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Relationships between farmers' cropping practices, pest profiles and cotton yield losses in Thailand

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Abstract: Insect pests represent one of the main factors influencing the steady reduction in Thai cotton production over the last three decades. Misuse of insecticides has brought about profound changes in the composition of the entomofauna. Nowadays, farmers' ability to control pests through ecologically and economically sustainable practices is a prerequisite to enhance cotton production in Thailand. A systems approach, consisting of on-farm experiments and surveys, was aimed at investigating the opportunities and obstacles for the integration of IPM techniques into current farmers' pest management practices. Correspondence analysis provides a holistic description of the relationships among components of cotton pathosystem: pest population dynamics, cropping practices and cotton yield losses. The results show that high yields are associated with early sowing and intensive use of insecticides, and thus tend to justify farmers' practices. A comparison of data sets from experiments and surveys helps to analyse the process that led farmers onto an insecticide treadmill. Insecticide use against early season sucking insects enhances the need for further control against bollworms. IPM innovation targeted to this specific multiple pest complex are proposed.

Keywords : Cotton, IPM, *Helicoverpa armigera*, *Amrasca biguttula*, Thailand.

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INTRODUCTION

Thailand is one historical case in the long list of cotton growing areas in the world where disastrous agro-ecological situations occurred (Deema *et al.*, 1974; Collins, 1986; Cox and Forrester, 1992). The process which has led to the collapse of cotton production has been extensively documented (Bottrell and Adkisson, 1977; Matthews, 1989) and can be referred as the 'pesticide syndrome' (Doutt and Smith, 1971). When integrated over large time and space scales, productivity-driven practices resorting to systematic use of insecticides as an insurance to minimize short term yield loss risk, have led farmers to a chemical treadmill (Kenmore *et al.*, 1987). Today, cotton production has become neither ecologically nor economically sustainable unless farmers can adopt alternative insect control strategies. There have been many examples of the many advantages of controlling cotton pests using IPM programs based on ecological principles in the past decade (Teng and Heong, 1988; Kenmore, 1991). However, despite efforts made in the recent years to make IPM innovations

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more attractive to cotton growers, it has not been successfully implemented in Thailand (Castella *et al.*, 1995). Napompeth (1993) explains the low level of farmers' adoption as a result of the very limited research done and lack of attempts to include socio-economic considerations in designing and implementing IPM programs. Despite the current ecological crisis situation, the transition from IPM academic speeches to effective implementation by farmers may still be achieved by bringing together the knowledge of both researchers' and practitioners'.

Agronomists have to produce technical references. These should be specific to the local environment, and identify solutions that are *technically desirable.* On the other hand, a good understanding of farmers' rationale for their current crop management practices is necessary to verify whether proposed solutions are *practically feasible* (Norton, 1982).

This study is part of a larger interdisciplinary research project conducted by DORAS (Development-Oriented Research on Agrarian Systems) project at Kasetsart University (Trébuil and Dufumier, 1993). A preliminary diagnostic phase on socio-economic and biophysical transformations of the rainfed agricultural area at the periphery of the Central Plain of Thailand was conducted. It showed the key role played by the cotton crop in the region's agricultural development (Trébuil *et al.*, 1994). On-farm and on-station studies were targeted at identifying and alleviating the main limiting factors of cotton production at regional, farm, and field levels (Trébuil, 1996). Crop protection studies at this latter level are reported in this paper.

A network of experiments was set up to characterise the status of insect pest constraints over a large range of production situations (de Wit, 1982). Detailed surveys were conducted at the same time, in the same areas, so as to address the agro-ecological and the socio-economic factors determining farmers' pest management practices. Farmers' strategies were then analysed in the light of experimental results (i.e. impact of crop management on insect pest populations, damage and yield) to assess their relevance and propose alternative IPM techniques.

MATERIALS & METHODS

Field experiments

A network of experiments, where increasing levels of insecticide protection were considered, was established during three successive years (1991 to 1993) in three contrasted agro-ecological areas located at the periphery of the Central Plain of Thailand. Three provinces, Kanjanaburi, Lopburi, and Nakhon Rachasima were chosen as they represent different cotton production histories. This was assumed to influence the local composition of the entomofauna (Castella, 1995). The variety Sri Samrong, commonly used by Thai farmers, was grown on four individual plots of 400 m^2 (20 m x 20 m), following crop husbandry recommendations from the Thai Department of Agriculture (DOA, 1984). A non-replicated design was used with four treatments corresponding to increasing insecticide protection (IP1 to IP4). No pesticide was used on IP1 treatment. IP2 treatment consisted only in a seed treatment with a systemic insecticide to prevent early attacks of sucking insects. IP3 was an insecticide spray program based on a set of intervention thresholds (DOA, 1992) for three pests: 20% of infested plants for aphids, 1 nymph per leaf for jassids, and 2 bollworms on 10 plants. IP4 plots received a weekly insecticide spray. The choice of active ingredients for treatments IP3 and IP4 was based on real-time monitoring, and composition of the pest complex. Since production situations varied between trials, the same treatment definition could locally translate into different sowing dates (according to the rainfall pattern), or different insecticide application among IP3 treatments (depending on the local pest population dynamics). This experimental design resulted in 19 trials spread over three years and three provinces. It yielded 76 elementary plots, each representing a unique combination of attributes.

Surveys

A total of 62 cotton fields were monitored and farmers' cultivation practices surveyed in the two regions of Lopburi and Kanjanaburi from 1991 to 1993. Cropping systems were selected to cover a large range of agro-ecological and socio-economic conditions (Trébuil *et al.*, 1994). Data on field operations were collected fortnightly during farmers' interviews. Amount of input, expenses, time, and labor involved in each field operation were recorded. The following variables were selected to characterize the patterns of cropping practices: sowing date, total quantity of insecticide, number of weedings, amount of nitrogen as soil application and foliar fertilizer (Table 1). The latter indicator was represented by the input cost per hectare, as the composition of most of the local brand of foliar fertiliser was unknown. This set of variable represented the minimum information necessary to compare cotton-growing strategies (Castella *et al.*, 1995).

Cotton plot monitoring

The same variables were considered, and data were collected weekly on experimental and survey plots. Insect pests were monitored over 4 subplots of 5 m^2 each selected at random in the central part of experimental plots as well as in farmers' fields. The insect pest complex was monitored as well as beneficials (mainly Coccinelidae and spiders). However, only two pests were included in the analysis, namely the jassid *Amrasca biguttula* and the bollworm *Helicoverpa armigera*, because of their major impact on cotton yield losses (Deema *et al.*, 1974; Ahmad *et al.*, 1985). By feeding on plant sap, jassids reduce the number of potential sites for yield accumulation, whereas bollworms destroy those sites by eating fruiting organs (Matthews, 1989).

