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Effectiveness and profitability of integrated pest management for improving yield on smallholder cocoa farms in Ghana

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Abstract. Many pests, especially capsid bugs, infest cocoa and contribute to low yields in producing countries. In Ghana, synthetic pesticides are recommended for controlling the insect pests, and a combination of synthetic pesticides and cultural practices for diseases and weeds. However, the farmers in Ghana are not motivated to adopt these recommendations due to the high cost of pesticides and low producer prices. There is also concern that use of synthetic pesticides on a wide scale can affect both human health and the environment. With the objective of improving cocoa yields through environmentally friendly pest control practices, evaluation of an integrated pest management (IPM) package based on aqueous neem (*Azadirachta indica* A. Juss.) seed extracts to control the insect pests and cultural practices to manage the diseases, weeds and parasitic plants was undertaken in farmers' fields with their active participation. The IPM package improved yields significantly and was found to be more profitable than the farmers' practices. However, there are two major constraints to adoption of the package by farmers: it is labour-intensive and currently, neem is not readily available to the community. The study recommends that these constraints must be tackled to motivate the farmers to adopt or adapt the IPM package.

Key words: *Azadirachta indica*, capsids, IPM package, adoption

Introduction

Annually, 30% of cocoa produced worldwide is lost to damage by insect pests and diseases (Lass, 2004). In Ghana, the main insect pests of cocoa are capsid bugs, shield bugs and mealybugs. In addition, epiphytes, various weed species and common diseases like blackpod are also significant constraints. It has been found that most farmers in Ghana do not control pests and diseases in accordance with research recommendations (Humado, 1999; Gerken *et al.*, 2001), which leads to relatively low yields of about 360 kg/ha when compared with 800 kg/ha in neighbouring Côte d'Ivoire and 1800 kg/ha in Malaysia (MoF, 1999). This research was carried out in Achiansah and Adarkwa, two villages in the Suhum–Kraboa–Coaltar District of the Eastern Region of Ghana, where the farmers attribute their non-adoption mainly to high costs of inputs, low returns on their investment due to low producer prices and inadequate capital besides the difficulties with accessing credit (Dormon *et al.*, 2004).

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Capsid bugs (Heteroptera: Miridae) cause damage to the cocoa crop through feeding. They create lesions on the pods, stems and leaves, which may become infected by fungi, notably *Calonectria rigidiuscula*. This fungus causes wilting and may ultimately lead to the death of the tree (Wilson, 1999). The most important species of capsids in Ghana are *Distantiella theobroma* (Distant), *Sahlbergella singularis* (Haglund) and *Helopeltis* sp. (Wood and Lass, 1985; Acquaah, 1999). Capsids cause 25–30% crop losses in Ghana (Padi, 1997; Padi, undated). Low-density populations are considered to be harmful, with an estimated economic threshold of six capsids per ten trees (Padi and Owusu, 1998). Capsids are inconspicuous and so make scouting an inappropriate option and, therefore, the recommendation is to control them through prophylactic spraying of synthetic pesticides monthly from August to October and in December.

The shield bug, *Bathycoelia thalassina* (Herrich-Schäffer) (Heteroptera: Pentatomidae), is also an economically important pest of cocoa in Ghana (Owusu-Manu, 1977; Panizzi, 1997). The pest is widely distributed in most cocoa growing areas of Ghana, but it is more abundant in certain areas, including the Suhum–Kraboa–Coalter District (Owusu-Manu, 1977). They are found mostly in the upper parts of the trunk and they feed on young cocoa pods, causing premature ripening (Owusu-Manu, 1977, 1990; Wood and Lass, 1985; Wilson, 1999). It is recommended to control the pest with insecticides from early August or September, when the population starts to build up, until the end of November (Owusu-Manu, 1977).

Blackpod disease occurs in all cocoa-growing regions of Ghana and is caused by *Phythophthora* spp. (Wood and Lass, 1985; Wilson, 1999). *Phythophthora palmivora* occurs in all the six cocoa growing regions, but *P. megakarya* occurs mainly in the Ashanti, Western and parts of the Brong-Ahafo Regions (Akrofi *et al.*, 2003). The fungus infects flower cushions, shoots, leaves, seedlings, roots and pods (Wilson, 1999). Blackpod spores may be spread through rain splashes by vectors such as ants, and by wind, with the newly infected pods (covered with sporangia) acting as infection sources for up to 14 days (Wood and Lass, 1985). Husk pieces on the ground add infective material to the soil, while root infection is an important part of the annual cycle of the fungus (Wood and Lass, 1985; Akrofi *et al.*, 2003); but farmers usually leave diseased pods and husks lying on the ground (Akrofi *et al.*, 2003). In Ghana, yield losses due to *P. palmivora* are between 5 and 19% of annual output (Dakwa, 1984), while *P. megakarya* can cause as high as 100% loss (Dakwa, 1987). It is recommended to control the disease by removing diseased pods and/or applying fungicides during the rainy season (Akrofi *et al.*, 2003). However, most farmers do not adopt these recommendations or do so only partially (Henderson, *et al.*, 1994; Opoku *et al.*, 1997; Akrofi *et al.*, 2003).

