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Final report

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1 Acknowledgments

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2 Executive summary

The project titled '*Integrated pest management of stem borers and insect vectors of viral diseases of sugarcane in Indonesia'* (HORT 2006 147) addressed key pest and disease issues affecting the Indonesian sugarcane industry.

Over the last 40 years, productivity has been declining. Pests and diseases are major contributors to this production slide, with moth borers particularly affecting crop yields in Java. Major borer species include *Chilo auricilius, C. sacchariphagus* and *Scirpophaga excerptalis.* Stem borer infestations in commercial Javan sugarcane fields in Java were estimated pre-project at > 10% and losses in $ millions. Major diseases include forms of sugarcane mosaic, caused by sugarcane mosaic virus and sugarcane streak mosaic virus (SCSMV); the prevalence of the latter was largely unknown – but is it common through SE Asia.

Project research included a survey of 931 commercial crops in west, central and eastern Java. Sampling of representative, replicated plots in each field provided quantitative data on pests and diseases. The most common and significant pests were *Chilo sacchariphagus* (stem borer) and *Scirpophaga excerptalis* (top borer); *C. auricilius* was less common and not as severe. Losses from these pests were estimated in yield loss trials at 15% (*C. sacchariphagus*) and up to 40% (*S. excerptalis*). Research also showed that increasing the dose / extending the period of release of the egg parasitoid (Trichogramma, a tiny parasitic wasp) greatly improved yields and decreased losses from moth borers. Economic analyses showed this treatment will greatly improve profitability of sugarcane farming.

White grubs (*Lepidiota stigma*, a root feeder) was also found to significantly decrease yields in affected fields. Research identified a better chemical management strategy that will reduce the release of insecticides into the environment, provide better control of the pest and provide greater profitability to farmers.

The most common form of sugarcane mosaic is caused by sugarcane streak mosaic virus (SCSMV); surveys suggested that over 90% of crops displaying mosaic symptoms were affected by this virus and that the disease was very common in Java. Research showed both mechanical (knife) and vector (insect) transmission of the disease and this suggests there is a very significant need to find alternative management strategies, particularly improved crop resistance to SCSMV.

Extension of research results occurred via regional meetings with industry decision makers, through specific farmer training schools, through the use of champion farmers, development of fact sheets and a pest and disease field guide (written in Indonesia), Significant feedback from those attending provided a good indication on how to extend information to Indonesian sugar factory workers and individual cane farmers.

3 Background

Sugarcane production contributes Rupiah 11,500 billion ($Aus 1.57 billion) to the Indonesian rural economy. Sugarcane is grown by over 140,000 farmers, and the industry supports over 1.3m workers in associated industries. There are 58 sugarcane factories in Indonesia processing 30m tonnes of sugarcane from 380-400,000 ha land. Over three-quarters of the sugarcane production occurs on the island of Java.

Over the last 40 years, productivity has been declining. Pests and diseases are major contributors to this production slide, and stem borers particularly are dramatically affecting crop yields in Java. Major borers include the top borer *Scirpophaga excerptalis* (Walker) and the stemborers *Chilo auricilius* Dudgeon and *C. sacchariphagus* Bojer; losses are estimated at 0.5% tonnes cane for every 1% bored nodes. Other borers include *Tetramoera schistaceana* (Snellen) and *Sesamia inferens* (Walker). Estimates made by BSES Officers in southern Sumatera suggest combined infestations of *C. auricilius* (stalk borer) and *Scirpophaga excerptalis* (top borer) reduced sugar production by 50% on a 20,000 ha estate; 20% of the estate was very badly infested. In the 2002-2003 season income on the same estate was reduced by 40% because of infestations by these borers. This led to losses of $Aus 20m over a three year period. Stem borer infestations in commercial Javan sugarcane fields were estimated pre-project at > 10%. *C. auricilius* and *Sesamia inferens* also attack rice.

Pests also include vectors of sugarcane mosaic and sugarcane streak mosaic viruses. These viruses are widespread through S.E. Asia, and indeed Indonesia, and also cause significant losses. Disease levels in commercial Javan fields were estimated pre-project at between 30-50%; 90% of the germplasm is diseased. Yield losses are estimated at 10% or greater. The mosaic vectors from overseas research are known to include *Rhopalosiphum maidis, Hysteroneura setariae, Schizaphis graminum, Dactynotus ambrosiae* and a number of other species. It was unknown in the pre-project how many of these vectors reside in Indonesia.

Since pests and diseases are causing large losses in Indonesia, there was a strong need to implement effective control programs, especially the implementation of effective Integrated Pest Management (IPM) strategies on Javan sugarcane farms. The project aimed to improve sugarcane productivity by reducing losses from stem-borers and viruses.

Results from studies (CP/1996/140; CS2/1991/680*)* in other countries, (such as PNG where IPM strategies for the closely related stem borer *Sesamia grisescens* have been very successful), were drawn upon in this project. Results from project CP/1996/140 were used to provide important information for the proposed research.

BSES has had a long-term relationship with the PNG sugarcane industry through consultative visits; the experience gained was drawn upon to provide advice on pests and diseases within the region. This experienced was also used in preparing the sugarcane pests and diseases field guide.

Impact of the project include better stem borer and insect vector control, reduced yield losses and higher financial returns for local cane farmers. This will affect the livelihood of over 138,000 canefarmers on the island of Java.

4 Objectives

The project had the following objectives:

1. Determine the distribution and incidence of stem borers, insect vectors and natural enemies in Java,

2. Identify insect vectors and assess their transmissibility for mosaic-type virus diseases,

3. Develop an integrated pest management (IPM) program

4. Transfer new technologies using appropriate extension methods to the farming, scientific, and quarantine community

5 Methodology

Section 5: Methods

5.1 Introduction

There were many facets to this project researching a wide range of issues facing the Indonesian sugarcane industry. The main emphasis was on IPM of moth borers but a range of other activities were undertaken addressing important industry issues. Methods associated with this research are detailed below.

5.2 Survey

5.2.1 Introduction

Introduction: Surveys sought to gain an understanding of pest and disease incidence in Java and to identify the highest priority areas for research and extension. Incidence of the major pests and diseases was quantified through systematic observations in multiple plots within a large number of crops across Java.

A total of 931 farms belonging to 30 sugar factories were surveyed for pests and diseases between April 2008–April 2009. Of these, 620, 226 and 85 fields were in the three main regions - East, Central and West Java respectively. In each field, all plants in a 10-metre transect were checked for symptoms of moth borer infestation and diseases, and this was repeated 10 times in each field, giving a total of 10 transects/field. Fields examined represented a range of crop ages (in months), crop classes (plant cane or ratoon crops) and management systems (factory managed or grower managed). Samples of mosaic-infected leaves were collected for molecular analysis to determine the pathogen involved, while borers and their parasitoids were also collected for identification at the ISRI Pasuruan laboratory.

5.2.2 Stem borers

Plants showing borer symptoms in leaves, shoots, stalks or the growing point were recorded. Shoots, stalks and growing points were dissected and, if present, the pest stage was collected; other relevant details were also recorded (date, field name, location – village and sugar factory). The pest species causing crop damage was identified in the field based on the feeding pattern on the leaves, shape of the feeding tunnel, shape of the exit hole and the presence or absence of a dead heart. Immature borer specimens were collected, taken to the ISRI laboratory and reared until it either emerged as an adult moth or produced a parasitoid. In the latter case, the parasitoid was identified. Data on crop age, class and farm management were analysed to determine trends and underlying factors governing incidence.

5.2.3 Diseases

Diseases were identified either by symptoms alone, or in combination with molecular assay. Sugarcane mosaic-type symptoms were a case in point, where definitive symptoms are lacking that enable *sugarcane streak mosaic virus* to be separated from *sugarcane mosaic virus*. Leaf samples were accordingly collected and the leaves sent to BSES Indooroopilly, Australia (under quarantine) for molecular assay. This enabled a definitive answer on which virus was causing the mosaic symptoms.

5.3 Parasitoid research

5.3.1 Parasitoid dose

In Java, moth borers cause significant economic losses to the sugarcane industry. Detailed information on the stalk borer effects cane growth, particularly on the stalk components, is important when assessing crop losses. Of the various approaches that may be adopted, manipulation of pest pressure in the field through insecticide treatment and/or appropriate artificial infestation techniques is the most effective and the most accurate assessment method (Walker, 1987).

Sugarcane yield losses due to stemborers were successfully determined using this approach in Reunion Island for *C. sacchariphagus* Bojer (Goebel *et al*., 1999) and South Africa for *Eldana saccharina* (Goebel and Way, 2003).

In addition, to assess the efficacy of biological control using releases of the egg parasitoid *Trichogramma spp.*, two other treatments were incorporated in our trial. Here we present only the impact on yield components from stemborers and *S. excerptalis* (top borer) for which there is a paucity of detailed information. In this regard, we then determined how stalk weight and plant growth parameters were influenced by attack by these borers.

Experimental design

The experiment was conducted on a new plantation near Pesantren Baru Sugar Factory, East Java, over the period August 2009 to July 2010. The canefield was divided into five blocks of four treatments in a randomized design. Each of the 20 plots was 500 m^2 in size with 20 m of cane buffer between plots to create an effective break against both insecticide applications and *Trichogramma* dispersion and migration. The variety used was PS 862, which is rated as intermediate/susceptible to *Chilo* spp. Each plot received one of the following treatments: -

- ***T1 (Tricho1):*** 'factory method' with 8 weekly releases of two species, *T. chilonis* and *T. japonicum* (dose: 10000 Tr./ha), from 1.5 to 4 months after planting; and

- ***T2 (Tricho2)*** 'recommended released' with 14 weekly releases (dose: 100 000 Tr/ha) started at 1 month until 4.5 months. Releases were done by stapling cards of parasitised eggs (from the rice moth *Corcyra cephalonica)* on top leaves. *Trichogramma* cards were provided by the production unit located at Pesantren Baru Factory.

- ***T3 Insecticide***: plots treated with insecticide to minimise borer infestation. These plots were intended to provide an indication of potential yield in an undamaged crop. The insecticide used was Ampligo 150 ZC (a.i. = Chlorantraniliprole 100 g/L + lambda-cyhalothrin 50 g/L), a broad-spectrum foliar application to control various moths such as leaf miners, armyworms and moth borers (fruits), among other pests. Applications were done using a knapsack sprayer (20 L) every 14 days from 1 to 8 months after planting.

- ***T4, untreated control*** (UTC) had no protection from insect pressure, representing plots naturally infested by moths.

Damage assessment at harvest

Borer damage was determined by field examination of 100 successive millable stalks in the centre row of each plot. The length, diameter and weight of each stalk were recorded before it was split longitudinally to assess borer damage. Also noted for each stalk were: number of internodes, number of internodes bored, the length of borer tunnels for each damaged internode and number of larvae present.

Statistical analysis

Data were analysed with XLSTAT software (Addinsoft). Initially data were subjected to analysis of variance (ANOVA) to compare the effect of each treatment on all components. Then the relationship between the percentage of stalk internodes bored and *S. excerptalis* (top borer) infestation (independent variables) were plotted against the main cane and sugar yield characteristics (dependent variables) to determine the correlation coefficients. Regression lines were fitted using a general linear model.

5.3.2 Rearing Scirpophaga larvae (top borer) on artificial diet

Introduction:

The ability to culture *Scirpophaga excerptalis* (top borer) in the laboratory would be a huge advantage for management of this pest in Indonesia; parasitoids for *S. excerptalis* could then be reared for mass release as part of an IPM strategy. No synthetic medium has been identified for *S. excerptalis* multiplication. Research on the topic was conducted during the course of this project.

Method

Multiplication of top borer larvae has been attempted using several different artificial diets in other countries. Some of these were included in the experiments conducted; details of the diets are provided in Table 1.

Table 1. Artificial diets for larvae of top borer (*Scirpophaga excerptalis*)

Main ingredients	Diet adapted from..	Diet
Bean powder	*Chilo partellus*	1 A
Bean powder + sugarcane leaf powder		1 B
Bean powder + sugarcane leaf powder	*Chilo partellus*	2
Bean powder + sugarcane leaf powder	*Busseola fusca*	3
Bean powder + sugarcane leaf powder	*B. fusca* & *S. calamistis*	4
Wheat germ	*Bathytricha truncata*	5
Green bean + maize powder	*Sesamia inferens*	6
Kidney bean	*Ostrinia nubilalis*	7
Bean + sugarcane leaf powder	*Chilo partellus*	8
Dried crushed cane+ground chickpea	*S. excerptalis*	9

After the initial experiment, modification of diet 7 was made by adding ingredients such as sucrose, vitamin E, cane powder, either separately or in combination, to determine if larval survival could be enhanced.

5.3.3 *Rearing Cotesia flavipes (larval parasitoid)*

Cotesia flavipes (Hymenoptera: Braconidae) is the main natural enemy of two stem borer species, *Chilo sacchariphagus* and *C. auricilius*. This parasitoid has been used as a stem borer bio-control agent in many countries around the world. The release of *C. flavipes* populations has successfully reduced stem borer populations in some Asian countries, South America and in the USA. In Indonesia, *C. flavipes* has been reared at three sugar factories: Bungamayang, Subang and Jatitujuh. Seed populations of this parasitoid were collected from one of these factories and taken to ISRI to establish a population in eastern Java.

5.4 Borer yield loss assessment

Biomass yield (tonnes cane/ha) was estimated in each plot in the *Trichogramma* parasitoid dose response experiment (see section 5.3.1) so that yield losses caused by each borer could be quantified.

The weight of 100 stalks x number of stalks/ha of each plot was calculated. Sugar parameters (quality) were determined on bundles of 20 stalks for each of the four treatments, replicated five times. All samples were brought to the factory laboratory and analysed for various stalk parameters such as stalk weight, fibre % cane, brix % cane (total soluble solids in cane juice), purity, pol % cane (total recoverable sugar) and, commercially recoverable sugar content (CCS, expressed as a percentage). Sucrose yield in tonnes per hectare was calculated as = cane yield (t/ha) × CCS (%)/100.

Statistical analysis

Data were analysed with XLSTAT software (Addinsoft). Initially data were subjected to analysis of variance (ANOVA) to compare the effect of each treatment on all components.

5.5 Monitoring and management of borers (stem / top) using pheromones

Synthetic sex pheromones have been used in pest control for agricultural commodities such as rice and corn. Pheromones naturally produced by insects influence their behaviour, including mating, defence and population movements.

Population data can be used as an early warning system for impending population (and damage) spikes enabling better management under commercial cropping conditions. Trap numbers provide information enabling well-timed parasitoid/predator releases. Application of insecticides can also be optimised (both in timing and application dose) when population dynamics in crops is better understood, thus minimising yield losses.

Mating disruption can be exploited if there are sufficient traps to lure males away from females. Mating disruption occurs when males are attracted to the pheromone arising from a pheromone trap, rather than from live females. With no male, females lay infertile eggs leading to reduced borer populations – and hence reduced damage to sugarcane crops.

Pheromone experiments were conducted in fields located at Ngadirejo and Subang sugar factories. These experiments aimed to study moth borer population dynamics (Figure 4 and 5) and to see whether mating disruption would occur. The synthetic sex pheromones used in the experiments were produced by The Natural Resource Institute, The University of Greenwich, UK. They were selected to attract both the top borer (S*cirpophaga excerptalis*) and stem borer (*Chilo sacchariphagus*). Pheromones were placed in a delta trap in two fields at each of Ngadirejo and Subang sugar factories. The number of male moths caught in the traps was quantified every week.

The Indonesian Sugar Research Institute (ISRI) arranged for another blend of a pheromone to be produced and this was tested in fields of the Cintamanis sugar factory, south Sumatera. The following trapping scenarios were established: water trap containing a synthetic pheromone produced by The Natural Resource Institute, University of Greenwich (T 1); water trap containing pheromones produced by ISRI (T 2), water traps containing either a virgin female or newly hatched, unmated moth (T 3), and water traps without pheromone (T 4). A randomized block design was employed with three replicates. Moth borer populations and crop damage was estimated.

5.6 White grub control

5.6.1 Introduction:

Results from the pest and disease survey, plus advice from project and factory staff highlighted white grubs as a high priority pest. Accordingly, small field trials were established during 2010 to test the efficacy of control products against *Lepidiota stigma*, the main pest species. Trials were established in plant crops in May and ratoon crops in September.

Sugar factories currently attempt control of white grubs in plant crops with insecticides such as diazinon, cadusafos and carbofuran. These are hazardous chemicals that are also likely to be ineffective. Accordingly, we compared the efficacy of one of them, diazinon, with that of imidacloprid, an insecticide that has proved very effective against canegrubs in sugarcane in Australia. Two trials were established in plant crops at Sumber Lumbu (Ngadiredjo Sugar Factory) and Jengkol (Pesantren Baru Sugar Factory), two areas that have on-going problems with canegrubs despite use of products such as diazinon.

Two times of insecticide application were included in each plant cane trial, either application at planting or application at fill-in of the planting furrows. Nine treatments were include, with diazinon at 25 kg/ha and liquid imidacloprid at three rates, 250, 375 and 500 g ai/ha, at planting or at fill-in, plus untreated controls, replicated five times,

No control of canegrubs is currently attempted in ratoon crops and so damage often escalates with resulting yield loss. Therefore, we established two trials in ratoon crops at Ngadiredjo and Pesantren Baru sugar factories.

Two methods of insecticide application were included in each ratoon cane trial. In the first method, furrows were made by hand either side of the cane rows and liquid insecticide was applied in a single stream onto the side of the furrow adjacent to the cane row. The two lines of insecticide either side of the row were 250-400 mm apart. The furrow was then re-filled with soil. This imitates what is currently done in Australia using tractor-powered coulters. In the second more experimental method, diluted imidacloprid was applied into the soil from an ISRI-developed injector. The injector had four 1 mm orifices around its circumference behind the tip. Five treatments were included in each trial: liquid imidacloprid at three rates, 375, 500 and 625 g ai/ha either side of row, liquid imidacloprid at 500 g ai/ha, injected, and untreated controls, replicated five times.

Numbers of canegrubs were counted under five stools in each plot in March 2011. Cane yield was assessed at the 2011 harvest by weighing stalks in three 10 m lengths of row in each plot. Numbers of stools and gaps in each plot were counted after harvest.

5.7 Economic analysis of borer and white grub controls

5.7.1 Borer control using Trichogramma

One of the significant outcomes from project research has been improved management options for stem borer management. Economic analysis of these options is important to determine the potential benefit to local industry; analyses relied on results from the *Trichogramma* population experiment undertaken in crops of the Pesantren Baru sugar factory. The experiments were conducted between 2009–2011 (PC and RC 1). Treatments applied were:

- T 1 Traditional Trichogramma release practice.
- T2. Project research Trichogramma released recommendation.
- T3 Insecticide application
- T4 Untreated control

The following assumptions were made in calculating the costs / benefits associated with the modified IPM strategies; i. sugar price Rp. 8,500.00 /kg; ii cost of *Trichogramma* Rp. 620.00/card; iii. cost to place 1 card/Ha Rp. 200.00; iv. chemical price Rp. 36,000.00/ml; and, v. cost of harvesting Rp. 60,000.00/tonne cane.

5.7.2 White grub control using imidacloprid

The white grub experiments conducted at the two Javan sugar factories sites (Pesantren Baru and Ngadirejo) were used as a basis for the economic calculations. Treatments applied were as detailed in Tables 2 and 3.

5.7.2.1 Plant crop (PC)

Table 2: Treatments applied for white grub control in a plant crop at Pesantren Baru / Ngadirejo sugar factories

Treatment	Dose (g a.i./ha)	Timing
Imidacloprid	250	Planting
	375	Planting
	500	Planting
	250	Fill-in stage
	375	Fill-in
	500	Fill-in
Diazinon	25 kg/ha	Planting
Control (no treatment)		

5.7.2.2 First ratoon (1R)

Table 3: Treatments applied for white grub control in a ratoon crop at Pesantren Baru / Ngadirejo sugar factories

Treatment	Dose (g a.i./ha)	Timing
Imidacloprid	375	At ratooning
	500	At ratooning
	625	At ratooning
	500	Injected around root systems
Control (no treatment)		

Economic analyses drew on the following assumptions: i. sugar price Rp. 8.500,00 /kg, ii. diazinon price Rp. 24.700,00/kg; iii. Imidacloprid price Rp. 35.500,00/100 g (active ingredient).

5.8 Sugarcane streak mosaic virus (SCSMV) research

5.8.1 *SCSMV transmission experiments*

5.8.1.1 *Mechanical transmission*

There are several viruses that cause mosaic-type symptoms in Indonesian crops: *sugarcane mosaic virus* (SCMV), *sugarcane streak mosaic virus* (SCSMV) and *sorghum mosaic virus* (SrMV). Of these, sugarcane streak mosaic (SCSMV) is the most common mosaic causal agent.