Seed-cotton yield in kg/ha and the number of bolls harvested per m^2 were recorded on the same observation units. Pest damage was calculated as :

$$D = (Ya - Y)/Ya$$

with Y (= actual yield), and Ya (= attainable yield) calculated empirically (Castella *et al.*, 1999).

Weed infestations were recorded fortnightly on farmers' fields on the same four observation units as for insect scouting. Weed infestation was scored using a 6 - class scale based on the percentage of ground area covered by weeds. The variable obtained is the average rating over the four observation spots.

Data analysis

Categorization, followed by correspondence analysis (Benzécri, 1973) was applied to the data set. Quantitative variables were converted into qualitative, ranked variables (Savary *et al.*, 1994) as shown in Figure 1.

Insect pest data transformation Pest data, represented by insect density plotted against time, were transformed as follows: weekly insect scouting were integrated over 30 days intervals (Forrester and Fitt, 1991) by calculating the area under infestation curve (Johnson *et al.*, 1986; Campbell and Madden, 1990) at three key periods of cotton plant development process: 30-60 days after sowing (DAS) (vegetative stage), 60-90 DAS (fruiting stage) and 90-120 DAS (maturing stage) (Castella *et al.*, 1999). The Neperian logarithm of the area under infestation curve was then calculated to reduce variance heterogeneity (Draper and Smith, 1981; Savary and Zadoks, 1992). Insect pest dynamics were thus represented by six variables : J1, J2, J3 for jassids and B1, B2, B3 for bollworms (Table 1).

Quantitative variables were categorized into a limited number of classes (Savary *et al.*, 1995), whose numerical boundaries were determined by the frequency distributions of each variable. Numerical boundaries of classes were defined such that even class-fillings were obtained (Table 1). The data sets involved 76 (experimental) and 62 (surveyed) plots. Three classes were thus defined, each containing 20 to 25 individual plots. In the case of highly asymmetric distributions, as for variables J3 and B3 (in experiments) or J1 (in surveys), only two classes were defined.

Cluster analysis Pest profiles integrate interactions between pests (combination of jassids and bollworms), their dynamics, and their effects on yield loss over time (crop development stages 1, 2 and 3). A discrete number of pests profiles were identified using hierarchical cluster analysis. Plots presenting similar combinations of the six variables J1, J2, J3, B1, B2 and B3 were grouped into clusters. Four clusters were obtained from the experimental data set (PE1-4) as well as Lopburi survey (PL1-4) and three clusters were identified for Kanjanaburi data set (PK1-3). Pest profiles, represented by PE, PL and PK variables, were different from the levels of insecticide protection IP1-4. Chi-square tests were performed to measure the contribution of variables to clustering (Tables 2, 3 and 4). The same procedure was applied to the data set on farmers' cropping practices and resulted in three patterns of practices for each cotton production area : Lopburi and Kanjanaburi (Tables 5 and 6).

Correspondence analysis The linkages between patterns of cropping practices, pest profiles and yields were studied through correspondence analysis (Benzécri, 1973). Data handling consisted first in building a Burt table (Dervin, 1988), where categorized variables were distributed in rows and columns. Cells at the intersection of two classes corresponded to the number of plots sharing common attributes. Using this matrix, relationships between pairs of variables were studied. A chi-square test was performed, where the null hypothesis was the independence of the distribution frequency of each pair of variable (Table 7).

Multiple correspondence analysis was applied to the Burt table to produce a graphical

Table 1. Date compaction over ranges : categorization of quantitative variables into qualitative data.

Variable acronym	Attributes - Unit	Experiments			Surveys		
		Low	Medium	High	Low	Medium	High
Pests							
J1	Neperian logarithm of the area under jassid infestation curve at	< 2.7	2.7 - 4.2	> 4.2	< 2.6	2.6 - 4.2	> 4.2
J2	three cotton development phases (J1 = 30-60, J2 = 60-90 and	< 3.7	3.7 - 5.2	>5.2	< 1.4	1.4 - 3.4	> 3.4
J3	J3 = 90-120 days after sowing)	< 5	> 5		< 2.2	2.2 - 3.8	> 3.8
B1	Neperian logarithm of the area under bollworm infestation	< 0.3	0.3 - 2.3	> 2.3	< 0.08	> 0.08	
B2	curve at three cotton development phases (B1 = 30-60, B2 =	< 1.9	1.9 - 2.5	> 2.5	< 0.7	0.7 - 1.7	> 1.7
B3	60-90 and B3 = 90-120 days after sowing)	< 1.9	> 1.9		< 1.3	1.3 - 2.3	> 2.3
W	Mark from 0 to 5 depending on ground area covered by weeds				< 0.3	0.3 - 1.1	> 1.1
Cropping pratices							
SD	Sowing date experiments (julian days)	< 190	190-200	> 200			
SD	Sowing date : Lopburi (julian days)				< 185	> 185	
SD	Sowing date : Kanjanaburi (julian days)				< 195	> 195	
IP	Quantity of insecticide (l/ha)				< 7.8	7.8 - 13.8	> 13.8
WN	Number of weeding				< 0.3	0.3 - 1.1	> 1.1
NS	Quantity nitrogen supplied (kg/ha)				< 16	16 -30	> 30
FF	Foliar fertilizer cost (Baht/ha)				< 160	160 -440	> 440
Yield - damage							
Y	Yield (t/ha)	< 0.6	0.6 - 1.3	> 1.3	< 0.9	0.9 - 1.3	> 1.3
NB	Number of harvested bolls / m^2	< 20	20 - 35	> 35	< 22	22 -42	> 42
D	Pest damage (% yield loss)	< 0.45	0.45 - 0.75	> 0.75	< 0.36	0.36 - 0.60	> 0.60