The mistletoe (*Tapinanthus bangwensis*) is a parasitic plant found on some forest trees including cocoa. They affect yields by extracting water and nutrients from the cocoa plant, and eventually, may kill the branch beyond the parasitized zone (Wilson, 1999). In Ghana, farmers consider mistletoe as a major problem in their cocoa farms (Dormon *et al.*, 2004). The recommended control measure is to remove the parasitic weeds manually with cutlasses or pruners.

A number of epiphytes that grow on cocoa trees, which include *Bulbophyllum* sp., *Chasmanthera dependens* and *Cyrtorchis hamerta*, were identified in the study area (Dormon *et al.*, 2004). There is no conclusive evidence about their effect on yield (Wood and Lass, 1985). Our field observations in the research sites indicate that these epiphytes are not abundant; however, cocoa trees with *Bulbophyllum* sp. were not productive and showed signs of dying. These epiphytes can be controlled by removing them with a cutlass or pruner.

To reduce the incidence of pests and to improve cocoa yields, the Ghanaian government introduced the Cocoa Disease and Pest Control (CODAPEC) programme in 2001, which involves 'mass-spraying' of all cocoa farms using synthetic insecticides and fungicides against capsids and blackpod disease, respectively (MoF, 2002). The programme is not only expensive but also faces administrative and logistic difficulties (Asante *et al.*, 2002).

The present recommendations for managing pests and diseases of cocoa have encountered three main constraints: (1) most farmers do not adopt the research recommendations for controlling pests and diseases and this contributes to low yields, (2) the recommended pest management practices are over-reliant on synthetic pesticides, which have environmental drawbacks and (3) the government intervention through the CODAPEC programme may not be a sustainable option for environmental reasons and also not cost effective because it is calendar-based rather than need-based.

Using synthetic pesticides on such a wide scale as recommended can also affect human health and the environment by contaminating sources of drinking water (Waibel, 1994; Gerken *et al.*, 2001). Synthetic pesticides can also induce resistance in pests and destroy natural enemies, which can lead to resurgence and secondary pest outbreaks and may result in the 'insecticide treadmill' (Luck *et al.*, 1977; van Den Bosch, 1980; van Huis, 1992; Prakash and Rao, 1997; Gallagher, 1998). Examples of secondary pest outbreaks in Ghana are *B. thalassina*, which became a major pest of cocoa because of the widespread use of synthetic insecticides to control capsids; *Tragocephala* beetles and the moths *Eulophonotus myrmeleon* and *Metarbela* sp. after dieldrin was used to control mealybugs (Wood and Lass, 1985; Wilson, 1999).

The objective of the present study, therefore, was to explore the possibility of using a pest management strategy that does not rely on synthetic pesticides and is applicable for smallholder cocoa farmers. We hypothesized that an IPM package (Fig. 1) using aqueous neem seed extracts (ANSE) and need-based control of insect pests, phytosanitary measures for blackpod and other cultural practices could together help reduce the pest and disease incidence and thereby improve cocoa yields.

The neem plant (*Azadirachta indica* A. Juss.) contains a complex array of compounds that have diverse behavioural and physiological effects on insects (Schmutterer and Hellpap, 1989), deterring the development of resistance (National Research Council, 1992; Rice, 1993). Repellence, anti-feeding, oviposition deterrence, growth and reproduction inhibition and other negative effects on pests have been attributed to the many neem compounds such as azadirachtin, gedunin, nimbinen, salanin, meliantriol, expoxazadiradion, selanno–acetate and deacetylnimbinen (Jones *et al.*, 1989; Schmutterer, 1990). About 413 species of insects, belonging to the orders Isoptera, Ensifera, Thysanoptera, Heteroptera, Homoptera, Hymenoptera, Coleoptera, Lepidoptera and Diptera, are found to be sensitive to neem products in one way or another (Schmutterer, 1995, 1998). The seed and leaf extracts have a systemic effect and are active at low concentrations, with negligible mammalian toxicity (Lowery *et al.*, 1993). In laboratory and field evaluation of aqueous neem seed extracts (ANSE), Adu-Acheampong (1997) and Padi *et al.* (2003) showed that 200/g l of ANSE can be effective in controlling capsids. Considering the broad insecticidal properties of neem extracts, we believe that it is also capable of controlling *B. thalassina*, which, like capsids, belongs to the order Heteroptera.

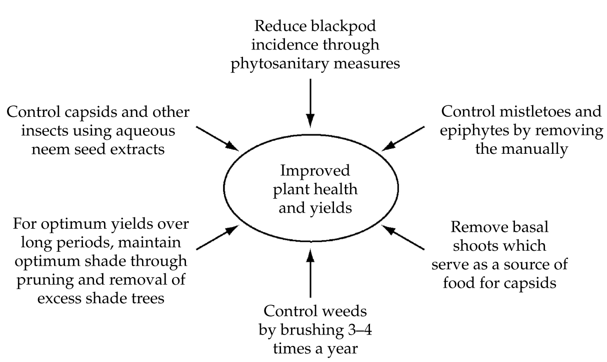

Fig. 1. Proposed IPM package to improve cocoa plant health and yields

For blackpod, Soberanis *et al.* (1999) showed that weekly removal of diseased pods reduced *P. palmivora* by 35–66% in Peru, and the economic returns compensated for the increased labour costs. Their study also showed that removal of diseased pods was 32% more profitable than control with fungicides. We therefore chose, in this study, to use phytosanitary measures (removal of diseased pods from trees and the ground, and pod husks) and shade management to control blackpod. Mistletoe, epiphytes and weeds were controlled using cultural practices.

