farmers initially already knew a lot about this, making the opportunity for learning smaller.

Personal characteristics of farmers also influenced learning. We looked at the role of gender, education level, farm acreage, and past involvement in LEC. Men learned more than women. Being a minority in the group, female participants may have received less attention during the weekly meetings, perhaps due to shyness and reluctance to ask questions. During our supervision, they did not express themselves as male farmers did; they were sometimes teased by the latter during on-going discussions. To respond better to the needs of female farmers, it is probably important to include female scientists in the facilitating team.

The number of years of schooling that participants had, generally had a negative effect on learning. This unexpected result might be explained by the fact that higher-educated farmers often have more off-farm work. For this reason, the frequency of their attendance was low. Interests outside agriculture are likely to reduce their interest in farming issues, especially in labour-intensive threshold techniques.

Farmers with more land learned less than those with smaller farms. This is surprising because farmers with more land have a potentially higher return to their learning investments. The negative relation is in line, however, with the frequent absence of farmers with large acreage in the weekly group activities. Most of them were also members of the board of local and regional farmers associations, and the weekly group sessions coincided sometimes with the meetings of these organisations. An alternative explanation is that, as large farmers often use hired labour, they rely particularly on the skills of the workers they hire rather than on their own skills.

Having experience in LEC did not have any significant effect on learning. The passage of time may have caused an ''erosion of knowledge''. This knowledge decrease may have occurred because of unavailability of the specific pesticides needed for the LEC method (Silvie et al., 2001; Silvie et al., 2013; Togbé et al., 2012). Farmers who had previous experience in LEC may have taken the learning process lightly, perhaps because they had previously experienced the challenges of obtaining pesticides during similar training programmes.

Overall, the participatory research programme was effective in transferring knowledge to farmers about cotton pest management. Our results tally with many previous studies regarding the positive impact of farmers' participation in research activities on their knowledge levels (Erbaugh et al., 2002; Erbaugh et al., 2001; Godtland et al., 2004; Liebenehm et al., 2009; Nuntapanich, 2012; Thiele et al., 2001).

Changes in farming practices in the 2012-2013 cotton season

Many studies showed that the gains in knowledge from participatory research or farmer field school lead to a more judicious use of pesticides (Feder et al., 2004a; Godtland et al., 2004; Hussain et al., 1994; Price, 2001). The results of the current study are more ambiguous in this respect. On the one hand, we found that, after the learning process, there is a significant increase in the proportion of cotton farmers making threshold-based decisions on spraying. On the other hand, the learning experience did not result in significant changes in the use of neem oil and Beauveria.

Our results suggest that changes in farmers' pest management practices depend on the kind of innovation dealt with during the participatory research. Beauveria was applied by farmers on their own plots neither before nor after their learning activity. The clear rejection of this pest management strategy has to do with its high labour demands; using Beauveria requires the collection of dead bollworms and their conservation until the next season. Our finding result is in agreement with previous studies that highlight the rejection of labour-intensive and complicated integrated pest management strategies by farmers (Orr, 2003).

The main reason stated by farmers for not using neem oil was the unavailability of this product. The real reason may be financial constraints, however, which are critical for smallholder farmers (Jama and Pizarro, 2008; Poulton et al., 2006). Because of cash constraints, even farmers preferring neem oil might be forced to use conventional pesticides, which are available to all cotton growers on a credit basis. In Benin, the advantage of conventional pesticides over neem oil is exacerbated by subsidies provided by the government. Under these circumstances, the capabilities of farmers and the effectiveness of innovations are not enough to induce adoption of more environmentally compatible pest control technologies. In addition, proper institutional arrangements such as credit services are needed to facilitate adoption, as suggested by Singla et al. (2012) on the sustainability of the rodent control in wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) production in India.

After participating in the learning experiment, more farmers applied threshold-based spraying. The interest of farmers in using the threshold values for the occurrence of various pests as the basis for decision making about spraying has to do with their motivation to reduce pest management costs, regardless of the specific kind of pesticide (conventional or bio-pesticides). Yet most farmers still refrained from scouting the field before applying pesticides. The complexity of the threshold-based strategy could be responsible for this - 40 plants need to be sampled to evaluate the infestation level. The search for reliable alternative methods that require fewer plants to be sampled can be of great interest for farmers.

Conclusions and lessons learnt

In our participatory research, farmers were involved throughout the process from the definition of the research agenda through to post-research monitoring. However, the significant level of absenteeism during the weekly meetings suggests that farmers' interests must be taken into account to ensure their effective involvement in participatory research projects. To this end, financial compensation for their time could be a proper solution. From the perspective of research organisations, the provision of financial incentives will lead to increased intervention costs. Therefore, future studies might go beyond the effectiveness of participatory research in knowledge development and change in practices to assess the efficiency from the perspective of costs and benefits. We suggest that such studies include an estimate of the eventual reduction in the amount of pesticides used and the increase in the yields on the farmer's own fields. One-season training might not be sufficient for sustained behaviour change. There is a need for a comparative study of programs which used a similar approach over longer time periods to establish the time required for cost-effective impact.

Overall, our participatory research has been effective in increasing farmers' knowledge about cotton pest management. An ambiguous picture emerged from the assessment of changes in farmers' practices induced by the involvement in the participatory research. Significant progress was made in implementing threshold-based application of pesticides. However, no significant change occurred as far as the use of bio-pesticides (neem oil and Beauveria) is concerned. The study confirmed the reluctance of farmers to adopt labour-intensive strategies of integrated pest management.

Besides the proven effectiveness of technologies and increased knowledge among farmers, policy makers and project managers must closely look at the proper institutional arrangements (incentives) to support the adoption of innovations. A conducive environment in which farmers may have easy access to the tested products is thus a matter of high priority. Such products may be delivered on a credit basis as is the case with the synthetic pesticides. Knowing the willingness of farmers to produce neem oil themselves, a further step needs to be taken by the CoS-SIS programme to provide training either to farmers or women's organizations to produce such a product. By doing so, we expect great changes to occur in pest management in the cotton sector in the experimental areas.

Chapter 7

General discussion

Codjo Euloge Togbé

Introduction

An editorial in Nature (Anonymous, 2008) discussed the power of innovation to shape and transform society. The linear model of innovation posits that new ideas and technologies originate in the nursery of basic research. The editorial states: “A more accurate picture is that of a nonlinear 'ecosystem', in which innovation is driven by multiple players, forces and feedback loops working simultaneously. Such an ecosystem cannot be managed — at least, not in the conventional sense of top-down control. But it can be cultivated, in the way that a gardener can try to create the right conditions for plants to grow, while accepting that unforeseen elements ultimately dictate the outcome.” Innovation development has been pursued in the cotton sector in Benin, focussing mainly on innovation processes rather than their outcome. We tried to create an institutional environment favourable to innovation development by involving all the stakeholders in the cotton sector from the onset of the process (Röling et al., 2012). The rational was to avoid failures attached to the linear approach. In this transfer of technology (ToT) model (the linear approach) scientists are considered as the single source of innovation (Barnett, 1994; Chambers and Jiggins, 1987; Clark, 1995). Failures using such an approach occur particularly when the technological knowledge is complex (Baptista, 1999; Clark, 1995) and the technology must function in a non-uniform context (Chambers and Jiggins, 1987; Douthwaite et al., 2001). Innovation development is then likely to take place when it is performed by multiple actors, including public agencies, universities, the private sector, and non-profit and intermediary organisations.

In the programme “Convergence of Sciences, strengthening innovation system” (CoS-SIS), we devoted research time and resources to ensure that choices about focus, design, experiments, partners, beneficiaries, etc., were made as much as possible on the basis of (some) knowledge of the domain and an understanding of the perspectives of the actors (Röling et al., 2012). We also used an interdisciplinary approach by involving scientists from various backgrounds to guarantee that process and outcome fit with scientific and developmental requirements concerning the technology that will emerge. An exploratory study (Adjei-Nsiah et al., 2013) led to the selection of the entry point and the circumscription of the study. Integrated pest management emerged with a special focus on the ‘’Lutte Etagée Ciblée’’, known as LEC in French. The LEC strategy is a low-end IPM (Benbrook, 2002), which consists of the use of a basic protection (calendar-based) followed by the application of threshold-based tactics using specific pesticides (Silvie et al., 2001; Silvie et al., 2013; Togbé et al., 2012). The scope of application of this pest management strategy is still limited. This led to an important question: what are the reasons why the LEC strategy is not widespread, despite its numerous advantages? This question gave rise to the overall issues addressed in this study.

Main points emerging from the thesis

The IS approach was used in this study by involving the knowledge and interests of actors and stakeholders during each phase, from exploratory through implementation.

This study posits the LEC approach (calendar-based spraying followed by threshold-based applications) as a technological artifact and searches the alignment of the socio-organisational arrangements in the cotton sector to make this work. We used the framework provided by Geels (2002) to establish the current socio-technical configuration of the LEC strategy. Any transformation requires addressing hardware, software and orgware issues (Smits, 2002). Many organisations, research centers and projects focus on the hardware (developing technology), but neglect to build the socio-organisational framework that supports, sustains and makes the technology work (orgware).