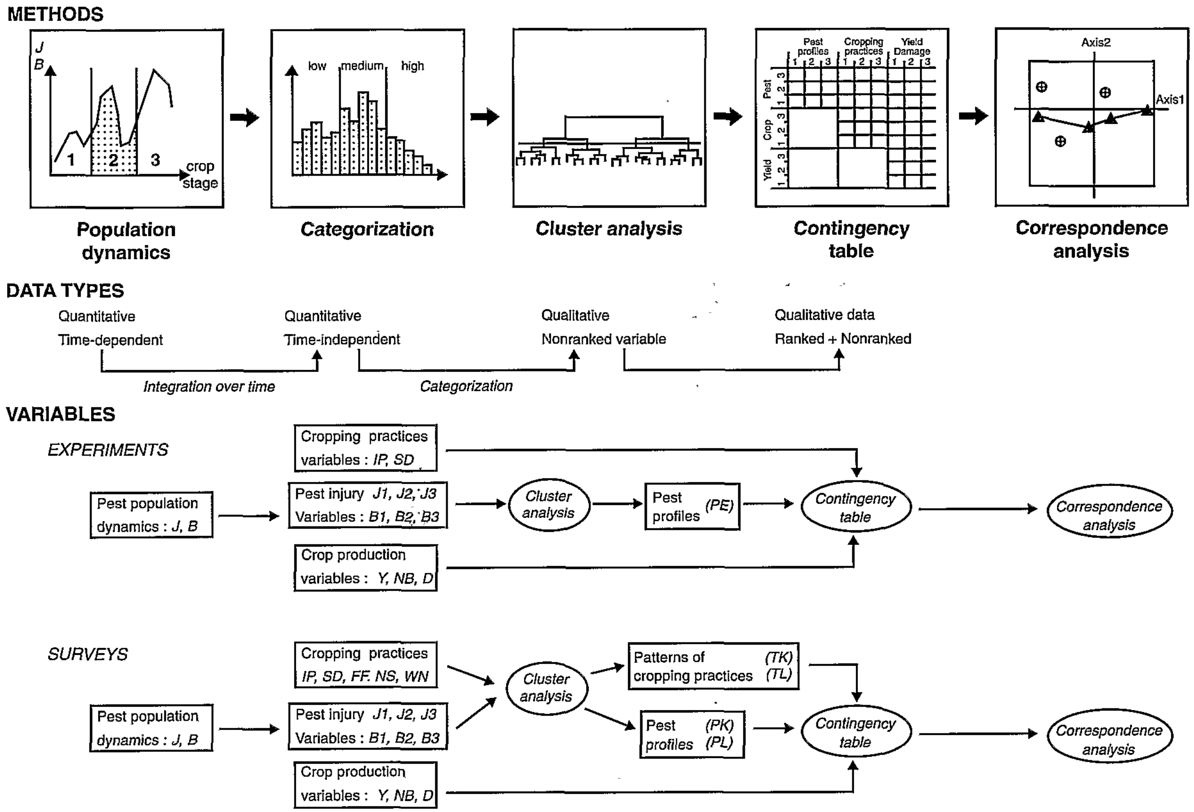

Figure 1 : Successive steps of data analysis (adapted from Savary *et al.*, 1995).
NB: J1, J2, J3 represent increasing levels of jassid injuries; B1, B2, B3: bollworm injuries. Five sets of variables are combined in the successive steps of the correspondence analysis: cropping practices (IP : insecticide protection, SD : sowing date, FF : foliar fertilisation, NS : nitrogen supply, WN : number of weeding), pest profiles (PE), patterns of cropping practices (TK, TL), insect damages (D) and yield (Y : yield and NB : number of bolls)

Table 2. Cluster analysis of pest profiles from the experimental data set (PEs).

Variables[a]	PE1	PE2	PE3	PE4	χ^2_c [b]	$P(\chi^2 > \chi^2_c)$*
J1	low	~	high	medium	91.5	< 0.0001
J2	low	medium	high	~	60.2	< 0.0001
J3	low	~	~	~	16.0	0.001
B1	low	high	~	high	73.5	< 0.0001
B2	~	high	med. - low	~	26.1	< 0.0001
B3	low	~	low	~	33.0	< 0.0001

[a] Variables used to classify the pest profiles are represented by their dominant modes or categories within the cluster. The range covered by each class : low, medium, high is presented in Table 1.
[b] χ^2 c : Chi-square value for each variable on the corresponding contingency table (Variable x Pest profile).
* $P(\chi^2>\chi^2c)$ (probability of a chi-square superior to the calculated chi-square) : risk of error when concluding on dependency of Variable and Pest profile.
~ : variable.

Table 3. Cluster analysis of pest profiles from Lopburi survey data (PLs)

Variables[a]	PL1	PL2	PL3	PL4	χ^2_b
J1	~	high	low - medium	low - medium	16.8*
J2	high	high	low - medium	~	21.7*
J3	~	high	~	low - medium	6.2*
B1	low	~	~	~	7.4*
B2	low - medium	~	~	high	9.1*
B3	medium	medium	low	high	15.7*

[a] Variables used to classify the pest profiles are represented by their dominant modes or categories within the cluster. The range covered by each class : low, medium, high is presented in Table 1.
[b] Chi-square value for each variable on the corresponding contingency table (Variable x Pest profile).
* Chi-square test significant at $P < 0.05$
~ : variable.

representation of the relationships between variables (Benzécri, 1973; Greenacre, 1984). As in principal component analysis, eigenvalues and independent eigenvectors define the axes. Axes are characterized by the relative contribution of variables to their inertia (proportion of information included in contingency table, accounted for by each axis). Square cosines (associated with each class of the different variables pertaining to each axis) measure the quality of classes representation (in projection) in the space defined by selected axes (Lebart *et al.*, 1982). The result of the analysis is a graph representing a series of trends for each of the

Table 4. Cluster analysis of pest profiles from Kanjanaburi survey data (PKs)

Variables[a]	PK1	PK2	PK3	χ^2_b
J1	~	~	~	3.3
J2	medium - high	~	low	13.9*
J3	~	~	~	1.2
B1	~	high	~	4.2
B2	low	~	~	8.8*
B3	low	high	medium	42.8*

a Variables used to classify the pest profiles are represented by their dominant modes or categories within the cluster. The range covered by each class : low, medium, high is presented in Table 1.
b Chi-square value for each variable on the corresponding contingency table (Variable x Pest profile).
* Chi-square test significant at P < 0.05
~ : variable.

Table 5. Cluster analysis : pattern of cropping practices from on-farm survey in Lopburi province (TLs)

Variable[a]	TL1	TL2	TL3	χ^2_b
SD	early	late	~	9.5*
NS	~	~	~	2.0
FF	high	medium	low	40.2*
WN	~	~	~	1.8
IP	high	low - medium	~	23.9*

a Variables used to classify the pest profiles are represented by their dominant modes or categories within the cluster. The range covered by each class : low, medium, high, early, late, is presented in Table 1.
b Chi-square value for each variable on the corresponding contingency table (Variable x Pattern of cropping practices).
* Chi-square test significant at P < 0.05
~ : variable.

initial variables, depicted as path, which may or may not indicate correspondences (Savary *et al.*, 1995).