It is recognized that farmers will only adopt this package if they find it feasible to implement and also profitable and hence the present study involved the active participation of farmers and an economic analysis of the intervention.

Materials and methods

The study area

The research was done in Achiansah and Adarkwa, two villages in the Suhum–Kraboa–Coalter District of the Eastern Region of Ghana. The district has a history of cocoa production spanning a century. It is located in the forest zone, with an average daily temperature between 24 and 29°C, a relative humidity between 87 and 91% and annual rainfall between 1270 and 1651 mm (Anon., 2000).

Demarcation of experimental plots

Twenty-four experimental plots, each 30 × 30 m (900 m^2), were initially demarcated on nine farmers' fields (four in Adarkwa and five in Achiansah). The proposed IPM package (Fig. 1) was designed and implemented on 12 of the plots and the other 12 were left as control, with the active participation of farmers in all field activities. However, when the farmers observed reductions in the number of damaged pods after about 4 months, they started implementing some of the IPM practices on the 12 control plots, which are henceforth described as 'farmer-adopted-IPM (FA-IPM) practices'. This interference meant that yield data from the original control plots would not reflect a true control situation. To remedy the situation, 12 additional plots were demarcated and designated as 'farmers practice' (FP) plots, bringing the total number of 'treatments' to three (Table 1). The three treatments were replicated five times in Adarkwa (involving four farmers) and seven times in Achiansah (with five farmers), making the total number of plots 36. The distance between plots was 30 m with IPM

Table 1. Description of the three treatments

Plots	Description of treatment
Integrated pest management plots (IPM)	Remove all blackpod-infested pods both on trees and on the ground; control weeds on average thrice a year; remove all mistletoe; control shade for optimum light penetration, remove basal chupons, and control capsids and other insect pests with aqueous neem seed extracts
Farmer-adopted-IPM (FA-IPM)	Remove all blackpod-infested pods both on trees and on the ground; control weeds twice a year on average; remove all mistletoe; control shade; remove basal chupons and rely on government mass-spraying for capsid control
Farmers' original practice (FP)	Control weeds once a year, remove 30% or less of the mistletoe, leave blackpod-infested pods on the trees and on the ground, and rely on government mass-spraying exercise for capsid control

plots alternating with FA-IPM plots on the same farm. The FP plots were demarcated at least 30 m from either IPM or FA-IPM plots on the same farm or in adjacent farms.

Preparation and application of ANSE

Neem seeds collected from Kordiabe, a village in the Greater Accra Region, were ground in a corn mill. The ground seeds were soaked in water at a concentration of 250 g/l for 18 h and a double-folded mosquito net was used to filter the suspension. The extract was applied on a calendar basis in 2003 following the existing recommendations, but in 2004 and 2005, it was applied 'need-based' by examining the extent of capsid damage to pods monthly, and when more than 25% of pods had lesions resulting from capsid feeding, the neem extract was sprayed at a rate of 8.5 litres per plot (± 100/l ha) using a motorized knapsack sprayer. In 2003, a total of four applications were made in September, October, November and December; in 2004 it was in April, October, November and December, and in 2005, in March and April. To obtain uniform coverage, spraying was done by systematically aiming the nozzle up at the trunk of each tree, into and across the canopy and then down the trunk of the adjacent tree as described by Owusu-Manu (1997).

Determination of effectiveness and profitability of the IPM package

Three main factors were considered in evaluating the impact of IPM. These were: (1) changes in pest and disease incidence after implementation, (2) impact on yields and (3) relative profitability.

Changes in pest/disease incidence

To determine changes in pest and disease incidence, damage on pods was used as a proxy indicator. On IPM plots, a system of grading harvested pods was established jointly with the farmers to evaluate IPM impact. From May 2003 to September 2005, all ripe and healthy pods were harvested monthly by the researcher and farmers, while mature and immature diseased pods were removed as a sanitation measure. Pods were categorized into five grades depending on the level of pest injury and the effect on the beans irrespective of which pest/disease caused the injury and at what stage of pod maturity. The five grades were: pods with 0% (1), 25% (2), 50% (3), 75% (4) and 100% (5) damaged seeds. Category 5 also included pods that failed to mature because of pest or disease attack. Beans from the mature diseased pods, which were not completely damaged, were included in the harvest data.