By using a Policy Arrangement approach the instability, that was brought about by the reform implemented in the cotton sector, was captured (Chapter 3). In this reform a top-down approach was used, in which actors did not interact and therefore were unable to influence the process. The outcome of the process of implementation of reform depends on whether the process is goal-oriented or iterative (Crabbé and Leroy, 2008). The goal-oriented approach was used in which political decisions did not take into consideration the existing framework of actors and coalitions, discourses, resources and institutions. The exclusion of farmer based organisations (FBOs) and actors from public services, the ‘caution solidaire’, and farmers’ supervision proved to be inappropriate for solving the institutional problems posed at the four nodes of the policy arrangement, thereby further undermining the cotton sector.

Field experiments (Chapters 4 and 5) were based on the technical recommendations made in the diagnostic study (Chapter 2). The impact of farmers participating in IPM experiments was analysed with regard to their IPM knowledge and the use of that knowledge in practice (Chapter 6). The fact that practices learned were not always implemented on their own farm was partly due to the absence of a conducive environment. In particular the failure of the institutional environment to provide the necessary pesticides compromised the chance of innovation to occur for IPM in the cotton sector in Benin.

Conventional calendar-based spraying in sub-Saharan Africa

Cotton is one of the most important cash crops in sub-Saharan Africa, involving 1.67 million smallholder farmers. This crop is cultivated on roughly 3.17 million ha in sub-Saharan Africa, which corresponds to approximately 1.55% of all agricultural land (Peltzer and Röttger, 2013). Conventionally grown cotton is by far the most dominant production system, which accounts for about 98% of the total acreage cultivated.

The advantage of conventional calendar-based treatments is that no specific knowledge about pests and natural enemies is required; it is not even necessary to be familiar with the mode of action of pesticides. This is an advantage for farmers in developing countries where the majority of them are illiterate and often lack knowledge about the agro-ecological conditions. The conventional treatment does not require scouting, and saves labour, which is often in short supply. Labour shortages have become even more acute, as increasing numbers of children are being enrolled in schooling programmes. This was strengthened by governmental politics exempting parents from the payment of primary school fees.

However, conventional (calendar-based) treatments have a number of drawbacks, the first being the environmental effects. This relates to the effect on wildlife, birds, fishes, and the soil fauna (Ton et al., 2000). Second, safety precautions are often disregarded, due to a farmers' illiteracy, causing intoxication and human death (Glin et al., 2006). Also pesticides are often used as a means to commit suicide (Ton et al., 2000; Tovignan et al., 2001). Third, the use of synthetic pesticides is responsible for resurgence and secondary pest outbreaks. This is because the natural enemy complex is more vulnerable to the impact of pesticides than the pest itself (Croft and Brown, 1975; Pimentel and Edwards, 1982) (Chapters 4 & 5). This means that natural control is no longer effective, requiring more frequent pesticide applications at higher dosages. Fourth, pests become increasingly resistant to pesticides, requiring more pesticide applications at even higher dosages. A side-effect of increased pesticide applications is that the malaria-carrying mosquito is becoming increasingly resistant to pesticides. The resistance of *Anopheles gambiae* to pyrethroids has been noticed in northern Benin, where farmers use insecticides against cotton pests (Akogbeto and Yakoubou, 1999; Akogbeto et al., 2005; Yadouleton et al., 2011). The implications of agricultural use of pesticides in the selection for vector resistance has been clearly established in many other countries in West Africa, such as Burkina Faso (Diabate et al., 2002), Mali (Fane et al., 2012), Nigeria (Djouaka et al., 2008) and Cote d'Ivoire (Elissa et al., 1993). Cross resistance (Chandre et al., 1999) caused a decrease of the knock-down effect of pesticides when they are used to impregnate bednets. This may have been the reasons for the adoption of the new and updated vector control plans by the World Health Organisation (WHO), reverting to the use of Dichloro-diphenyl-trichloroethane (DDT) in 2011 (WHO, 2011). Knowing the impact of malaria on infant and pregnant women mortality rates in developing countries, alternatives to conventional treatments in the cotton growing areas are urgently needed.

Regulation and internalization of these externalities of synthetic pesticides (costs involved in mediating environmental quality and human health issues) would be desirable, but could increase farmers' production costs. However, because price adjustments would occur, farmers' income will increase due to possible welfare shifts from consumers to producers (Koleva and Schneider, 2009; Koleva et al., 2011).

Essential criteria for biopesticide production and use for experiment

Decisions to choose a pest management strategy involve a number of issues, in particular when botanical or entomopathogenic pesticides are involved.

Many of the biopesticides have not been successful in the market, and companies failed to achieve profitability of the product (Ravensberg, 2011). At present, there is no universally acceptable registration procedure for biopesticides as there is in the case of synthetic pesticides. This gives rise to a poor and erratic quality of biopesticides (Butt et al., 2001). As a consequence, sales of microbial pesticides are limited. Evans (2008) reported the annual sales of biopesticides to be $750 million globally, amounting only to 2.5% of the chemical market. Three stages are critical for ensuring the desired quality of the biopesticides: the selection of the microbial agent, its mass production and product development. The selection parameter for an effective microbial agent is the percentage of pests killed in the shortest time possible, at affordable costs (Ravensberg, 2011). During mass production and product development, the main focus is to obtain a stable product that is cost-effective and able to deliver effective pest control. The development of the product entails a set of steps that consists of ensuring that the final product is stable, has a long shelf life, and provides an effective pest control in the field at the lowest dose. This requires a formulation which is meant to: (i) maintain the infective propagules viable and virulent during a long period of storage after the final product has been packaged; (ii) enhance the desired effect on the targeted pest; (iii) protect the propagules from undesired effects of the environment and increase its persistence on the targeted pest; this means protecting against desiccation, high temperature, de-activation by sunlight, and washing off due to irrigation or rain (Wraight et al., 2001); (iv) minimise the risk of exposure during handling and application. The type of formulation used depends on the mode of action of the microbial agents, the nature of the propagules, and the type of applications either foliar or soil applications. Various formulants are then used to comply with these requirements, such as stimulants, surfactants, spreaders, stickers, and humectants. The stimulants modify the insect behaviours in such a way to increase the uptake of propagules by the pest. Finally, formulations are used that prevent contaminants from germination and growth. This is meant to avoid any harm to the active ingredients during storage and interference with the biological activity once applied.

Field experiments remain the ultimate tests in which the real efficacy of a selected microbial isolate will be revealed. All this information is important for the registration of the product and crucial for the success of the product on the ground. We therefore suggest that actors at the international level initiate a universally accepted regulation for the registration of microbial pest control agents.

Importance of stabilization and standardization in botanical insecticide production and experimentation

As in the case of biopesticides, the quality of the phytochemicals needs improvement in stabilization and the standardization of the product. The stabilization of the phytochemicals is important because of their rapid degradation/transformation when they are in contact with the atmosphere. This transformation occurs through the free radical chain reaction that leads to oxidation and hence the rapid loss of activity of the botanical insecticides. Factors such as temperature, UV and sunlight, pH, rainfall, humidity and other environmental factors have a negative influence on the stability of botanical pesticides (Johnson et al., 2003; Parmar and Walia, 2000; Stokes and Redfern, 1982). Two ways of stabilizing the botanical pesticides can be explored: first by using stabilizers, including anti-oxidants and UV-screens as with pyrethrins (Miskus and Andrews, 1972; Pieper and Rappaport, 1982) and second by replacing the photolabile sites in the molecules with photostable moieties. The second method was successfully used to obtain the photostable molecules in the pyrethroids (Parmar and Walia, 2000) and can be explored with other botanicals insecticides. The use of various stabilizers was trialed by several authors to enhance the stability of azadirachtin and azadirachtin neem oil. The increase of 26-60% in the stability of azadirachtin and azadirachtin neem oil was observed by incorporating anthraquinone or epichlorohydrin as stabilisers (Kumar and Parmar, 1999). Also the stability of azadirachtin and azadirachtin neem oil was enhanced by using stabilizers isolated from *Curcuma longa* such as curcumins, turmeric oil and neem oil in various proportions (Choudhury, 1996). These results provide evidence for the possible enhancement of the stability of such botanical insecticides. However, the value added might increase the cost of production and therefore be a handicap in the development of such products.

Variations in the physico-chemical, chemical, phytocompatibility, toxicological and other related parameters of botanical insecticides have always been a matter of concern and call for a profound reflection on the standardization of the product. The agro-climatic zones and the plant growth stage contribute to such variation. It has been reported that the content of azadirachtin is at a maximum when the fruit turns from green to yellow. Also, Parmar and Walia (2000) indicated that the bioactive efficacy of neem-based products may not necessarily be the result of a high content of azadirachtin, emphasizing the importance of other compounds such as meliacins in conferring their bioactivity to these products. These authors also highlighted the necessity of preventing neem-based pesticides from physical, chemical and microbial contaminants such as aflatoxins by improving handling, processing and storage conditions of neem seeds.