Transmission research was undertaken to compare how mechanisms for SCSMV compare with SCMV. Several experiments were conducted including cutting disease-free seed-cane with a knife contaminated with SCSMV-infected cane juice. Healthy planting material was obtained and infected juice spread on a knife before cutting the healthy stalk material; suitable control treatments were also established. In addition, normal SCMV inoculation procedures were also used (pushing pins through infected leaves and into the young spindle leaves of healthy test canes). Replicated tests were performed at Pasuruan and ongoing observations made of all test plants.

5.8.1.2 *Homopteran insects*

Introduction: A project objective was to identify the vectors associated with the transmission of sugarcane mosaic in Indonesia. Vectors for each virus may be different so it is important to establish the vectors leading to transmission of each.

Method: Caged glasshouse plants of both mosaic-infected and healthy test plants were propagated at Pasuruan in ISRI facilities. Three insect species, collected from field crops, were maintained at Pasuruan for transmission studies; these were an aphid sp., *Rhophalosipum maydis* and *Ceratovacuna lanigera*. The aphid sp. was collected from the weed *Chloris barbata,* which is commonly found in canefields. *R. maydis* was collected from maize and *C. lanigera* was taken from a commercial crop of sugarcane. Insects were moved onto plants of the susceptible variety, PS 864 displaying mosaic symptoms. The insects were maintained on plants with cages; they were bred on these plants for 2 days. Insects were taken from the infected plants and transferred to healthy test plants of the same variety (1.5 months-old plants). The potential vectors were removed from the test plants after 1, 6 or 12 hours. Experiments were undertaken between August 2009 and January 2010. Leaf samples of healthy plants were collected for molecular assays pre- and post-infestation. At the same time the three insects were bred for 1 week in healthy sugarcane plants (PS 864) in separate cages. Observations for visual symptoms were then made for the remainder of the trial period (approximately four months).

5.8.2 *Serial hot water treatment for elimination of SCSMV*

The provision of clean planting material is very important for mosaic disease control. Experiments investigated whether different hot water treatment time x temperature combinations could eliminate the virus. In this experiment SCSMV-infected cane cuttings were immersed in hot water contained in a temperature-controlled water bath. Pre-treatment at 35°C for 30 minutes followed by treatment 50-60°C at various times. Combinations of temperature between 50 and 58^0 C were tested for periods ranging from 10-30 minutes. Some treatments were also applied to setts pre-hot water treatment to assess the potential for pre-disposing (protecting) the cane from the effects of hot water; pre-treatments were at 35^0 C.

5.8.2.1 Trial 1

Two-bud setts of the susceptible variety PS 864 showing streak mosaic symptoms were collected from a commercial crop in near Pasuruan. To confirm the presence of SCSMV, leaf samples were collected for PCR assay. Infected two-bud setts were treated as below (Table 4).

Table 4: Treatments applied to attempt elimination of SCSMV from infected two-bud setts.

No.	Pre-treatment	Treatment	
		Temperature (°C)	Time (minute)
1	35°, 1 day before HWT	50	30

2	As above	50	60
3	As above	50	120
4	As above	52	30
5	As above	52	60
6	As above	52	120
7	As above	55	30
8	As above	55	60
9	As above	55	120
10	As above	57	30
11	As above	57	60
12	As above	57	120
13	As above	60	30
14	As above	60	60
15	As above	60	120
16	As above	No	No
17	No	No	No

Each heat treatment was applied to 5 two-bud setts infected with SCSMV. Each treated sett was planted in a pot containing soil. The pots were on-grown in a glasshouse at Pasuruan.

Mosaic symptom observations were conducted from weeks 3 to 8 after planting. Mosaic symptom incidence was recorded on a regular basis; sett germination in each treatment was also recorded. Leaf samples were taken from each treatment for PCR assay eight weeks after sett germination was initiated.

5.8.2.2 Second trial

The second trial included the following treatments (Table 5).

Table 5: Hot water treatments applied to SCSMV-infected two-bud setts to attempt elimination of the virus from planting material.

No.	Treatment : soaked on hot water	
	Temperature (°C)	Time (minute)
1	52	10
2	52	20
3	52	30
4	53	10
5	53	20
6	53	30
7	54	10
8	54	20
9	54	30
10	55	10
11	55	20
12	55	30

5.8.3 Tissue culture to eliminate SCSMV

Research investigating tissue culture as a means for freeing sugarcane from SCSMV was investigated. Healthy plants of the susceptible PS 864 were established in a glasshouse at Pasuruan; after 1.5 months, some plants were sap-inoculated with SCSMV and maintained until six months of age. Callus, meristem and shoot tip culture treatments were then applied to SCSMV-affected plants; 41 replicates of each method were established (Table 6).

Table 6: Tissue culture treatments to eliminate SCSMV from diseased sugarcane

No.	Treatment	Materials	Top number	Number of plantlets	Plantlets grown in acclimatization stage
1.	Callus culture	Healthy PS 864	1	28	9
				43	41
		Infected PS 864	1	32	18
				47	39
2.	Shoot tip culture	-	-	-	-
3.	Meristem culture	-	-	-	-

5.8.4 Yield losses caused by SCSMV

Assessing yield losses caused by SCSMV is important in order to prioritise the disease as a cause of poor profitability in the Indonesian sugarcane industry. SCSMV is commonly found in Javan commercial crops, especially in the popular, but susceptible variety PS 864.

Yield losses were assessed by selecting an isolated field near Pasuruan. Five different levels of SCSMV severity were created by planting mixtures of diseased and healthy planting material to create the following proportion of diseased stools in plot: 0, 25, 50, 75 and 100% diseased. Each treatment was replicated 10 times; each replicate consisted of 2 rows x 6 m in length. Each 6 m length of row contained 20 stools.

Monitoring for SCSMV symptoms in each stool occurred monthly. Agronomic parameters such as stalk height, stalk diameter and number of stalks were recorded monthly when the crop was 6-12 months of age. At harvest, the weight of biomass and sugar content were calculated.

5.9 Extension activities

5.9.1 *Extension philosophy*

Extension is the process of enabling change in individuals, communities and industries involved in the primary industry sector and with natural resource management. Extension adds value to investment by ‘providing a bridge between science (and) changed practice’. Extension in this project aimed to convey the survey findings / research outputs, plus prior research and knowledge, to effect change among Javan cane farmers and plantation managers.

Integrated pest management (IPM) is a complex issue to extend. It involves major changes of attitude (from pesticides to natural or biological control) plus the overturning of beliefs that there is a pesticide solution to every problem before changes in practice can occur. In general terms it has been found that the more complex the innovation, the greater the resistance to innovation. During project extension activities, local survey data were presented along with information on successful control programs in other sugar industries where borers are a major pest. This challenged old attitudes amongst participants, There was also a strong emphasis on ‘hands on’ experience for participants. Previous work by Rustam in East Java showed that farmers and managers were prepared to adopt IPM. Rustam surveyed farmers who had attended IPM farmer field schools to determine the effects of the training. He found that attending the farmer field schools significantly increased the IPM skills and knowledge among participating farmers and improved diffusion of IPM by those farmers to other farmers.

Given that there are around 750,000 Java cane farmers, only key groups could be targeted through an extension campaign associated with this project; changes outside the target group rely on diffusion of new skills and knowledge.

5.9.2 Extension strategy

The sugar industry in Java comprises 35 government-owned and 11 private sugar factories and associated plantations. The factories are also supplied with cane by private farmers, mostly small producers from mixed farms. To cater for the industry's structure, extension activities were conducted using two main approaches: one was to raise awareness of productivity impacts of pests and diseases / the project itself amongst factory board members, factory and plantation managers and some larger farmers. These are key industry decision-makers. Large industry meetings (100–200 attendees) were held at ISRI, Pasuruan (East Java) in 2009, 2010 and 2011 with these people. At the meetings, presentations by project scientists highlighted the project aims, research outputs and potential industry outcomes.

The second approach was aimed at end users. It was with this group in mind that group activities such as champion farmer days, training workshops and farmer field schools were conducted; other resources used to support these activities included borer fact sheets and the field guide.

5.9.2.1 Industry-wide meetings – Pasuruan

Three large annual meetings were held in Pasuruan to keep industry leaders and decision makers informed about the aims and progress of the project. At the first meeting in April 2009, team members spoke on the aims of the project, early project findings and experience with similar borers in other countries. At the initial meeting, Indonesian team members surveyed participants to gauge industry leaders' attitudes to pest and disease management. Latter meetings concentrated on key research findings.

5.9.2.2 Regional training workshops

Five regional training workshops were held between November 2009 and April 2010 for 46 sugar factories across Java. Total attendance at the workshops was 239 with more than 30% of the participants being private cane growers. Topics at the workshops included: -

- identification of pests and diseases and their management
- objectives of the project and up-to-date project results
- biological control of borers including quality control
- disease-free nursery material.

Presentations were made by ISRI scientists Ari Kristini, Etik Achadian and Trikuntari Dianpratiwi; Peter McGuire (Australian extension specialist) was an observer. The workshop format included presentation of pest and disease information in the morning sessions followed by pest and disease identification after lunch - using specimens collected that morning. All registered participants received a workshop manual.

Extension also addressed technology transfer in the form of Farmer Field Schools (FFS). In 2012, training and FFS activities focused on farmers and sugar factory staff under the management of the PTPN IX and XI sugar factory groups. Training addressed *Trichogramma* breeding in the laboratory, while the farmer field schools focused on IPM of sugarcane borers. In July 2012, training / farmer field schools were undertaken for PTPN XI at Jatiroto sugar factory, while for PTPN IX, this was conducted in November 2012 at the Sragi sugar factory.

A simple questionnaire was distributed to participants at these training sessions to better understand knowledge of pests and diseases possessed by sugar factory staff / farmers. The questionnaire for PTPN XI contained eight questions with four addressing pests and four on diseases. For PTPN IX factory staff, the questionnaire contained 10 questions (five on pests, five on diseases). Participants were asked to evaluate the experience at the end of each workshop.

5.9.2.3 Borer workshop

Consistent with the project's aim to develop an IPM program for borers, workshops focussed on borer management using *Trichogramma* wasps. François-Régis Goebel and Etik Achadian presented on biological control of moth borers, particularly the use of *Trichogramma* parasitoids. Presentations focused on the results of the borer trial at Pesantren Baru (East Java), recommended doses and release times, quality control for *Trichogramma* rearing facilities, monitoring treatment effectiveness and release techniques in the field.

5.9.2.4 Champion farmers

Champion farmers are farmers who are seen as role models by their peers. They are respected as farmers because of their high production and they have high credibility among their fellow farmers. Other traits of champion farmers may include: innovative and a greater willingness to accept/adopt new ideas compared to their peers; higher formal education compared to peers; better use of media; empathetic; willing social participants. They should also be farming on a significant scale and be knowledgeable about the timing of operations. These social and technical characteristics give them the ability to impart skills and knowledge to other farmers.

At least four group activities were conducted on each champion's farm with technical help available on each occasion. Activities centred on identifying borers and borer damage as well as correct timing, dosage and placement of the egg cards (containing *Trichogramma* parasitoids). A final field visit was held just prior to harvest to assess the success or otherwise of the treatments. Visiting farmers were encouraged to apply IPM treatments themselves to ensure they were doing it correctly.

Farmer Field Schools were held on the farms of local champions. François-Régis Goebel and Peter McGuire participated in the Farmer Field School held near Kediri in East Java. The format of the field schools is similar to the workshops but everything occurs in the field, some presentations were made in a marquee amongst the champion farmer's fields. These events were catered for, and had a strong social aspect which encourages a good learning environment. Farmer Field Schools are a preferred way to disseminate new technology among growers in Indonesia. As well as being in a familiar environment, farmers can discuss issues present in the field as well as seeing first-hand best-practice management methods.

5.9.2.5 Extension of the economics of borer control

Project research by François-Regis Goebel and Etik Achadian investigated current vs best practice management techniques for stem borers. The extension program made use of these data in farmer training; this became an important part of project extension activities.

5.9.2.6 Borer fact sheets

Two fact sheets on moth borer damage and management were prepared by entomology and extension project staff. The first, titled 'Moth Borers: Major Pests of Sugarcane' describes borer damage, the differences between top borers and stem borers, how to monitor for the pests, what farming practices influence borer damage and the importance of maintaining biodiversity in cane fields. The second, 'Controlling sugarcane borers with Trichogramma', provides information on biological control (using *Trichogramma* wasps), how the wasps parasitise the moth borer eggs, recommended parasitoid numbers and timing of release plus the importance of monitoring and avoiding the use of insecticides after release.

Both fact sheets make extensive use of photos and were initially written in English before being translated into Bahasa by Indonesian team members. The fact sheets will be used to support Indonesian extension activities into the future.

5.9.2.7 Field guide

A pocket-sized field guide of Indonesian and exotic pests and diseases was produced and distributed to industry as a significant project activity. The 150-page guide contains extensive colour photos showing the symptoms/effects of insect and disease infestation as well as brief descriptions of damage and causal agents, means of transmission/spread when the damage occurs and the economic significance of the pest or disease. Control measures and other aids to identification are also given.

6 Achievements against activities and outputs/milestones

Objective 1: To determine the distribution and incidence of stem borers, insect vectors and natural enemies in Java

no.	Activity	outputs/ milestones	completion date	comments
1.1	Surveys	Data on incidence and severity of pests, diseases and parasitoids	June 2009	Data are presented in this paper. *Chilo sacchariphagus* / *Scirpophaga excerptalis* were the most important mother borers. Sugarcane streak mosaic virus was widespread and the main cause of mosaic symptoms.
1.2	Sequential sampling plan	Crops were sampled and data recorded.	June 2008	Survey data was obtained, analysed and reported.
1.3	Ecological studies	Data on incidence of moth borers on a monthly basis and in four locations	June 2009	Monthly monitoring of crops was undertaken at four sites over a long period and this provided valuable data on variation through season and sites.

PC = partner country, A = Australia

Objective 2: To identify insect vectors and assess their transmissibility for mosaic-type virus

no.	Activity	outputs/ milestones	completion date	comments
2.1	Identify vectors	Insect vectors were collected and potential agents recognised	June 2010	Four species were tested and two found that led to transmission of SCSMV.

PC = partner country, A = Australia

Objective 3: To develop an integrated pest management (IPM) program

no.	Activity	outputs/ milestones	completion date	Comments
3.1	Role of natural enemies	Evaluate and measure the role of natural enemies	June 2011	Parasitoids were collected from the field and identified. Their incidence and effect on moth borers in the field were assessed through visual observation. The most important ones were identified..
3.2	Soft pesticides	Test the effect of soft pesticides	Not completed	A decision was made to not test soft pesticides as the introduction of chemicals into the Indonesian environment was considered deleterious (Indonesian scientists were not keen). Their effect on parasitoids was also considered undesirable

PC = partner country, A = Australia

Objective 4: To transfer new technologies using appropriate extension methods to the farming, scientific and quarantine community

no.	Activity	outputs/ milestones	completion date	comments

4.1	IPM training	Training workshops conducted	January 2013 (on-going)	A number of training workshops were conducted, including larger regional meetings and smaller local meetings. There was a good response at each of these forums.
4.2	Industry leaders / champion farmers	Select suitable leaders / farmers	June 2009	Champion farmer technique worked well; other farmers were invited to attend local meetings on these farms; local and international scientists gave presentations at these meetings
4.3	Training workshops	Train 200 farmers in IPM	June 2012	Over 250 farmers received training in IPM strategies; this included both sugar factory staff and local farmers.
4.4	Demonstration plots	Select four sites and put in place IPM strategies	June 2010	Sites were selected and IPM strategies demonstrated. They provided very useful locations to illustrate the advantages of improved PM strategies.
4.5	Extension materials	Leaflets, Field guide, manuals and videos	June 2012	2,000 copies of the Indonesian pest and disease field guide were produced and distributed; this will be a lasting legacy for the project. Additional funds were obtained from ACIAR to translate the guide into English and this will be a valuable resource for scientists from other countries. Fact sheets and manuals were produced and these also proved valuable in extension work.

PC = partner country, A = Australia

7 Key results and discussion

Section 7: Results and Discussion

7.1 Introduction

Project outputs included increased awareness of pest-associated losses, more effective IPM strategies for stem borer, improved understanding of *sugarcane streak mosaic virus*, improved extension materials for local cane farmers, a better understanding of stem borer ecology, and improved biological control laboratory outputs and applications. A field guide was produced to enable easier identification of pests and diseases and adoption of technologies by cane farmers. Technical reports, conference papers and journal articles were written to ensure the scientific community was made aware of research and extension developments.

7.2 Survey:

7.2.1 Stem borers

7.2.1.1 *Species identification and damage symptoms*

During the general survey, in which 931 commercial crops in Java were surveyed, five species of moth borers belonging to four families were encountered; these were*: Chilo auricilius, Chilo sacchariphagus* (Lepidoptera: Crambidae), *Scirpophaga excerptalis* (Lepidoptera: Pyralidae), *Sesamia inferens* (Lepidoptera: Noctuidae) and *Tetramoera schistaceana* (Lepidoptera: Tortricidae). Both *S. inferens* and *T. schistaceana* were very rarely encountered and were not included in statistical analyses. The following are useful identification characteristics / damage symptoms of these pest species.

***Chilo auricilius* (Stalk borer)**

This pest causes dead heart in young cane and damages internodes in advanced crops. The larval stage is distinguishable by the existence of five dark longitudinal lines along the body, while damage symptoms can be distinguished by the transparent feeding marks early instar larvae cause on young leaves before they unfold. Feeding by mature larvae causes a thin, straight feeding tunnel inside the internode (Figure 1), while the moth's exit hole is neatly round.

***Chilo sacchariphagus* (Stalk borer)**

Similarly to *C. auricilius*, this pest causes dead heart in young cane and damages internodes in advanced crops. The larval stage can be distinguished by the existence of four longitudinal stripes formed by the spots on the dorsal side. Unlike *C. auricilius*, feeding by young larvae leaves a line of holes on young leaves, while mature larvae cause uneven-branchy tunnels inside the internodes (Figure 1). The moth's exit hole is oval in shape.

***Scirpophaga excerptalis* (Top borer)**

Feeding by young *S. excerptalis* larvae leaves horizontal parallel rows of 'shot holes' that become apparent when young leaves unfold (Figure 1). Unlike species of *Chilo*, the larval stage of *S. excerptalis* does not tunnel in cane stalks (hence does not damage the internodes) but rather moves down the plant shoot (top) towards the growing point, mainly causing dead heart and a bunchy top appearance of shoots (Arora 2000).

***Sesamia inferens* (Shoot borer)**

This species is mainly a pest of rice and is rarely found infesting sugarcane in Java. It was occasionally encountered during the general survey in East and Central Java but not in West Java. This species is a shoot borer and causes dead heart in young cane plants. Larvae are distinguished by their purple or pink dorsal colour and white ventral colour (Kalshoven 1981; David *et al.* 1991) (Figure 1).

Tetramoera schistaceana (Shoot borer)

This species was occasionally encountered in all three regions of Java (East, Central and West Java). *Tetramoera schistaceana* is an early shoot borer which mainly causes dead heart in young plants (Williams 1978; Cheng and Wang 1997). In mature plants, larvae feed externally on the internodes and around the buds but usually cause minor damage (Figure. 1).

