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Participatory evaluation of synthetic and botanical pesticide mixtures for cotton bollworm control

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Abstract. The bioefficacy of various plant extracts, namely *Azadirachta indica* A. Juss, *Khaya senegalensis* Desrousseaux (A. Jussieu) and *Hyptis suavuolens* (L.) Poit, either alone or in combination with half the recommended dose of synthetic pesticides, was studied with farmers to find a more sustainable strategy for the management of bollworms in cotton. A number of treatments were farmer innovations. The treatments were compared six times during the season to the application of the fully recommended dose of synthetic pesticides and to a control with no pesticide application. Applications of either the fully recommended dose of the synthetic pesticides or the combinations with a neem seed extract (6 kg/ha) were most effective in reducing bollworm incidence and damage. Both the treatments gave the highest yields of cottonseed, the latter being the most cost-effective. All the pesticides used, except neem alone, had a toxic effect on bollworm predators. This study has increased farmers' confidence in endogenous technology. The researcher's interaction among the local learning group members, who conducted the experiments, facilitated the introduction of a cost-effective alternative to the standard full-dose synthetic pesticide recommendation.

Key words: cotton, plant extracts, synthetic pesticides, bollworms, endogenous technology

Résumé. Dans le but de trouver une méthode de lutte durable contre les chenilles ravageuses du cotonnier, I'efficacité biologique de différents extraits de plantes (*Azadirachta indica, Kaya senegalensis* et *Hyptis suavolens*) a été évaluée, en milieu paysan, seule ou en association avec des demi-doses d'insecticides de synthèse. Certains des traitements sont le résultat d'innovations paysannes. Les traitements ont été comparés six fois au cours de la saison culturale à des applications normales d'insecticides ou la combinaison de synthèse et á des traitements témoins. Les traitements, avec des doses normales d'insecticides ou la combinaison de I'extrait de graine de neem (6 kg/ha) associé à une demi-dose d'insecticides de sysynthèse, ont été les plus efficaces pour réduire la densité des chenilles et leurs dégâts. Ces deux traitements ont donné les meilleurs rendements avec un ratio coût/bénéfice plus avantageux pour la mixture insecticide de synthése-exrait de graine de neem. Tous les insecticides utilisés à I'exception de I'extrait de neem utilisé seul, ont eu un effet toxique sur les prédateurs des ravageurs du cotonnier. Cette étude accroît la confiance des fermiers dans les locales. L'interaction entre le

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chercheur et les actuers locaux, qui ont participé à l'étude, a innovations facilité l'introduction d'une méthode alternative plus économique que le programme standard d' insecticides de synthèse recommandés.

Mots clés: coton, extraits de plantes, insecticides de synthése, chenilles du cotonnier, technologie endogène

Introduction

Bollworms are one of the major cotton pests in most of the cotton-growing areas of the world (Bruno *et al.*, 1997; Reddy and Manjunatha, 2000), and particularly in Benin (Youdeowei, 2001; Ton, 2002). Synthetic pesticides are often used to control these pests. In Benin, it is the only control strategy recommended by the national cotton research institute 'Centre de Recherche Agricole Coton et Fibre' (CRA-CF) (INRAB, 2002). However, the use of synthetic pesticides is not sustainable because of: (i) the high costs involved (PAN, 2000; Reddy and Manjunatha 2000; OBEPAB, 2002), (ii) the development of resistance (Martin *et al.*, 2000; Ochou and Martin, 2002) and (iii) the occurrence of resurgence and secondary pest outbreaks. Cotton farmers in Benin have questioned the effectiveness of synthetic pesticides against bollworms, and complain about the high costs of procurement (Sinzogan *et al.*, 2004). Therefore, alternative and more sustainable control measures are sought. The use of plant-based pesticides would be an option. Numerous plant materials have proven to be effective against bollworms either as repellents or as toxicants. Among these, neem (*Azadirachta indica* A. Juss) (Meliaceae) is the most well known (Schmutterer, 1990, 1995), and formulations based on neem plant parts have been recommended to control cotton bollworms (Gupta and Sharma, 1997; Gahukar, 2000). However, the effectiveness of neem-based pesticides for cotton bollworm control has been questioned (Bharpoda *et al.*, 2000; Sarode *et al.*, 2000; Rawale *et al.*, 2002). This corroborates the farmers' saying: 'Neem seed extract only pushes bollworms into a dream' (Sinzogan *et al.*, 2004).

In practice, farmers have been found to adapt the research recommendations to suit their socio-economic and environmental conditions (Sinzogan *et al.*, 2004). These 'reinvented' technologies have been incorporated into their production system. Schouwbroeck (1999) demonstrated such a process when dealing with fruit fly control methods in Bhutan. In that context, the technology supplied by research and extension systems became the 'raw material' for farmer's experimentation (Sumberg and Okali, 1997).