Overview of the LEC evolution since its launching in 1988 in Africa

Apart from Benin, many countries were involved in LEC implementation in Africa, such as Burkina Faso, Cameroon, Côte d'Ivoire, Guinea, Mali, Senegal and Togo. Based on the specific conditions prevailing in each country and on the expertise available, some alterations and adaptations have taken place, making the LEC fit the local conditions. In Benin, two different types of LEC were tailored, based on the occurrence and diversity of carpophagous pests with cryptic regime: partial LEC and complete LEC. Partial LEC was adopted in the southern and central regions. It consists of the application of the full dose of pyrethroid while the complete LEC uses half the dose of pyrethoid. Mali, Cameroon and recently Senegal adopted the full threshold-based application, called "true threshold-based" programme. Moreover, in Cameroon, a sequential plan for individual decision programme or LOIC (Lutte après observation individuelle des chenilles – control after individual monitoring of caterpillars) was developed. LOIC is based on control after sequential sampling of bollworms. Togo adopted calendar sprayings followed by some threshold-based applications made after scouting done for *H. armigera*. In Côte d'Ivoire, the true threshold was limited to the beginning of cotton growth; while in Burkina-Faso, the true threshold followed the application of two calendar-based sprayings (Silvie et al., 2013). The variation in the LEC methodology may have been the result of its complexity, with each country trying to fine-tune it, but also the lack of coordination across the various countries.

The acreages under LEC and its derivatives vary over years and tend to not go beyond a certain limit (Table 1). These figures show that Cameroon, Mali and Benin were mainly the countries where the LEC was implemented. The highest acreage in these countries was 92,643 ha (70%), 101,796 ha (22%) and 21,234 (12%) recorded in 1994, 2006 and 2010, respectively. Benin was able to reach this level of 12% under LEC because of the Competitive African Cotton Initiative (ComPACI programme) and the triennial plan of LEC promotion (Chapter 1) which put special emphasis on increasing LEC acreage. This result was not really consistent, as the acreage in LEC dropped the following year with about 30%. In Cameroon and Mali, the decrease in LEC acreage from the reference years of highest acreage (1994 and 2006 respectively) to 2010 are 98 and 34%, respectively, and may have decreased drastically since then.

This provides evidence of the difficulty for the technology to thrive and diffuse. Farmers were empowered but it seems that only the semi-literate ones became skilful enough to conduct the scouting by themselves. This situation explained the recourse to an outsourced workforce to handle the scouting. This hired labour, also called LEC observers, monitored infestation levels, and assisted fellow farmers in making appropriate and timely pesticide applications. The outsourced expertise for scouting transformed the knowledge from being a public good into a private service that farmers need yearly (Moussa, 2006). This implied for extension services to hand over some of their prerogatives to private actors. The farmers in the scouting service are able to speak and write in French, as they also serve as intermediaries between researchers and their fellow farmers. However, this was not a success because the fellow farmers often did not accept to pay the observers after the scouting was done (Togbé et al., 2012).

Input supplier companies negotiated from a power base as they are politically anchored and have the mono/oligopoly in supplying inputs. They supply cotton inputs in all the countries where LEC is implemented. However, in Benin they only provided inputs for the conventional and not for the LEC strategy, which seriously hampered its implementation. As a consequence, the acreages using LEC drastically declined. Some farmers still monitor their cotton field before applying pesticides (Chapter 6), but their number is not enough to have a substantial impact. Also, the diffusion of the knowledge of threshold-based applications by farmers used as LEC observers was limited to their direct friends (Moussa, 2006; Togbé et al., 2012).

Table 1: Evolution of LEC acreages and its derivatives in various countries

Years	Cameroon		Mali		Benin	Togo	Senegal
	LEC	LOIC	LEC	TTP	LEC	LEC	TTP
1988	-	-	-	-	30	-	-
1989	-	-	-	-	25	-	-
1990	407	-	-	-	30	-	-
1991	3720	-	-	-	30	-	-
1992	13002	-	-	-	55	-	-
1993	35386	-	-	-	92	-	-
1994	92643	-	104	-	96	-	-
1995	85266	-	259	-	606	50	-
1996	71043	-	2117	-	1273	1023	-
1997	50314	-	5313	-	736	2942	-
1998	39122	-	7351	-	100	5833	-
1999	2593	-	19821	-	3000	6089	-
2000	5214	-	16578	-	3991	7000	-
2001	5214	-	36521	611	9784	-	-
2002	3028	-	28980	2515	10605	-	-
2003	1647	-	36985	6297	17440	-	-
2004	490	-	39496	8683	8895	-	-
2005	143	-	71812	15133	8174	-	-
2006	418	132	101796	24026	10674	-	-
2007	-	312	63599	15640	11157	-	-
2008	-	838	52232	14248	10954	-	-
2009	-	1170	65286	15722	17223	-	-
2010	-	1783	66945	25551	21234	-	4259
2011	-	Not available			15000	Not available	1722

LEC: Lutte étagée ciblée (targeted staggered control).
LOIC: Lutte après observation individuelle des chenilles (sequential plan for individual decision making).
TTP: true threshold-based program
Sources: adapted from Silvie et al. (2013)

Integrated Pest Management: burden or tool for revenue increase to farmers

The success of the integrated pest management requires a set of conditions which seem difficult to meet in the context of smallholder farming in the developing countries.

The scouting methods used in our experiment were based on the thresholds established since the late 1980s by the cotton research centre (CRA-CF). The threshold indications were provided only for the larvae of the bollworms, the main one being *Helicoverpa armigera*, but not for the eggs. Given that the eggs of *H. armigera* can hatch twice a week (Matthews, 1996), and that scouting is done only once a week, one may consider including the egg stage in the threshold. Horne and Page (2008) also discussed the problems of thresholds, which often elude many variables such as the presence of natural enemies, the influence of planting date, the planting rates, the weather conditions and the value of the crop. This prompted others to develop the concept of dynamic thresholds (Hutchins, 1995) whose application is more difficult than the existing one. However, in the cotton production context in Benin, the planting date may no longer be appropriate considering the possible effect of climate change on the distribution of rainfall, plant growth and consequently productivity. At the beginning of each season, farmers expect the first rains before ploughing the land. Due to the late arrival of rainfall major delays occur in the execution of all the activities of cotton growing (Chapter 3). It has been noticed that the planting calendar set up by past research no longer matches the distribution of rainfall. Also, the rainfall appears to stop earlier than in the past. Farmers are requesting a revision of the planting period (Guibert et al., 2010). Also an increase in input costs has lowered the net revenue to farmers. The concept of a dynamic threshold may better fit the context of cotton production in Benin. Based on the above, one could question the reliability of the thresholds and the scouting methods used in cotton production. The integration of eggs in the scouting may be recommendable but would increase the workload to farmers and this may be a reason for them not to apply it. Farmers need incentives to do so, such as an increase in producers' price. This would compensate the extra scouting effort or the cost of outsourcing the scouting. Hutchins (1995) argued that for IPM to be successfully implemented, the scouting activity should be accomplished by someone other than farmers or by an enterprise whose performance would be shown through the increase in quality and quantity of the final product. He differentiated between ''idealistic IPM'' where societal values are assumed (e.g., reduce pesticides) and ''realistic IPM'' where farmers clearly consider their goals and personal values. Hutchins also posited IPM service within the economic perspective and suggested that farmers in developing countries should be empowered to make decisions based on a cost-benefit analysis. Is the reluctance of farmers to apply IPM based on such rationale? It seems that farmers have too little control over the framework conditions such as the producers' price of cotton, the variety to be sown or the timely delivery of specific inputs (Baffes, 2007).

Besides IPM being more labour intensive, farmers regard IPM as more risky. Cotton is produced in an erratic environment characterized by uneven rainfall, fluctuating pest occurrence and unpredictable yields. Under such conditions it may be difficult to arrive at meaningful thresholds. If external factors can be controlled better than under the current regime the outcome would be more predictable. Perhaps under such conditions, IPM would stand a better chance to strive and compete with other pest control strategies. Such conditions are met with high-value crops produced in greenhouse conditions with multiple harvests a year (Orr, 2003). Van Huis and Meerman (1997) explain that the IPM concept of economic threshold was not initially developed for resource-poor farmers, such as those involved in cotton production in developing countries, but for market-oriented agriculture in industrialized countries with large contiguous areas devoted to a single crop with predictable yields and stable prices. They argued that resource-poor farms ‘‘are very different, being small, and having crops in different developmental stages, often planted in mixtures’’. Although, cotton is planted in monoculture, most of the cotton fields are ‘‘adjacent to non-cultivated area and thus forming ‘islands’ in the wild vegetation’’.

These features may have an important effect on the dynamics of pest populations and may greatly affect the long-term success of IPM. Most of the countries such as the Philippines, Indonesia and Laos, where the adoption of IPM methods reduced the application of synthetic pesticides, now seem to experience a shifting back to non-IPM practices, in particular by relying on the use of pesticide applications (Islam et al., 2012). As a result, the rich biodiversity of natural enemies, being the basis of any IPM strategy, is being endangered and compromised. Besides field characteristics and location, the reasons might also be the lack of political support from the central government to sustain the IPM programme (Williamson, 2005) and the aggressive marketing strategies of pesticide companies using synthetic pesticides as ‘fast moving customer goods’ (Islam et al., 2012). Changing the view of IPM from idealistic to realistic would have helped farmers to build their own motivations and prevented them from returning to non-IPM practices.