RESULTS

Cluster analysis

Pest profiles: *Experiments.* Four classes of pest profiles were identified by cluster analysis. They were associated with significant χ^2 tests for each couple of variable (Table 2). PE1 (23 plots) were characterized by very low jassid infestation throughout the three successive development stages of cotton crop. Early bollworm attacks were very low, but they increased strongly at the end of crop cycle. PE2 (20 plots) corresponded to medium levels of jassid infestation during the fructification phase associated with heavy bollworm attacks during

Table 6. Cluster analysis : pattern of cropping practices from on-farm survey in Kanjanaburi province (TKs).

Variables[a]	TK1	TK2	TK3	χ^2_b
SD	~	~	~	0.6
NS	high	~	low	17.3*
FF	low	high	~	17.1*
WN	high	low	medium	27.5*
IP	low	medium -high	~	12.7*

[a] Variables used to classify the pest profiles are represented by their dominant modes or categories within the cluster. The range covered by each class : low, medium, high, is presented in Table 1.

[b] Chi-square value for each variable on the corresponding contingency table (Variable x Pattern of cropping practices).

* Chi-square test significant at $P < 0.05$

~ : variable.

vegetative and fructification periods. PE3 (19 plots) represented cotton plots heavily infested by jassids all along crop cycle but almost unaffected by bollworms. PE4 (14 plots) included plots moderately attacked by jassids and bollworms during the vegetative stage. Then, variable levels of infestation for both pests characterized the two following development stages.

Survey. A narrower range of injuries than in experiments characterized insect pest population on farmers' plots. The numerical boundaries that were thus chosen were generally lower than for experimental data. For example, a jassid attack during the fructification period (J2), which would have been classified in the "medium" group of experiment analysis, corresponds to the group "high" level of the survey (Table 1). The ranges of yield variations however were similar for experiments and surveys, suggesting that yield variability in farmers' fields was caused by others production factors (sowing date, fertilization, etc.) than insecticide protection only. The lower variation of pest profiles in farmers fields associated to the relatively few number of farmers' fields monitored, led to reduction in the number of pest profile classes, and focus on the most contrasted patterns of insect attacks.

Four classes were identified in Lopburi province, with significant values for all couples of variables (Table 3) : PL1 was characterized by heavy jassid attacks during fructification phase. Bollworm infestations were relatively low. PL2 corresponded to very high levels of jassid populations all along crop cycle. Bollworm attacks were variable. PL3 included plots weakly attacked by jassids during the first and second period of the cycle, with some bollworm infestations during the phase of maturation. PL4 represented crops not affected by jassids but heavily attacked by bollworms, especially during the fructification period.

Cluster analysis performed on Kanjanaburi data set yielded three pest profiles (Table 4): Heavy jassid infestations but low bollworm populations, especially during crop fructification stage characterized PK1. PK2 corresponded to variable levels of jassid infestation but heavy bollworm attacks during the vegetative and maturation phases of cotton crop development. PK3 represented low jassid infestations all along crop cycle, with bollworm attacks at the end of the cycle.

These classifications suggest that jassid constraint is the main discriminating factor in Lopburi area. PL1 and PL2 (high jassid pressure) are opposed to PL3 and PL4 (low jassid pressure). In Kanjanaburi, the bollworms variables explain most of the differentiation between the three types of pest profiles.

Patterns of cropping practices

Three cropping practice clusters were generated in each of the surveyed areas (Table 5):

Lopburi : TL1 was primarily characterized by an early sowing and an heavy use of foliar fertilizer and insecticide. TL2 was opposed to TL1, with a late sowing and low use of chemical inputs. TL3 main feature was the absence of foliar fertilizer.

Kanjanaburi : TK1 was associated predominantly with soil fertilization and several weedings. Use of foliar fertilizer and insecticide was relatively low. TK2 corresponded to situations opposite to the previous ones, with a high consumption of foliar fertilizer and insecticide, associated with a reduced number of weeding. TK3 was primarily characterized by low soil fertilization.

Chi-square tests (right column in Tables 5 and 6) provide indications about the contribution of cropping practices to the definition of clusters. Sowing date (SD), foliar fertilization (FF) and insecticide protection (IP) differentiate the three patterns of cropping practices in Lopburi. In Kanjanaburi, the sowing date did not appear as a discriminating variable from the cluster analysis, since sowings are more grouped in time than in Lopburi province. However, soil fertilization in Kanjanaburi plays a more important role in the classification than in Lopburi. The variable NS (nitrogen supply) seems to be linked to the variable WN (weeding number) as well as IP associated with FF. However, these two couples of variables are opposed in the different clusters, suggesting that TK1 type farmers compensate for a low use of insecticide and foliar fertilizer by an increased soil fertilization and weed control. Kanjanaburi and Lopburi share a common characteristic in the major role played by the couple IP - FF in the clustering of cropping patterns.

Correspondence analysis

Experiments. A contingency table was built, which showed the distribution of individual fields according to the categorized variables (Table 7). It allows for instance to visualize the yield profile (Y1-3) associated with a given pattern of cropping practices (IP1-4 and SD1-3) or with a given pest profile (PE1-4). The chi-square test applied to each couple of variable showed significant relationship between yield, pest profiles and patterns of cropping practices. A correspondence analysis was further applied to the contingency table to investigate relationships between variables.

The two first axes (Table 8) yielded by the correspondence analysis accounted respectively for 49% and 15% of the total inertia. The next

Table 7. Burt table from the experiment data set: classes 1 to 3 (or 4) for the four sets of variables: cropping practices , pest profiles , insect damages and yield[1].

	PE1	PE2	PE3	PE4	IP1	IP2	IP3	IP4	SD1	SD2	SD3	NB1	NB2	NB3	D1	D2	D3	Y1	Y2	Y3
PE1	23	0	0	0	3	3	5	12	11	8	4	6	10	7	9	10	4	4	8	11
PE2	0	20	0	0	4	3	9	4	5	9	6	8	7	5	6	8	6	5	9	6
PE3	0	0	19	0	10	4	3	2	2	4	13	13	4	2	6	6	7	13	3	3
PE4	0	0	0	14	2	2	5	5	5	5	4	4	4	6	7	4	3	5	4	5
IP1					19	0	0	0	4	8	7	13	5	1	3	5	11	12	6	1
IP2					0	12	0	0	3	2	7	7	2	3	3	6	3	7	3	2
IP3					0	0	22	0	8	8	6	7	8	7	9	9	4	5	7	10
IP4					0	0	0	23	8	8	7	4	10	9	13	8	2	3	8	12
SD1									23	0	0	2	7	14	12	9	2	2	8	13
SD2									0	26	0	8	12	6	7	11	8	3	11	12
SD3									0	0	27	21	6	0	9	8	10	22	5	0
NB1												31	0	0	6	6	19	26	5	0
NB2												0	25	0	7	17	1	1	15	9
NB3												0	0	20	15	5	0	0	4	16
D1															28	0	0	6	7	15
D2															0	28	0	7	11	10
D3															0	0	20	14	6	0
Y1																		27	0	0
Y2																		0	24	0
Y3																		0	0	25

[1]IP: Insecticide protection; SD: Sowing date; PE: Pest profiles; D: Insect damages; Y: Yield and NB: Number of bolls

Table 8. Correspondence analysis: quality of variables representation on the two first axes (square cosine) and their relative contribution to axes.