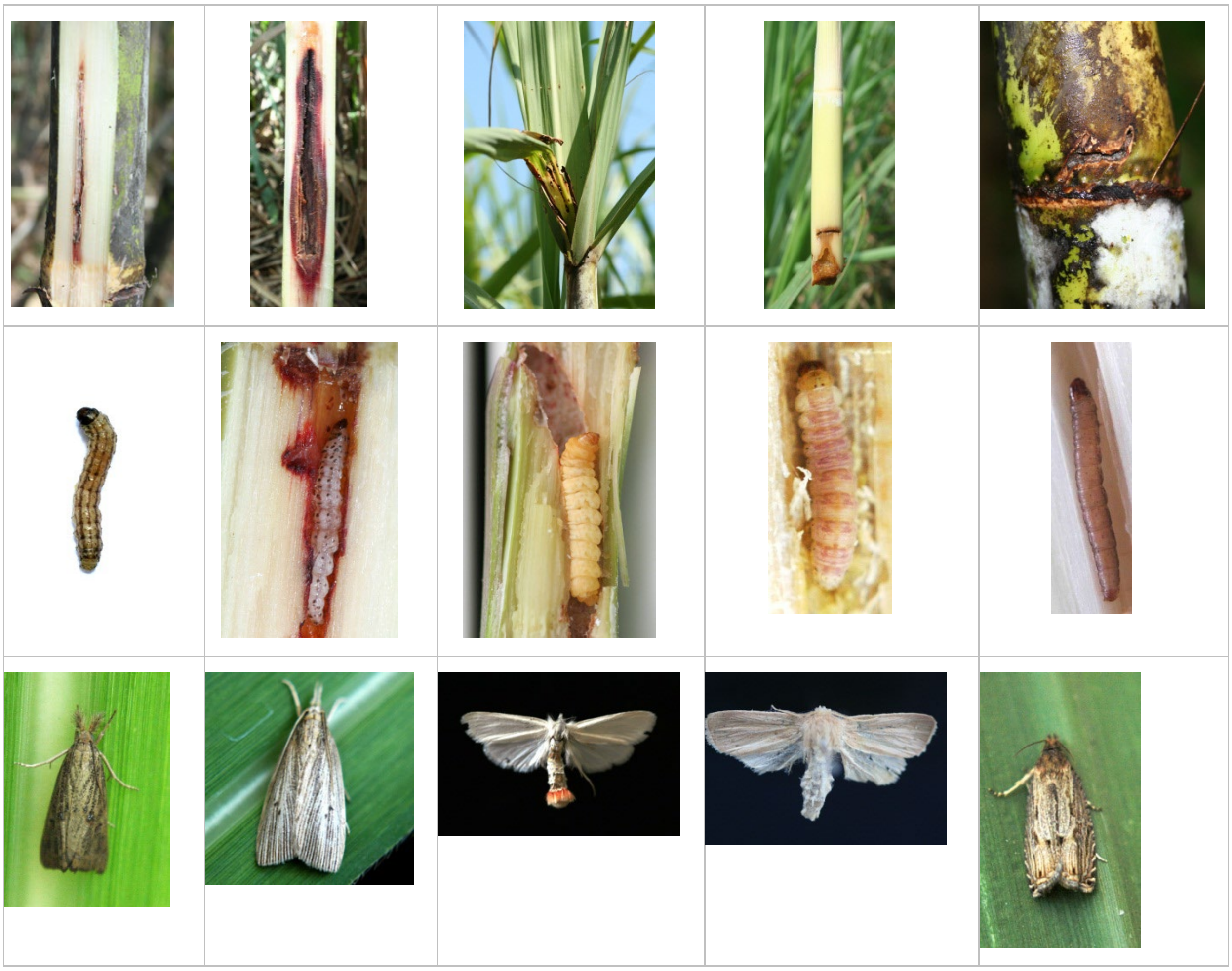
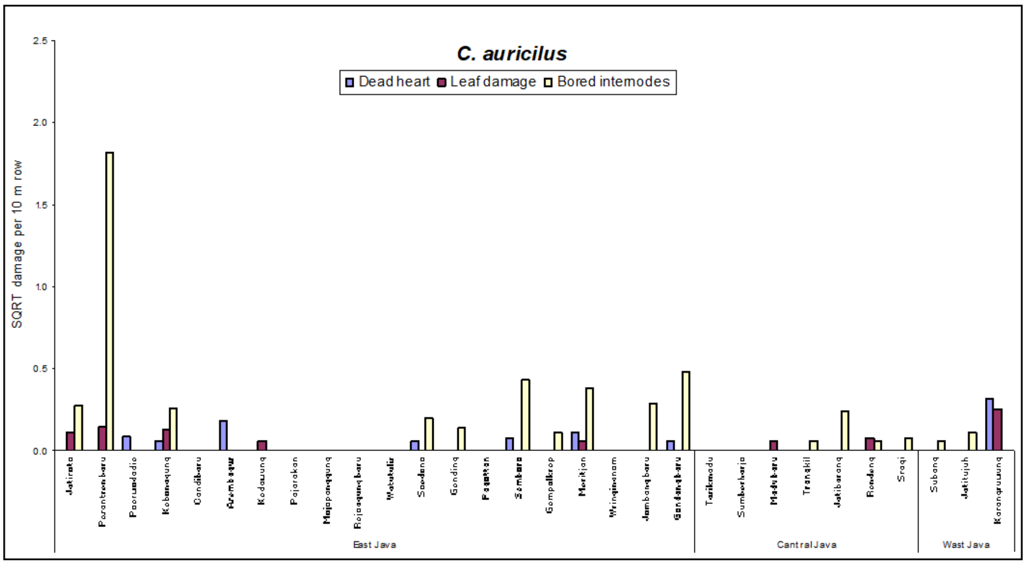


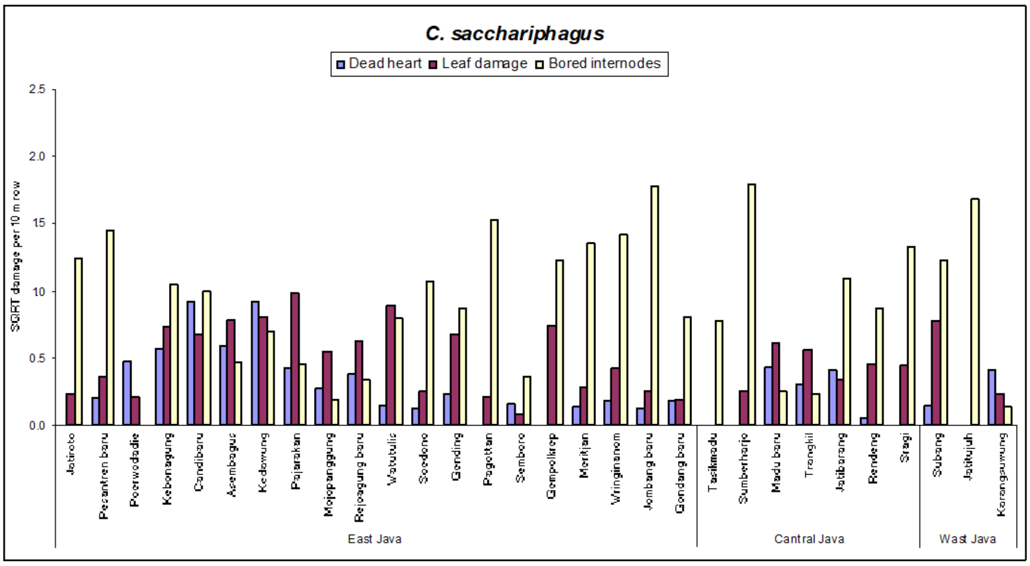
Figure 1: Damage symptoms (first row), larval stages (second row) and adult stages (third row) of *Chilo auricilius, Chilo sacchariphagus*, *Scirpophaga excerptalis*, *Sesamia inferens* and *Tetramoera schistaceana*.

7.2.1.2 Infestation levels

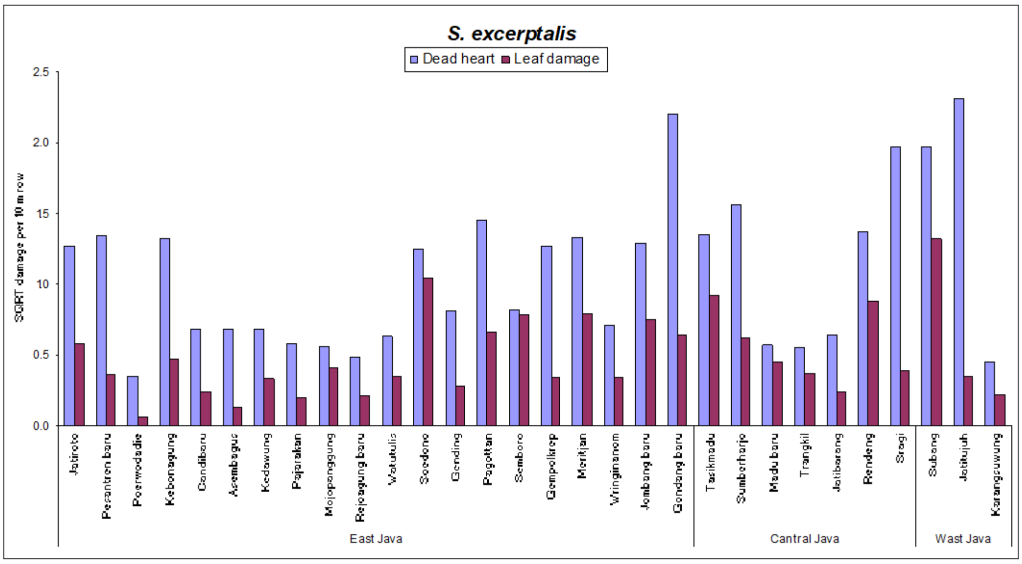
Figure 2. (a, b and c) illustrates damage levels for *C. auricilius*, *C. sacchariphagus* and *S. excerptalis* in 30 sugar factories across the island of Java. Survey results showed that *C. auricilius* was responsible for low damage levels in a number of sugar factories, but it was widespread in Pesantren Baru sugar factory (East Java), where infestation resulted in an average of 3.3 bored internodes/10 m row. This was significantly higher than damage levels caused by this species in all other sugar factories (0.0 – 0.2 damaged internodes/10 m row ($F= 17.49$; $DF=29,901$; $P<0.0001$).


C. auricilus
Dead heart
Leaf damage
Bored internodes
SQRT damage per 10 m row
2.5
2.0
1.5
1.0
0.5
0.0
East Java
Cantral Java
Wast Java

(a)


C. sacchariphagus
Dead heart
Leaf damage
Bored internodes
SQRT damage per 10 m row
2.5
2.0
1.5
1.0
0.5
0.0
Jatiroto
Pesantren baru
Poerwodadie
Kebonagung
Candibaru
Asembagus
Kedawung
Pajarakan
Mojopanggung
Rejoagung baru
Watutulis
Soedono
Gending
Pagottan
Semboro
Gempolkrep
Meritjan
Wringinanom
Jombang baru
Gondang baru
Tasikmadu
Sumberharjo
Madu baru
Trangkil
Jatibarang
Rendeng
Sragi
Subang
Jatitujuh
Karangsuwung
East Java
Cantral Java
Wast Java

(b)


S. excerptalis
Dead heart
Leaf damage
SQRT damage per 10 m row
2.5
2.0
1.5
1.0
0.5
0.0
Jatiroto
Pesantren baru
Poerwodadie
Kebonagung
Candibaru
Asembagus
Kedawung
Pajarakan
Mojopanggung
Rejoagung baru
Watutulis
Soedono
Gending
Pagottan
Semboro
Gempolkrep
Meritjan
Wringinanom
Jombang baru
Gondang baru
Tasikmadu
Sumberharjo
Madu baru
Trangkil
Jatibarang
Rendeng
Sragi
Subang
Jatitujuh
Karangsuwung
East Java
Cantral Java
Wast Java

(c)

Figure 2: Mean damage caused by a) *C. auricilius*, b) *C. sacchariphagus* and c) *S. excerptalis* in 30 sugar factories across Java.

On the other hand, *C. sacchariphagus* symptoms were encountered in all sugar factories across Java, with significantly high damage levels in Sumberharjo and Jombang Baru sugar factories (F= 9.44; DF=29,901; P<0.0001), where infestation levels averaged 3.2 and 3.1 bored internodes/10 m row, respectively; damage levels > 0.2 bored internodes/10 m row were experienced in most factory areas. This species was found to be the main cause of bored stalks in Java, with an overall average of 1.13 bored internodes/10 m row (compared to 0.19 / 0.0 bored internodes/10 m row from *C. auricilius* and *S. excerptalis* respectively (F= 193.75; DF=2, 2790; P<0.0001) (Figure 3).

S. excerptalis was present in all surveyed sugar factories. This species was the main cause of dead heart symptoms in young and mature plants. Results suggested damage ranged between 0.12-5.3 dead hearts/10m row, with 15 sugar factories recording more than 1.5 dead hearts/10m row. On the whole, *S. excerptalis* caused an overall average of 1.4 dead heart/10 m row, significantly higher than mean data for *C. sacchariphagus* and *C. auricilius* (0.13 / 0.005 dead heart/10 m, respectively) (F=293.87; DF=2,2790; P<0.0001).

In addition, this species was also the main cause of leaf damage due to borers, with an overall average of 0.33 damaged leaf tops/10 m row. This was significantly higher that leaf damage caused by *C. sacchariphagus* and *C. auricilius* (0.27 and 0.005 bored leaf tops/10 m, respectively) (F=77.76; DF=2,2790; P<0.0001) (Figure 3).

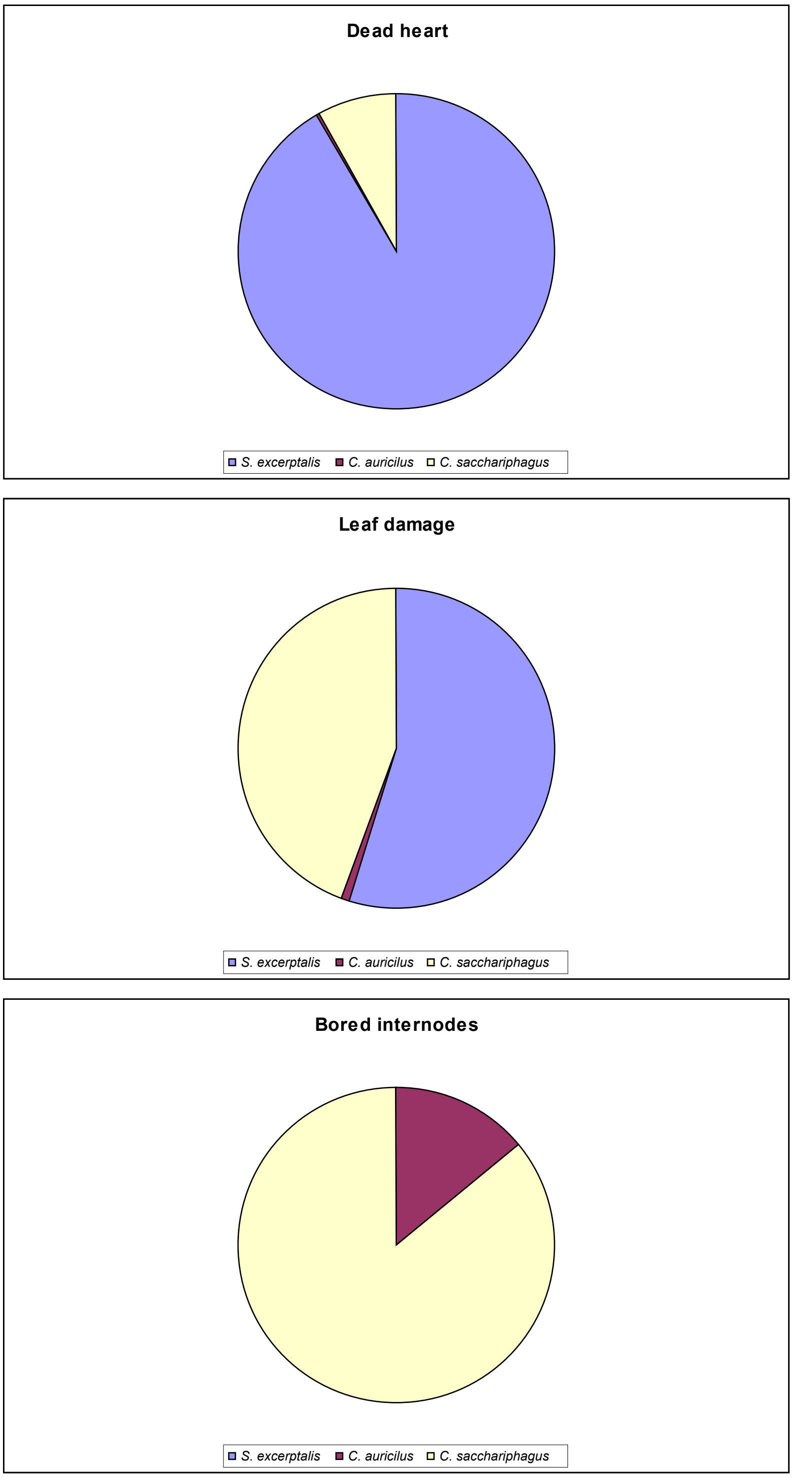
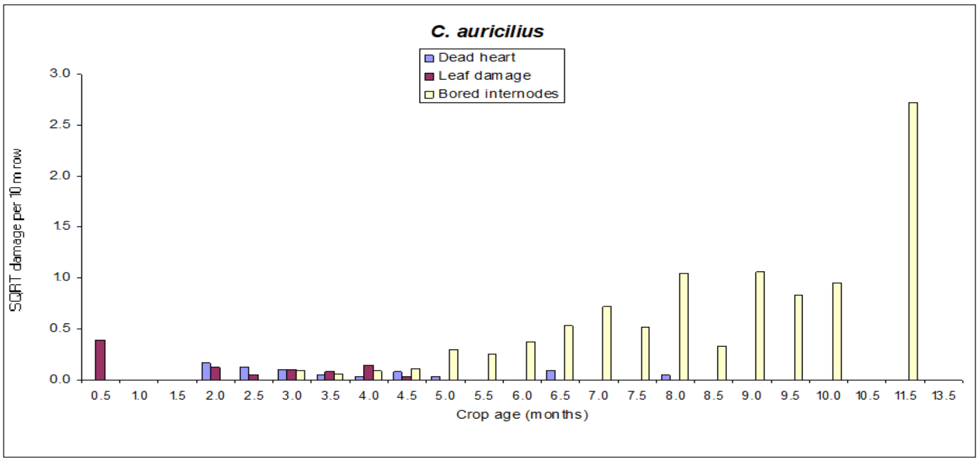


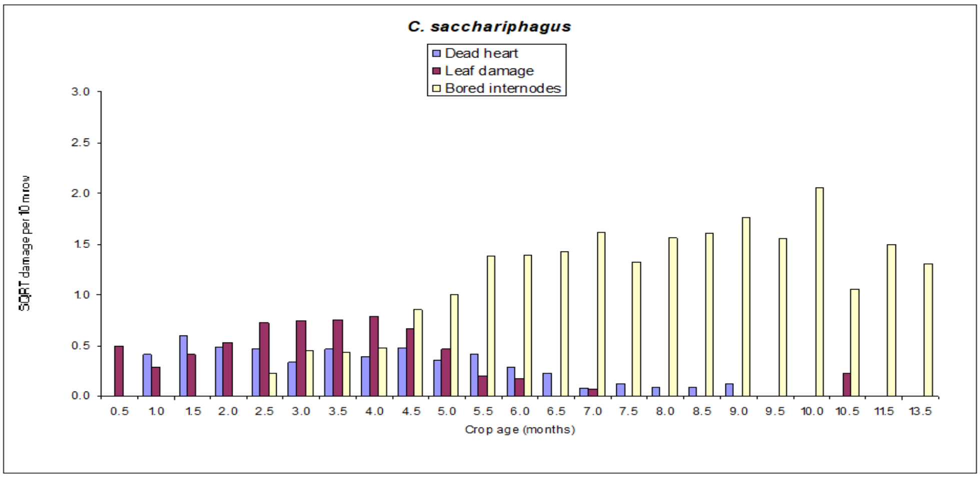
Figure 3: Comparison of dead heart, leaf damage and bored internodes overall mean / 10 m or row caused by *C. auricilius*, *C. sacchariphagus* and *S. excerptalis* across Java.

Borer infestations varied according to crop age (in months) and crop class (plant cane or successive ratoons). Infestations by *C. sacchariphagus* and *C. auricilius* resulted in dead heart and leaf damage symptoms in younger cane; in older cane, bored internodes was the predominant symptom.

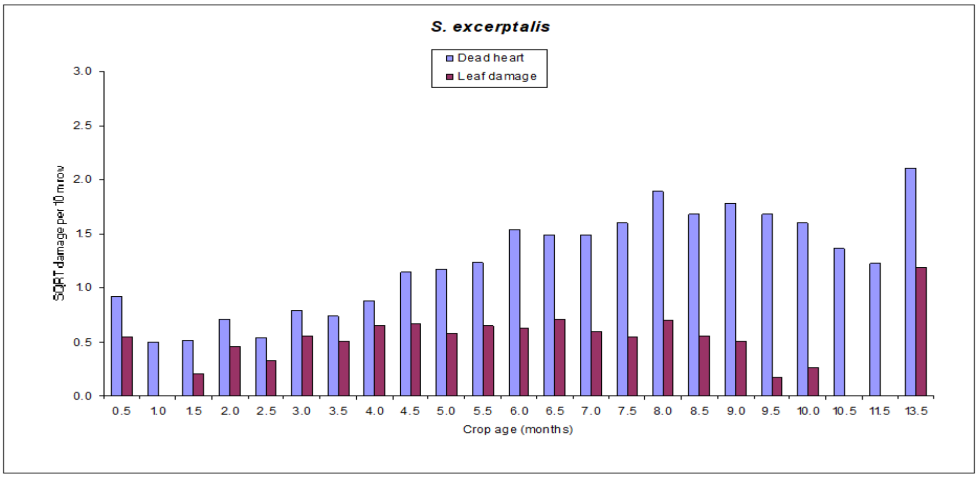
With *S. excerptalis*, there was a tendency for more leaf damage / dead heart symptoms to become more apparent as the crop aged, and in older ratoons; 5th and 6th ratoons showed significantly more dead heart symptoms compared to early ratoons or plant cane (F=3.87; DF=6,924; P=0.0008) (Figures 4 and 5).