Influence of the international landscape on cotton farmer’ revenue

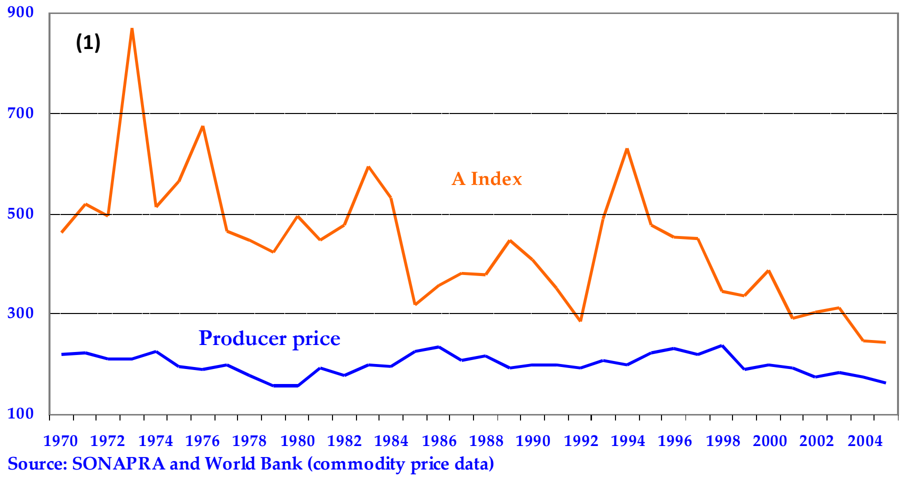
Geels (2002, 2005) analysed the conditions of success of technology and came up with the assumption that the further success of a new technology is not only governed by processes within the niche (micro-level), but also by developments at the level of the regime (meso-level) and the sociotechnical landscape (macro-level). Niche is a space of radical innovation (seed for change) and as such very relevant. Niches act as ‘’incubation rooms’’ for radical novelties (Schot, 1998), and need to be protected or sheltered from the assaults of outside forces such as ‘normal’ market selection in the regime. From the niche, an innovation enters the sociotechnical regime (ST-regime) at the meso-level. The ST-regime represents a site of dominant practices, interests, rules, shared believes and assumptions (Rotmans et al., 2001).

The world market price and the cotton quality requirements are two factors that exert a great effect on the cotton value chain. Although the world price for cotton is the result of the interaction between the supply and demand, the market is distorted by subsidies and exchange rate fluctuations. Cotton production increased over the last two decades due to technological improvements including the introduction of improved varieties, the increased use of irrigation and chemical fertilizers. Also, many developing countries implemented the genetically modified (GM) seed technology. The acreage planted with GM cotton varieties globally, accounting for one quarter of the total acreage. As a result, the world average yield has increased, while the world consumption of cotton per capita remains stagnant. This resulted in declining world cotton price. The most important trade distortion comes from the domestic support provided by the United States (USA) to their cotton growers. The West and Central Africa (WCA) cotton producing countries receive lower prices because of these subsidies. Nearly $150 million in potential export earnings annually are lost by these countries due to this support (Baffes and Estur, 2009). Baffes (2007) calculated that the share of the world market price paid to farmers would increase by 10 to 15% in the absence of USA subsidies to American cotton growers. Moreover, cotton is traded in US dollars and therefore its fluctuation has an effect on prices paid to the farmers in other countries. Due to the fixed exchange rate between CFA franc[1] and the Euro, an appreciation of the Euro against the US dollars implies a collapse of the cotton price in WCA; on the other hand a depreciation of this currency raises the cotton price in these countries.

When the international cotton price increases, it seems logical that farmers expect more revenue for their cotton sold. This would motivate farmers to produce more. Innovations are then also more likely to occur. However, for farmers the producer price of cotton has remained almost constant (Figure 1) and does not seem to relate much to world market price (Baffes, 2007). The slight increase noticed during the last years in Benin was ascribed to the "philanthropy" of the government toward cotton farmers, and seems to be related to election campaigns (2011). The establishment of producer prices by government bodies is not very transparent.

The cotton lint quality is another important factor in the cotton landscape. Increasingly, there is a stringent demand for better quality fiber. The cotton quality determines the price that manufacturers are willing to pay. A more stringent demand for quality cotton opens windows of opportunities for the LEC cotton growers, which always provide first standard quality (Chapter 2). Thus, ginners at the regime level could promote the LEC application by paying a bit more to encourage higher quality.

[1] FCFA : ‘‘Franc de la Communauté Française d'Afrique’’.



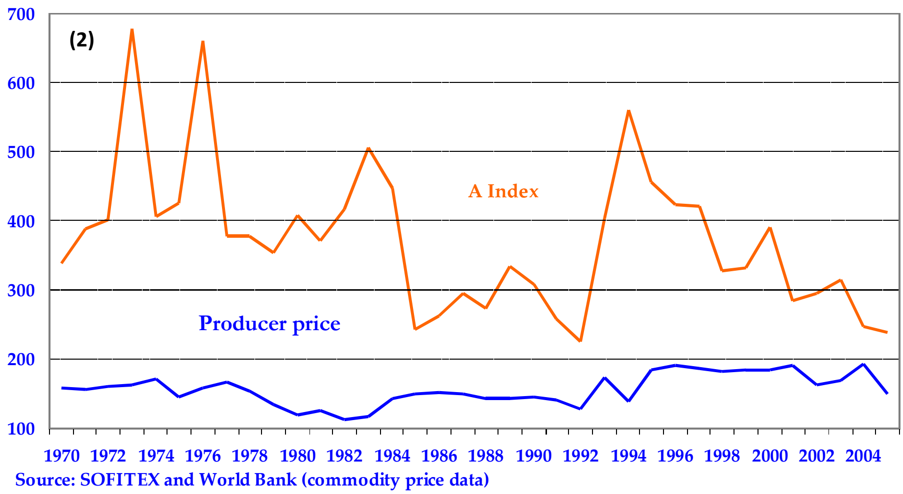


Figure 1: World Price for Benin (1) and Burkina-Faso cotton (2) (A-Index) and producer price (CFAf/kg, real 2000)
Source: Baffes 2007. A Index = well-defined world price indicator

Among the actors in the cotton value chain, only farmers bear the risks associated with cotton production; ginners and input suppliers are always safe. One risk is the decrease in cotton yield during the last 10 years. Although this may be partly due to climate change, farmers doubt the efficacy of pesticides (Chapter 3).

Does Fairtrade cotton offer opportunities for farmers? Implementing fair trade cotton addresses fundamental inequities at national and international levels. Mali and Burkina-Faso have had experiences with a fair trade cotton programme. Another experiment with fair trade was established in Benin within some cotton growing areas through the ‘Cotton made in Africa’ (CmiA) initiative. In this initiative, the LEC strategy was one of the practices that were promoted to improve incomes and livelihood of farmers. Apart from CmiA, Helvetas and OBEPAB are also actively involved in fair trade cotton production. OBEPAB was reported to have a significantly longer history in organic cotton in Benin (Peltzer and Röttger, 2013). These three programmes have the following in common: to improve the living conditions through increase in price paid to farmers and/or the productivity using good agricultural practices. They are successful for having contributed to the increase in women’s participation in cash crop cultivation, higher cotton quality, the diffusion of organic farming techniques (Bassett, 2010) and the exclusion of child labour (Peltzer and Röttger, 2013).

However, most of the fair trade cotton organisations are still operating in the same commodity chain as conventional cotton (Bassett, 2010) and are unable to pay a rewarding price to farmers. Shreck (2005) already warned that fair trade may not be the appropriate recipe to go against the conventional commodity system, if qualitative transformation is not made in the former setting. The lesson learnt from such experiences is that the implementation of fair trade initiatives necessitate the transformation of the existing setting and the changing view of actors toward farmers’ interests. Another alternative would be to establish a completely new chain, in which the effort of farmers can be highly valued and rewarded. In this regard, an effort should be made by farmers and their organisations to adhere to the fair trade initiatives, in order to improve the fair trade production that currently represents only 1% of the total seed cotton in West Africa (Bassett, 2010).

Creating conducive space for innovation in pest management

In order for a policy to be successful in the cotton sector, many conflicting interests and powers need to be considered. This can be achieved if an interaction process is followed instead of thriving for goal-oriented solutions. The setting up of a stakeholder platform is a means of arriving at collective decisions.

One of the major problems has been input delivery to farmers. The company that won the input bidding virtually has a monopoly. Farmers are bound by these rules and cannot approach other companies to acquire the inputs. Each year, there are great delays in the supply of some inputs during the season, causing the inability to prevent pest attack and resulting in yield loss. Also, farmers complain about the inefficacy of some inputs, and this refers in particular to the insecticides provided. Input suppliers also were accused of repackaging obsolete pesticides, which they can sell due to the monopoly arrangements (Chapter 3). These conditions seem to be reflected in the steady decrease of cotton production.

Extension agents monitor whether farmers use inputs from other companies. Inputs are also supplied on a credit basis. Resource-poor farmers are trapped in such arrangements and depend on the appointed input suppliers, and on the input supplied whatever the quality is.

In the organisation of the cotton sector in Benin, there are many actors that are powerful. On the other hand, farmers are very weak and are in a dependent position. Under the reform initiated in 2009, FBOs were abolished from national to the district level. New cooperatives were set up with new regulations, so that the regulatory body (Association Interprofessionnelle du Coton, AIC) could connect directly to farmers. Also, actors from the public sector such as a cotton research centre, cotton grading service, and extension service were removed from the cotton sector. This exclusion generated conflicts which ended up with the abolition of AIC. Currently, the government has re-established all the actors under this reform. Also, the 'Société Nationale de Promotion Agricole SONAPRA', formerly in charge of the cotton sector activity, took over prerogatives of AIC. The exact configuration that should lead the cotton sector is still under discussion. Farmers' initiatives need to be encouraged by involving them in the definition of constraints, the research agenda and the implementation of solutions in the field. The Innovation System approach represents an appropriate tool to reach this goal. Will the involvement of farmers in such innovation platforms be rewarded?