Class	Class size	Coordinate		Relative contribution (%)		Square cosine	
		Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Pest Profile							
PE1	23	0.55	-0.07	2.7	0.1	0.336	0.003
PE2	20	0.06	-0.52	0.0	3.9	0.004	0.158
PE3	19	-0.94	0.26	6.5	1.0	0.609	0.026
PE4	14	0.29	0.50	0.4	2.5	0.058	0.095
Insecticide Protection							
IP1	19	-0.87	-0.28	5.7	1.1	0.533	0.030
IP2	12	-0.49	0.32	1.1	0.9	0.132	0.031
IP3	22	0.33	-0.09	1.0	0.1	0.132	0.005
IP4	23	0.66	0.15	3.9	0.4	0.438	0.012
Sowing Date							
SD1	23	0.81	0.46	5.9	3.6	0.576	0.102
SD2	26	0.25	-0.67	0.6	8.6	0.087	0.340
SD3	27	-0.93	0.25	9.2	1.2	0.753	0.030
Yield							
Y1	27	-1.17	0.41	14.4	3.3	0.906	0.060
Y2	24	0.26	-0.94	0.6	15.2	0.082	0.560
Y3	25	1.01	0.46	9.9	3.8	0.765	0.085
Number of harvested bolls							
NB1	31	-1.07	0.20	13.9	0.9	0.942	0.017
NB2	25	0.49	-1.02	2.4	18.7	0.248	0.567
NB3	20	1.04	0.97	8.5	13.5	0.620	0.288
Damage							
D1	28	0.53	0.75	3.0	11.4	0.357	0.389
D2	28	0.26	-0.69	0.7	9.6	0.100	0.388
D3	20	-1.10	-0.08	9.4	0.1	0.737	0.002

three axes contributed to 8, 7 and 5% to the inertia, respectively. The two-dimensional representation including the two first axes was considered sufficient to interpret a large fraction (64%) of the information involved in the contingency table.

Axis 1 represents a gradient of increasing yields (Figure 2). Y1 (with a negative sign) and Y3 (positive sign) contribute most to this axis. Along the first axis high damages D3 are associated with low yields (Y1) and low damages with the high yield class (Y3). Late sowing (SD3) is associated to low yield and opposed along the first axis to early sowing (SD1). No insecticide protection (IP1), associated to low yields is located opposite to high protection (IP4) along the gradient of increasing yields. High level of jassid injuries (PE3) are also associated to the lowest yields and opposed to the three other types of pest profiles along the first axis.

Axis 2 opposes medium (Y2, NB2) to high yield levels (Y3, NB3) in the positive direction, as indicated by their contribution to this axis (Table 8). The same trend as along the first axis is observed for damage with D2 opposed to D1. SD2 has a negative value and strongly contributes to axis 2. Axis 2 accounts for the relative impact of mid-season sowing as compared with early or late sowing. Whereas the contributions of insecticide protection variables to the second axis are very low, axis 2 accounted for the contrast between PE2 (negative) and PE4 (positive).

Examination of square cosines provides a measure for the quality of the representation by the two first axes of the various yield levels, cluster of pests and cropping practices. The variables corresponding to yield (Y, NB), damage (D) and sowing date (SD) are well described by the two first axes. The relative contribution of these axes to the different classes of each variable are particularly high (Y : 0.64 to 0.97; Nh : 0.81 to 0.96; D : 0.49 to 0.75 and SD : 0.42 to 0.78). Pest profiles are well accounted for by the combination of axes 1 and 2. Axis 1 is also a good descriptor of insecticide protection and the projection of the four classes of this variable (IP) over axis 1 results in a gradient of increasing insecticide use (Figure 2b). Yield levels and clusters of pest and cropping patterns were plotted on a two-dimensional graph using the coordinates of Table 8. To help in the interpretation, the three groups of variables of Figure 2a were subdivided in clusters of cropping practices (Figure 2b) and pest profiles (Figure 2c).

Relationship between cropping practices, damage and yield. The paths representing increasing yield and decreasing damage are in close correspondence. A delay in sowing date seems to follow the same path of increasing damage. The so-called 'Guttman effect', often characteristic of small class size (Dervin, 1988), is not responsible in this case for the V-shape of these paths, which is caused instead by a strong relationship between variables (Savary *et al.*, 1995).

The gradient of increasing insecticide use which is accounted for by axis 1 is linked to a reduction in damage, as shown by the opposition of D1 and D3 on this axis. The combination of early sowing and intensive crop protection is also associated with increasing yield levels.

Relationship between cropping practices and pest profiles. Pest profile, an intermediate variable between crop management and damage, provides information on interaction between sowing date and insecticide use on yield. Pest profile PE3, characterized by high jassid infestations associated with low bollworm attacks, is strongly opposed to other classes of this variable on the first axis. The proximity of categories PE3 with SD3 as well as IP1 and IP2 suggest that strong jassid constraints were associated with late sowing. This was independent from insecticide use since IP2 and IP1 correspond to insecticide treatment targeting sucking insects, and no protection at all, respectively. The location of the latter three profiles (characterized by low jassid infestation and variable levels of bollworm attacks) at the right hand side of the graph (Figure 2c) show the effectiveness of insecticide use in reducing

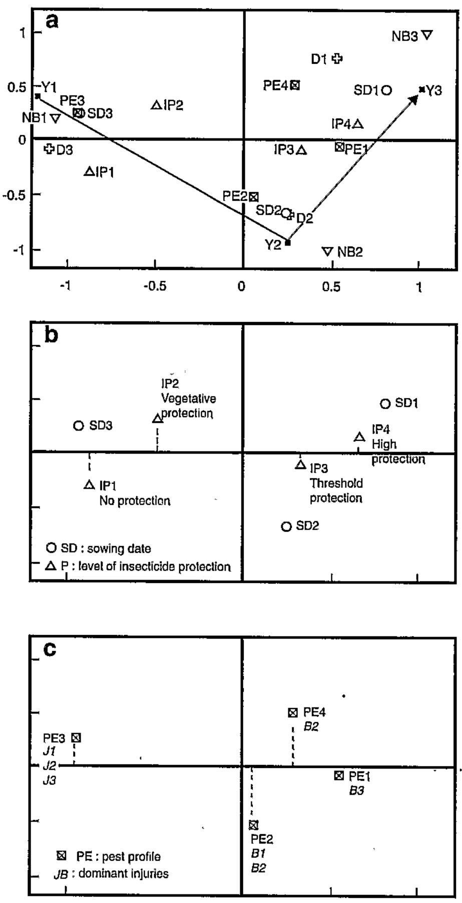

Figure 2 : Graphic representation on axes 1 and 2 of the results of the correspondence analysis between cropping practices (IP : △ and SD : O), pest profiles (PE : ⊠), insect damages (D : ✥) and yield (Y : ■ and NB : ▽) from the experimental data set. (a) Plot of the various categories of the overall set of variables (the figures indicate chi-square distance along the axes). (b) Plot of the two cropping practices. (c) Plot of the clusters representing the types of pest profiles and their main features (acronyms are explained in the text).

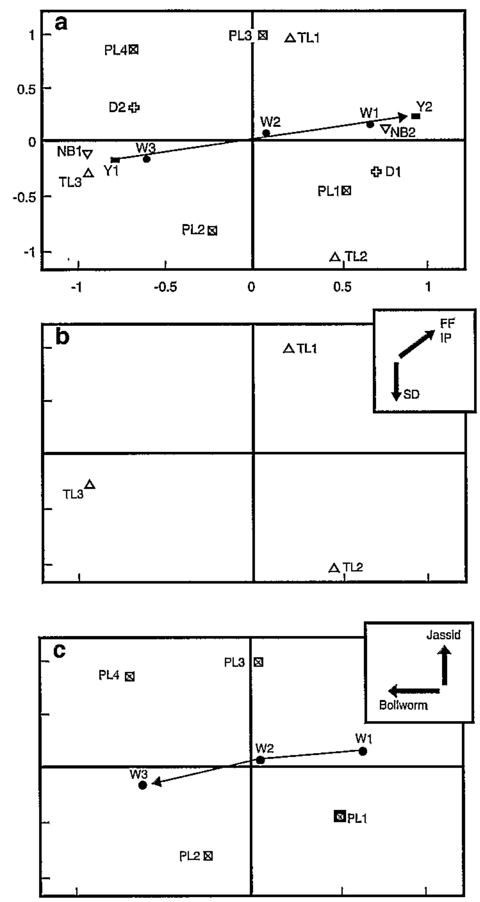

Figure 3 : Graphic representation on axes 1 and 2 of the results of the correspondence analysis between : patterns of cropping practices (TL : △), pests (PL : ⊠ and W : ●), insect damage (D : ✥) and yield (Y : ■ and NB : ▽) from the survey data set in Lopburi province. (a) Plot of the various categories of the overall set of variables (the figures indicate chi-square distance along the axes). (b) Plot of the cluster representing the patterns of cropping practices. (c) Plot of the clusters representing the types of pest profiles and their main features (acronyms are explained in the text).

jassid populations. Bollworms thus appear as a major constraint. Axis 2 opposes pest profiles corresponding to high bollworm constraints. However, the poor representation of these three pest profiles on axes 1 and 2, requires cautious interpretation of the resulting correspondences, which can be at best considered as trends. χ^2 test between paired variables PE x IP and PE x SD [χ^2(SD,PE) = 15, $P < 0.05$] (Table 7) further confirms graphical interpretation. PE1, characterized by heavy jassid attacks during the maturation phase corresponds to early sowing dates and maximal insecticide protection. Pest profiles PE2 and PE4 differ predominantly by higher bollworm populations during fructification (for PE2). Projected on axis 2, PE2 is also associated with SD2 whereas PE4 is closer to early sowing, SD1.

Relationship between pest profiles damage and yield. The succession: PE3, PE2, PE4 and PE1 projected on axis 1 corresponds to a gradient of increasing yields. PE3 (with a negative sign), associated with low yield (Y1, NB1), and high damage (D3), is opposed to PE1 (positive) corresponding to high yield and medium to low levels of damage. On the second axis, PE2 is associated with higher levels of damage than PE4, although both classes belong to the same yield category.

Surveys

The same procedure of correspondence analysis was applied separately to the two survey data sets (Tables 9 and 10). Whereas agro-ecological environment and cropping practices differed markedly between Kanjanaburi and Lopburi areas, the two analyses yielded very similar axes (Figure 3 and 4). Since the two first axes accounted together for more than 80% of the total inertia (Tables 9 and 10), the succeeding axes were not further considered.

Axis 1 represents an overall increase in yield opposed to a gradient of increasing damage as well as a gradient of weed constraint for both data sets. The first axis distinguishes also pest profiles according to bollworm population dynamics. Pest profiles characterized by high bollworms (PL2 and PL4 in Lopburi, PK2 in Kanjanaburi) are associated with high damage and low yield while the opposite trend is observed for a crop less affected by this pest (PL1 and PL3 as well as PK1 and PK3). The projection of cropping practices along axis 1 show a positive relationship between insecticide and foliar fertilizer use and yield (Figures 3b and 4b).

Axis 2 predominantly opposes pest profiles according to the extent of jassid constraint. For a similar level of bollworm infestation, PL2 (negative) and PL3 (positive) are opposed on axis 2 due to the difference in jassid populations. The same relation is observed in Kanjanaburi between PK1 and PK3. Axis 2 represents differing information with respect to cropping practices in Lopburi and Kanjanaburi areas. This axis opposes in Lopburi the types of crop management according to their sowing dates. The path TL1, TL3 and TL2 corresponds to increasing delays in sowing. In Kanjanaburi, the patterns of cropping practices are contrasted along the second axis by the combination of the two variables: soil fertilization and weeding. TK1, characterized by high values of these two features, is opposed to TK2 and TK3.