Comparison of yields from plots with IPM practices and farmers' practices

Yields from the IPM plots were compared with the two other control treatments, namely FA-IPM and FP. The data were taken from trees in a 20 × 20 m (400 m^2) inner perimeter demarcated in the plots. A tree population count was made for the inner perimeter of each plot, where 30 trees were randomly selected and tagged. Between November 2003 and September 2005, the researcher together with the farmers harvested pods from the tagged trees monthly: they were opened, the beans removed, fermented, dried and weighed. Yields were subjected to a oneway ANOVA test using SPSS version 12 to determine significance in differences between the treatments.

Relative profitability of the three treatments

The profitability of the IPM package was determined by calculating the additional income per ha and returns on the additional investment in adopting the IPM package or the FA-IPM. These were calculated as follows:

(i) Yield from 30 trees was converted to yield per ha as follows:
Average number of trees per plot of $20 \times 20\,m = 35$
Therefore, average number of trees per $ha = (10{,}000\,m^2 \div 400\,m^2) \times 35 = 875$

(ii) Rate of return on additional investment (R) = [(additional revenue) − (additional cost) /(additional cost)] × 100%

(iii) Additional income (I) = additional revenue (AR)−additional cost (AC) where additional revenue (AR) = additional yield (kg) × price/kg (price/kg = ¢9000 which is equivalent to US $0.99[1]).

Additional yield $= Y_{ti} - Y_o$
where Y_{ti} = yield of treatment (IPM or FA-IPM)
Y_o = yield of control (FP)
Yieldha = (number of trees/ha) × (average yieldtree)

To assess returns on additional investment for IPM and FA-IPM, two scenarios were considered:

(a) *The present situation where government pays for capsid control in the study area*
(i) Returns on additional investment by adopting IPM ($R_{(IPM)}$) = (AR − AC)/AC
where AC = CC + $CL_{(i)}$;
CC = Cost of capsid control and
$CL_{(i)}$ = Cost of additional labour for weeding + estimated cost of labour for removing diseased pods and other cultural practices + additional cost of harvesting, fermenting, drying and transporting additional pods and beans.
(ii) $R_{(FA-IPM)} = (AR - AC)/AC$
where AC = $CL_{(i)}$

(b) *Assuming farmers paid for cost of capsid control*
(i) $R_{(IPM)} = (AR - AC)/AC$
(ii) $R_{(FA-IPM)} = (AR - AC)/AC$
where AC = $CL_{(i)}$
and AC = ($CC_{(IPM)} - CC_{(FP)}$) + $CL_{(i)}$;
$CC_{(IPM)}$ = Cost of capsid control for the IPM treatment; this consists of the cost of neem seeds, transportation, processing and labour for spraying the neem extracts
$CC_{(FA\text{-}IPM)}$ = Cost of capsid control for the FA-IPM and FP plots; this is the cost of Confidor (used in 2003/2004) and Cocostar (used in 2004/2005) plus the cost of labour for spraying and
$CL_{(i)}$ = Cost of additional labour for weeding + estimated cost of labour for removing diseased pods and other cultural practices + additional cost of harvesting, fermenting, drying and transporting additional pods and beans.

For both FP and FA-IPM, the cost of capsid control is included in the calculation of the second scenario, where we assume that farmers bear the full cost of pest management. This is calculated using the cost of Confidor in 2003/2004 and Cocostar in 2004/2005, which were the chemical pesticides used in the two years respectively, applied twice each year.

All costs of labour are real costs estimated from interviews with farmers except the cost of harvesting, fermenting, drying and transporting pods and beans which was calculated as ¢1745/kg (± US $0.19) using the prevailing cost of ¢15,000 and ¢20,000/man-day of labour in 2003/2004 and 2004/2005, respectively, in the study area, and based on the estimated time required as calculated by Abenyega and Gockowski (2001) in a study on cocoa production in West Africa, including Ghana.

Results

Effectiveness of IPM in reducing pest/disease incidence

The IPM treatment was found to generally result in marked reduction in pest and disease incidence within 5–6 months from the start of implementation in both Achiansah and Adarkwa. Although the trend was sustained in Achiansah, it fluctuated after the initial reduction in Adarkwa (Fig. 2).

Impact on yield

Yields from plots treated with the IPM package in both villages became increasingly higher over time when compared with the controls, but were generally higher in Achiansah than in Adarkwa (Fig. 3).

In the first year, there were significant differences in yields ($P < 0.05$) between IPM and FP practices in Achiansah, but no difference between IPM and FA-IPM and also between FA-IPM and FP (summarized in Table 2 with details in Appendix 1). In the second year, however, all three treatments were significantly different from one other. Yield from the IPM package was almost three times higher than the farmers' practice and double that obtained from the adapted control (Table 2).

[1]US $1.00 = ¢9089 This was calculated using monthly interbank rates quoted by the Bank of Ghana in 2005 (http://www.bog.gov.gh/)

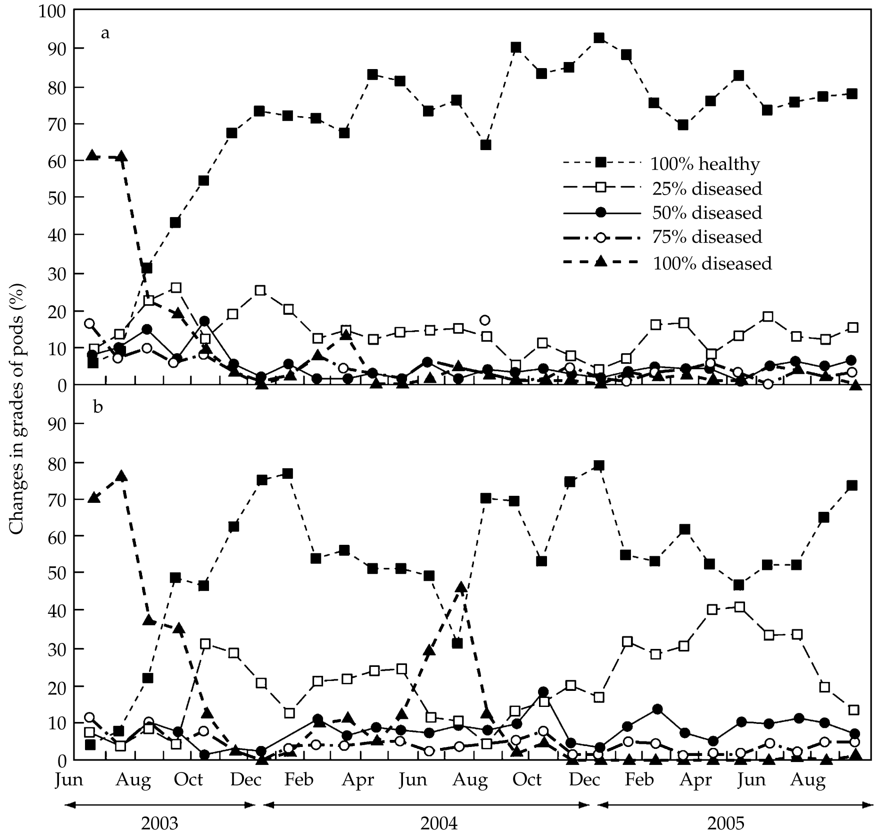

Fig. 2. Changes in diseased cocoa pods for IPM plots in (a) Achiansah and (b) Adarkwa, Ghana

In Adarkwa, the mean yield from the IPM treatment was significantly higher ($P < 0.01$) than the controls for both years and in the second crop season about twice as high as the farmers' original practice. Yields between the FA-IPM and FP practice were not different in both crop years (summarized in Table 3 with details in Appendix 2).

Relative profitability of the IPM package

Profitability of the treatments was considered in two scenarios: (1) the present situation where the government bears part of the cost of pest management through the CODAPEC programme and (2) assuming that farmers will bear the full cost.

Relative profitability under direct intervention by the government

In both villages, profitability and returns on additional investment for IPM generally followed an increasing trend with time. In Adarkwa, both additional income and returns in the first and second years were similar for FA-IPM, but both increased substantially in the second year for IPM (Table 4). In Achiansah, for FA-IPM, there was an increase in additional income of about US $75/ha in the second year, but returns were similar to the first. However, for IPM, additional income tripled in the second year and returns doubled (Table 4).

Relative profitability assuming farmers take full responsibility for pest management

Assuming that farmers took full responsibility for pest management, additional income for FA-IPM was estimated to be the same in Adarkwa for both years, but returns would increase by about 70% in the second year over that of the first. For IPM, additional income would increase by US $52/ha and 20% more on returns. In Achiansah, additional income tripled in the second year for both FA-IPM and IPM, while returns increased substantially for both FA-IPM and IPM in the second year (Table 5).

Discussion

The extent of yield increase seems to depend on the sustained effort of removing diseased pods from the fields and other cultural practices (controlling weeds, removing mistletoe and epiphytes, managing shade, etc.) together with neem application (controlling capsids) as evidenced from the results in both villages (Figs 2 and 3; Table 2). Usually, low