The CoS-SIS programme tried to mediate these issues by setting up a Consultation and Innovation Group (CIG) in which different stakeholders, including farmers, are represented. The CIG was facilitated by a postdoctoral Research Associate (RA) in charge of creating an enabling environment for innovations to emerge. Neem oil was identified as a potential solution to the problem of input delivery. Based on the encouraging results from the field with this product in our experiment (Chapter 4), women's associations in the experimental villages expressed the need to be trained in producing neem oil themselves. A training proposal was written by farmers and funded by the CoS-SIS project at the national level (Zannou, 2013). Women’s associations produced 1000 litres of neem oil packaged in small bottles appropriate for small-scale use. This initiative, which is the result of IS approach shows that such an innovation platform (the CIGs) can be a good driver for innovation development and poverty alleviation. Women’s associations would increase not only their revenue, but also contribute to the development of the cotton revival in their region. Neem oil could be used when the delay of pesticide occurs, but the scope of its application can also be extended to vegetable production. By using neem oil instead of synthetic pesticides, they can furthermore contribute to safeguarding the environment and human health. Farmer empowerment is a key for the development of the cotton sector. The re-establishment of FBOs from district to national level will be of pivotal interest to reach this goal.

The recurrent changes in policy (policy incoherence) that occurred in the cotton sector indicate that the actors were not well prepared to take over the responsibilities given by the liberalization of the cotton sector. This is the case in all east, west and central African countries in which cotton is produced. The entrance of many private companies in the cotton sector has affected pest management, research activities and the governance of the sector as a whole. Farmers remain the weak point of the sector because of the high illiteracy rate. Literacy rate is one of the common criteria for assessing human development. Cotton production could go differently if the majority of farmers were well-educated and empowered by themselves to play the role to which they are entitled. This may balance the power relationship in favor of the farmers and contribute greatly to an increase in cotton production, resulting in the improvement of their livelihood.

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Summary

In cotton production in Benin, the key problems faced by farmers since 2005 are high input costs, decline in yields, and low quality of the lint produced. Most prominent among the proposed solutions are the application of good agricultural practices (as recommended by the Cotton Research Centre) and an improved pest management strategy (Togbé et al., 2011). Implementing an integrated pest management strategy requires considerable knowledge on the part of farmers (Orr, 2003). An exploratory study was made which led to the entry point for the thesis and determined the scope of the study. Cotton integrated pest management emerged with a special focus on staggered targeted control, or “Lutte Etagée Ciblée”, (LEC in French). The LEC is a low-end IPM strategy (Benbrook, 2002), consisting of an initial basic protection (security protection, applications completely calendar-based) followed by threshold-based tactics using specific pesticides. However, the adoption of this pest management strategy has been limited. This led to the question: why is the LEC strategy not widespread, despite its large number of advantages?

A diagnostic study was conducted to understand the characteristics of the LEC strategy and the technical and institutional constraints that hinder its widespread adoption. First, we used the framework provided by Geels (2002) to determine the current socio-technical configuration around the LEC strategy and to identify the socio-organisational factors hindering its widespread adoption. Technical constraints related to field scouting led to LEC being wrongly applied. This misapplication has to do with the expertise required by the scouting and the extension model used for its large-scale adoption. Also, because the applications are need-based, the amount of pesticides required are normally less than with the conventional treatments and this lowers the profit of input suppliers. This explains the reluctance of input suppliers to deliver LEC pesticides and this has generated conflicts with farmer-based organisations (FBOs). The socio-technical reconfiguration needed to transform the existing cotton sector would involve hardware, software and orgware (Smits, 2002). The lessons learned were that many organisations, research centres and projects focused on developing technology (hardware) but neglected to build the social-organisational arrangements (orgware) that can support, sustain and actually put the technology to work.

In line with the national policy to revive the agricultural sector in Benin, the ‘Projet d’Assainissement et de Relance de la Filière Coton au Bénin’ (PARFCB) was launched in 2009. This project aimed to improve the governance of farmer-based organisations (FBOs) in the cotton sector and build trust within these organisations, as well as to guarantee prompt

payment to farmers upon delivery of their seed cotton to the ginneries. This reform during the time of our research provided an opportunity to study institutional transformation in action and to understand the complexities of the cotton sector. The goal of this natural experiment was to identify the opportunities brought about by the reconfiguration of actors, favourable for the wide-scale application of LEC (alignment). The policy arrangements approach (PAA) (Arts et al., 2006) was used. The PAA provides an analytical framework based on four interrelated factors which enables one to analyse a concrete policy domain. Such factors are (i) the actors and their coalitions (including their oppositions); (ii) the resources which refer to the knowledge, personnel, expertise, financial and other sources of power; (iii) the institutions including formal and informal laws, norms, values and routines; and finally (iv) the discourses which refer to the interpretative scheme that confers meanings and understanding of the way problems and solutions are framed (Schmidt, 2008). The reform initiated change at the node of actors and coalitions, followed by a chain reaction at the other nodes of the policy arrangements. Until 2012, the reform failed to bring about a new and stable reconfiguration, suggesting disagreement of actors with regard to decisions underpinning the reform. There was a lack of consultation concerning problem definition and agenda setting (solution formulation). The reform was goal-oriented and not an iterative process (Crabbé and Leroy, 2008).

Was there another way to address the non-delivery of LEC pesticides? Two field-experiments were conducted in 2010-2011 and 2011-2012. The first was to test the efficacy of neem oil alone and combined with the entomopathogenic fungus *Beauveria bassiana* (isolate Bb11) for controlling major pests targeted by the LEC strategy. The second was to evaluate under field conditions the synergistic effect of neem oil with either *B. bassiana* or *Bacillus thuringiensis* (Bt). In the first experiment, the neem oil used alone or together with *B. bassiana* (neem oil-Bb11) did not perform to the extent that the LEC and conventional treatment did: yields under the conventional treatments and LEC were 25 and 39% higher, respectively, than those obtained in the plots treated with neem oil and neem oil combined with Bb11. This difference may be explained by the products themselves or by environmental conditions. As with other phytochemicals, neem oil is not persistent in the environment and disappears shortly after application. This property is associated with the presence of bioactive organic chemicals which offer to phytochemicals an advantage over synthetic pesticides because they are less toxic, less prone to the development of resistance and easily biodegradable (Dhaliwal and Arora, 2001; Ravensberg, 2011). Following the recommendations from the first experiment, we investigated in the second experiment the synergistic effect of a mixed formulation of neem oil and *B. bassiana*, and neem oil and *B. thuringiensis*. Yields obtained with the mixed formulations and neem oil used alone and separately with *B. bassiana* were not different, suggesting the absence of a synergistic effect between neem oil and *B. bassiana* and between neem oil and *B. thuringiensis*. Also, the combination of bio-insecticides increased the production costs more than that of the conventional treatment, compromising the profitability of such formulations, especially when there is no synergistic effect. These results show that the combination of entomopathogens with other pesticides do not always lead to an enhanced effect, and may even lead to a reduced impact (Ravensberg, 2011). These two experiments were managed and conducted in a collaborative way with farmers, extension agents, and a researcher who facilitated the process. We were finally interested in the changes that occurred in farmers' knowledge and farming practices due to their participation in the first year experiment.

Difference-in-Differences methodology was used to document the changes. This methodology is a combination of the longitudinal and the latitudinal designs and was applied to measure the contribution of farmers' participation in the change in their knowledge and practices (Van den Berg and Jiggins, 2007). The participation in the research increased the knowledge of farmers on pest and natural enemy recognition and their knowledge on threshold use and biopesticide applications. However, the increase in knowledge did not lead to any modification in farmer practices with respect to the use of neem oil and *Beauveria*, but it led to a significant change towards threshold-based pesticide applications. The clear rejection of using *B. bassiana* can be related to its high labour demand. In fact, using *Beauveria* requires the collection of dead worms and their conservation until the new season. The non-application of neem oil by farmers in their own fields may be associated to financial constraints, which are critical for smallholder farmers. Conventional pesticides are subsidised and available to all cotton growers on a credit basis, while neem oil is not. Under such circumstances, the capabilities of farmers and the effectiveness of innovations are not enough to induce the adoption of more environmentally compatible pest control technologies. In addition, proper institutional arrangements such as a credit service may be needed to facilitate the adoption, as suggested by (Singla et al. (2012) on the sustainability of rodent control in wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) production in India.

The widespread adoption of the LEC approach has not been successful in the cotton sector in Benin, mainly due to institutional constraints. The reforms of the cotton sector were top-down, and proved inappropriate for solving institutional problems between stakeholders. A wider consultation involving all actors, such as used in an innovation approach, may have been more appropriate. Furthermore, a larger and more important role of FBOs is also required to achieve a viable cotton sector in Benin.

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Samenvatting

Sinds 2005 zijn de belangrijkste problemen van katoenboeren in Benin de hoge productiekosten, daling van de opbrengst en de lage kwaliteit van de katoen. De meest veelbelovend oplossingen zijn het toepassen van goede productiemethoden (zoals aanbevolen door het Cotton Research Centre) en een verbeterde strategie van gewasbescherming (Togbé et al., 2011). Het toepassen van een strategie van geïntegreerde bestrijding heeft wel als nadeel dat het veel kennis van de boer vereist (Orr, 2003). Een verkennende studie leidde tot het thema van het proefschrift: geïntegreerde bestrijding van plagen in de katoen met als speciale focus " Lutte Etagée Ciblée" (LEC in het Frans). LEC is een strategie van bestrijding (Benbrook, 2002), die bestaat uit een aantal voorgeprogrammeerde behandelingen met insecticiden, gevolgd door bespuitingen met specifieke pesticiden die alleen worden uitgevoerd als een zekere plaagdichtheid wordt overschreden. Echter, deze LEC strategie kwam niet echt van de grond. De vraag was waarom, want deze benadering heeft een groot aantal voordelen.