Diagnostic studies were conducted in several cotton production zones of Benin (Sinzogan *et al.*, 2004) to assess farmers' problems, needs and opportunities. Farmers were found to have adapted the recommended bollworm control technology by mixing half the dose of the recommended pesticides with locally available botanicals such as *Khaya senegalensis* Desrousseaux (A. Jussieu) (Meliaceae). They indicated that the mixture has a synergistic effect on bollworms. Neem-based products combined with synthetic pesticides have been found elsewhere to be effective against cotton bollworms (Bharpoda *et al.*, 2000; Sarode *et al.*, 2000). However, no study has been reported on bioefficacy of neem- or other plant-based products when combined with synthetic pesticides. A 'stakeholder-learning group' composed of farmers, extension agent, local research agent (LRA) (the national research institute representative in the research area) and the first author (as scientist and facilitator) was established to test several control practices. A survey intended to ground the research in the needs and opportunities of these farmers was conducted and revealed the various local practices (Sinzogan *et al.*, 2004).

Two farmers in the learning group used mixed applications of *K. senegalensis* with synthetic pesticides to control bollworms. The other farmers in the group and the LRAs were very much interested in testing this technology. They suggested adding to the trial two other plants known to have toxic or repellent properties, namely neem (*A. indica*) and *Hyptis suaveolens* (L.) Poit.

The study aimed to assess jointly with the 'stakeholder-learning group' the bioefficacy of three botanical extracts, namely *A. indica* seed extract, *H. suaveolens* leaf extract and *K. senegalensis* bark extract, either alone or in combination with half the dose of the recommended pesticides against cotton bollworms.

Materials and methods

The experiment was carried out from June to November 2004 in the village of Gounin (northern part of Benin, Borgou department) where farmers used a mixture of botanical and recommended synthetic pesticides (see Table 1 for a listing of pesticides applied). It was a 'farmer-managed and farmer-implemented' experiment (Strud and Kirkby, 2000). The topic, the experimental set-up, as well as the non-experimental variables (such as the roles of different learning group members) were

Table 1. Spray schedule (DAS, days after sowing) and dosages of recommended synthetic pesticides (RI) in l/ha, and mixtures (M) of synthetic pesticides (l/ha) plus extracts of botanicals (kg/ha)

Dates (DAS)	Active ingredients (g/l)	RI dosage (l/ha)	M dosage per ha (l/ha + kg/ha)		
			Neem	*Khaya*	*Hyptis*
51	350 Endosulfan[1]	2	1 + 6	1 + 25	1 + 37.5
65	350 Endosulfan	2	1 + 6	1 + 25	1 + 37.5
89	72 Cypermethrin, 16 acetamiprid, 300 triazophos[2]	0.5	0.25 + 6	0.25 + 25	0.25 + 37.5
93	480 Spinosad[3]	0.1	0.05 + 6	0.05 + 25	0.05 + 37.5
107	72 Cypermethrin, 16 acetamiprid, 300 triazophos	0.5	0.25 + 6	0.25 + 25	0.25 + 37.5
121	72 Cypermethrin, 16 acetamiprid, 300 triazophos	0.5	0.25 + 6	0.25 + 25	0.25 + 37.5

Commercial names:
[1] Thionex 350 EC.
[2] Conquest plus 388 EC.
[3] Laser 480 SC.

negotiated with the 'stakeholder-learning group' constituted by ten farmers, two LRAs from the cotton research institute, one extension worker and the first author of this article. The group decided on all the implementation modalities, except for the layout, which was planned by the researchers as a randomized block design. To assess the effect of the treatments, the researcher, the LRAs and the farmers developed their own criteria (see below).

Neem seeds were obtained at Setto village (central part of Benin, Zou department) from organic cotton producers. The other plants were collected locally. The collected vegetal materials were weighed and pounded, and the soft paste obtained soaked overnight and sieved the day after to obtain the plant extract solution.

Experimental design

The layout was a complete randomized block design with the following eight treatments replicated four times: (1) no pesticides (control), (2) recommended synthetic pesticides (SP), (3) neem seed extract (neem), (4) *Hyptis* leaf extract (Hyptis), (5) *Khaya* bark extract (Khaya) and three treatments involving the above-mentioned botanicals plus half the dose of recommended synthetic pesticides, respectively, (6) neem-SP, (7) Hyptis-SP and (8) Khaya-SP. The botanical pesticides were sprayed weekly and the mixtures, made up of these and the synthetic pesticides, and the synthetic products alone were applied at 2-week intervals. Neem seed extract was applied by spraying at a dosage of 6 kg/ha (Stoll, 2002 and farmers' practice), *Hyptis* leaf extract at 37.5 kg/ha (Kossou *et al.*, 2001) and *Khaya* bark extract at 25 kg/ha (farmers' practice) (see Table 1).