(a)



(b)



(c)

Figure 4: Comparison of mean damage caused by (a) *C. auricilius*, (b) *C. sacchariphagus* and (c) *S. excerptalis* at different crop ages across Java.

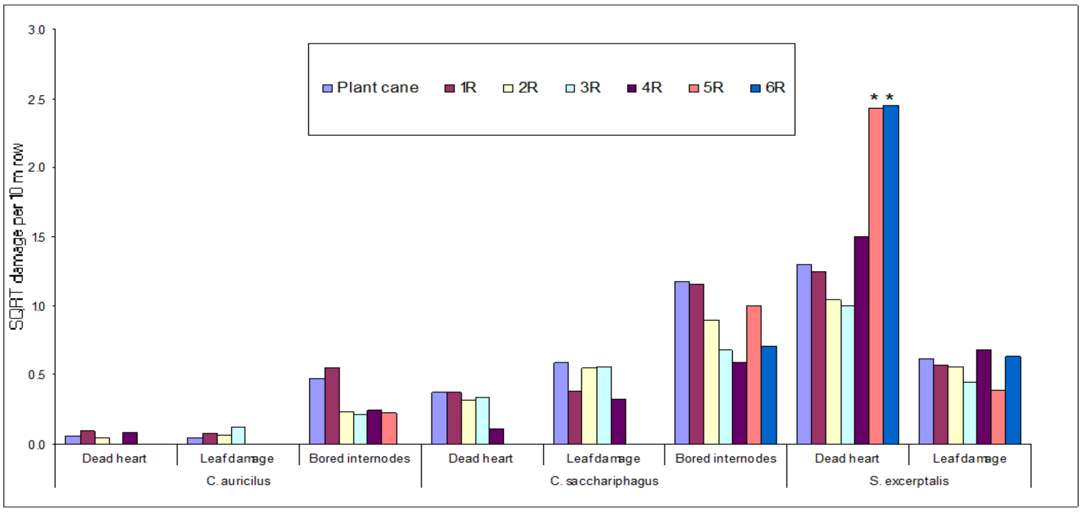


Figure 5: Comparison of mean damage caused by *C. auricilius*, *C. sacchariphagus* and *S. excerptalis* in plant and ratoon crops across Java. (*) indicates significant difference within the same category and borer species.

Data analysis showed that *S. excerptalis* damage varied according to farm ownership, with farms managed by sugar factories suffering significantly more dead heart (1.82) and leaf damage (0.42) per 10 m row, (compared 1.23 dead heart / 0.27 leaf damage per 10 m row in farms managed by farmers, respectively (F=13.44; DF=1,929; P=0.0003) and (F=8.81; DF=1,929; P=0.0031) (Figure 6). This is probably due to individual farmers diversifying their cropping practices and not relying on sugarcane alone. Individual farmers also tend not to grow as many ratoons as sugar factory-owned estates, and this is likely to result in the interruption of the pest's life cycle. Conversely, this correlation with farm ownership was not significant in most cases for *C. sacchariphagus* and *C. auricilius* damage.

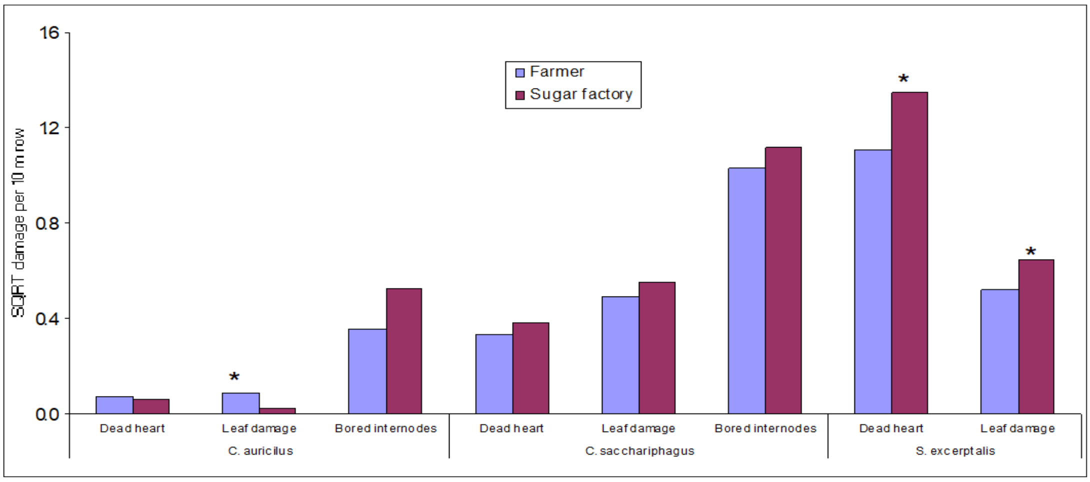


Figure 6: Comparison of mean damage caused by *C. auricilius*, *C. sacchariphagus* and S. *excerptalis* in farms owned by the sugar factory or by individual framers in Java. (*) indicates significant difference within the same category and borer species.

It was also interesting to observe that *C. sacchariphagus* damage symptoms were more prevalent than those caused by *C. auricilius* in irrigated (vs rain-fed) plantations (Figure 7). *C. sacchariphagus* may be better adapted to wetter regions, compared to *C. auricilius*. This agrees with studies by Suhartawan (1998), who observed that high humidity was correlated with increased infestation levels by *C. sacchariphagus*. However, other studies by Soma & Ganeshan (1999) in Mauritius showed that the highest *C. sacchariphagus* infestation was in the subhumid non-irrigated zone in 1996 and in the humid non-irrigated zone in 1997. An additional consideration is that it is not clear if the species referred to as *C. sacchariphagus* is in fact one species; it is often treated as three subspecies: *Chilo sacchariphagus sacchariphagus* (Bojer), *Chilo sacchariphagus stramineellus* (Caradja) and *Chilo sacchariphagus indicus* (Kapur). Bleszynski (1970) concluded that all populations belong either to one widely-spread species or to several phylogenetically young species. Nevertheless, it is evident that different populations show considerable variation in behaviour. Further genetic studies are required to clarify the status of the *C. sacchariphagus* complex.

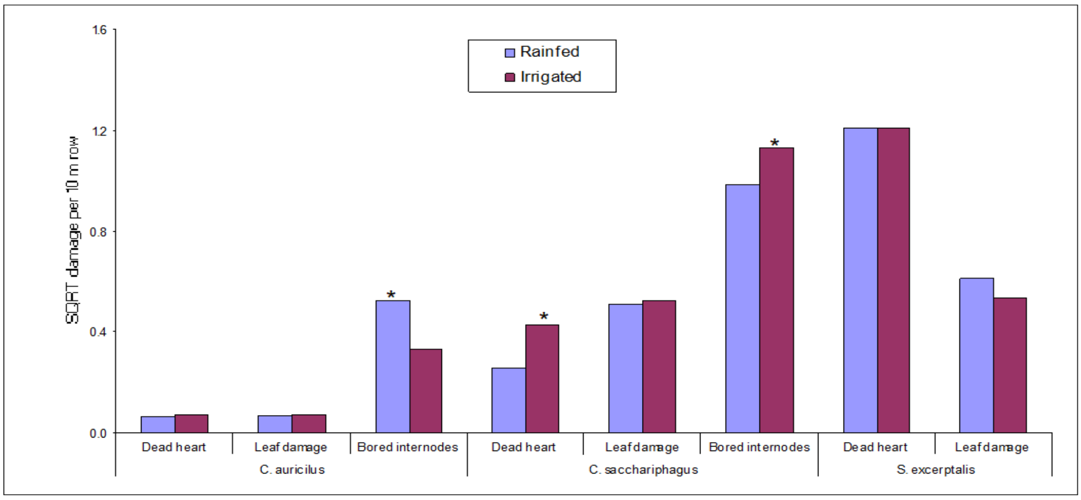


Figure 7: Comparison of mean damage caused by *C. auricilius*, *C. sacchariphagus* and S. *excerptalis* in irrigated and rain-fed cane plantations across Java. (*) indicates significant difference within the same category and borer species.

Similarly, while the current survey suggests that *C. auricilius* is a less abundant stalk borer compared to *C. sacchariphagus* in Java, that species was recognised by Indonesian scientists as more widely distributed than *C. sacchariphagus* in Java in the early 1990s; its status seems to have changed in recent years (Joko Pramono, personal communication).

C. auricilius is considered to be one of the most damaging cane pests in northern India and it is also recorded to feed on rice and considered to be one of its key pests in Bangladesh and parts of India and China (Husain & Begum 1985; Meng *et al.* 1997; Neupane 1990). Yet *C. auricilius* is not recorded as a significant pest of rice in Java, where it feeds predominantly on sugarcane. Hattori & Siwi (1986) reported it feeding on rice for the first time in Java and South Kalimantan in the 1980s.

It is clear that more DNA phylogenetic studies are needed for both *Chilo sacchariphagus* and *C. auricilius* to ensure the establishment of the most appropriate pest management strategies.

For *S. excerptalis*, four parasitoid species were recorded attacking the larval stage; these were *Rhaconotus roslinensis* Lal., *Rhaconotus scirpophagae* Wilkinson, *Stenobracon* sp. (Hymenoptera: Braconidae), *Elasmus* sp. (Hymenoptera: Elasmidae), while one species was recorded to attack the pre-pupal stage, and that is *Isotima* sp. (Hymenoptera: Ichneumonidae). All parasitoids were responsible for fairly low parasitism levels, and more work is required to investigate ways of improving their impact in cane fields in Java.

7.2.2 Parasitoids

During the survey it was not possible to collect egg parasitoids (*Trichogramma* sp and others). Two main parasitoids attacked *C. sacchariphagus* larvae - *Diatraeophaga striatalis* Townsend (Diptera: Tachinidae) and *Cotesia flavipes* (Hymenoptera: Braconidae). However, *C. flavipes* was not recovered from *C. auricilius* despite it being widely regarded as a key parasitoid of this species across Asia (Nair, 1958; Butani, 1972; Nigam, 1984; Tanwar and Varma, 1996). Mohyuddin (1991) stated that a local Indonesian strain of *C. flavipes* was encapsulated in *C. auricilius* in Sumatra, but a strain from Thailand was introduced and this resulted in high rates of parasitism of both *C. auricilius* and *C. sacchariphagus*. Our results suggest that encapsulation may remain a problem in Java, where *C. auricilius* has proven to be an unsuitable host for *C. flavipes* even when larvae were stung by parasitoids in the laboratory (Etik Achadian, unpublished data); more work is needed to investigate this problem. For *S. excerptalis*, four parasitoids attacked the larval stage - *Rhaconotus roslinensis* Lal., *Rhaconotus scirpophagae* Wilkinson, *Stenobracon* sp. (Hymenoptera: Braconidae) and *Elasmus* sp. (Hymenoptera: Elasmidae) - while one species attacked the pre-pupal stage, *Isotima* sp. (Hymenoptera: Ichneumonidae). All parasitoids were responsible for low parasitism levels, and more work is required to investigate ways of improving their impact in cane fields in Java.

7.2.3 Pest Implications for Australia

Climatic indices were used to match environmental conditions in the townships of Pasuruan (East Java) and Bogor (West Java) to selected sugarcane-growing areas in Australia. It was found that similar conditions were present in towns in central and northern Queensland; it is likely that the Indonesian moth borers would quickly colonise areas of tropical and subtropical regions of Queensland, if an incursion occurred. Plans to prepare for any sudden incursion are most important. It is also understood that species status changes sporadically over time; this study highlighted behavioural variation between Indonesian moth borers and the same species in Asia and on the Indian Ocean islands. Moreover, information gained during this work highlighted the importance of further studying the pest/natural enemy relationship in the sugarcane ecosystem in Java, and investigating reasons for the failure of *Cotesia flavipes* to parasitise larvae of *Chilo auricilius*.

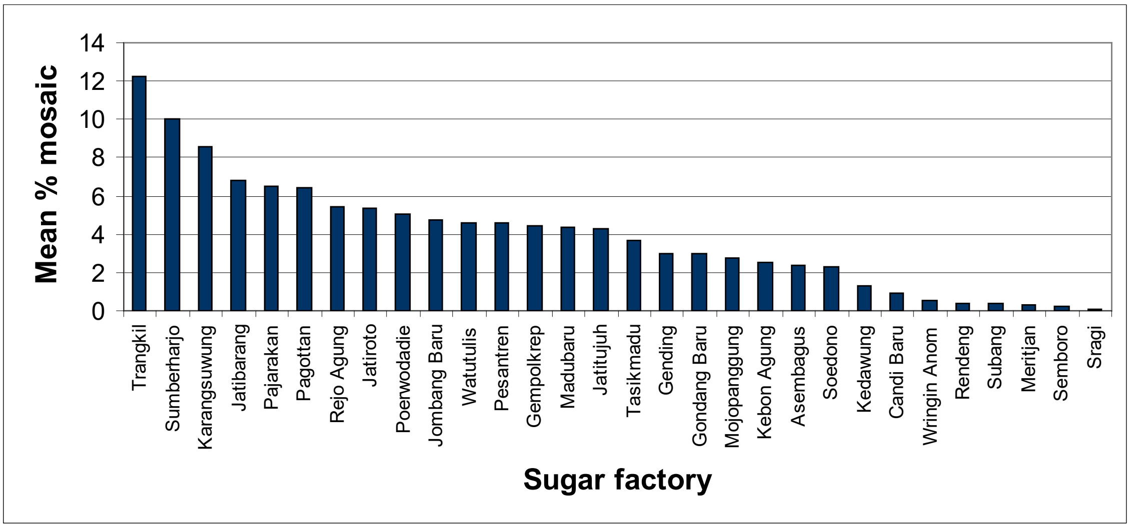
There is also a need to examine the range of natural enemies in Australia and whether they can parasitise exotic species. Incursion Management Plans have been compiled by BSES, and these contain comprehensive dossiers on the biology, ecology and management of world moth borers, including the Indonesian species (Sallam and Allsopp 2008 a and b). An Australian study has tested the Australian *Cotesia nonagriae* (Olliff) (Hymenoptera: Braconidae) against exotic moth borers (Kate Muirhead, Personal Communication). In light of the information obtained in this work, it is apparent that moth borer monitoring in Indonesia should continue and be considered a key part of any management program. This will ensure accurate targeting of the correct pest species, and will enable the timely detection of any change in pest status and distribution over time. Information obtained during the general / monthly surveys will improve our knowledge of the nature of these pests, and will ultimately ensure a coordinated Emergency Response by the Australian sugar industry in the case of a sudden pest incursion.

7.2.4 Disease survey data

The timing of disease assessments in some crops did not coincide with maximum severity, this particularly applied to leaf diseases. It was not possible to undertake such a large scale survey with optimal timing for all pests and diseases. This resulted in an under-estimate of their severity. One of the most important diseases in Java, are various forms of sugarcane mosaic. Symptoms of these diseases are evident through the season and survey results provide a reasonable assessment of their likely severity and affected areas. Leaf samples collected from the survey were assayed at BSES laboratories; SCSMV was found to be present in around 90% of leaves showing mosaic symptoms, while SCMV accounted for the remaining samples. These results were pivotal in understanding the role of each virus in Javan cane crops.

7.2.4.1 Mosaic

The incidence of mosaic in crops in the different sugar factories and in the infestation levels in individual crops are detailed in Figure 8.



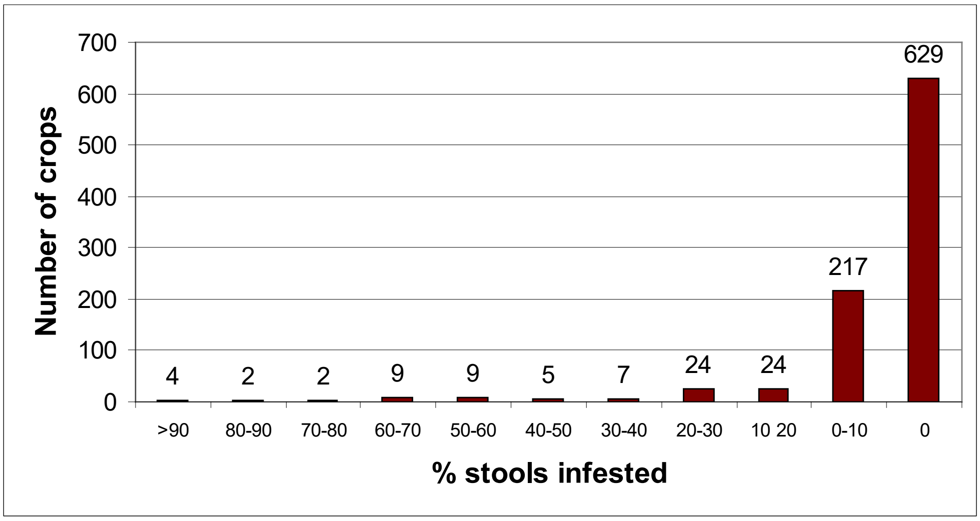


Figure 8: The frequency of mosaic-affected crops in each surveyed sugar factory area in Indonesia (top), expressed as a percentage of number of sampled crops infested, and the incidence of mosaic in individual crops expressed as the percentage of stools infested (bottom); most crops were not infested in this survey.

Molecular assay of general survey specimens

Data of mosaic samples collected from surveys are listed in Table 1.

Table 1: details of mosaic samples collected from the general disease surveys and assay results.

No.	Sugar Factory	# fields	# mosaic samples
1	Jatiroto	40	Mosaic samples not collected
2	Sumberharjo	40	Mosaic samples not collected
3	Jatitujuh	25	No mosaic
4	Tasikmadu	38	Mosaic samples not collected
5	Pesantren Baru	44	Mosaic samples not collected
6	Madubaru	30	6 samples from 5 fields
7	Purwodadi	30	11 samples /10 fields
8	Kebonagung	30	16 samples / 15 fields
9	Candi Baru	30	19 samples / 19 fields
10	Asembagus	30	21 samples / 21 fields
11	Karang Suwung	30	12samples / 12 fields
12	Kedawung	30	24 samples / 24 fields
13	Trangkil	30	14 samples / 14 fields
14	Mojopanggung	30	6 samples / 5 fields
15	Pajarakan	30	14 samples / 14 fields
16	Rejoagung	30	11 samples / 10 fields
17	Watutulis	27	22 samples / 22 fields
18	Jatibarang	30	8 samples / 8 fields
19	Gending	30	14 samples / 13 fields
20	Sudono	30	9 samples / 8 fields
21	Rendeng	30	7 samples / 7 fields
22	Pagotan	30	7 samples / 7 fields
23	Semboro	30	3 samples / 3 fields
24	Gempolkrep	30	19 samples / 19 fields
25	Mrican	30	1 samples / 1 fields
26	Subang	30	No mosaic
27	Wringin Anom	30	18 samples / 18 fields
28	Jombang Baru	30	16 samples / 14 fields
29	Sragi	30	4 samples / 4 fields
30	Gondang Baru	30	3 samples / 3 fields

Suspected vectors collected from the survey are listed in Table 2.

Table 2: potential vectors sugarcane streak mosaic virus collected during the survey.