Een diagnostisch studie werd uitgevoerd om de kenmerken van de LEC-strategie te begrijpen alsmede om de technische en institutionele beperkingen te identificeren die de grootschalige invoering ervan belemmeren. We gebruikten het kader van Geels (2002) om de huidige socio-technische configuratie rond de LEC strategie te bepalen. Het bleek dat de LEC strategie verkeerd werd toegepast doordat het bepalen van de insectendichtheid niet goed werd gedaan. Dat komt omdat er nogal wat kennis nodig is om dit goed te doen en de voorlichtingsdienst was niet voldoende toegerust om dit grootschalig aan te pakken. Een ander probleem is dat bij de LEC strategie allen pesticiden worden toegedient als de plaagdichtheid boven een bepaalde drempel komt. De hoeveelheid pesticiden nodig in een LEC strategie is om die reden over het algemeen minder dan bij de conventionele strategie (bespuitingen volgens de kalender onafhankelijk van het feit of het plaaginsect voorkomt). Dat betekent dat LEC minder interessant is voor de pesticide leveranciers, die bij adoptie hiervan hun winsten zien dalen. Dit verklaart de terughoudendheid van deze leveranciers om de LEC pesticiden te leveren en dat leidde op zijn beurt tot conflicten met boerenorganisaties. Er is een socio-technische reconfiguratie nodig om de bestaande katoensector te transformeren volgens de ‘hardware’, ‘software’ en ‘orgware’ theorie zoals door Smits (2002) beschreven. De les, die we hebben geleerd is dat organisaties , onderzoekscentra en projecten zich over het algemeen richten op het ontwikkelen van technologie (hardware), maar vergeten om de noodzakelijke sociaal-organisatorische voorwaarden (orgware) hiervoor te creëren.

In lijn met het nationale beleid om de landbouwsector in Benin nieuw leven in te blazen, werd in 2009 het 'Projet d' Assainissement et de Relance de la Filière Coton au Benin' (PARFCB) gelanceerd. Dit project is erop gericht om boerenorganisaties in de katoensector te versterken, meer vertrouwen te kweken binnen deze organisaties, en tevens om te garanderen dat boeren direct worden betaald bij het leveren van de katoen aan de verwerkingsbedrijven. Deze hervorming (PARFCB), die plaatsvond tijdens ons onderzoek was een gelegenheid om deze institutionele transformatie te bestuderen en om de complexiteit van de katoensector te begrijpen. Het doel van dit 'natuurlijke experiment' was om de kansen te identificeren die ontstonden bij de nieuwe configuratie van actoren en met name of deze gunstig was voor de grootschalige toepassing van LEC. De "policy arrangements approach" (PAA) van Arts et al. (2006) werd hiervoor gebruikt . De PAA benadering biedt een analytisch kader gebaseerd op vier onderling samenhangende factoren die het mogelijk maakt om een beleidsdomein concreet te analyseren. De factoren zijn: (i) de spelers en hun coalities (met inbegrip van hun opponenten); (ii) de bronnen die betrekking hebben op kennis, personeel, deskundigheid, financiën en andere bronnen van macht; (iii) de instituties, waaronder formele en informele wetten, normen, waarden en routines; en (iv) de interpretaties, betekenissen en inzichten van hoe problemen zijn ingekaderd (Schmidt, 2008). De hervormingen initieerden veranderingen in de interacties van de spelers en hun coalities. Dit leidde tot een kettingreactie van veranderingen op andere onderdelen van het beleid. Tot 2012 was de hervorming niet in staat om een nieuwe en stabiele configuratie tot stand te brengen. Dit suggereert dat er onenigheid was onder de belanghebbenden ten aanzien van besluiten, die ten grondslag liggen aan de hervorming. Er was een gebrek aan overleg met betrekking tot de identificatie van de problemen en de manier om het aan te pakken. De hervorming was doelgericht en niet een iteratief proces (Crabbe en Leroy, 2008).

Was er een andere manier om de niet-levering van LEC bestrijdingsmiddelen aan te pakken? We deden twee veldexperimenten in 2010-2011 en 2011-2012. De eerste was om de werkzaamheid van neem olie (een botanisch pesticide) te testen, alleen en in combinatie met de entomopathogene schimmel *Beauveria bassiana* (isolaat BB11) om de belangrijkste plagen, waarop de LEC strategie zich richt, te bestrijden. Ten tweede wilden we evalueren of onder veldomstandigheden er een synergetische effect op zou treden van olie van *neem* (een botanisch pesticide) met zowel *B. bassiana* als *Bacillus thuringiensis* (Bt). In het eerste experiment, bleek dat de neemolie alleen of samen met *B. bassiana* (neem olie - Bb11) het niet zo goed deed als de LEC en de conventionele behandeling: de opbrengsten van de laatsten waren respectievelijk 25% en 39% hoger. Dit verschil kan worden verklaard door de aard van de producten zelf of door het optreden van bepaalde omgevingsfactoren. Zoals met andere fytochemicaliën, is neemolie is niet persistent in het milieu en verdwijnt kort na de toepassing. Deze eigenschap wordt in verband gebracht met de aanwezigheid van bioactieve organische stoffen die juist fytochemicaliën een voordeel geven ten opzichte van synthetische pesticiden , omdat ze minder giftig zijn, minder gevoelig voor resistentieontwikkeling en gemakkelijk biologisch afbreekbaar (Dhaliwal en Arora, 2001; Ravensberg, 2011).

Op grond van de resultaten van het eerste experiment, onderzochten we in een tweede experiment het synergetische effect van een mengformulering van zowel neemolie en *B. bassiana* als neemolie en *B. thuringiensis*. De opbrengsten van de mengformuleringen en neemolie alleen of samen met *B. bassiana* waren niet verschillend. Dit suggereert de afwezigheid van een synergistisch effect tussen neemolie en *B. bassiana* en tussen neemolie en *B. thuringiensis*. Het samenvoegen van de bio-insecticiden verhoogde ook de kosten ten opzichte van die van de conventionele behandeling. Deze resultaten tonen aan dat de combinatie van entomopathogenen met andere bestrijdingsmiddelen niet altijd leiden tot een verbeterde werking, en dat het zelfs kan leiden tot een verminderd effect (Ravensberg, 2011). Deze twee experimenten werden beheerd en uitgevoerd samen met boeren, voorlichters, en een onderzoeker die faciliteerde. We waren geïnteresseerd of er veranderingen waren opgetreden in de kennis van de boeren die aan het experiment hadden deelgenomen en of dat ze hun bedrijfsvoering hadden veranderd.

De methode genaamd “Difference-in-Differences” wordt toegepast om te evalueren of deelname van boeren een verandering heeft teweeggebracht in hun kennis en de toepassingen ervan (Van den Berg en Jiggins, 2007). Het resultaat was dat de deelname aan het onderzoek de kennis van boeren over de herkenning van plagen en hun natuurlijke vijanden heeft vergroot. Dit gold ook voor hun kennis over het gebruik van economische schadedrempels en het toepassen van biopesticiden. De toename van de kennis leidde niet tot wijzigingen in het toepassen van neemolie en Beauveria, maar leidde wel tot een significante verandering in het gebruik van economische schadedrempels. De duidelijke afwijzing van het gebruik van *B. bassiana* is waarschijnlijk terug te leiden op de hoeveelheid arbeid, die voor de toepassing is verreist, nl. rupsen besmet met *B. bassiana* moeten worden verzameld en bewaard tot het volgende seizoen. Het niet toepassen van neemolie door boeren in hun eigen velden kunnen worden herleid tot voor boeren cruciale financiële belemmeringen. Conventionele pesticiden zijn gesubsidieerd en beschikbaar voor alle katoentelers op een krediet basis; neemolie is dat niet. Onder dergelijke omstandigheden, is de effectiviteit van innovaties niet genoeg om meer milieuvriendelijke methoden van plaagbestrijding te introduceren. Daarnaast zijn betere institutionele voorwaarden nodig, zoals kredietverlening, zoals toegepast bij de knaagdierbestrijding in tarwe (*Triticum aestivum* L.) en rijst (*Oryza sativa* L.) in India (Singla et al., 2012).

Grootschalige invoering van de LEC strategie is geen succes geweest voor de katoensector in Benin en dit is vooral te wijten aan institutionele belemmeringen. De hervorming van de katoensector was top-down, en bleek ongeschikt voor het oplossen van problemen tussen belanghebbenden. Een breder overlegkader met alle belanghebbenden, zoals gebruikt in een innovatie platform benadering, zou beter zijn geweest. Verder is er een grotere en belangrijkere rol van boerenorganisaties nodig om katoen in Benin levensvatbaar te maken.