The cotton was sown in $20 \times 10\,m^2$ plots at a theoretical planting density of 1250 plants per plot. Plants were spaced 0.8 m between rows and 0.4 m within the row. Between plots, there were 10 buffer rows (8 m).

Data collection

By farmers and local research agents

Farmers considered replicated observations in space as unnecessary. They therefore selected for observation only two plots in each of the four blocks, so that the eight treatments were covered. Within each plot (12 rows of 20 m), they selected two rows (numbers 4 and 7) and counted the number of bolls damaged by bollworms on the plants in the row. At 114 days after sowing (DAS), on three randomly selected plants in each selected row, the number of bolls on the terminal area of a plant (20 cm) was recorded. The general appearance of the whole plot and that of individual plants were also used as assessment criteria of treatment effectiveness.

To assess the efficacy of the pesticides, the LRAs carried out destructive sampling on bolls at 106, 110 and 113 DAS in the weekly sprayed plots; and at 106 and 114 DAS in the two-weekly sprayed plots; at 1 day before the spraying day for both botanicals or mixtures (D-1); at 3 days after the spraying day (D + 3), 1 day before the subsequent botanical spraying day (D + 6) and 1 week after the day the mixture was sprayed (D + 7). Three bolls were collected on each of the five randomly selected plants each time when walking diagonally through the plot. The number of healthy as well as damaged bolls was counted. The number and species of bollworms found were recorded.

By research scientists

Research scientists counted the bollworms and their predators, and assessed bollworm damage (Youdeowei, 2001; INRAB, 2002; OBEPAB, 2002;

Ton, 2002; Sinzogan *et al.*, 2004). Sampling was conducted in all plots at 7-day intervals throughout the whole cotton-growing season (from July to September).

Samples of 10 cotton plants per plot were randomly selected during the whole growing season. Each of the 10 plants was examined weekly for bollworm larvae. Sampling concentrated on the terminal area (upper 20–30 cm) (MSU, 2003) and reproductive organs (flower buds and bolls). In addition, developing squares were checked for small larvae (Van den Berg, 1993). The number of healthy and bollworm damaged flower buds and bolls were also recorded.

After checking without touching any plant parts for predators on all 10 plants (Van den Berg, 1993), the plants, including the flowering/fruiting parts, were scrutinized. The predators encountered were recorded and collected for identification at the Insect Museum of the International Institute of Tropical Agriculture, in Cotonou, Benin, and at the Laboratory of Entomology of the Wageningen University in the Netherlands.

Cottonseeds were harvested 29 October and 15 November in an area of $4 \times 8\,m^2$ located in the middle of the plot to avoid border effects.

Data analysis

The sampling data were pooled per plot. Transformations ($2.\text{arcsine}\sqrt{X}$, x = percentage; $\log_{10}[x+1]$, x = number of insects) were used to achieve normality and homoscedasticity before analysis. ANOVA statistical analyses were made using SAS software version 8. Farmers' data were evaluated using a ranking system that combined the results for the number of damaged bolls and bolls on the terminal area of the plant (20 cm), and completed with the general appreciation of the plot.

The incremental cost-benefit ratio (ICBR) (Sarode *et al.*, 2000) for each treatment was based on pooled data over 3 years using costs of the pesticides (excluding application costs), labour (to prepare the botanical pesticides) and the price to producer of the cottonseed. The 'stakeholder-learning group' together estimated the labour price for preparing the botanical pesticide.

Results

Effect of pesticide treatment on bollworm damage

Flower buds and bolls were significantly less damaged in the plots sprayed with the recommended synthetic pesticides (SP), at full dose, and with the neem, *Khaya* and *Hyptis* mixtures combined with half the dose of SP applied six times at fortnightly intervals, than in the control plots (Table 2). The bolls were significantly less damaged in the plots sprayed with the SP-full-dose and the neem-SP mixture than in the plots treated with botanical pesticides alone.