No.	Sugar Factory	# fields vectors found	Suspected vectors
1	Jatiroto	34 out of 40	*Perkinsiella* spp., *Proutista* spp., *X1, X2*
2	Sumberharjo	26 / 40	*Perkinsiella* spp. *Proutista* spp, *X2*
3	Jatitujuh	6 / 25	*Perkinsiella* spp. *Proutista* spp, *X2*
4	Tasikmadu	32 / 38	*Perkinsiella* spp. *Proutista* spp, *X2*
5	Pesantren Baru	25 / 44	*Perkinsiella* spp., *Proutista* spp.
6	Madubaru	5 / 28	*Perkinsiella* spp., *Proutista* spp., X1
7	Purwodadi	1 / 29	Perkinsiella spp.
8	Kebonagung	22 / 30	*Perkinsiella* spp., *Proutista* spp., *X1 and X2*
9	Candi Baru	15 / 30	*Perkinsiella* spp., *Proutista* spp.
10	Asembagus	1 / 30	*Proutista* spp.
11	Karang Suwung	6 / 30	*Proutista* spp.
12	Kedawung	20 / 30	*Perkinsiella* spp., *Proutista* spp. *Dactylus* sp., X1 and X2, aphid sp.
13	Trangkil	4 / 30	*Proutista* spp.
14	Mojopanggung	23 / 30	*Perkinsiella* spp., *Proutista* spp., *Dactylus* sp., *X1, X2, aphid sp.*
15	Pajarakan	8 / 30	*Proutista* spp.
16	Rejoagung	19 / 30	*Perkinsiella* spp., *Proutista* spp., *Dactylus* sp., *X1, X2, aphid sp.*
17	Watutulis	18 / 27	*Perkinsiella* spp., *Proutista* spp.
18	Jatibarang	24 / 30	*Perkinsiella* spp., *Proutista* spp., *Dactylus* sp.
19	Gending	25 / 30	*Perkinsiella* spp., *Proutista* spp., *X1*
20	Sudono	25 / 30	*Perkinsiella* spp., *Proutista* spp.
21	Rendeng	21 / 30	*Perkinsiella* spp., *Proutista* spp., *Dactylus* spp.
22	Pagotan	22 / 30	*Perkinsiella* spp., *Proutista* spp., *X1, Dactylus* sp.
23	Semboro	29 / 30	*Perkinsiella* spp., *Proutista* spp., *Dactylus* sp.
24	Gempolkrep	25 / 30	*Proutista* spp.
25	Mrican	30 / 30	*Perkinsiella* spp., *Proutista* spp.
26	Subang	9 / 30	*Perkinsiella* spp., *Proutista* spp. *X2, Dactylus* sp.
27	Wringin Anom	23 / 30	*Perkinsiella* spp., *Proutista* spp.
28	Jombang Baru	28 / 30	*Perkinsiella* spp., *Proutista* spp
29	Sragi	12 / 30	*Perkinsiella* spp., *Proutista* spp.
30	Gondang Baru	30 / 30	*Perkinsiella* spp., *Proutista* spp., *X2, Dactylus* sp.

Important points: Outcomes from the general survey included: i. mosaic is one of the most widely distributed diseases in sugarcane fields in Java, ii. mosaic severity varied widely (a few crops had 90-100% diseased stools while many had low infestation levels), iii. incidence in Java suggests some areas are more heavily diseased; the reasons for this distribution require further investigation. Varietal susceptibility is likely to be one of the controlling factors.

7.2.4.2 Chlorotic streak

The survey highlighted the incidence of chlorotic streak in Java. Previously, the disease had not been the focus of pest and disease observations and was not widely acknowledged as a disease of importance (Figure 9).

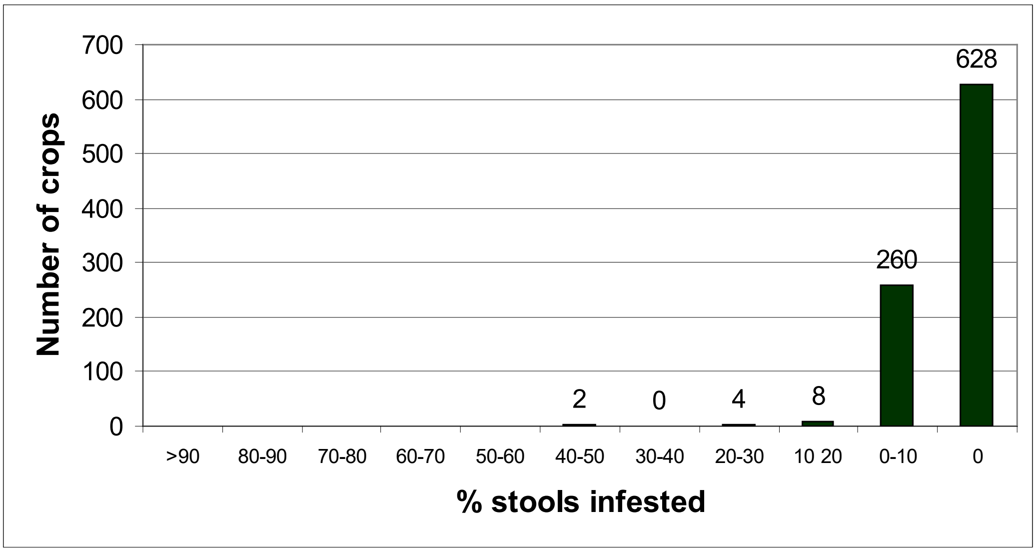


Figure 9: The incidence of chlorotic streak in individual crops expressed as a percentage of stools infested.

Important points: i. chlorotic streak was found for the first time in parts of central Java ii. there were a number of crops (274) where chlorotic streak was recorded; the disease is obviously widely distributed and may be causing significant yield losses in some crops iii. further information is needed on the distribution and severity of chlorotic streak.

7.2.4.3 Yellow spot

Yellow spot incidence was probably under-estimated from the general survey since some crops were observed when they were too young or when environmental conditions did not favour disease development (Figure 10).

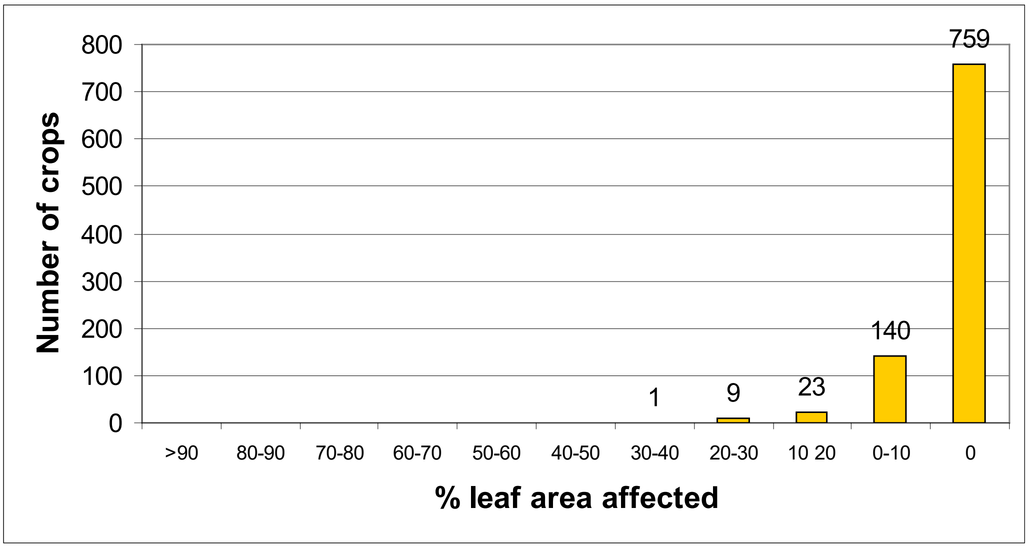


Figure 10: The frequency of yellow spot in individual crops with severity expressed as a percentage of leaf area affected by the disease.

Important points: i. records for leaf diseases need to be treated with caution since some data were collected at an inappropriate crop growth stage; yellow spot usually occurs in older crops during and just after the wet season. The data presented can therefore be assumed to be an under-estimate of the actual incidence of yellow spot in Java, ii. further analyses of disease incidence by crop age, and the use of climate data to ascertain the underlying factors (besides variety) that may be influencing disease severity, are required.

7.2.4.4 Leaf scald

The incidence of the important systemic disease leaf scald was highlighted by the general survey (Figure 11).

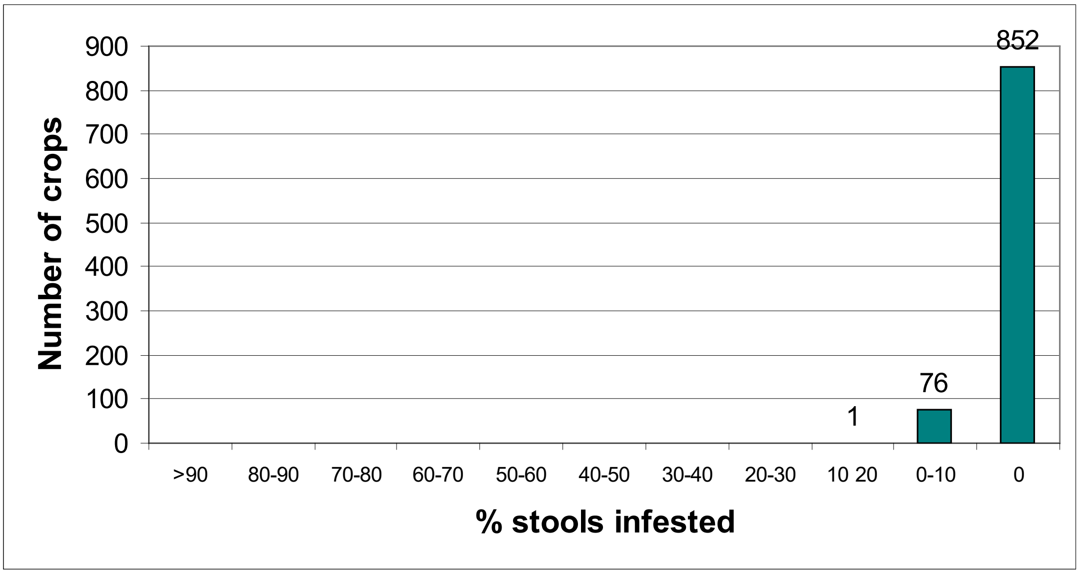


Figure 11: The frequency of leaf scald in individual crops expressed as a percentage of stools infested. There were relatively few crops affected and these were at a low disease severity.

Important points: i. leaf scald is restricted in incidence and very few crops are infested. This is a good outcome since leaf scald has the potential to kill crops of susceptible varieties. However, 10% diseased stools in some crops is a serious infestation of this major disease. ii. further analyses are required on the incidence of leaf scald among varieties to determine the influence of resistance on disease records.

7.2.4.5 Leaf scorch

Previous Indonesian records for leaf scorch have been from Sumatra and it is thought this is where the first disease incursion occurred (leaf scorch originally was not found in Indonesia). It is capable of defoliating the canopy and can significantly reduce the yield of susceptible varieties. The finding of this disease in central Java is of real significance to the Indonesian sugarcane industry as it could spread to affect many more sugarcane crops in Indonesia.

7.2.4.6 Target blotch

The first record of target blotch in Java was also made during this survey. The disease is found in Papua New Guinea and is generally of minor concern, but individual susceptible varieties could be badly affected by the disease.

7.3 Parasitoid research

7.3.1 Parasitoid dose

The results from the field trial investigating the traditional application (T1) of *Trichogramma chilonis and japonicum* (species identified in 2010) with a higher dose (T2), and comparisons to full chemical control (T3) and no control (T4) were analysed and are presented below.

Differences between treatments

The methods used to manipulate borer levels were effective, and infestations were highest in T4 (no treatment) and much lower in T3 plots (Insecticide) (Table 3). Of significance, there were significant differences in some parameters between the traditional application (T1) dosage and that recommended by project staff (T4). This was reflected in yield differences as well (see section 7.4). These results suggest that better IPM strategies can be implemented using existing technologies and that these would reduce the crop damage from the borers present in Indonesia.

Table 3: Effect of treatments T1, T2, T3 and T4 on stalk damage by *C. sacchariphagus, C. auricilius* (stemborers) *and S. excerptalis* (top borer) at Pesantren Baru (East Java).

Treatment	% Stalk damaged (Top borer)	%Stalk damaged (Stemborer)	% Internodes bored (Stemborer)	Length of tunnel bored (cm)	% Stalk length bored
T1	13.4 a	81.2 a	11.9 b	9.2 a	3.7 a
T2	8.8 b	74.8 a	9.8 c	7.5 a	2.7 b
T3-insecticide	3.8 c	50.2 b	4.6 d	3.3 b	1.2 c
T4- no control	15.8 a	84.8 a	14.5 a	8.9 a	4.0 a
F	19,28	16.45	25.69	14.79	18.47
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Pest infestation data (%) were transformed using arcsine before statistical analysis but are presented untransformed. For each variable, the means following by the same letter are not statistically different (P>0.05, Student-Newmans-Keuls)

7.3.2 Rearing Scirpophaga larvae on artificial diets

The survival of larvae of each of the artificial diet used in this experiment is shown in Table 4. No top borer larvae survived in the diet except with diet 7. All first instar larvae placed on an artificial diet died within 2 days.

Table 4: Artificial diet used for rearing top borer larvae

Main ingredients	Diet adapted from	Diet	Larval longevity (days)	Larvae feeding?	Tunnelling?
Bean powder	*Chilo partellus*	1 A	2	N	N
Bean powder + sugarcane leaf powder		1 B	2	N	N
Bean powder + sugarcane leaf powder	*Chilo partellus*	2	2	N	N
Bean powder + sugarcane leaf powder	*Busseola fusca*	3	2	N	N
Bean powder + sugarcane leaf powder	*B. fusca* & *S. calamistis*	4	2	N	N
Wheat germ	*Bathytricha truncata*	5	2	N	N
Green bean + maize powder	*Sesamia inferens*	6	3	N	N
Kidney bean	*Ostrinia nubilalis*	7	3	Y	Y
Bean + sugarcane leaf powder	*Chilo partellus*	8	2	N	N
Dried crushed cane+ground chickpea	*S. excerptalis*	9	2	N	N

Results of larval survival on modified diet 7 show a slightly extended survival period - but not sufficiently long to offer a viable artificial diet for sustainable production of insects (Table 5).

Table 5: Results of diet modification and *S. excerptalis* larval survival

Diet composition	Diet code	Longevity of larvae (days)	Larvae feeding?	Tunnelling?
Kidney bean, brewer's yeast, Vit C, Na-benzoat, Agar, Formaldehyde, HCL 0.1 M, Aquadest	7 A	3	Y	Y
7 A + sucrose	7 B	2	N	N
7 A + cane powder	7 C	3	N	N
7 A + vitamin E	7 D	3	N	N
7 A + sucrose + cane powder	7 E	4	Y	N

7.3.3 Rearing Cotesia flavipes

C. flavipes provides a potential IPM strategy for management of stem borers, especially *C. sacchariphagus*. The rearing technique for this parasitoid is not difficult since the materials are easy to locate. For that reason, *C. flavipes* rearing facilities could be developed at many sugar factories in Java where there is a high infestation of stem borers.

The introduction of this strategy to sugar factories started with training factory staff under the management of PTPN X factory group. For that purpose, a bio-control agent laboratory at Jengkol Kediri wass used as a pilot project for the parasitoid rearing; techniques were demonstrated to factory staff. Introduction of the technology is expected in other sugar factories in Java over time.

7.4 Borer yield loss assessment

Results from the field trial investigating varying doses of the parasitoid *Trichogramma* (T1 and T2), a full insecticide application (T3) coupled with a 'no treatment control' (T4) were used to provide quantify the yield losses caused by *S. excerptalis* and the *Chilo* spp. (see section 7.3.1)

Differences in overall damage (Table 3), stalk weights and heights were significant between T3 and T4 plots and for a few parameters between T2 and T4 (Table 6). Borer damage impacted negatively on stalk biomass. Furthermore, the stalk density was also affected in plots suffering the greatest damage, with a reduction of 10.9% in T4 and13.6% in T2 (Table 6). Sugar quality (CCS) and sucrose content were lower in T4 plots, and fibre content was significantly higher In T4 plots, losses in cane yield were estimated at 34.5%, (based on comparison with T3 plots) which represented a significant reduction of 46 t/ha. There was also a significant reduction in sucrose yield (4.2 t/ha, –39.6%) due to the effect of a reduction in cane biomass combined with inferior juice quality (Tables 6, 7, 8 and 9).

Table 6: Effect of treatments T1, T2, T3 and T4 on stalk characteristics and yields.

Treatment	Stalk height (cm)	Diameter (cm)	Weight (kg/stalk)	Cane (t/ha)	Sucrose (t/ha)
T1-Tricho1	246.0 bc	2.57 a	2.00 a	98.9 b	7.4 b
T2-Tricho2	271.9 ab	2.70 a	2.11 ab	115.9 ab	9.1 ab
T3-insecticide	288.9 a	2.74 a	2.33 ab	133.8 a	10.6 a
T4-control	219.5 c	2.58 a	1.73 b	87.6 b	6.4 c
F	6.25	1.61	4.99	4.21	5.60
P	0.003	0.223	0.008	0.014	0.005

For each variable, the means following by the same letter are not statistically different (P>0.05, Student-Newmans-Keuls)

Table 7: Effect of treatments T1, T2, T3 and T4 on fibre and sucrose contents

Treatment	Fibre % cane	Brix % cane	Purity	Pol % cane	Sucrose (CCS)
T1-Tricho1	11.1 a	18.2 a	76.4 ab	13.8 a	7.6 a
T2-Tricho2	10.2 ab	18.4 a	76.8 a	14.2 a	7.8 a
T3-insecticide	9.2 b	19.4 a	77.0 a	14.9 a	8.0 a
T4-control	12.1 a	17.8 a	75.8 b	13.5 a	7.3 a
F	6.01	2.50	2.67	1.65	1.79
P	0.004	0.109	0.065	0.213	0.179

For each variable, the means following by the same letter are not statistically different (P>0.05, Student-Newmans-Keuls)

Table 8: Estimated crop losses in comparison with the best treatment (T3-insecticide)

Treatment	No stalks/ha	Loss (%)	Cane yield (t/ha)	Loss (%)	Sucrose yield (t/ha)	Loss (%)
T3*	57458	-	133.8	-	10.6	-
T2	54833	4.6	115.8	13.4	9.1	14.1
T1	49667	13.6	98.9	26.0	7.4	30.2
T4	51167	10.9	87.6	34.5	6.4	39.6

* attainable yield = maximum potential of the crop without any significant impact from the moth borers.

Loss % = T3-Tn/T3 x 100

Table 9: Comparison of losses (height/weight) from damaged and undamaged stalks by the top borer *S. excerptalis*.

Stalk samples	N	Height (cm)	Loss (cm)	Weight (kg/stalk)	Loss (kg/stalk)
Undamaged stalks (T3)	481	288.9	-	2.33	-
Stalks without TBD (T4)	420	245.3	43.6 (15.1%)	1.98	0.35 (15.0%)
Stalks with TBD (T4)	80	181.5	107.0 (37.0%)	1.38	0.95 (40.8%)

TBD = Top Borer Damage; Loss % = T3-Tn/T3 x 100

All data from the 20 plots were regressed against percentage of borer infestation (internodes damaged by *Chilo* spp. and stalks damaged by *S. excerptalis*). Apart from stalk weight and diameter, all the other yield parameters were inversely related to the percentage of bored internodes, particularly for sucrose variables (Figures 12 to 17). As predicted, the fibre content was found to increase with the intensity of damage for both stem and top borers (Figures 14 and 17). Impact on cane yield and stalk height components was less clear but a decrease was observed with borer infestation, hence explaining part of the losses indicated in Table 6. In that situation, loss of sucrose is also expected as a consequence of loss in biomass. In addition, as it is usually the case for most stemborers (Sampson and Kumar, 1983; Goebel *et al*., 1999; Goebel and Way, 2003), a strong correlation was found between internodes bored and damaged stalks (R^2 = 0.82; y = 0.22 × –0.61), suggesting that damaged stalks can be used as a reliable index for routine surveys.