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Résumé

Depuis 2005, les producteurs de coton sont confrontés aux problèmes d'augmentation du prix des intrants, de chute des rendements, et de faible qualité du coton fibre. Les plus importantes solutions proposées sont entre autres l'application des bonnes pratiques agricoles comme recommandées par la recherche et l'amélioration des techniques de gestion des ravageurs (Togbé et al., 2011). L'adoption de la lutte intégrée exige assez de connaissance de la part des producteurs (Orr, 2003). Une étude exploratoire a été menée et a permis de sélectionner le point d'entrée et de cerner les contours de l'étude. La lutte intégrée est ressortie de cette étude comme un atout important pour les producteurs avec une attention spéciale sur la ''Lutte Etagée Ciblée'' (LEC). La LEC est une variante de la lutte intégrée (Benbrook, 2002), qui consiste en l'utilisation d'une protection de fonds réalisée de façon calendaire, suivie par une utilisation des pesticides spécifiques dont l'application se fait sur seuil. L'étendue de l'application de la LEC est encore très faible ; ce qui soulève une question importante à savoir : quelle sont les raisons pour lesquelles la LEC a toujours des difficultés d'être généralisée, malgré les avantages qui s'y rattachent ?

Une étude diagnostique a été conduite et a permis d'identifier les contraintes techniques et institutionnelles qui freinent l'adoption de la LEC à grande échelle. Le cadre conceptuel proposé par Geels (2002) au sujet de la configuration socio-technique a été utilisé à cette fin. Les contraintes techniques sont relatives à l'observation des ravageurs pour la détermination des seuils. Ceci exige de l'expertise dont les producteurs ne sont souvent pas en possession, du fait de la complexité de la technologie et des connaissances nécessaires sur les ravageurs et les ennemis naturels. Aussi, du fait que l'implication des seuils, les quantités de pesticide utilisées sont souvent inférieures à celles du traitement conventionnel. Ce qui explique la résistance des importateurs et distributeurs d'intrants à fournir les pesticides de la LEC ; et est à la base des conflits de ces derniers avec les organisations de producteurs. Il est aussi ressorti que la reconfiguration socio-technique qui pourrait transformer le secteur cotonnier aura nécessité la combinaison de technologie en tant matériel (hardware), mais aussi un certain niveau de connaissance (software) et d'organisation (orgware) qui pourrait prendre en charge par exemple les questions de gestion des pesticides spécifiques de la LEC (Smits, 2002). Les leçons tirées sont que la plupart des centres et organisations de recherche se focalisent de développer des technologies, négligeant les arrangements socio-organisationnels (orgware) qui doivent les accompagner pour garantir leur succès.

En rapport avec la politique nationale de relance des filières agricoles au Benin, le ʻProjet d'Assainissement et de Relance de la Filière Coton au Bénin' (PARFCB) a été lancé en 2009. Ce projet visait à améliorer la gouvernance au sein des organisations paysannes en suscitant le regain de la confiance mutuelle au sein des producteurs, et garantir le paiement rapide aux producteurs après la vente du coton. Lancée pendant la période de cette thèse, cette

réforme nous a offert l'opportunité d'étudier les transformations institutionnelles au sein du secteur coton. Le but d'étudier cette expérience naturelle, est de saisir les opportunités générées par cette réforme dans le domaine des acteurs et coalitions afin de réaliser l'alignement nécessaire pour que la LEC soit adoptée sur une grande échelle. Le 'policy arrangements approach (PAA) (Arts et al., 2006) a été utilisé. Le PAA offre un cadre analytique basé sur quatre dimensions qui constituent les piliers essentiels qui sont affectés par toute décision politique. Il s'agit (i) des acteurs et coalitions (et aussi des oppositions) ; (ii) des ressources qui se réfèrent aux connaissances, l'expertise, des ressources financières qui confèrent un pouvoir à celui qui les détient; (iii) les institutions formelles et informelles incluant les normes, règles, valeurs, routines et pratiques et finalement ; (iv) les discours qui se réfèrent au schéma d'interprétation qui donne une signification et une compréhension à la façon dont les problèmes et les solutions sont définis (Schmidt, 2008). Les changements essentiels ont été produits au niveau des acteurs et coalitions, et il s'en est suivi une réaction en chaîne au niveau des autres piliers du PAA. Depuis 2012, la réforme peine à aboutir à une stabilité au niveau de la filière. Ce qui implique l'existence d'importants désaccords au sujet des décisions prises par la réforme. Ceci montre aussi le manque de consultation pour la mise en place de l'agenda de la réforme et de la formulation des solutions. La réforme est restée trop directive ; elle aurait pu être un processus itératif impliquant l'ensemble des acteurs (Crabbé and Leroy, 2008).

Y a-t-il une autre manière de régler les problèmes de non approvisionnement des pesticides utilisés dans la LEC ? Pour répondre à la question, deux expériences ont été conduites en champs pendant les saisons 2010-2011 et 2011-2012. La première était de tester l'efficacité de l'huile de neem seule ou combinée avec le champignon entomopathogene *Beauveria bassiana* (isolate Bb11) pour le control des ravageurs cibles de la LEC. La seconde experience était d'évaluer en champs l'effet synergétique de l'huile de neem soit avec *B. bassiana* ou avec *Bacillus thuringiensis* (Bt). Dans la première expérience, l'huile de neem utilisée seule ou de façon combinée n'ont pas été aussi efficace que la LEC et le traitement conventionnel. Le rendement de traitement conventionnel et de la LEC sont supérieurs respectivement de 25 et 39% au rendement obtenu sur les parcelles traitées à l'huile de neem et huile de neem plus *B. bassiana* (neem oil-Bb11). Cette différence peut être due à la nature des produits utilisés ou aux conditions environnementales qui ont prévalues pendant l'expérimentation. Comme dans le cas d'autres pesticides botaniques, l'huile de neem est très peu persistante et de ce fait disparait de l'environnement peu de temps après son application. Cette propriété de l'huile de neem est associée à la présence des radicaux libres très sensibles qui donnent aux pesticides botaniques l'avantage sur les pesticides chimiques puisque non toxiques, moins enclin au développement de la résistance et rapidement biodégradables (Dhaliwal and Arora, 2001; Ravensberg, 2011). Suivant les recommandations de la première expérience, nous avons évalué dans le deuxième essai, l'effet synergétique de la combinaison de l'huile de neem et *B. bassiana*, et l'huile de neem et *B. thuringiensis*. Les rendements obtenus avec l'huile de neem seule et combinée avec *B. bassiana et B. thuringiensis* ne sont différents ; ce qui indique l'absence de synergie entre l'huile de neem et *B. bassiana* et entre l'huile de neem et *B. thuringiensis*. Aussi, l'association des bioinsecticides augmentent les coûts de production au-delà de celui du traitement conventionnel, compromettant la rentabilité de ces formulations, surtout en l'absence de l'effet additionnel. Ces résultats montrent que la combinaison des entomopathogènes avec d'autres pesticides ne conduit toujours pas à un effet additionnel (Ravensberg, 2011). Ces deux essais ont été conduits et gérés de façon participative avec les producteurs, les agents du service d'encadrement et un chercheur qui a facilité le processus.

Nous nous sommes enfin intéressés aux changements dans la connaissance et les pratiques des producteurs dus à leur participation aux premiers essais. La méthodologie de la double différence, 'double delta design' a été utilisée pour documenter lesdits changements. Cette méthodologie est la combinaison du dispositifs longitudinal et latitudinal et a été utilisé pour évaluer la contribution de la participation des producteurs dans les changements du niveau de connaissance et dans les pratiques (Van den Berg and Jiggins, 2007). La participation des producteurs a permis une augmentation de leur niveau de connaissance sur les ravageurs, les ennemies naturels et de leur niveau de connaissance sur l'utilisation des seuils et des biopesticides. Cependant, l'augmentation du niveau de connaissance n'a pas été accompagnée d'un changement dans les pratiques des producteurs en rapport avec l'utilisation de l'huile de neem et du *B. bassiana*, mais elle est suivie de façon significative d'une augmentation des traitements basés sur l'utilisation des seuils. Le rejet de l'utilisation de *B. bassiana* peut être relié à son exigence élevée en main d'œuvre. En effet, l'utilisation de *B. bassiana* exige que soit collectées et conservées les chenilles mortes jusqu'à la prochaine saison. La non application de l'huile de neem par les producteurs serait due aux contraintes financières qui auxquelles les producteurs sont souvent confrontées à chaque début de saison. Les traitements conventionnels sont subventionnés et disponibles à crédit, alors que l'huile de neem ne l'est pas. Dans de pareilles circonstances, les capacités des producteurs et les performances des innovations ne sont pas suffisantes pour induire l'adoption de technologies de protection plus compatibles avec l'environnement. De plus, des arrangements institutionnels appropriés tels que l'octroi de crédit peuvent être souhaités pour faciliter l'adoption, comme l'a suggéré Singla et al. (2012) en ce qui concerne la durabilité de la lutte contre les rongeurs dans la production du blé (*Triticum aestivum* L.) et le riz (*Oryza sativa* L.) en Inde.

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Annex : What is CoS-SIS?

1. Definition and Purpose

Convergence of Sciences-Strengthening Innovation Systems is an action research programme in Benin, Ghana and Mali. It carries out scoping and diagnostic studies, agrarian system analyses and participatory field experiments with innovation platforms at the local, district and national levels. Its purpose is to identify pathways for creating opportunity for smallholder farmers in West Africa. Focusing on the enabling conditions at levels higher than the field and farm, the Programme supports sustainable intensification of smallholder farming for food security.