Table 2. Effect of mixtures of botanicals and synthetic pesticides (SP) on the damage of bollworms on buds and bolls, as evaluated by researchers, local research agents (LRA) and farmers, using different criteria as described earlier

	Researcher		LRA	Farmers		
Treatments	Bud damage (% ± SE)[1]	Boll damage (% ± SE)[2]	Non-damaged bolls/60 bolls (% ± SE)[2]	Average number of damaged bolls/two rows[3]	Average number of bolls on terminal area/plant[4]	Rank
Control	5.2 ± 2.2 a (0.43)	10.2 ± 1.0 a (0.65)	40.0 ± 3.1 a (1.37)	16.25	3	8
Hyptis	2.2 ± 0.6 ab (0.29)	9.2 ± 0.4 ab (0.61)	51.0 ± 3.0 b (1.59)	11.00	4	7
Khaya	3.5 ± 1.5 ab (0.34)	8.5 ± 0.8 ab (0.59)	51.5 ± 1.5 b (1.60)	11.25	5	6
Neem	2.0 ± 0.4 ab (0.27)	9.2 ± 1.4 ab (0.61)	52.7 ± 2.9 b (1.62)	9.00	5	5
Hyptis-SP	0.7 ± 0.2 b (0.15)	5.7 ± 0.8 bc (0.48)	69.2 ± 0.8 c (1.96)	8.50	5	4
Khaya-SP	1.0 ± 0.0 b (0.20)	6.0 ± 0.9 bc (0.49)	68.7 ± 1.4 c (1.95)	7.00	6	3
Neem-SP	0.7 ± 0.2 b (0.15)	4.2 ± 0.2 c (0.41)	80.0 ± 2.1 d (2.21)	4.00	8	2
SP	1.0 ± 0.0 b (0.20)	4.0 ± 0.7 c (0.40)	81.5 ± 1.8 d (2.25)	2.75	9	1
F-value	3.54	8.03	41.81	–	–	–
Pr > *F*	0.009	0.0001	0.0001	–	–	–

Figures in parentheses are $\text{arcsine}\sqrt{(x/100)}$ values (x being percentages). Values in columns followed by the same letter are not significantly different at $P > 0.05$ by Student–Newman–Keuls test.

[1] Based on mean of four replications of 10 observations recorded on 10 plants at weekly intervals starting from 50 days after sowing (DAS).

[2] Based on mean of four replications of data collected at 113 DAS for plant extract; and 114 for the mixture and recommended pesticides.

[3] Based on mean of 10 observations recorded on two rows of 25 plants at weekly intervals starting from 50 DAS (not statistically analysed).

[4] From data collected at 114 DAS on six plants (not statistically analysed).

There was no statistically significant difference in the number of flower buds and bolls damaged by bollworms between the plots treated with botanical pesticides alone and those not treated.

When using the number of damaged bolls and bolls on the plant terminal area (20 cm) as evaluation criteria for treatment efficacy, the farmers ranked the SP treatment first, followed by neem-SP and Khaya-SP.

The analysis of the destructive sampling of bolls made by the local research agents revealed that the synthetic pesticides treatment alone, and the combination of synthetic pesticides with neem, had significantly more non-damaged bolls (about 80%) than the control (40%), while the other treatments ranged between 50 and 70%.

Effect of pesticide spraying on bollworm larvae

The damage by bollworms on the plant was recorded at 85 DAS, i.e. more than a month after the emergence of the first flower buds. Four species of bollworms were identified and grouped into three categories depending on their feeding habit: *Sylepta derogata* F. (Lepidoptera: Pyralidae) larvae, which feed on vegetative parts; and *Earias* spp., *Helicoverpa armigera* (Hübner) (both Lepidoptera: Noctuidae), *Cryptophlebia leucotreta* (Meyrick) (Lepidoptera: Tortricidae) and *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) larvae, which feed on bolls. Each larva of the first two species is capable of damaging several bolls, while each larva of *C. leucotreta* and *P. gossypiella* damages only one.

The botanical pesticides neem, *Khaya* and *Hyptis*, and their mixtures with synthetic pesticides, as well as synthetic pesticides alone, suppressed the *S. derogata* larval population under the economic threshold level (ETL) determined by Silvie *et al.* (2001) and CRA-CF (2003) (Table 3). All treatments with botanicals, and the mixtures of botanicals with synthetic pesticides, and the synthetic pesticides alone, lowered significantly the incidence of all bollworm species compared with the untreated control. The botanicals and the synthetic pesticide mixtures, and the synthetic pesticide mixtures alone, seem to suppress the different bollworm species better than botanical pesticides alone. In the untreated plot, the bollworm population rate surpassed the ETL (0.29 for *Earias* spp. and *H. armigera* and 0.22 for *C. leucotreta* and *P. gossypiella*). In all plots treated with botanical and synthetic pesticide mixtures, and with the synthetic pesticides alone, the population was below the ETL.