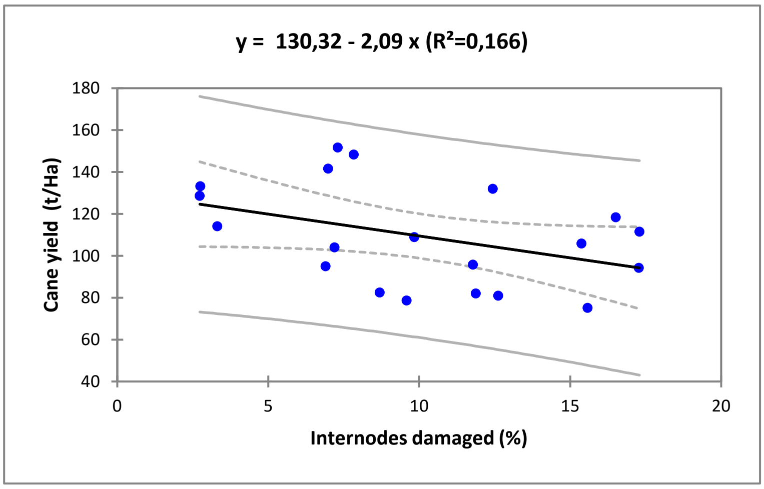


Figure 12: Relationship between stemborer damage vs cane yield (confidence interval= 0.95%)

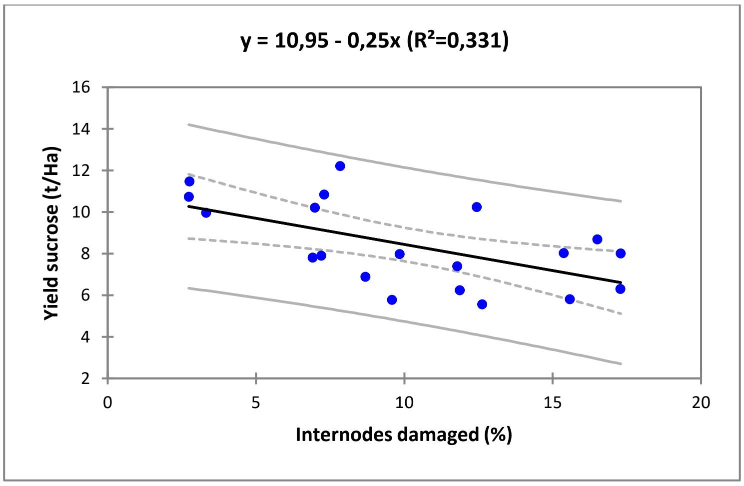


Figure.13 Relationship between stemborer damage and sucrose yield (confidence interval= 0.95%)

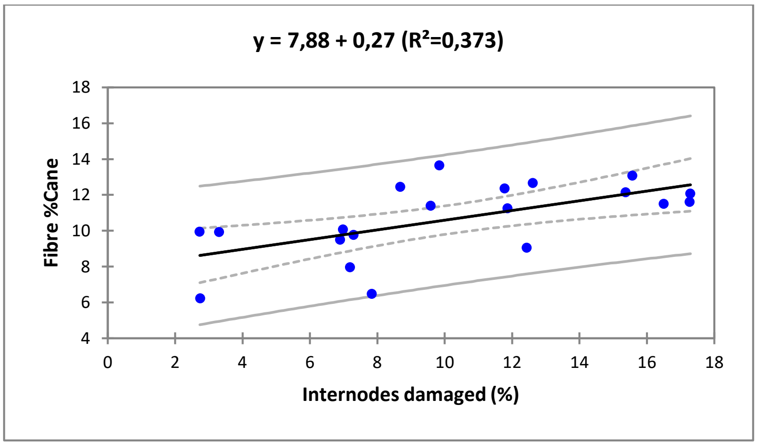


Figure.14 Relationship between stemborer damage and fibre content (confidence interval= 0.95%)

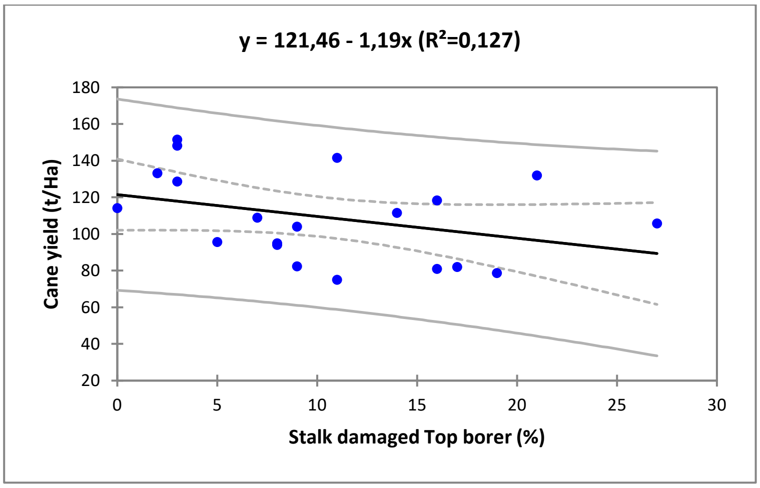


Figure.15: Relationship between top borer damage and cane yield (confidence interval= 0.95%)

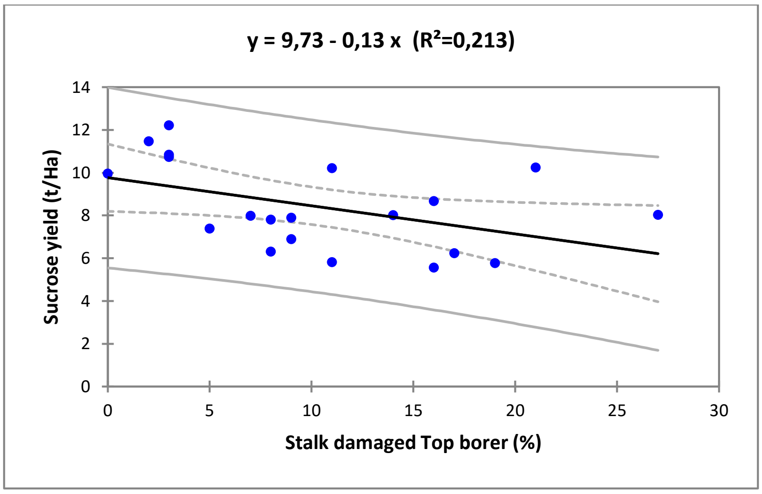


Figure 16: Relationship between top borer damage and sucrose yield (confidence interval= 0.95%)

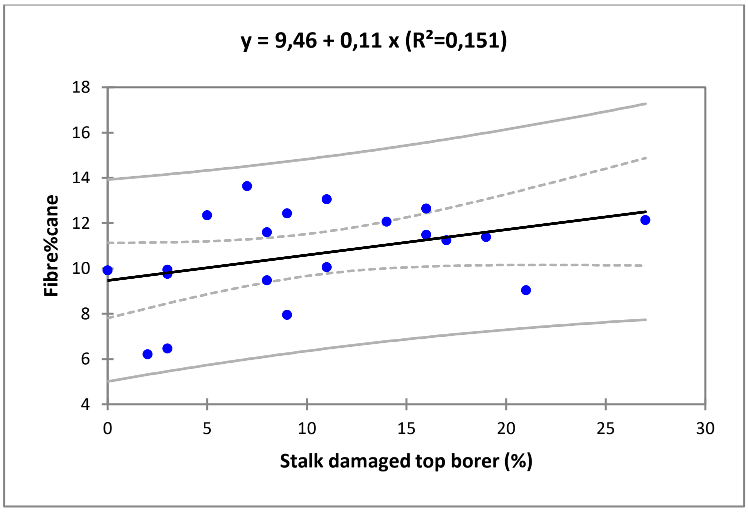


Figure 17: Relationship between top borer damage and fibre content (confidence interval= 0.95%)

To better understand the particular impact of the top borer and stemborers on yield, losses were also investigated for two main parameters (stalk height and weight) by comparing stalks in T4 plots damaged by top borer only, stalks in T4 plots with stemborer damage but without top borer damage and undamaged stalks from T3 plots considered as borer-free. On the basis of these data, the impact of the *S. excerptalis* (top borer) is greater with more than 1 m reduction in stalk height (107.8 cm, 37%) while the impact of stemborers on this component is estimated at 15,1%. In fact, *S. excerptalis* kills the growing point ('dead-hearts') and then stops cane growth, which is not the case for stemborers as they damage only internodes. As a consequence, stalk weight is also significantly affected by *S. excerptalis* with a loss of 40.8%, while stemborer infestation had less impact on stalk weight (15%). However, top borer damaged only 15.8% of cane stalks (Table 3), which reduced the losses suffered.

Two types of impact of borers on the yield components have been highlighted in this trial. The first led to a clear loss in sugar quality and its components. It is also confirmed that percent fibre increased with higher levels of bored internodes, which is a consequence of borings and reduction of water uptake, reflected by lower juice levels. Our results are consistent with previous studies on other stalk borers such as *Diatraea saccharalis*

(Hensley, 1971; Gonzalez *et al*., 1977; Ogunwolu *et al*., 1991; White *et al*., 2008), *Eoreuma loftini* (Legaspi *et al*., 1999; Reay-Jones *et al*., 2005), *Chilo sacchariphagus* (Rajabalee *et al*., 1990; Goebel *et al*., 1999) and *Eldana saccharina* (Sampson and Kumar, 1983; Goebel and Way, 2003, 2006).

The second impact was on sugarcane biomass - but this type of loss appeared to be more difficult to estimate. We found that this component is mainly affected by *S. excerptalis*. Though the relationship is less strong than with sucrose, regression analysis indicated that cane yield is affected significantly by the presence of dead-hearts in mature cane, which is the typical 'signature' of this borer. The interruption to plant growth is reflected by a significant reduction in stalk height.

In addition to these losses in mature cane is a reduction in stalk density, which suggests that both moth borers have also caused the death of younger canes. A similar observation was made for *C. sacchariphagus* in Reunion (Goebel *et al.,* 1999) which seemed to have a stronger impact on cane yield than the *Chilo* species present in Java. However, in Reunion it was shown that the earlier borer infestation occurred, the greater the impact on yield. Loss in cane weight is not easy to discern and requires a specific study with samples taken within the same population of stalks. Past studies on crop loss were usually based on single stalks collected in fields with different degrees of damage (Rajabalee *et al*., 1990; Way, 2001). Though this method allows detection of sucrose yield losses, reduction in stalk biomass couldn't be determined because the samples were taken at a different field location, increasing variability in weight between the stalks collected.

This issue of variability has already been addressed in our studies on *E. saccharina* (Goebel and Way, 2003, 2006). This experiment confirms the importance of comparing stalks from the same location to minimise the biases due to different growing conditions (variability of soil types, fertilisers, etc.) and stalk age. In addition, moth borers tend to attack stalks that have suffered from stress (drought, soil deficiency, etc.). For example, to reduce the variability in stalk weight, it is advised to take a minimum of 25 consecutive stalks as a sample unit in the same row (Hall, 1986).

Our experiment has also facilitated the comparison between plots by using a full insecticide treatment (expected to guarantee 'minimal borer infestation'). As in previous experiments conducted in Reunion and South-Africa, we have been able to create different levels of infestation, which is important in obtaining reliable crop loss results.

This study has clearly shown the importance of considering all aspects of yield, from the quality (sucrose) to the quantity of sugarcane (biomass) produced. These results enabled a calculation of economic thresholds for the Javan sugarcane industry, which will differ according to the borer encountered.

7.5 Monitoring / management of borers (stem / top) using pheromones

The results showed that the synthetic pheromone was effective for monitoring stem borer populations, while the top borer pheromone didn't attract / catch any male moths (Figures 18 and 19).

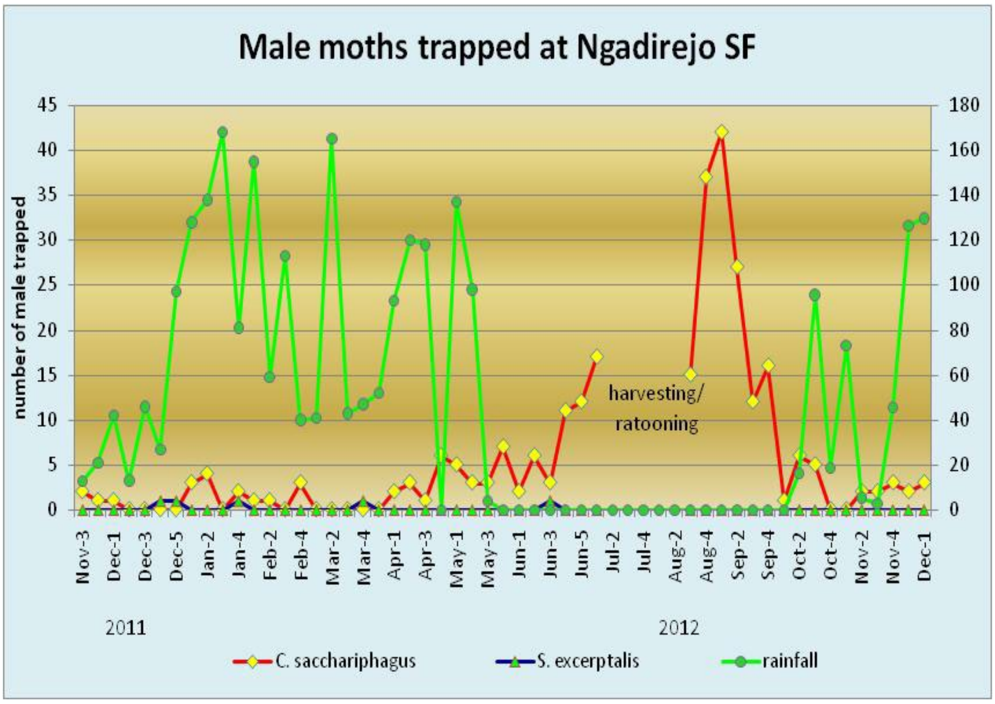


Figure 18: Male moth borer trapped in the field at Ngadirejo sugar factory

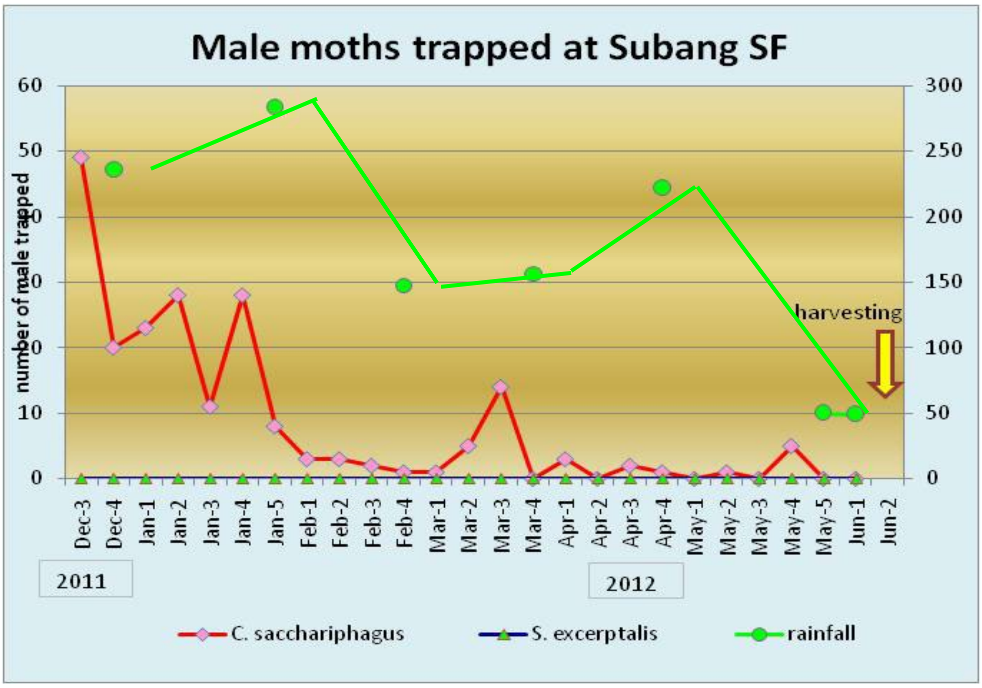


Figure 19: Male moth borer trapped in the field at Subang sugar factory

Pheromone traps didn't reduce crop borer infestations (Figures 20 and 21). This is not surprising since the pheromone traps were not principally established for this purpose, only to monitor adult moth populations enabling peak flight activity periods to be identified.

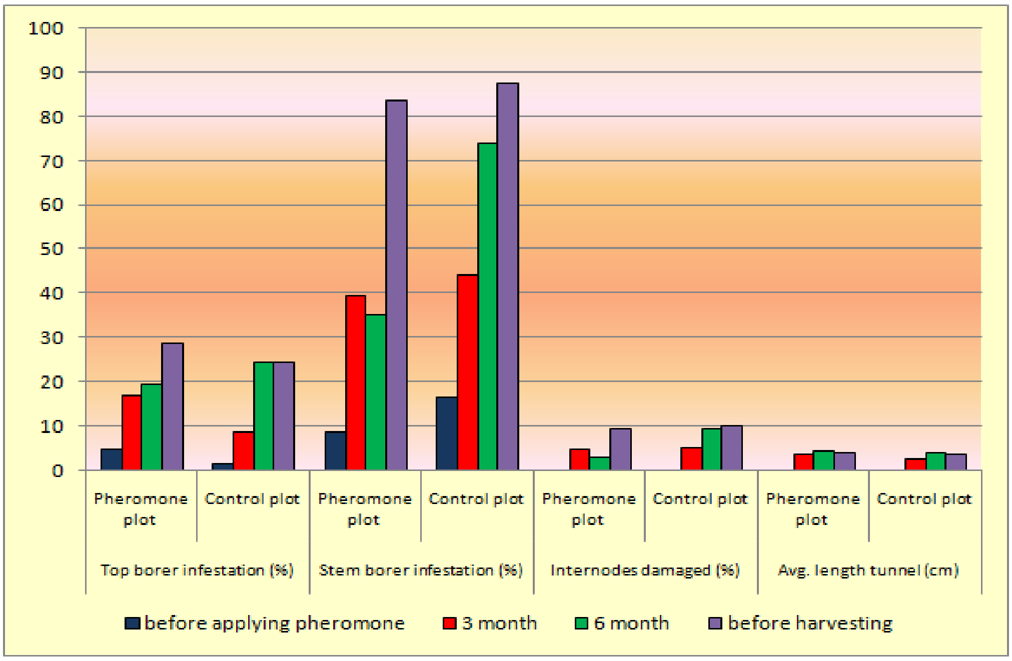


Figure 20: Damage levels from *Scirpophaga excerptalis* (top borer) and stem borer at Ngadirejo sugar factory.

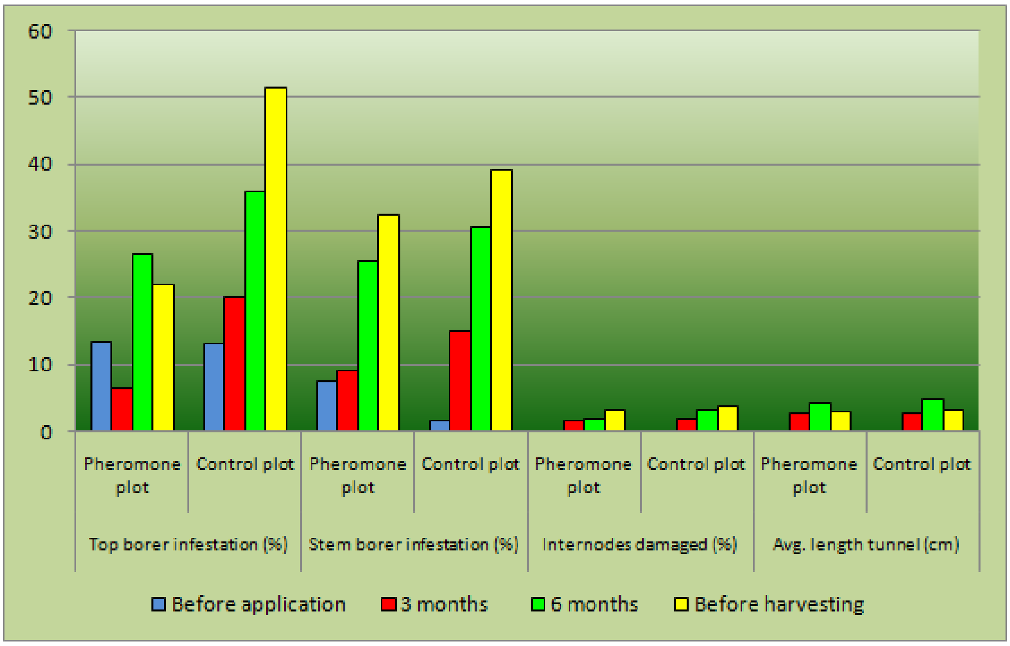


Figure 21: Damage levels from *S. excerptalis* (top borer) and *Chilo* spp. (stem borer) at Subang sugarcane factory.

Another interesting result from pheromone experiments was the use of the new *S. excerptalis* pheromones formulated by ISRI staff (Djoenadi Samoedi, ISRI entomologist). This pheromone led to trapping of more male moths than the commercial pheromone from the UK (Table 10 and Figure 22). The use of water traps gave better results than the standard delta trap (Table 11). The ISRI pheromone can now be used to monitor *S. excerptalis* populations, a significant step forward.

Table 10: Male moths caught using different pheromones

Day of observation	Individuals trapped (*S. excerptalis* male)	
	UG pheromone *S.excerptalis*	ISRI pheromone *S.excerptalis*
1	1	10
2	1	3
3	0	6

Table11: Male moths caught using different traps.

Day of observation	Individuals trapped (*S. excerptalis* male)	
	Water trap	Delta trap
1	12	0
2	3	0
3	4	0
4	4	0
5	3	0
6	3	0
7	7	0

The interim results are promising; more data are needed before conclusions are drawn.