2. Partners and Funding

CoS-SIS is a partnership among the *Université d'Abomey-Calavi* at Cotonou, Benin; the *University of Ghana* at Legon, Ghana, and the *Instut Polytechnique Rural de Formation et Recherche Appliquée*, at Katibougou, Mali; and *Wageningen University*, and the *Royal Tropical Institute* in the Netherlands. It is funded to a total of € 4.5 million for six years (end 2008-mid 2014) by Dutch International Cooperation.

3. History and future

CoS-SIS is the second phase of CoS. CoS1 (2001-2006) focused on participatory technology development (PTD) in Benin and Ghana. It showed that smallholders can capture only limited benefits from even the best-adapted and appropriate technologies because of their constrained opportunities. Hence CoS1 researchers started to experiment with institutional change (in addition to their agronomic work). Their early results inspired CoS-SIS in that they convincingly demonstrated that institutional change is both important and feasible. CoS-SIS is currently supporting CORAF in implementing its IAR4D strategy with its West African partners.

4. Personnel

CoS-SIS employs eight post-doc Research Associates (RAs), recruited part-time from national research organisations and universities, and nine African Ph.D. researchers. Some of the RAs are graduates of the COS1 programme. The RAs facilitate Concerted action and Innovation Groups (CIGs) (multi-stakeholder platforms composed of key actors in an agricultural domain) at the district and national levels to experiment with institutional change.

The Ph.D. researchers work at community level with groups of local people to analyse constraints and experimentally develop livelihood opportunities. The doctoral research feeds into the deliberations of the CIGs. The work is overseen by National, Regional and International Programme Coordinators, who together form the Programme Management Committee (PMC). Responsibility for each country programme rests with a Programme Management Team (PMT) composed of senior representatives of universities, ministries, R&D organisations, the private sector, NGOs and FBOs. The PMTs and coordinators are proving to be high-level networkers and important advocates of the institutional change initiated by the CIGs and PhDs.

5. Domains reflect national priorities

- *Benin*: cotton, oil palm (inter-cropping oil palm and annual crops, and the oil palm seed system) and integrated water management (agro-pastoral dams in the North, and rice production in valley bottoms in the South);
- *Ghana*: palm oil and cocoa (work in the domain of small ruminants ended when the RA was promoted to another location by his home organisation);
- *Mali*: integrated water management, integration of crop and livestock production (both in the Office de Niger), and shea butter (*karité*).

6. Key activities

- Identifying key constraints that specific categories of smallholder farmers and processors experience when trying to improve their livelihoods and incomes through productive or value adding activities.
- Identifying and researching the institutional reasons for the constraints at the local and higher system levels.
- Identifying key actors, networks and mechanisms that maintain the constraints, as well as entry points for action to by-pass, or transform the institutional context to overcome them.
- Assembling multi-stakeholder platforms of key actors who can be expected to engage in institutional change in their respective domains.
- Enabling platform actors to experiment with institutional arrangements.
- Institutionalising achievements in university curricula, the programmes of research institutes, government policies, the structure of agricultural industries, and arrangements among enterprises and services and in value chains.

- Researching the processes of change and the work of the CIGs by means of real-time monitoring and a form of modified causal process tracing, based on two declared theories of change (intervention theory focused on internal and external activities and relationships of the CIGs; and power theory, focused on networks that have power to change or maintain institutional contexts linked to each domain).
- Ensuring that the outcomes of the action research are published and disseminated through international scientific media, and shared with local, national, and regional government agencies and political decision makers.

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Curriculum Vitae

Codjo Euloge Togbé was born on March 13, 1974 in Bopa, Republic of Benin. In 2000 he obtained his 'Ingénieur Agronome' degree at the 'Faculté des Sciences Agronomiques, Université d'Abomey-Calavi' (FSA/UAC), Benin. As part of his 'Ingénieur Agronome' degree, he performed a laboratory and field study on the allelopathic effects of *Justicia anselliana* on cowpea. At the end of his 'Ingénieur Agronome' degree, from 2000 to 2001, he worked as a fellow research assistant in a cowpea project in Benin (Projet Niébé, FSA/UAC). This project used a Farmer Field School approach. He conducted field experiments with farmers on botanicals to control insects pests. From 2002 to 2003, he worked as a research fellow at the Agricultural Policy Analysis Unit of the National Institute of Agricultural Research (PAPA/INRAB). He was involved in assessing the impact of research interventions on farmers' livelihood, analysing farmers' perceptions, and monitoring social change. From 2006 to 2007, he did his Master in crop protection at the 'Université Catholique de Louvain-la-Neuve' (UCL) and the 'Faculté Universitaire des Sciences Agronomiques de Gembloux' (FUSAGx), both in Belgium. The subject of his master thesis was the modeling of the effect of temperature and relative humidity on the development of soft rot in potato. In 2009, he enrolled as a PhD student at Wageningen University, The Netherlands, and FSA/UAC, Benin. His PhD was part of the programme 'Convergence of Sciences - Strengthening Innovation Systems in Benin, Ghana and Mali' (CoS-SIS). During his PhD, he carried out field research, focussing on alternative methods for cotton pest control using threshold application of biopesticides and botanical insecticides. The title of his PhD study is '*Cotton in Benin: governance and pest management*'.

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List of publications

Peer reviewed publications

Togbé C.E., Zannou E.T., Vodouhê S.D., Haagsma R., Gbèhounou G., Kossou D.K., van Huis A. 2012. Technical and institutional constraints of a cotton pest management strategy in Benin, NJAS-Wageningen Journal of Life Sciences 60-63: 67-78.

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Togbé C.E., Zannou E.T., Gbèhounou G., Kossou D.K., van Huis A. (To be submitted). Field evaluation of synergistic effects of *Beauveria bassiana* and *Bacillus thuringiensis* with neem oil.

Togbé C.E., Haagsma R., Vodouhê S.D., Ahoudji A. (To be submitted). Effect of participatory research on farmers' knowledge and practice of IPM: the case of cotton in Benin.

Monographs

Togbé C.E. 2007. Etude des facteurs écologiques (température, humidité relative) influençant le développement de la pourriture molle sur tubercule de pommes de terre. Travaux de fin d'études en Master Protection des Cultures tropicales et Subtropicales ; FUSAGx/UCL Belgium. 61 pages.

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Conferences, Posters and Workshop proceedings

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Togbé C.E. 2010. Alleviating technical and institutional constraints of ''Lutte Étagée Ciblée'' LEC for improvement of cotton production in Benin, In: Consolidating the CoS-SIS Research Agenda, Proceedings of the CoS-SIS Cotonou, Benin Workshop October 26 - 29, 2010 pp 27-32.

PE&RC PhD Training Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (5.6 ECTS)

- IPM Cotton in Benin: institutional and technical constraints

Writing of project proposal (4.5 ECTS)

- Developing integrated pest management in cotton in Benin with a focus onthe interface of technical and institutional constraints

Post-graduate courses (7.5 ECTS)

- History, theoretical basis and methodological approach of the research programme 'strengthening agricultural innovation systems in Benin, Ghana and Mali'; CoS-SID Programme (2009)
- Experimentation and technography courses (2009)
- Generalized linear models; PE&RC (2013)

Invited review of (unpublished) journal manuscript (2 ECTS)

- Bulletin de la recherche agricole du Benin: impact de la Gestion Intégrée de la Fertilité des Sols et des Ravageurs sur le Revenu des Producteurs de Coton au Nord-Bénin (2012)
- African Journal of Agricultural Research AJAR: storage insects on yam chips and their traditional management in northern Benin (2013)

Deficiency, refresh, brush-up courses (3 ECTS)

- Methods, techniques and data analysis of field research (2009)
- Advanced statistics (2009)
- Economics of agricultural and rural development II (2009)
- Basic statistics (2013)

Competence strengthening / skills courses (3.7 ECTS)

- Competencies for integrated agricultural research; WGS (2009)
- Entrepreneurial boot camp; WGS (2009)
- PhD Competence assessment; WGS (2009)
- Career assessment; WGS (2013)
- Reviewing a scientific paper; WGS (2013)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- PE&RC Day (2009)
- Entomologendag (2009)
- PE&RC Weekend (2013)
- WASS Day (2013)

Discussion groups / local seminars / other scientific meetings (7.5 ECTS)

- PhD Students lunch discussions; Entomology (2009, 2010 and 2013)
- Field data presentation 1&2; INRAB, Cotonou, Benin (2009)
- CoS-SIS Seminar; Bamako, Mali (2010)
- CoS-SIS Seminar; Accra, Ghana (2011)
- CoS-SIS Seminar; Cotonou, Benin (2012)

International symposia, workshops and conferences (9 ECTS)

- CoS-SIS Convergence of Sciences workshops; Cotonou (2010)
- "3eme Colloque de l'UAC des Sciences, Cultures et Technologies; Abomey-Calavi (2011)
- CoS-SIS Convergence of Sciences workshops; Bamako (2011)
- XXIV International Congress of Entomology; Korea (2012)
- CoS-SIS Convergence of Sciences workshops; Cape Coast (2012)

Supervision of 3 MSc students

- Evaluating alternatives to conventional cotton pest control in Benin
- Evaluation of the 2009 reform of the cotton sector in Benin: perspectives from the field
- On field evaluation of the synergistic effect of *Beauveria bassiana, Bacillus thuringiensis* with neem oil