The results of the destructive sampling of the green bolls carried out by the local research assistants were similar to those mentioned above. All treatments lowered the larval population of the bollworm in comparison with the untreated control (Fig. 1 a–f).

Effect of pesticides on predators

A number of potential natural enemies of bollworms were collected from the field. Ants, ladybird beetles and spiders were the groups present in a large enough number to be analysed. Three coccinellid species (both adults and larvae), *Cheilomenes vicina* (Mulsant), *C. propinqua* (Mulsant) and *C. lunata* (Fabricius), were repeatedly observed within the fields. Among the ants collected, we identified species from three different genera:

Table 3. Larval populations of bollworms in cotton in comparison with the economic threshold level (ETL)

	Sylepta derogata		*Earias* spp./*Helicoverpa armigera*		*Cryptophlebia leucotreta*/*Pectinophora gossypiella*	
Treatments	Average no./plant[1]	No. over ETL[2]	Average no./plant[1]	No. over ETL[2]	Average no./plant[1]	No. over ETL[2]
Control	0.51 ± 0.04 a	0.01	0.54 ± 0.02 a	0.29	0.47 ± 0.08 a	0.22
Hyptis	0.20 ± 0.07 b	−0.30	0.30 ± 0.06 bc	0.05	0.29 ± 0.01 b	0.04
Khaya	0.26 ± 0.06 b	−0.24	0.27 ± 0.03 bc	0.02	0.29 ± 0.03 b	0.04
Neem	0.26 ± 0.03 b	−0.24	0.37 ± 0.05 b	0.12	0.32 ± 0.01 b	0.07
Hyptis-SP	0.14 ± 0.03 b	−0.36	0.11 ± 0.02 d	−0.14	0.05 ± 0.01 c	−0.20
Khaya-SP	0.12 ± 0.06 b	−0.38	0.21 ± 0.05 cd	−0.04	0.11 ± 0.04 c	−0.14
Neem-SP	0.19 ± 0.06 b	−0.31	0.15 ± 0.00 cd	−0.10	0.11 ± 0.01 c	−0.14
SP	0.09 ± 0.04 b	−0.41	0.12 ± 0.01 d	−0.13	0.11 ± 0.01 c	−0.14
F-value	5.6		12.34		17.05	
Pr > *F*	0.0006		0.0001		0.0001	

Means in columns followed by the same letter are not significantly different at $P > 0.05$ by Student–Newman–Keuls test.
[1] Mean per plant ± SE (Computed from four replications of 10 observations on 10 plants at weekly intervals starting from 50 DAS).
[2] 0.5 for *S. derogata* (20 larvae/40 plants/ha); 0.25 for *E. insulana, H. armigera* and *C. leucotreta* (10 larvae/40 plants/ha) (CRA-CF, 2003; Silvie *et al.*, 2001).