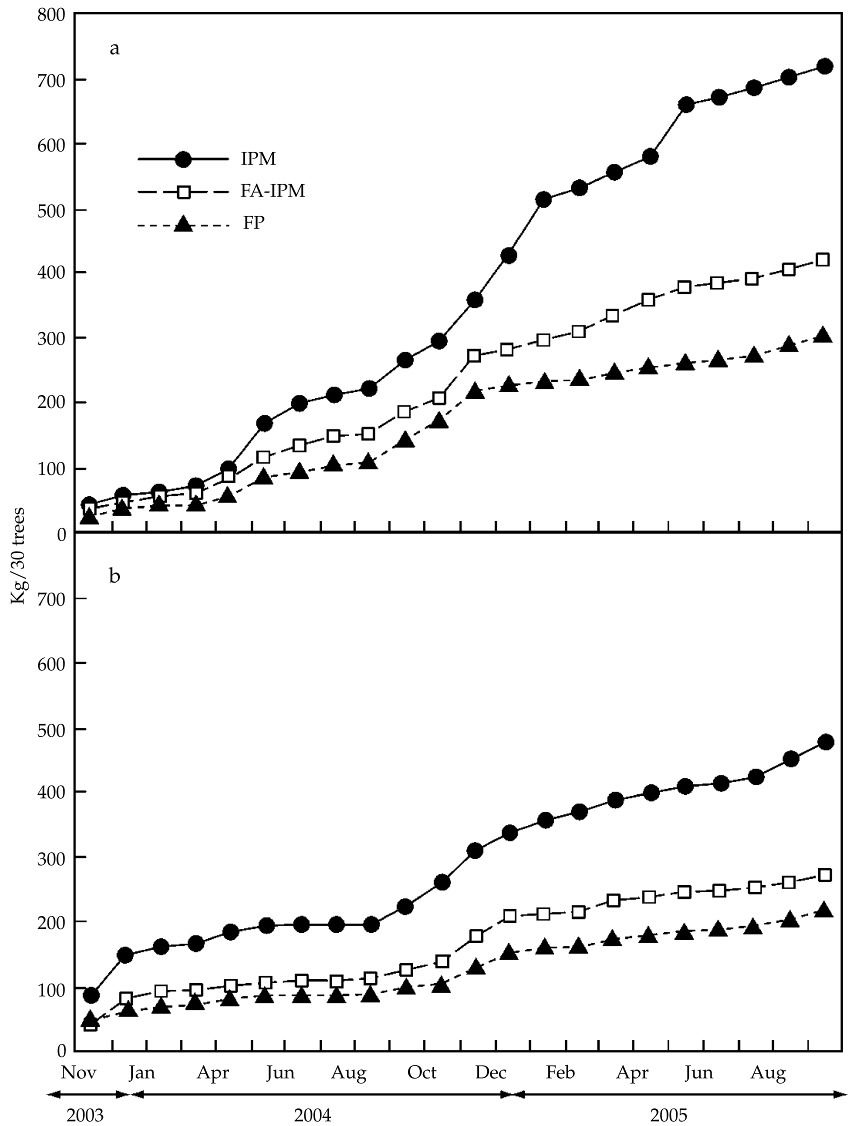

Fig. 3. Cumulative cocoa yields from IPM practices and the controls in (a) Achiansah and (b) Adarkwa, Ghana

external input technologies are labour-intensive and farmers may not adopt them if the labour requirements are too high (Tripp, 2006) and this was a challenge in this study. The generally higher yields in Achiansah were realized, because the farmers there worked as a group and used reciprocal labour arrangements to implement the labour-intensive cultural practices in the package. This, to a large extent, explains the differences in the results from the two villages.

Table 2. Mean cocoa yields from IPM and controls in Achiansah, Ghana

Management practice	Mean yield (kg/30 trees) 2003/2004 crop season	2004/2005 crop season
IPM	38.14^{a}	64.49^{A}
FA-IPM	$27.14^{a,b}$	32.67^{b}
FP	21.00^{b}	22.29^{c}

Means not followed by the same letters in columns are significantly different ($P \leq 0.05$; A $= P \leq 0.01$).

Table 3. Mean cocoa yields from IPM and controls in Adarkwa, Ghana

Management practice	Mean yield (kg/30 trees) 2003 –2004 crop season	2004–2005 crop season
IPM	44.60^{a}	50.48^{a}
FA-IPM	24.86^{b}	28.98^{b}
FP	19.43^{b}	24.50^{b}

Means not followed by the same letters in columns are significantly different ($P \leq 0.01$).

Table 4. Estimated income and returns on additional investment from considering present situation where government bears part of pest management cost

Year/Month	Practices	Yield kg/ha	Total revenue (US$)	Additional revenue (US$)	Capsid control (CC) (US$)	Original labour cost (CL) (US$)	Additional labour cost ($CL_{(i)}$) (US$)	Total additional investment (US$)	Total income (US$)	Additional income (US$)	Returns on additional investment (%)
Adarkwa											
Nov ′03 to Sept ′04	FP	567	561			110			451		
	FA-IPM	725	718	157		110	63	63	545	94	149
	IPM	1301	1288	727	119	110	284	403	775	324	80
Oct ′04 to Sept ′05	FP	715	707			139			569		
	FA-IPM	845	837	129		139	52	52	646	77	149
	IPM	1482	1467	759	61	139	296	357	971	402	113
Achiansah											
Nov ′03 to Sept ′04	FP	613	606			119			487		
	FA-IPM	792	784	177		119	71	36	594	106	150
	IPM	1112	1101	495	119	119	194	217	669	182	58
Oct ′04 to Sept ′05	FP	650	644			126			517		
	FA-IPM	953	943	300		126	119	119	698	181	152
	IPM	1881	1862	1219	61	126	475	539	1200	682	127

Table 5. Estimated income and returns on additional investment assuming farmers were to bear the full cost of pest management

Year/Month	Practices	Yield kg/ha	Total revenue (US$)	Additional revenue (US$)	Capsid control (CC) (US$)	Original labour cost (CL) (US$)	Additional labour cost ($CL_{(i)}$) (US$)	Total additional investment (US$)	Total income (US$)	Additional income (US$)	Returns on additional investment (%)
Adarkwa											
Nov ′03 to Sept ′04	FP	567	561		50	110			400		
	FA-IPM	725	718	157	50	110	63	113	494	43	38
	IPM	1301	1288	727	119	110	284	353	775	374	106
Oct ′04 to Sept ′05	FP	715	707		29	139			540		
	FA-IPM	845	837	129	29	139	56	85	613	45	53
	IPM	1482	1467	759	61	139	301	334	966	426	128
Achiansah											
Nov ′03 to Sept ′04	FP	613	606		50	119			437		
	FA-IPM	792	784	177	50	119	78	128	536	49	38
	IPM	1112	1101	495	119	119	164	233	699	262	113
Oct ′04 to Sept ′05	FP	650	644		29	126			489		
	FA-IPM	953	943	300	29	126	123	152	666	148	98
	IPM	1881	1862	1219	61	126	421	454	1254	765	169

Improvements in yield in the second year for IPM treatment can generally be attributed to the cumulative effect of reduced pest incidence and subsequent improvement in plant health with time. It is expected that the same results, or probably even better, can be expected because of cumulative benefits in the subsequent years, if the farmers continue to carry out the IPM practices in the same farms adequately. Partial adoption of the package tends to give mixed results. Where the cultural practices are implemented effectively, as in Achiansah, yields in the second year will be better than the farmers' original practice; otherwise they remain the same, as in Adarkwa, and may not be worth adopting.

Although the impact of ANSE on the results cannot be separated from the cultural practices, the potential for ANSE in controlling both capsids and blackpod could have contributed to the significantly higher yields in the IPM treatment compared with the others where Confidor and Cocostar, which control only capsids, were applied. The toxicity of ANSE on capsids has earlier been reported (Adu-Acheampong, 1997; Padi *et al.*, 2003), while Duindam (2006) demonstrated its repellence and insect growth disruption properties. Neem extracts are also known to have fungicidal properties (Singh *et al.*, 1980; Locke, 1990, 1995; Achimu and Schlösser, 1992) and Duindam (2006) showed that 150 g/l of ANSE significantly inhibited the growth of *P. palmivora* by up to 40% in an *in vitro* test. Diseased pods covered with sporangia and still hanging on the trees were the dominant source of inoculum (Akrofi *et al.*, 2003), but the farmers' practice over the years has been to leave such diseased pods to hang on the trees. Although these were removed on both IPM and FA-IPM plots, spraying 250 g/l of ANSE into the canopy of IPM plots to target capsids could have contributed to inhibiting the spread of the fungus from diseased pods that could not be removed. It could also have provided protection to fresh pods against infection. Furthermore, the impact of capsid feeding is high when fungi infect the pods and shoots through the lesions created by the capsids (Wood and Lass, 1985; Wilson, 1999), but this effect could have been minimized by the fungicidal properties of ANSE.

Assuming that returns provide a good basis for decision-making, and considering that informal interest rates can be 100% per annum, farmers in the two villages can be advised to adopt the IPM package because returns in all cases were above 100% in the second year. Returns increased with time because there were only marginal increases in the cost of pest management in the second year, while yields increased substantially during the same period. A lot of labour was initially required for controlling the high levels of pests and diseases; however, with time, the labour requirement decreased as the incidence levels of these pests and disease reduced. The increase in labour cost for IPM was largely due to the cost of harvesting, breaking, drying and transporting beans to the buying centres rather than labour for controlling pests and diseases. In the two-year period for which results are presented in this paper, cost of labour per man-day increased by about 30%; however, the producer price remained unchanged over the same period. If producer prices continue to stagnate while labour and the cost of other inputs continue to rise, it would become less profitable to adopt the IPM package. However, if the producer price is raised enough to enable farmers to realize returns that are considerably higher than 100%, farmers would be motivated to adopt the IPM package, provided the required inputs are available to them.

Actual data on the environmental impact were not taken; however, the environmental costs of the controls, which relied on synthetic pesticides, would be higher than that for the IPM. Calculations for cost of pesticide used in crop production do not include the indirect costs to society due to their effects on the environment. When the cost to society is considered, the cost curve shifts upwards; therefore, the cost of pesticides normally used in calculating production costs is usually lower than the actual cost (Waibel, 1994).

Synthetic pesticides are known to affect the beneficials and natural enemies of capsids (Wood and Lass, 1985) such as *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae). Although neem extracts may not be completely free of adverse non-target effects, several studies have shown that, overall, their effect on beneficial insects is negligible when compared with most synthetic pesticides (Schmutterer, 1990, 2002). Whereas synthetic pesticides affect the beneficial insects in the cocoa ecosystem (Leston, 1970; Wood and Lass, 1985), Duindam (2006), in a study in the same research area, showed that when sprayed with 200 g/l of ANSE, *O. longinoda* did not abandon their nests until after 28 days; an indication that the effect of neem extracts on them was minimal.

We conclude that a combination of cultural practices and ANSE can improve cocoa yields significantly and is a profitable option for farmers to adopt. The two most important pests of cocoa are capsids and blackpod disease; therefore, a single formulation like ANSE that could control both offers great potential for use in cocoa production as an alternative for using synthetic pesticides. When combined with adequate control of other pests, and phytosanitary measures to control blackpod, the yields can improve significantly in a profitable manner.

Although the IPM package can give higher returns, it requires higher labour and capital investment, which the farmers are mostly unable to secure. Moreover, neem is also not readily available to the community. Until these constraints are adequately addressed, the present IPM package, like many other research recommendations for pest management, will remain without wide-scale adoption by farmers. Consequently, further studies have been undertaken to explore ways of addressing these constraints (Dormon *et al.*, in press). Further, in the present study, it was not possible to separate the impact of ANSE and other factors in the IPM package on yield. Further studies are needed in this regard, which could make the potential of neem for cocoa production clearer.

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APPENDIX 1: ANOVA for Achiansah

Post hoc tests

Multiple comparisons

Dependent variable: Yield04
LSD

(I) Practice	(J) Practice	Mean difference (I−J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
IPM	FA-IPM	11.00000	5.35323	0.055	− 0.2467	22.2467
	FP	17.14286*	5.35323	0.055	5.8961	28.3896
FA-IPM	IPM	− 11.00000	5.35323	0.055	− 22.2467	0.2467
	FP	6.14286	5.35323	0.266	− 5.1039	17.3896
FP	IPM	− 17.14286*	5.35323	0.055	− 28.3896	− 5.8961
	FA-IPM	− 6.14286	5.35323	0.266	− 17.3896	5.1039

Oneway

ANOVA

Yield05

	Sum of squares	df	Mean square	F	Sig.
Between groups	6768.654	2	3384.327	48.026	0.000
Within groups	1268.431	18	70.468		
Total	8037.086	20			

Post hoc tests

Multiple comparisons

Dependent variable: Yield05
LSD

(I) Practice	(J) Practice	Mean difference (I−J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
IPM	FA-IPM	31.81429*	4.48707	0.000	22.3873	41.2413
	FP	42.20000*	4.48707	0.000	32.7730	51.6270
FA-IPM	IPM	− 31.81429*	4.48707	0.000	− 41.2413	− 22.3873
	FP	10.38571*	4.48707	0.003	0.9587	19.8127
FP	IPM	− 42.20000*	4.48707	0.000	− 51.6270	− 32.7730
	FA-IPM	− 10.38571*	4.48707	0.003	− 19.8127	− 0.9587

*The mean difference is significant at the 0.05 level.

Post hoc tests

Multiple comparisons

Dependent variable: Yield05
LSD

(I) Practice	(J) Practice	Mean difference (I−J)	Std. error	Sig.	99% Confidence interval	
					Lower bound	Upper bound
IPM	FA-IPM	31.81429*	4.48707	0.000	18.8985	44.7301
	FP	42.20000*	4.48707	0.000	29.2842	55.1158
FA-IPM	IPM	− 31.81429*	4.48707	0.000	− 44.7301	− 18.8985
	FP	10.38571	4.48707	0.033	− 2.5301	23.3015
FP	IPM	− 42.20000*	4.48707	0.000	− 55.1158	− 29.2842
	FA-IPM	− 10.38571	4.48707	0.033	− 23.3015	2.5301

*The mean difference is significant at the 0.01 level.

Appendix 2: ANOVA for Adarkwa

Oneway

ANOVA

Yield04

	Sum of squares	df	Mean square	F	Sig.
Between groups	1754.061	2	877.031	15.033	0.001
Within groups	700.061	12	58.338		
Total	2454.122	14			

Post hoc test

Multiple comparisons

Dependent variable: Yield04
LSD

					99% Confidence interval	
(I) Practice	(J) Practice	Mean difference (I–J)	Std. error	Sig.	Lower bound	Upper bound
IPM	FA-IPM	19.74000*	4.83067	0.002	4.9845	34.4955
	FP	25.16600*	4.83067	0.000	10.4105	39.9215
FA-IPM	IPM	− 19.74000*	4.83067	0.002	− 34.4955	− 4.9845
	FP	5.42600	4.83067	0.283	− 9.3295	20.1815
FP	IPM	− 25.16600*	4.83067	0.000	− 39.9215	− 10.4105
	FA-IPM	− 5.42600	4.83067	0.283	− 20.1815	9.3295

*The mean difference is significant at the 0.01 level.

Oneway

ANOVA

Yield05

	Sum of squares	df	Mean square	F	Sig.
Between groups	1928.801	2	964.401	22.778	0.000
Within groups	508.076	12			
Total	2436.877	14			

Post hoc tests

Multiple comparisons

Dependent variable: Yield05
LSD

					99% Confidence interval	
(I) Practice	(J) Practice	Mean difference (I–J)	Std. error	Sig.	Lower bound	Upper bound
IPM	FA-IPM	21.50000*	4.11532	0.000	8.9296	34.0704
	FP	25.98000*	4.11532	0.000	13.4096	38.5504
FA-IPM	IPM	− 21.50000*	4.11532	0.000	− 34.0704	− 8.9296
	FP	4.48000	4.11532	0.298	− 8.0904	17.0504
FP	IPM	− 25.98000*	4.11532	0.000	− 38.5504	− 13.4096
	FA-IPM	− 4.48000	4.11532	0.298	− 17.0504	8.0904

*The mean difference is significant at the 0.01 level.