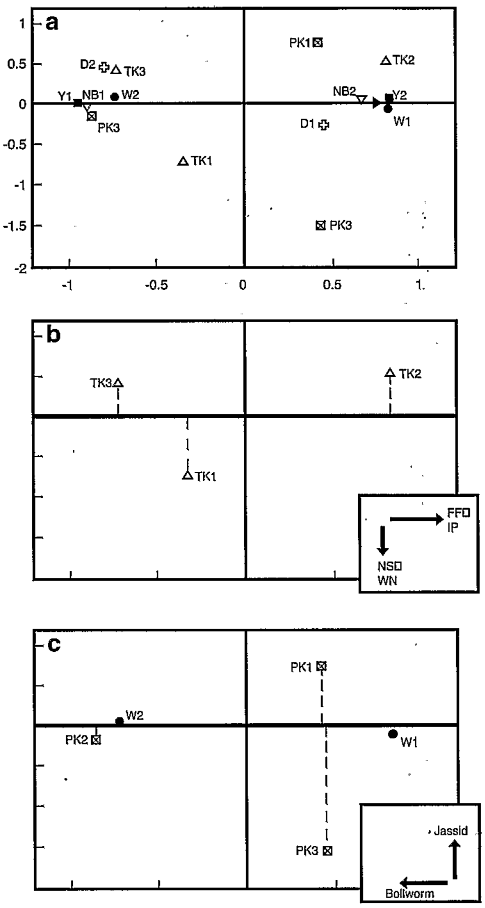

Figure 4 : Graphic representation on axes 1 and 2 of the results of the correspondence analysis between : patterns of cropping practices (TK : △), pests (PL : ⊠ and W : ●), insect damage (D : ✤) and yield (Y : ■ and NB : ▽) from the survey data set in Kanjanaburi province. (a) Plot of the various categories of the overall set of variables (the figures indicate chi-square distance along the axes). (b) Plot of the cluster representing the patterns of cropping practices. (c) Plot of the clusters representing the types of pest profiles and their main features (acronyms are explained in the text).

DISCUSSION

Comparison of experimental and survey data

Comparison of the three data sets brings into perspective the relationships between crop management practices, insect pest dynamics, and yield in farmers' fields. Cluster analysis indicated strong relationships between the two considered insect pests, resulting in a limited number of pest profiles. A separate analysis of this experimental data set (Castella *et al.*, 1999) showed negative relationships between jassid infestations and further attacks of bollworms. The antagonism between these pests with respect to damage is related to the differing types of injuries they cause (Castella *et al.*, 1999). This is reflected by the various pest profiles encoded as PE3 (experiments), PL1, PL2 (Lopburi), and PK1 (Kanjanaburi).

However, cautious interpretation is required due to the small sample size of the survey data sets. Thus the discussion will focus on the overall trends indicated by the three correspondence analyses.

Comparison of experimental and survey data exhibits a major difference in the status of jassids towards crop damage. In experiments, jassids appeared as one of the main yield reducing factor, especially in unsprayed plots IP1 and IP2. PE3, opposed to the three other pest profiles on the first axis, corresponds to the lowest yields (Figure 2). However, jassids were easily controlled by insecticides as shown by the correspondence of the shift from IP2 to IP3 (on the path of increasing insecticide use) with the shift in pest profile from high to low jassid infestations on Figure 2. Jassids showed very little impact on damage and yield in farmers' fields, as indicated by the orthogonal direction of jassid constraint increasing path (parallel to axis 2) and yield gradient supported by axis 1 in the two correspondence analysis on survey data sets (Figure 3 and 4). Since all farmers sprayed insecticides during the vegetative phase, one can understand from the experimental results that none of them experienced jassid populations as high as in the non-sprayed treatment of on-farm trials. Such a result suggests that farmers could not grow cotton profitably if they could not control jassid populations.

The analysis of survey data showed a strong correspondence along the second axis between the earliness of sowing and a reduction of jassid constraint in the corresponding pest profiles, independently of the level of insecticide protection (which is accounted for by axis 1). This supports the observation that early sowing reduces the probability of jassid infestation in the vegetative stage (Rasmidatta, 1984). This practice is not directly related to an increase in yield but allows easier bollworm control, as it allows a build-up of its natural enemy populations that are not destroyed by early sprays that were targeting jassids (Bottrell and Adkisson, 1977; Matthews, 1989).

When jassid populations were low, an increase in bollworm induced damage was observed. Bollworms raised to the rank of major pest in farmers' fields, by opposition to our experimental results where jassids were dominant. Three types of pest profiles characterized by high bollworm populations were distinguished according to the type of crop injury they caused. Castella *et al.* (1999) showed from the same experimental data set that bollworm injuries, which occurred during the vegetative phase of crop development (e.g. pest profile PE4), resulted in low damage since the crop could compensate for fruit losses. However, for a similar yield, the relative damage (i.e., difference between attainable yield and actual yield over attainable yield) was increased by early bollworm injuries. The attainable yield, related to the number of fruiting sites per unit area, was higher than for uninjured crops. Bollworm attacks had the largest injurious effect when they occur during cotton fructification (type PE2 profile). The extent of damage also depends on crop's ability to compensate and is indirectly influenced by the sowing date. Under rainfed conditions that typically prevail in Thai cotton growing areas the sowing date determines the amount of water available for the crop during its development. Along axis 2, the path between SD1 and SD2 (delay in sowing date) corresponds to increasing crop damage due to bollworms : succession PE1 to PE4 and PE2 (χ^2[SD,PE] = 15, P = 0.02, dl = 6). During the maturation phase, the crop is more tolerant to bollworm attacks since ripening fruits progressively become less susceptible to bollworm injuries. High bollworm infestations were generally observed at maturation stage on crops less injured during the previous stages: profile PE1. Crops presenting high boll load attracted bollworms (Wilson and Waite, 1982). However, these late bollworm attacks have little impact on damage. These types of pest profiles, which led to the highest yields in the network of experiments, were also associated with the highest insecticide use (IP4). This result suggests that beyond mere bollworm attraction for healthy crop, a resurgence of bollworm populations may be caused by weekly insecticide applications that lead to a peak late in the cropping season. The path of increasing insecticide protection, from IP3 to IP4, was associated with a shift from PE2 (characterized by heavy bollworm attacks during vegetative and fructification phase) to PE1 pest profile (infested by bollworms during crop stages less sensitive to this pest) (χ^2[(IP1-2, IP3-4), (PE1, PE2, PE3, PE4)] = 11.7, P < 0.01, dl = 3). Calendar-based insecticide applications did not decrease the overall bollworm density but concentrate the pest attacks during the crop development stages that are more tolerant to injuries. Sowing dates seem also to interact with insecticide efficiency. A shift in sowing date moves the periods of crop tolerance to bollworm relative to the seasonal dynamics of pest populations (from PE2 to PE4 and PE1 profiles). Insecticides appear to be more efficient early in the season when population densities are low rather than later when several cohorts of larvae are overlapping (Slosser, 1993). Also late in the season, the insecticide efficiency decreases, as deposition is poorer on larger plants, when infestations are higher due to more flowers attracting the moths.

One might conclude from the experimental results that intensive sprays associated with early sowing leads to the highest yields, and such a conclusion would explain farmers' intensive practices observed in the survey. However, the relationships between components of the pest system are too complex for such a simplification. While bollworms are the main yield reducing factor in farmers' fields, weed control also plays an important role, as shown in Figures 3 and 4 by the close correspondence between the path of increasing weed infestation and decreasing yields (χ^2[W,Y] = 8.8, P = 0.003, dl = 1 in Kanjanaburi and χ^2[W,Y] = 3.8, P = 0.05, dl = 1 in Lopburi). It is difficult to draw conclusions from this relationship. Three non-exclusive interpretations may be forwarded: (i) direct weed-crop competition, (ii) the role of weeds as a reservoir for insect pests, and (iii) weeding intensity reflects the intensiveness of crop husbandry.

The main difference between the Lopburi and Kanjanaburi areas lays in the role played by the sowing date. This practice strongly differentiates the types of cropping patterns in Lopburi, but does not significantly intervene in the clustering on Kanjanaburi data set. The Lopburi cotton growers could rely on the choice of sowing dates as a technique to reduce crop damages caused by insect pests. Generally the farmers in Kanjanaburi sow their crop later but at the same time. Rainfall pattern distribution in Kanjanaburi is characterized by a long rainy season, which do not allow the farmers in that area to sow early. Such practice would then run the risk of them harvesting their crop under rainy conditions, resulting in poor quality yield. In the case of low insecticide use (thus, high likelihood of significant damage), correspondence analysis shows that the Kanjanaburi farmers rely on soil fertilization and weed control to mitigate the effect of pest injuries. When projected along axis 2, the pattern of cropping practices TK1, which corresponds to higher soil fertilization and weed control than TK3, results in lower damage (χ^2[TK,D] = 6, P = 0.05, dl = 2).

The analysis of farmers' crop management practices shows that, aside from insecticide applications, a large number of practices are linked to crop protection. Sowing date, fertilization, weed control are interacting with crop response to injuries, and thus are handled by farmers as crop protection practices just like insecticides (Castella *et al.*, 1995).

Consequences for the introduction of IPM innovations

To escape the spiral of insecticide use, the 'pest - crop - farmer' system should be considered in its integral complexity. Bollworms emerged as a pest from insecticide use targeted at jassids (Deema *et al.*, 1974, Brader, 1979). In the absence of insecticide, sucking insects particularly jassids account for most of the potential damage. A reasonable amount of insecticide can achieve an adequate control of jassids, but invites other pests. Among them, bollworm emerged as a major cause of damage as a result of (i) a low susceptibility to insecticides specific of sucking insects, (ii) the elimination of bollworm natural enemies by insecticides, and (iii) feeding habits that differ from those of sucking insects. Because of the succession in time of the cotton development stages susceptible to these two pests (i.e. jassids during the vegetative phase then bollworm during fructification) extensive damage can be experienced. The more insecticide is used early in the season, the more it is needed later against the bollworms. Broad spectrum insecticides or insecticide mixtures were used to control both pests simultaneously. But the more insecticide was used in one season, the more was needed in the next. This evolution of pest profiles in time exemplifies the inter-temporal trade-off between short-term expected utility of insecticides and the negative implications on the overall cropping system in the long run. Today, protection programs that address bollworms independently from jassids seem to have little chance of success in Thailand, even if the former appears to be more injurious to the crop and more difficult to control than the latter. Moreover, a multiple threshold would be very difficult to operationalize (Zadoks, 1985; Tüttinghoff, 1991) since insecticides have an impact on both insect pests at the same time, directly or via natural enemies.

Alternative solutions could aim to dissociate control techniques for both pests. Against jassids, varieties with hairy leaves provide a good natural protection (Parnell *et al.*, 1949; Niles, 1980). Traditional hairy cultivars were replaced by glabrous varieties for the sake of lint quality and productivity. Reintroduction of hairy cultivar gave promising results (Genay, 1994). However, these cultivars have three shortcomings:

(i) hairiness only appears a few days after leaf unfolding, and thus there is a need for an early protection against sucking insects. Seed treatments using narrow spectrum insecticide (e.g. imidachloprid) showed to be very efficient against jassids up to 45 days after emergence, while sparing the bollworm natural enemies (Genay, 1994),

(ii) a preference of hairy leaves for moth oviposition was noticed as well as a lower egg mortality due to ineffective mechanical wash-off from the leaves by rainfall. However, this increase in oviposition might only be due to a trap effect of small plot of hairy cultivars within large areas of glabrous varieties. Therefore, only the use of hairy cultivars over large areas may reduce bollworm attraction.

(iii) attention should also be given to other sucking insects, especially thrips, which are not affected by leave hairiness and could become more damaging in the future. Selection of cultivars presenting different levels of hairiness should allow to propose cotton variety adapted to the local composition of the insect pest complex.

Bollworm populations that are reduced by the build up of natural enemies early in the season, could be further managed by rational use of narrow spectrum insecticide, during the most susceptible cotton development stages (i.e. fructification). In the near future, the release of genetically engineered cotton cultivars with resistance to bollworms may further reduce the need for insecticides.

Analysis of the different patterns of cropping practices showed that all field operations are linked to crop protection. Farmers tend to reduce the risk of damage caused by their own pest management decisions by favoring the possibilities of crop compensation.

CONCLUSIONS

This paper is aimed at relating information that is heterogeneous in nature (quantitative, qualitative) and precision (surveys, experiments) pertaining to the cotton production system. Combination of time dependent factors were addressed through clustering method, allowing a three - stage approach of damage. This analysis of the 'pest - crop' system provided information on pest profiles prevailing under given patterns of cropping practices and the resulting damage patterns. This encompassing view of the issue represented by cotton protection in Thailand may be of help in setting research priorities as well as improving the implementation of research at the farm level. The type of outputs provided by correspondence analysis adequately reflects farmers' perception of the interactions between components of the system. Farmers have their own classification of yields, from very poor, over regular, to very good (Savary *et al.*, 1995). Such type of categorization arose also from discussions about inputs, pest infestations or damage, which may be seen by farmers as low, medium or high. Similarly, after refined design and testing, IPM innovations should be translated into a conceptual framework that is compatible with farmer's decision making (Zadoks, 1985). Farming systems diversity as well as an insight into the socio-economic aspects of cotton production are required to identify the paths of transformation from the current practices to IPM alternatives.

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