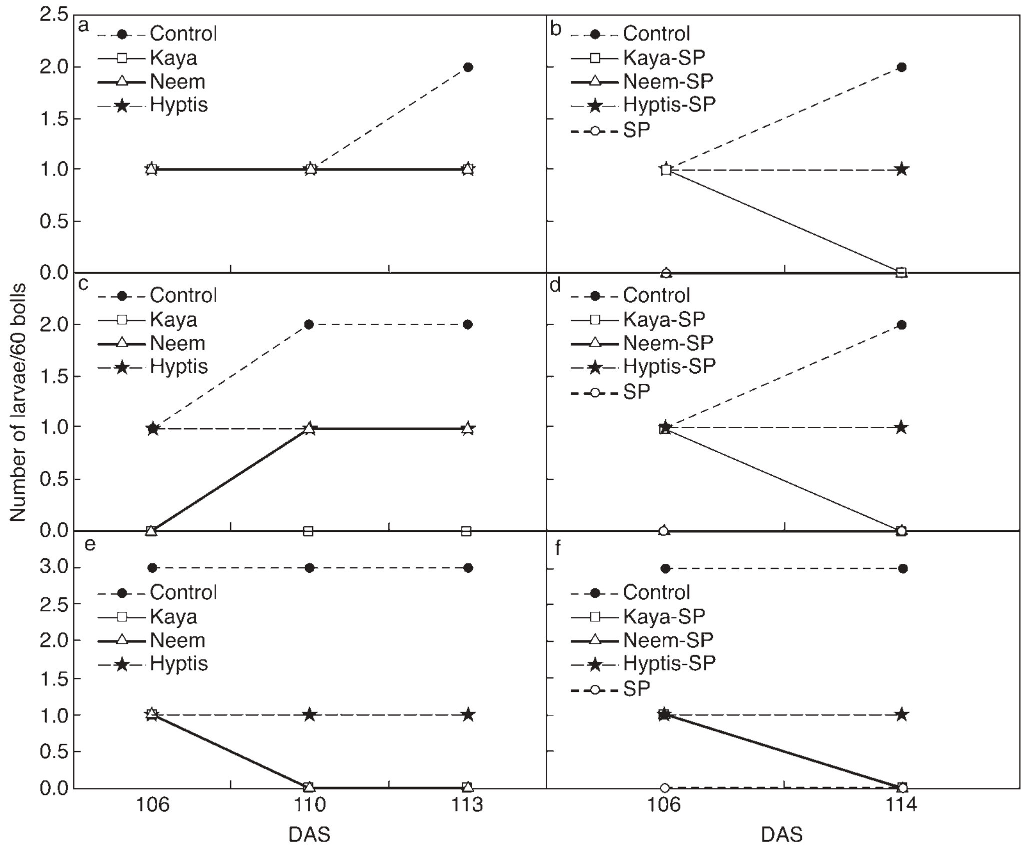

Fig. 1. Effect of plant extract alone and in combination with synthetic pesticides on larval populations of *Helicoverpa armigera* (A resp. D), *Earias* spp. (B resp. E) and *Cryptophlebia leucotreta* (C resp. F).

(i) *Camponotus* spp.: *Camponotus maculatus* (Fabricius), *C. sericeus* (Fabricius), *C. acvapimensis* Mayr, *C. flavomarginatus* (Mayr); (ii) *Lepisiota* spp.; (iii) *Dorylus bürmeisteri* (Shuckard) (all Hymenoptera: Formicidae). The spiders collected were not identified.

All treatments, except neem, lowered significantly the population of ants, coccinellids and spiders when compared with the control (Table 4).

Cost and benefits of the pesticide applications

The highest yield of 2.27 t/ha was recorded in the plots treated with neem combined with the synthetic pesticides (neem-SP), and was significantly higher than the yields obtained in the other treatments. It was followed by 1.84 t/ha in plots treated with synthetic pesticides (SP), which did not differ significantly from the yields obtained in plots treated with Khaya-SP and Hyptis-SP (1.77 and 1.54 t/ha, respectively) (Table 5). However, the yield recorded in plots treated with Hyptis-SP was similar to the one obtained in the untreated plot (1.13 t/ha).

The plots treated with the neem and synthetic pesticide mixtures had the highest incremental cost-benefit ratio (ICBR), namely 1:5.4. It was followed by the synthetic pesticides treatment combined with Khaya (1:2.7), and by the synthetic pesticides used alone (1:1.9). The costs of applying neem alone were higher than the benefits obtained, the ICBR being 1: − 1.82.

Discussion

The intensive use of synthetic pesticides in cotton has severe drawbacks (Van den Berg, 1993; Ton *et al.*, 2000). The motivating factor for farmers to grow cotton is the cash return and the opportunity to improve their livelihoods (Sinzogan *et al.*, 2004). This research sought to identify an efficacious pesticide, which would be both cost-effective and reduce negative impacts on human health and the environment. It also aimed to develop stakeholders' confidence in the effectiveness of endogenous technology (Sinzogan *et al.*, 2007). In fact, the selection of entry points that are relevant from farmers' perspectives is critical for the success of any integrated pest or crop management intervention (Morse and Buhler, 1997; Van Huis and Meerman, 1997; Meir and Williamson, 2005). Therefore, we focused on reducing the dependence

Table 4. Effect of botanical and synthetic pesticides alone and in combination on different predators in cotton fields

Treatments	Mean no. of adults/plant[1]		
	Ants	Coccinellids	Spiders
Control	4.3 ± 0.1 a (0.72)	0.9 ± 0.1 a (0.27)	0.4 ± 0.0 a (0.14)
Hyptis	3.0 ± 0.1 b(0.60)	0.3 ± 0.0 b (0.11)	0.2 ± 0.0 b (0.07)
Khaya	3.0 ± 0.1 b (0.60)	0.2 ± 0.1 b (0.07)	0.2 ± 0.0 b (0.07) b
Neem	4.1 ± 0.1 a (0.70)	0.7 ± 0.1 a (0.23)	0.3 ± 0.0 a (0.11)
Hyptis-SP	0.1 ± 0.0 d (0.04)	0.2 ± 0.1 b (0.07)	0.2 ± 0.0 b (0.07)
Khaya-SP	0.0 ± 0.0 e (0.00)	0.1 ± 0.0 b (0.04)	0.2 ± 0.0 b (0.07)
Neem-SP	1.4 ± 0.1 c (0.37)	0.2 ± 0.1 b (0.07)	0.2 ± 0.0 b (0.07)
SP	0.2 ± 0.0 d (0.07)	0.1 ± 0.0 b (0.04)	0.1 ± 0.0 c (0.04)
F-value	489.67	16.31	18.54
Pr > *F*	0.0001	0.0001	0.0001

Figures in parentheses are $\log_{10}(x+1)$ (x being number of insects). Means in columns followed by the same letter are not significantly different at $P > 0.05$ by Student–Newman–Keuls test.
[1] Mean per plant ± SE (computed from four replications of 10 observations on 10 plants at weekly intervals starting from 50 DAS).

on external inputs and lowering production costs (Williamson *et al.*, 2005), taking into account that pesticide treatments constitute 30–40% of the production costs (Ton, 2001; Sinzogan *et al.*, 2007).

All the treatments demonstrated efficacy in reducing populations of the key bollworm species *Earias* spp., *H. armigera*, *P. gossypiella* and *C. leucotreta* when compared with the untreated control. However, the botanicals (neem, *Khaya* and *Hyptis*) themselves did not lower populations below the economic threshold levels (ETLs) established for the three key bollworm species. The economic analysis of costs and benefit using these ETLs showed a negative result for the neem and the *Hyptis* treatments and a neutral one for the *Khaya* treatment. These results corroborated with the economic threshold level established by Silvie *et al*. (2001) and CRA-CF (2003).

The three botanical pesticides did not reduce the number of damaged bolls and squares, and in this respect they did not differ from the untreated control. A number of authors have found a lower efficacy for neem on bollworms when compared with synthetic pesticides (Samuthiravelu and David, 1990; Dhawan and Simwat, 1993; Bharpoda *et al.*, 2000; Patel and Vyas, 2000; Sarode *et al.*, 2000; Jeyakumar and Gupta, 2002; Rawale *et al.*, 2002). Neem is reported to be a fitness reducer and oviposition deterrent to bollworms only when consumed in large quantities (Schmutterer, 1990; Gahukar, 2000; Ma *et al.*, 2000). For *H. suaveolens*, Raja *et al.* (2005) found in the laboratory an antifeedant and an ovicidal effect on *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) and *H. armigera*. We have found no references on the effectiveness of the *K. senegalensis* on cotton pests.

Our results indicate that the recommended synthetic pesticides, followed by the neem seed extract mixed with half the dose of the recommended pesticides were most effective in reducing the incidence of bollworms, when assessed by researchers, local research assistants and farmers. This finding is in accordance with the results obtained by Samuthiravelu and David (1990), Dhawan and Simwat (1993), Sarode *et al.* (2000) and Bharpoda *et al.* (2000). However, with 2.27 t/ha the highest yield was recorded in the plots treated with the neem and reduced pesticide combination, probably because in this study only bollworms were considered. Both researchers in Benin and the local farmers regard bollworms as the most important cotton pests (Youdeowei, 2001; INRAB, 2002; OBEPAB, 2002; Ton, 2002; Sinzogan *et al.*, 2004). According to Ton (2002), below an average rainfall of 1000 mm per year (the drier zones where we did our experiments), the key pest species to monitor in cotton in Benin are *H. armigera*, *Erias* spp. and *Diparopsis* spp. (Lepidoptera: Noctuidae), assuming that other pests are controlled by their natural enemies. However, heavy pesticide applications in farmers' fields, especially the use of endosulfan at the beginning of the cotton crop-growing season, may have destroyed the natural enemy complex normally present in less disturbed agroecosystems. Secondary pests like sucking insects then become important and we assume that those insects were controlled concurrently with the bollworms when using the mixture of neem and synthetic pesticides, thus explaining the higher yield obtained in these plots. Ascher *et al.* (1996) and Gahukar (2000) found that when plant-derived products or biocides, such as neem are

Table 5. Effect of botanical pesticides, synthetic pesticides (SP) and combinations on cotton yields, in relation to pesticide costs, labour costs (to grind plant material) and the incremental cost-benefit ratio (ICBR)

Treatments	Pesticide quantity and labour per ha		Cost (euro/ha)			Yield	Yield increase over control (t/ha)		Incremental	ICBR	
	Quantity (D + kg)[1]	Labour (M/day)	Insecticide	Labour	Total A	(t/ha)	t/ha	euro/ha (B)	benefit B − A	(B − A)/A	Rank
Neem-SP	Half D + 36	3	46.1	5.1	51.2	2.27 a	1.14	330.6	279.4	1:5.4	1
SP	Full D + 0	0	70.5	0	70.5	1.84 b	0.71	205.9	135.4	1:1.9	3
Khaya-SP	Half D + 150	9	35.3	15.3	50.6	1.77 b	0.64	185.6	135.0	1:2.7	2
Hyptis-SP	Half D + 225	12	35.3	20.4	55.7	1.54 bc	0.41	118.9	63.2	1:1.1	4
Khaya	0 + 300	18	″	30.6	30.6	1.26 c	0.13	37.7	7.1	1:0.2	5
Hyptis	0 + 450	24	″	40.8	40.8	1.19 c	0.06	17.4	−23.4	1: − 0.6	6
Neem	0 + 72	6	21.6	10.2	31.8	1.04 c	−0.09	−26.1	−57.9	1: − 1.8	7
Control	″	″	″	″	″	1.13 c	″	″	″	″	″

Values in columns followed by the same letter are not different ($P > 0.05$) – M/day, man/day; D, dose. Note: (1) 1 man/day cost 1.7 euro. (2) Full dose in standard programme cost 70.5 euro. (3) 1 kg neem seed cost 0.3 euro. (4) Market sale cost of cottonseed based on pooled data of 3 years is 0.29 euro/kg. (5) 1 Euro = 655 CFA.

[1]Quantity (D + kg) = total quantity of [synthetic pesticide (D) + plant extract (kg)] used per hectare through the crop season.

combined with synthetic pesticides, cotton insects are better controlled, suggesting a synergistic effect. We presume that the antifeedant effect of neem provokes a higher mobility of the insects when searching for food. This exposes them more to the synthetic pesticide, and that this effect does not occur in treatments without the neem component. In general, botanicals often act as stress factors, increasing the vulnerability of pest insects to other sources of mortality (Murray *et al.*, 1993; Trisiyono and Whalon, 1999).

All the pesticides used, except neem, had a toxic effect on the predators (Table 4). The synthetic pesticides, alone and combined with the botanicals, are not selective in their mode of action (Matthews, 1989; Stoll, 2002). Yet, many authors found neem-derived products to be harmless against predators of cotton pests (Mansour *et al.*, 1986; Natarajan, 1990; Schmutterer, 1990; Spollen and Isman, 1996; Van de Veire *et al.*, 1996; Wazunj *et al.*, 1996).

In our experimental fields, ants were present in higher numbers than any other group of predatory insects, although three species of coccinellids (*C. propinqua*, *C. vicina* and *C. lunata*) and spiders were commonly observed. *Camponotus* spp. was the most numerous ant genus found and three species could be identified. *Camponotus* spp. has been referred to by Van den Berg and Cock (1993) as a predator of *H. armigera* in Kenya. *Dorylus* spp. was also quite abundant within our experimental fields. Dorilinae, or driver ants, are well-known predators of lepidopteran larvae in Kenya and their nests, as a conservation practice, can easily be transferred to crop fields (Stoll, 2002). By providing alternative food sources, such as floral exudates of other plants, ant foraging activity can also be enhanced (Cherry *et al.*, 2003). Artificial mixtures of water and sugar or molasses can also be sprayed over the fields. These solutions, in addition, have been shown to attract other natural enemies, such as Coccinellidae, lacewings and predatory bugs (Stoll, 2002). The neem with synthetic pesticides mixture was shown to have a toxic effect on predators and therefore should not be recommended whenever the conservation of natural enemies is required for control purposes.

Based on the economic analysis, the learning group concluded that the use of the synthetic pesticide alone was not the most economical (even when environmental, ecological and health costs are not considered). From among all the treatments evaluated, the neem seed extract mixed with half the dose of the recommended pesticides was the most cost-effective.

Another question to be asked is whether a neem mixture would be an acceptable alternative to the farmers in terms of availability and the amount of labour involved. This was not studied.

Finally, when considering botanicals and botanicals in combination with pesticides the following two points need to be considered: (i) Except for neem, all the products used were harmful to natural enemies of bollworms and (ii) the spraying was carried out on a prophylactic basis, and not as needed. Neem appears to have no negative effects on natural enemies of bollworms and other cotton pests, and therefore can be incorporated into an integrated pest management (IPM) strategy. The use of more selective pesticides like *Bacillus thuringiensis* would also conserve the natural enemies at the beginning of the season, allowing the natural enemies to build up. Later in the season, a mixture of neem and synthetic pesticides could be applied, though only when economic thresholds are reached. Such an IPM strategy is more labour intensive and requires investment by farmers in learning to recognize the insect complex, and scouting by the economic threshold concept, while at the same time taking into account the presence of natural enemies.

The way in which this study was conducted increased the participating farmers' confidence in their endogenous technology. The encounter among the learning group members allowed the introduction of cost-effective alternatives to the recommended synthetic pesticides applications practice.

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