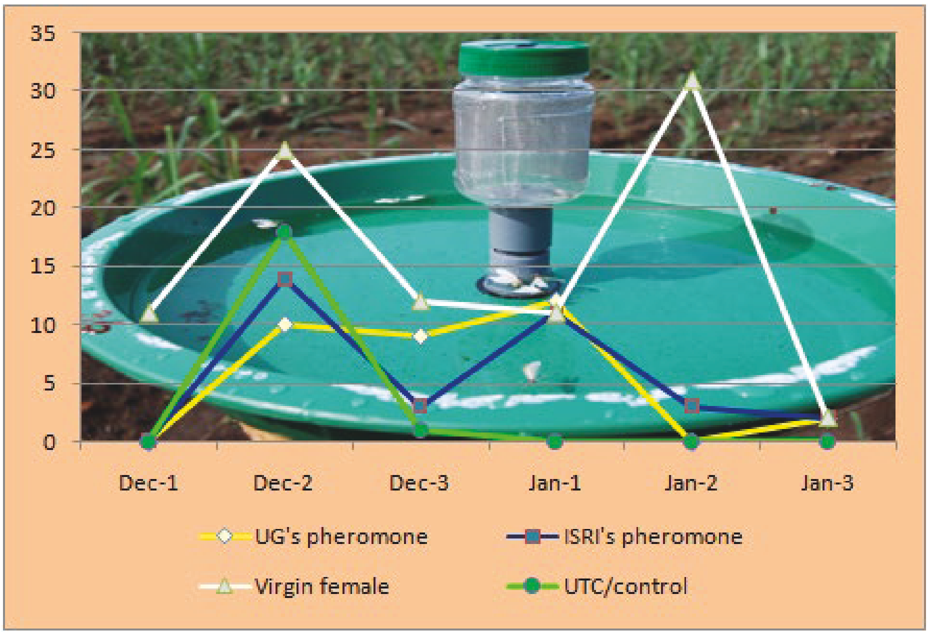


Figure 22: Male moths caught in South Sumatera using different pheromones

Conclusions:

- Positive results were obtained in pheromone experiments
- Effective traps have been tested and are ready for more widespread use.
- A pheromone for the top borer formulated by ISRI was more effective than the commercial formulation from the UK
- Moth flight peaks have been identified and will be confirmed in subsequent trapping research.

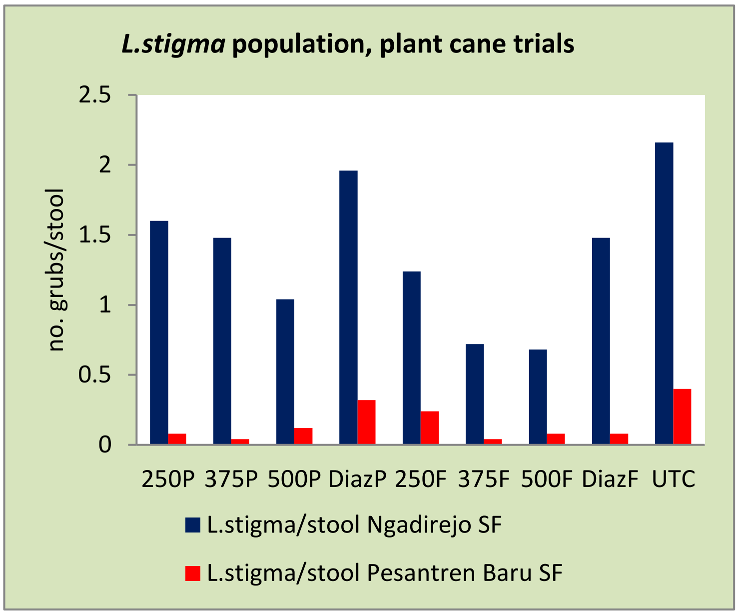
- Other experiments should aim to test mass trapping / mating disruption as possible management options.
- For a biosecurity perspective, pheromone traps could be used in northern Australia as a possible detection technique for Indonesian borers.

7.6 White grub control

7.6.1 *Results*

Two species of canegrubs were counted in the trials. In untreated plots, numbers per stool of the main target pest, *L. stigma*, with numbers of a second smaller species, *Euchlora viridis*, in brackets, were 2.2 (0.4) and 0.4 (2.4) in the plant cane trials and 2.2 (0.3) and 3.7 (0.6) in the ratoon cane trials at Ngadirejo and Pesantren Baru, respectively.

The standard treatment in plant cane, diazinon, was ineffective against *L. stigma* (figure 23). Imidacloprid reduced canegrub numbers (although the effect was not always statistically significant) when applied in both plant and ratoon cane. A similar result was apparent in the one trial in which *E. viridis* was abundant (results not shown). There was also a yield response (again not always statistically significant) to treatment (Figure 24), with the largest apparent response in the ratoon trial at Pesantren Baru where *L. stigma* was most abundant (refer to Figure 23).



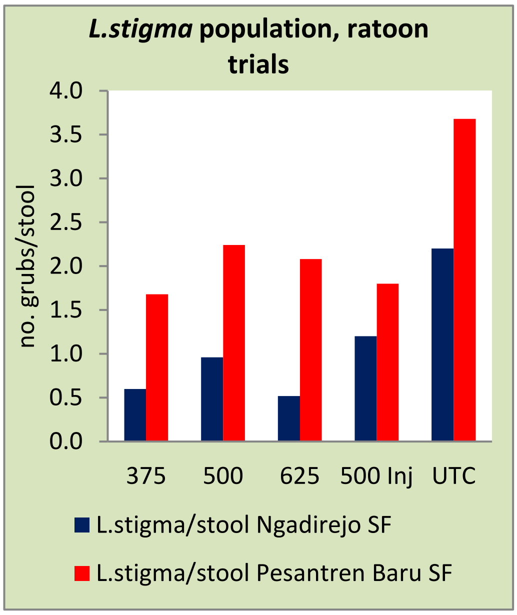
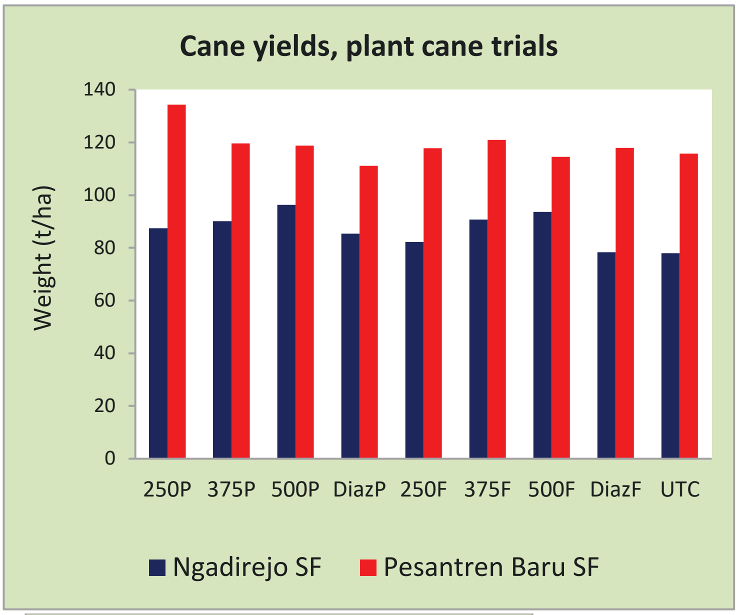


Figure 23**:** Numbers of *Lepidiota stigma* in trials in plant and ratoon cane. Axis labels: 250, 375, 500, 625 = g ai/ha imidacloprid, Diaz = diazinon, applied at planting (P), fill-in (F) or injected (Inj), UTC = untreated control



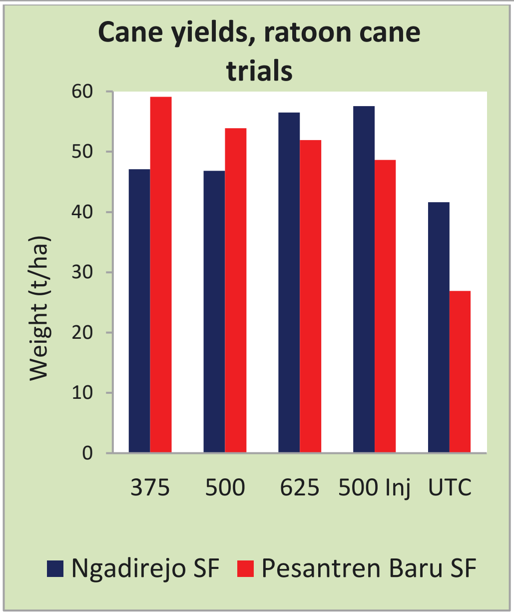


Figure 24: Cane yields in white grub trials, axis labels as in figure 23.

The results indicate that a control method commonly used for white grub management by sugarcane plantations in Indonesia (application of diazinon at planting), does not give effective control. This is unsurprising, as the product is applied at planting at a time when the grub population has mostly finished for that year, and it is unlikely to still be effective when the next generation begins feeding the following year. In contrast, imidacloprid has a longer residual life in the soil (although not so long as to cause environmental problems), which is why it has proved very successful for white grub management in the Australia sugar industry. Imidacloprid, being one of the new neonicotinoid compounds, is much less hazardous to use than the older organophosphate compounds such as diazinon and cadusafos.

Outcomes:

- The standard industry treatment (diazinon) proved ineffective for white grub control
- Imidacloprid provided very good control of *Lepidiota stigma* and is likely to be profitable where significant grub populations exist (Figure 23).
- Reasonable control of *Euchlora* was also achieved, although not quite as good as that achieved against *L. stigma*.

- Application of imidacloprid into ratoon crops was effective and has the potential to dramatically reduce the frequency of replanting and increase profitability.
- Hand-digging of application slots for applying imidacloprid into ratoon crops is not commercially practical but appropriate equipment could be designed to do this if there was sufficient interest from the Indonesian industry.
- Hand-held injection tynes could also provide a reasonable application technology for ratoon crops.

7.7 Economic analysis of borer and white grub management

7.7.1 Borer management using Trichogramma

Goebel *et al.* (2011) established a borer control trial to compare 'current' with 'best practice'. A treatment using high rates of chemical to simulate a 'no-loss' situation was also included. The trial was located on the plantation of Pesantren Baru sugar factory (East Java) and compared the standard practice of releasing 10,000 *Trichogramma* parasitoids per week for 8 weeks to the recommended practice of releasing 100,000 parasitoids per week for 14 weeks. The plant crop showed a large response to the recommended treatment. A cost/benefit analysis was done for all treatments to enable these data to be incorporated into extension messages, particularly activities aimed at factory board members, factory managers and plantation managers (Table 12). While the chemical treatment appeared to produce superior crops and returns, no application costs were included (chemical control of this pest is considered both impractical and undesirable). The large number of treatments required would lead to the destruction of borer natural enemies. This treatment was included solely to provide a yield potential. For the plantation (11,000 ha) on which the trial was situated, the net return would be IDR 62 Billion (AUD 6.7M) if the new recommended management option (T2) was implemented on 50% of the plantation.

Responses in the first ratoon trial were much lower.

Table 12: Economics of treatments used in borer trial at Pesantren Baru – plant cane only.

	Treatment			
	T1 Current treatment	T2 New Tichogramma treatment	T3 Chemical control	T4 Untreated
Cane (t/ha)	98.9	115.9	133.8	87.6
CCS	7.6	7.8	8.0	7.3
Sucrose (t/ha)	7.4	9.1	10.6	6.4
Gross return ('000 IDR/ha/yr)	**62 900**	**77 350**	**90 100**	**54 400**
Less costs ('000 IDR per ha)				
Trichogramma cards	31	581	0	0
Attaching cards	9	169	0	0
Insecticide	0	0	3200	0
Total treatment costs per ha/yr	40	750	3200	0
Harvesting costs	5934	6954	8028	5256
Total costs per ha/yr	5974	7704	11 228	5256
Net return ('000 IDR/ha/yr)	**56 926**	**69 646**	**78 872**	**49 144**

Trial data also provided economic threshold data for borer infestations in Indonesia. In plant crops, 1% shoots infested with *S. excerptalis* (top borer) and 2% stalks infested by stem borers would justify treatment. In ratoon cane there were lower levels of infestation and 2%

shoots infested with *S. excerptalis* and 5% stalks damaged by stem borers would justify treatment.

Conclusions:

- The new recommended Trichogramma IPM strategy increased profitability 3x compared with the current industry strategy.
- Crop losses from moth borers are significant in terms of biomass and sugar producton in plant cane; *S. excerptalis* (top borer) impacted yields to a greater extent (2.7 x) more than the stemborer (yield tonnes/ha). Fifteen percent losses could be expected from stem borer damage, while up to 45% from *S. excerptalis* (top borer).
- *S. excerptalis* affects yield to a greater extent because it kills the growing point and may dramatically reduce cane height.
- *S. excerptalis* should be considered the highest priority from an Australian biosecurity perspective – of those borers present in Indonesia.
- Field trials, such as implemented here, provide an ideal way to measure crop losses and to compare the effectivness of different management strategies (insecticides, biocontrol techniques)

7.7.2 White grub control using imidacloprid

Economic calculations accounting for the costs of insecticide application, harvesting and transportation and other costs suggested that when white grubs infest cane crops (as in this research) increased returns from the application of imidacloprid were evident, particularly for treatment 3 (500g applied at planting time) with profits around Rp 13.6 m / ha higher compared to 'no treatment'. This was over Rp 6.0m higher than the previously recommended treatment (Table 13).

Table 13: Economic analysis of white grub management strategies

	Tonnes cane/ha	**CCS**	**Crop value Rp**	**Insecticide cost Rp**	**Gross margin (1 year only)**	**Increase GM (1 year only)**
UTC	78.0	9.3	61,619,220	0	61,619,220	0
T1	87.4	8.9	66,451,385	500,000	65,951,385	4,332,165
T2	90.1	9.5	72,735,171	750,000	71,985,171	10,365,951
T3	96.3	9.3	76,069,617	1,000,000	75,069,617	13,450,397
T4	85.4	9.6	69,982,172	617,500	69,364,672	7,745,452
T5	82.2	9.4	65,346,111	500,000	64,846,111	3,226,891
T6	90.7	9.3	71,978,104	750,000	71,228,104	9,608,884
T7	93.7	9.0	71,575,383	1,000,000	70,575,383	8,956,163
T8	78.4	9.1	60,740,414	617,500	60,122,914	- 1,496,306

First ratoon results showed that the profit from using imidacloprid (375g active / ha) is more than double that from applying no treatment (Figure 25).

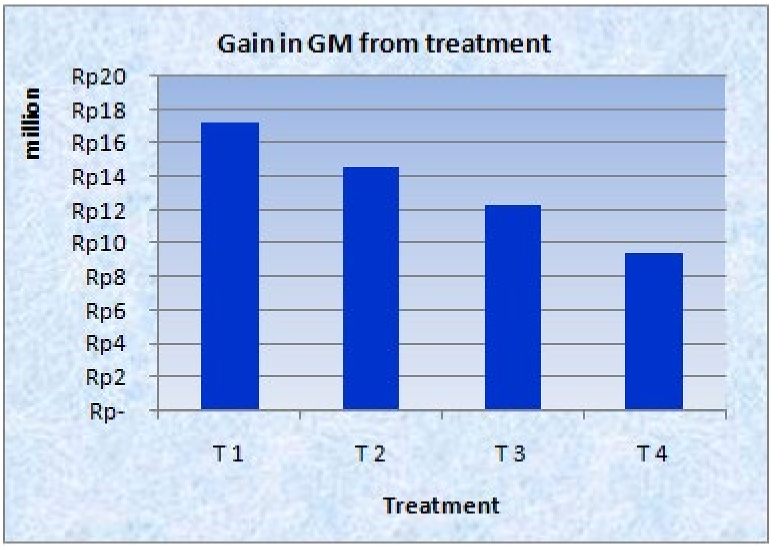


Figure 25: Increased profits achieved using the different insecticide strategies in the first ratoon crop

7.8 SCSMV research

7.8.1 *SCSMV transmission*

Several small experiments were undertaken to determine whether SCSMV can be transmitted by mechanical equipment. The research suggests that infected cane juice (on knives, and other equipment used to cut sugarcane stalks) is able to transmit the disease to healthy test plants. Up to 30% of plants grown from stalk material cut with a contaminated knife developed symptoms. This is in contrast to SCMV, the virus causing mosaic symptoms in Australian sugarcane crops. Though mechanical transmission is able to occur with SCMV, it is only possible under specific conditions and does not generally occur under field conditions. Knife transmission of SCSMV is of serious concern to the Australian sugar industry as rapid spread will then be possible via mechanical harvesters, planters and chain saws used in cutting propagation material. These experiments should be repeated in future project work.

7.8.1.1 Vectors (Homopteran insects)

Three species were investigated, i. 'brown aphid', a species feeding on weeds in sugarcane production areas and yet to be identified, ii. *Rhopalosiphum maidis* (corn aphid): a known vector of the disease, iii. a third unidentified insect. The results suggest that the brown aphid is a very effective vector of the disease but further studies are needed to confirm this initial result (Tables 14, 15 and 16). No other vector led to plant infection. Crop observations are also needed to assess the presence of the brown aphid in mosaic-infected sugarcane crops in Java.

The results indicated that the aphid species is a vector of SCSMV. Plants colonised by *R. maydis* and *C. lanigera* separately did not lead to development of mosaic symptoms. Leaf samples collected for mosaic assay confirmed the causal agent transmitted was SCSMV.

Table 14: Number of plants showing mosaic symptoms after inoculation with an aphid species that is bred in infected sugarcane plants

No	Incubation	Mosaic symptom			Number of plants with mosaic symptom
		1	2	3	
1	1 hour	0	1	1	2
2	6 hours	1	1	1	3
3	12 hours	1	1	1	3

Note: scoring used for mosaic symptom appearance was as follows: 0 = no mosaic symptoms; 1 = mosaic symptoms identified on leaves.

Table 15: Number of plants exhibiting mosaic symptoms after infestation by *C. lanigera* reared on diseased sugarcane plants

No	Incubation	Mosaic symptom			Number of plants with mosaic symptom
		1	2	3	
1	1 hour	0	0	0	0
2	6 hours	0	0	0	0
3	12 hours	0	0	0	0

Note: scoring used for mosaic symptom appearance was as follows: 0 = no mosaic symptoms; 1 = mosaic symptoms identified on leaves

Table 16: Number of plants exhibiting mosaic symptoms after infestation by *R. maydis* reared on diseased sugarcane plants.

No	Incubation	Mosaic symptom			Plants with mosaic symptoms
		1	2	3	
1	1 hour	0	0	0	0
2	6 hours	0	0	0	0
3	12 hours	0	0	0	0

Note: Scoring is used for appearance of mosaic symptom (0 means no mosaic symptom in sugarcane plants; 1 means mosaic symptom found in sugarcane plants

*Molecular assay for leaf samples was used to confirm SCSMV as the causal agent.

7.8.1.2 Transmission in infested cane juice

Experimental results showed that the traditional method for transmitting *sugarcane mosaic virus* (SCMV; pin-pricking through infected young leaves into the spindle leaves) was successful also for transmitting SCSMV. Infection of test plants varied between 30-70% with this method.

Knives contaminated with SCSMV-infected cane juice also led to disease transmission, with up to 30% of test plants diseased. This is a very significant finding and contrasts with SCMV where knife transmission is insignificant. This highlights a potential major avenue for disease spread in commercial crops because cutting implements, such as knives, are used extensively in both planting and harvesting operations. This may help explain (along with the other avenues of disease transmission - infected vegetative planting material and vector transmission) why the disease is found widely within crops and across regions / countries.

This research should be repeated, along with epidemiology studies, in a proposed new research project. Other aspects of the disease also require further research.

7.8.2 *Hot water treatment to eliminate SCSMV*

7.8.2.1 Trial 1

The results obtained from the trial were shown in the following table (Table 17).

Table 17: details of applied hot water treatments for elimination of SCSMV from planting material.

Pre-treatment	Treatment		Germination	% mosaic symptoms
24 hrs previously	Temperature (°C)	Time (min)	(%)	
35° C	50	30	100	100

35° C	50	60	100	100
35° C	50	120	100	100
35° C	52	30	60	100
35° C	52	60	0	-
35° C	52	120	0	-
35° C	55	30	0	-
35° C	55	60	0	-
35° C	55	120	0	-
35° C	57	30	0	-
35° C	57	60	0	-
35° C	57	120	0	-
35° C	60	30	0	-
35° C	60	60	0	-
35° C	60	120	0	-
35° C	-	-	100	100
-	-	-	100	100

The data shows that at temperatures > 50°C, sett germination was reduced to 0, except for treatment at 52°C for 30 minutes - where the germination was 60%. Disease incidence in the remaining test plants was 100% five weeks after the setts were germinated. PCR test results suggested infected leaves were indeed infected by SCSMV. Hot water treatment at 50°C for 2 hours, mostly effective for RSD control, did not eliminate SCSMV.

7.8.2.2 Second trial

The following table illustrates the results of the second trial (Table 18).

Table 18: Treatments applied in a second experiment to eliminate SCSMV from planting material.

Treatment		Germination (%)	Disease incidence (%)
Temperature (°C)	Time (min)		
52ºC	10	80	100
52ºC	20	80	100
52ºC	30	40	100
53ºC	10	100	100
53ºC	20	100	100
53ºC	30	20	100
54ºC	10	100	100
54ºC	20	100	100
54ºC	30	40	100
55ºC	10	100	100
55ºC	20	100	100
55ºC	30	80	100

Overall, hot water treatment of planting material was not effective for eliminating SCSMV.

7.8.3 Tissue culture to eliminate SCSMV

Ten healthy, and ten diseased shoots were cultured (callus culture) at the tissue culture laboratory, ISRI, Pasuruan in April 2009. The plantlets were acclimatized in a glasshouse at the facility six months later. The results showed that tissue culture eliminated mosaic (symptom-based assay) in 70% of the plantlets. These results suggest that tissue culture may be useful for eliminating the virus in valuable germplasm, but it currently is not useful as a tool for eliminating SCSMV in large quantities of planting material to be used to establish disease-free nurseries.

7.8.4 Yield loss

Monthly monitoring of SCSMV in plots showed that disease levels increased only slightly in each plot; infection levels of 0, 25, 50, and 75% became 0.63, 25.4, 50.3, and 75.6% infected stools respectively. Yield data showed that SCSMV leads to a reduction in sugarcane yield. Statistical analyses suggested that stalk height, number of stools, tonnage, and crystal sugar were significantly reduced by SCSMV. Maximum losses were around 16%. Stalk diameter, pol and brix were not affected however. This is similar to losses described elsewhere (Grisham 2000). There seemed to be no direct relationship between percent diseased planting material and yield loss parameters; this needs further research.

7.9 Extension activities

7.9.1 Industry-wide meetings – Pasuruan

Figure 26 shows the survey results of industry leaders' attitudes to the importance of different sugarcane pests. Participants believed that borers were the major sugarcane pests in Indonesia. Fifty six percent cited borers as their major pest problem with the result split 50:50 between *S. excerptalis* (top borer) and *Chilo spp* (stem borers). The other pests of significance were rats (16%) and white grubs (15%).

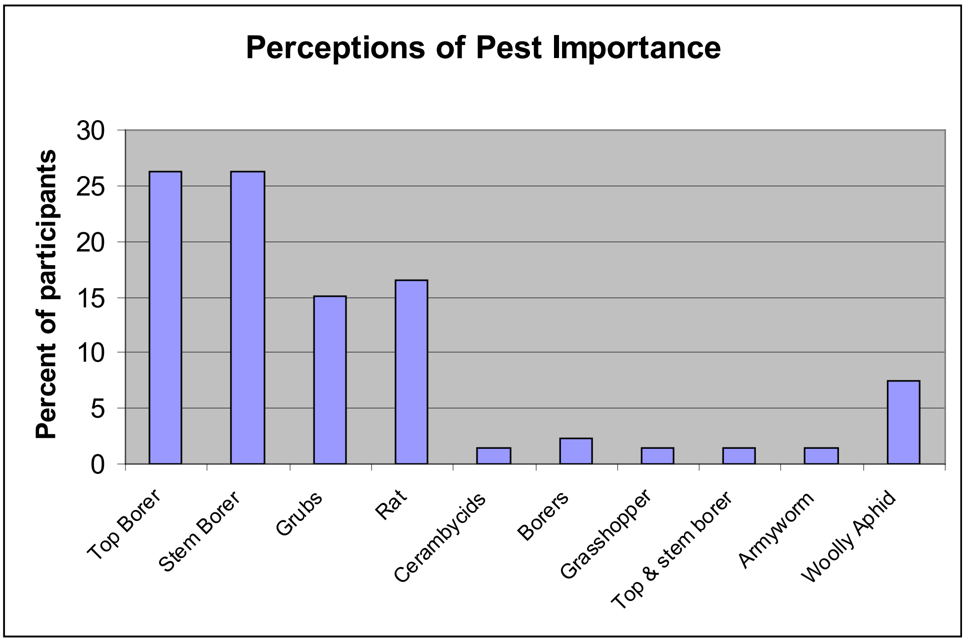


Figure 26: Perceptions of pest importance from a survey of participants at the industry leaders' seminar, Pasuruan, East Java, April 2009.

Similarly (Figure 27), the two major diseases (mosaic and smut) were recognised by over 50% of participants as their major disease problem. Rust and pokkah boeng were identified as the third and fourth most serious diseases. All four of these diseases generally have obvious symptoms. Ratoon stunting disease (RSD) which, although widespread, has no visible symptoms, was ranked as the most serious disease by only six percent of participants. It is likely to be far more important than rust or pokkah boeng, and of equivalent status as smut and SCSMV.

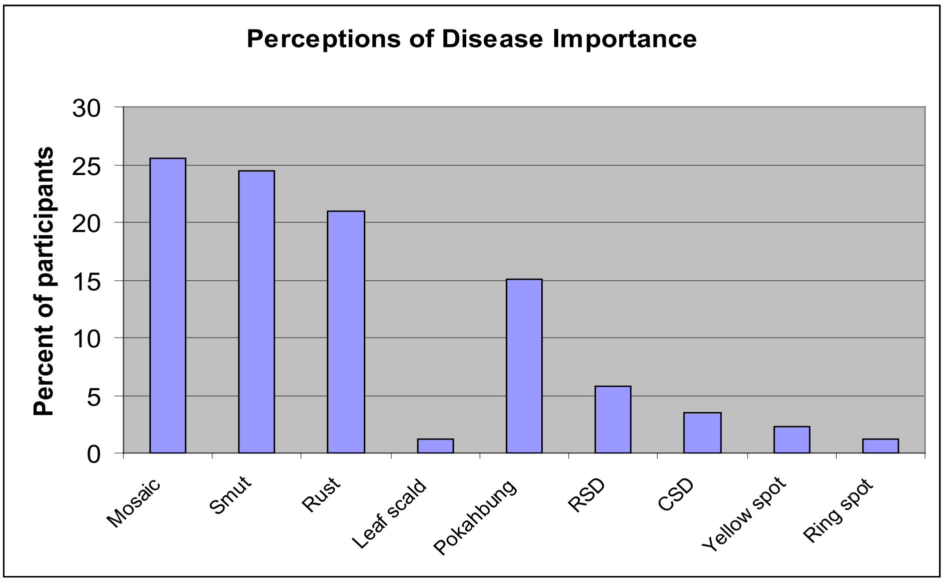


Figure 27: Perceptions of disease importance from survey of participants at industry leaders' seminar, Pasuruan, East Java, April 2009.

7.9.2 Regional training workshops

Participants were asked to evaluate their experience at the end of each workshop. Evaluations revealed this was the first pest and disease training experienced by 58.5% of participants. A similar number of participants said that the training was either 'absolutely needed' or 'needed' (Figure 28) while over 70% of participants indicated that they either 'fully understood'" or 'understood' (Figure 29) the workshop material.

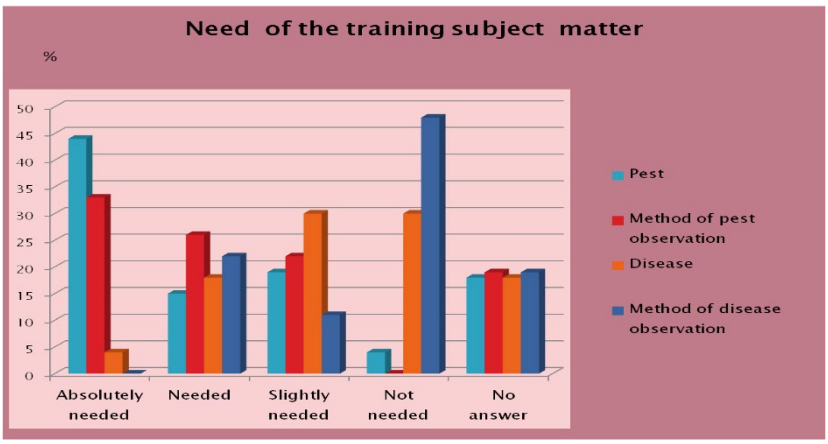


Figure 28: The need for training as perceived by workshop participants.

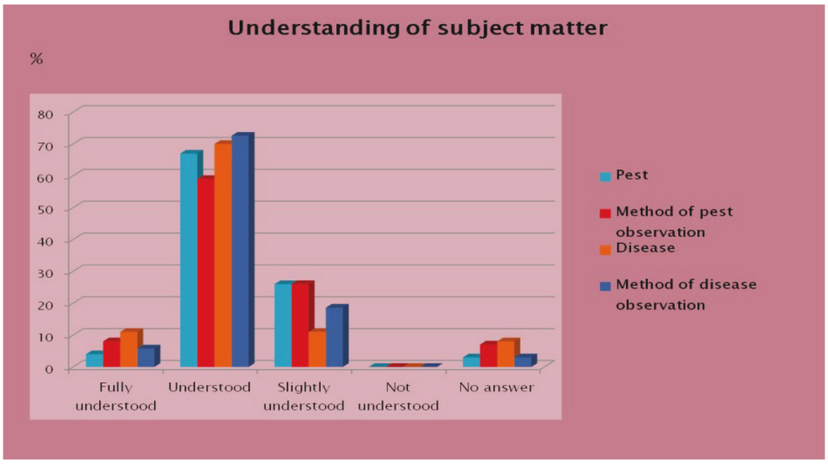


Figure 29: Understanding of workshop material reported by workshop participants.

Workshop evaluations indicated a need for a well-illustrated field guide showing crop losses and control measures for pests and diseases. Other feedback from participants included:

- more farmers should be invited
- allow more time in the field and less in the 'class room'
- present some subject matter as a video
- training should be done periodically and include monitoring for pest and disease attack
- more extension including an IPM Field School for cane farmers
- training on pest and disease management, with ISRI coaching, is important.

Almost all participants indicated they were confident to pass on their learnings to other farmers or sugar factory staff.

Workshop conclusions

- Participants are 'information hungry' and keen to attend. Many had travelled hours to attend; one participant had driven over 7 hours, three others drove 5 hours.
- Participants are concerned about declining productivity and aware of many of the problems. They want to know how to improve productivity.
- The information was well received. Participants were attentive, asked questions and participated well in the hands-on sessions after lunch. This was particularly true at a smaller workshop at Jatitujuh.
- ISRI presented information from the project including some excellent GIS data. These data were explained on a regional basis.
- As in Australia, white grubs get farmers more excited than any other pest.

7.9.3 Borer workshop

Borer workshops were held in January and May 2011 at Pesantren Baru; these focussed on borer control using *Trichogramma* wasps. Forty people attended the first workshop, including the plantation manager, R&D leader and staff from the *Trichogramma* production facility at Pesantren Baru.

The second workshop on borer control was held at Rejo Agung Baru and was attended by 20 plantation managers and R&D leaders. Régis Goebel and Etik Achadian gave a general presentation on biological control of moth borers, particularly the use of *Trichogramma* parasitoids.

This workshop format provided excellent opportunities for questions, answers and interaction between the entomologists and industry personnel. At the field visit on the following morning, participants were able to:

- see the correct method of placing 'Tricho cards'
- identify borer damage and diseases such as chlorotic streak (CSD)
- discuss borer identification and control with the entomologists.

This field visit reinforced what people had learned the previous day and gave participants hands-on experience identifying pests and diseases.

7.9.4 Champion farmers

The four group activities conducted on each champion's farm provided an excellent learning environment for the local sugarcane farmers. Practical activities enabled farmers to take a hands-on approach to identifying pests and diseases. Activities were centred on identifying borers and borer damage as well as correct timing, dosage and placement of the egg cards (containing *Trichogramma* parasitoids). A final field visit was held just prior to harvest to assess the success or otherwise of the treatments. When treatments were being applied, visiting farmers were encouraged to apply treatments themselves to ensure they did it correctly.

Régis Goebel and Peter McGuire made presentations at the Farmer Field School held near Kediri in East Java. These events were very successful in communicating the main messages generated in project research.

7.9.5 *Farmer field schools (FFS)*

Farmer field schools were held for both sugar factory staff as well as farmers. Project outcomes were extended via short presentations from scientists coupled with questionnaires and field demonstrations.

The age structure of those farmers attending FFS was recorded and analysed. Four age groups were evident for sugar factory workers attending: 21-30; 31-40; 41-50; and 51-60 years old, while farmers generally were older with five different age group categories: 21-30; 31-40; 41-50; 51-60; and 61-70 years old. The highest number of particpants were between 41-50 years old.

Responses to questionnaires revealed a range in the correct answers to questions about sugarcane pests and diseases (PTPN XI factory group). For factory staff, correct answers were made for between 37-100% of the questions asked, while for cane farmers, a lower percentage of correct answers was recorded (50-75% correct). 29% of sugar factory staff were able to answer all question correctly, while no cane farmer achieved 100%. The younger factory staff (21-30 years old) achieved higher scores than older age groups. It was not so clear for the farmers attending the course, and age had less of a bearing on their ability to answer the questions correctly.

The PTPN IX FFS participants were of similar age. Staff were allocated into four age group classes (same as at PTPNXI) and five for cane farmers (who tended to be older). The highest number of participants in both were 31-40 years old (sugar factory) and 41-50 years old (farmers).

Training for PTPN IX sugar factory staff showed many similarities to the other factory group; the youngest age group (21-30) again achieved the best results. A number of factory staff answered all questions correctly, but a much lower percentage of cane farmers were able to. In addition, a small percentage (17%) of farmers provided correct answers to <30% of questions; the ability of farmers thus varied markedly.

Conclusions:

- Sugar factory staff answered a higher percentage of answers correctly.
- Younger-aged attendees (21-30 years old) answered more questions correctly than their older counterparts.
- Workshops may need to cater specifically for farmers (vs sugar factory workers) In order for technology transfer to be achieved.

7.9.6 Economics of borer control (see section 7.6.1)

Borer management economic calculations were extremely useful in the project extension program and were incorporated into those activities proceeding after the associated research was completed. It is clear that all future extension activities should include the recommended borer management strategy with the accompany supporting profitability data to encourage farmers to switch management options.

7.9.7 Borer fact sheets

Borer fact sheets were produced and distributed to industry; the information contained has been well-received and has provided a source of important reference material for Indonesian farmers.

7.9.8 Field guide

Two thousand copies of the field guide in the Indonesian language were printed on water-proof paper; most of these have since been distributed to industry – to plantation managers, field supervisors and larger farmers. As a comprehensive guide to pest and disease identification, and their management, ‘Hama dan Penyakit Tebu’ (sugarcane pests and diseases) will be a lasting legacy of the project and has been very well received.

ACIAR also funded the printing of an English version of the guide; this has the advantage of using all the information on regional pests and diseases and making it accessible to scientists / technicians in countries in the western Pacific-Australasia region. This will provide a real advantage for Australian scientists who visit Indonesia / PNG in identifying pests and diseases. The English guides were distributed to Australian quarantine personnel and scientists working to the north of Australia.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The scientific impacts achieved in this research were significant. Research into moth borer control via parasitoids showed clearly that previous recommendations made over the last 30 years were clearly inadequate. A comparison of traditional vs. research project findings indicated that improved productivity and profitability will be obtained by application of project findings. Further information on pest and disease distribution, using data from 931 commercial cane crops has added a sound quantitative foundation to knowledge of pest and disease incidence in Java. Sugarcane streak mosaic was found to be the most common form of mosaic occurring in Java; this is new information. Chlorotic streak disease (CSD) was noted in central Java and this has highlighted the existence of the disease when it was largely ignored in the past. Molecular identification of the Trichogramma species colonising the moth borers has clarified the parasitoids currently being used in IPM laboratories in Java.

The release of a specific pest and disease field guide has provided sound scientific information on all the pests and diseases in Indonesia, plus the major ones present within the region and around the world.

The project a significant amount of training and younger Indonesian scientists were able to hear presentations from more experienced scientists and also to interact with them personally; this augurs well for their development into the future. ISRI scientists visited Australia to see what the Australian is doing and how they work within the industry. Australian scientists gained significantly from seeing the Indonesian industry and their local pests and diseases.

8.2 Capacity impacts – now and in 5 years

The capacity of scientists from the Indonesian Sugar Research Institute (ISRI) has been increased through their exposure to experts in their field from both Australia and France (François-Regis Goebel). A visit to Australia by ISRI scientists has added to their experience and their ability to recognise pests and diseases and to adopt new technologies from elsewhere. The sharing of much information through various extension activities we believe will have increased the capacity of the Indonesian industry though better understanding of their local pest and disease issues.

The capacity of the Australian scientists has been increased through their experience of Indonesian pests and diseases in the field and through discussions with their Indonesian counterparts. The writing of an Indonesian field guide has meant that information related to Indonesian pests and diseases has increased; the existence of an English version of the guide increases the ability of Australian scientists and field workers to diagnose incursions of important pests and diseases.

8.3 Community impacts – now and in 5 years

The full effects of project research will not be felt for a few years yet, until new information produced via the project filters out to the many cane farmers within the Indonesian sugarcane industry. There are major benefits to be gained from improved moth borer and white grub control treatments.

8.3.1 *Economic impacts*

The project identified pest control treatments (moth borer IPM) and chemical control strategies for white grubs) that are economic, significant and commercially feasible. The current recommended IPM strategy for moth borer control was shown to be sub-optimal and relatively poor. An improved recommendation was significantly more profitable for farmers and should lead to improved production in many parts of Java and much better economic outcomes. This is one of the most important results from project research.

8.3.2 *Social impacts*

Improved productivity and profitability should flow on to improved social outcomes for sugarcane farmers. Better returns on sugarcane crops may encourage further growth of this crop and improved living conditions for these farmers.

8.3.3 *Environmental impacts*

While the moth borer IPM strategy is not based on application of chemicals but release of parasitoids, management of white grubs currently relies on the application of large doses (25kg/ha) of diazinon. Our research suggests that the application of as little as 375g (a.i,)/ha of imidacloprid will achieve better control than diazinon – thud reducing the release of insecticide into the environment. Better white grub management will also lead to linger crop cycles and reduced soil disturbance, and reduced soil degradation and soil loss.

8.4 Communication and dissemination activities

A comprehensive approach to information dissemination is detailed in the methods and results section of this report. A combination of regional meetings, borer field days, champion farmers, fact sheets, farmer field schools using action learning techniques was utilised. A comprehensive pest and disease field guide (2,000 copies) was produced in Indonesian and distributed to farmers, factory field workers, scientists and other industry personnel. The same version was printed in English and distributed to Australian, French and other scientists working in the region.

In addition, papers were written regularly for scientific journals, Australian industry sugar journals, the Australian Society of Sugarcane Technologists and presentations made at cane farmer meetings in both Indonesia and Australia. Australian quarantine staff were kept informed and received the pest and disease field guide so that they are able to access relevant information in the field.

9 Conclusions and recommendations

There were a number of significant recommendations made from project outputs; these relate to the IPM strategy for moth borers, for management of white grubs in commercial crops, and for future research into sugarcane streak mosaic.

9.1 Conclusions

The most important conclusions from the research include: -

1. Increased dosage of the egg parasitoid *Trichogramma* significantly improved control of stem borers in research conducted in Indonesia.
2. Improved IPM strategies offer great scope for improved productivity and profitability; we showed significantly improved economic outcomes with adoption of the new IPM strategy.
3. Application of recommended management strategies for white grubs will also improve both productivity and profitability in areas affected by these pests.
4. Sugarcane streak mosaic virus is the major pathogen affecting sugarcane crops in Java and much research is needed in the areas of transmission, yield loss, epidemiology and varietal resistance.
5. The presence and occurrence of sugarcane pests and diseases in Java has now been quantified and knowledge of their impact on the industry will allow targeted control measures to be implemented.

9.2 Recommendations

1. That project results related to IPM for moth borers continue to be extended to the Indonesian industry using the extension techniques adopted in this project.
2. That the improved management strategy for white grubs be extended in those parts of the industry where greatest yield losses are experienced.
3. That research in various areas be conducted into sugarcane streak mosaic virus, particularly in understanding mechanisms of spread, associated yield losses, epidemiology and varietal resistance. This is needed urgently to reduce crop losses from this disease.
4. That continued interaction between Indonesian and Australian scientists occur to ensure relevant information is exchanged for the betterment of both industries.

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11 Appendixes

11.1 Appendix 1: