INVESTIGATIONS ON THE POTENTIAL USE OF PHEROMONES AS A MANAGEMENT TOOL FOR DIAMONDBACK MOTH, *Plutella xylostella* L. (LEPIDOPTERA: PLUTELLIDAE) IN INDONESIA

by

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ABSTRACT

Experiments to investigate the potential of using the sex pheromone of the diamondback moth (DBM), *Plutella xylostella* L. as a monitoring and control tool were carried out in West Java, Indonesia. It was determined that: 1) a 10 μg dose of pheromone ((*Z*)-11-hexadecen-1-ol acetate + (*Z*)-11-hexadecenal in a 4:6 ratio) is most attractive; 2) two-component lures are as attractive as three-component lures containing (*Z*)-9-tetradecen-1-ol acetate; 3) two-component blends in ratios between 8:2 and 4:6 are equally attractive; 4) three and five virgin females are more attractive than the two-component lure, suggesting that one or more components are not yet identified for Indonesian populations; 5) most male moth activity is about 1 h after sunset; 6) more males are caught in wing traps than water traps; 7) trap density has no effect on the number of moths captured per unit area of field; 8) trap catches of DBM males predicted populations (pooled larvae and pupae) in the field 3 weeks later in two of three fields in one trapping season and 2 weeks later in three of three fields in a second trapping season; 9) mating disruption of DBM has potential in areas large enough to minimize the impact of female immigration. Research is recommended on the further development and implementation of pheromone-based monitoring, on disruption based control, and on determining the identity of any missing pheromone components.

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Investigations on the potential use of pheromones as a management tool for diamondback moth, Plutella xylostella L. (Lepidoptera: Plutellidae) in Indonesia

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Table of Contents

List of Tables

List of Figures

INTRODUCTION

Crop Production and Pest Management in Indonesia

Agriculture in Indonesia contributes more than 25% to the Gross National Product. About 55% of the population are farmers (United Nations 1992). Since Indonesia became self-sufficient in rice in 1984, the government has placed a high priority on the development of vegetable production, so as to develop self-sufficiency in food production, improve nutritional status, increase rural employment and increase foreign exchange earnings through exports (Hardjono 1990; Sastrosiswojo 1990).

Cabbage is an important vegetable crop for cash income and home consumption for highland farmers in Indonesia (Sastrosiswojo 1990). The area under cabbage cultivation in Indonesia is about 39,700 ha. Approximately 73% of cabbage production in Indonesia, is on the island of Java with an average production of about 18 tonnes per ha (Bagian Statistik Tanaman Pangan 1989; Buurma 1989). This production is much higher than in other cabbage growing areas of Indonesia, but is less than half of the production potential demonstrated in research plots (Subijanto & Isbagyo 1988).

Pests and diseases and seed quality are the major factors limiting productivity of vegetables including cabbage (Asandhi & Sastrosiswojo 1988). To control the

diamondback moth (DBM) *Plutella xylostella* (Lepidoptera: Plutellidae), farmers use large quantities of insecticides, often spraying "cocktails" of chemicals (Ooi 1986). Insecticide resistance is a serious problem due to these practices, and is exacerbated by the rapid turnover of insect generations in the tropics (Sun *et al.* 1986). Consequences associated with excessive pesticide usage include increased costs, secondary pest outbreaks, human health problems and environmental contamination (Hansen 1987). There is a clear need for development of integrated pest management (IPM) programs that can result in a highly productive, sustainable agriculture.

Since 1986, the government has promoted rice IPM. In 1989, a national IPM programme for vegetables (*Pengendalian Terpadu Hama dan Penyakit Sayuran*) was initiated to train extension agents on IPM practices (Sastrosiswojo[1], pers. comm.).

The Diamondback Moth in Indonesia

DBM is an important pest of cruciferous crops worldwide, particularly in the tropics (Liu *et al.* 1982; Miyata *et al.* 1982). In Indonesia, DBM and the cabbagehead caterpillar, *Crocidolomia binotalis* Zeller (Lepidoptera: Pyralidae) are the most destructive insect pests on cabbage;

[1] Research Scientist, Lembang Horticultural Research Institute (LEHRI), West Java, Indonesia

if not controlled they can result in total yield loss (Sastrosiswojo & Sastrodihardjo 1986). DBM has been reported as causing serious damage to cabbage as early as 1916 in Indonesia (Vos 1953). Control of DBM has been heavily reliant on chemical insecticides. (Sastrosiswojo 1990). Insecticides are applied at three to six day intervals with most of the insecticides used belonging to organophosphate, carbamate and synthetic pyrethroid groups (Sastrosiswojo 1990)

An ichneumonid parasitoid, *Diadegma eucerophaga* Horstm., was introduced into Indonesia by Vos (1953), and has become established in most highland vegetable growing areas (Sastrosiswojo & Sastrodihardjo 1986). *D. eucerophaga* has the potential to suppress DBM populations with larval parasitism exceeding 80% in some locations. Failures in biological control have been attributed to excessive use of insecticides that are toxic to the parasitoid (Sastrosiswojo & Sastrodihardjo 1986). Current research efforts focus on identification of selective insecticides that are less toxic to *D. eucerophaga*, determination of action thresholds, and manipulation of cabbage through intercropping systems (Sastrosiswojo & Sastrodihardjo 1986).

Resistance to Insecticides

The DBM has developed resistance to most major classes of insecticides (Miyata *et al.* 1982; Liu *et al.* 1981, 1982; Tabashnik *et al.* 1987, 1990, Cheng 1988; Perng 1988; Kao *et al.* 1989). DBM resistance in tropical regions is a particular problem because of the rapid turnover of generations (Liu *et al.* 1981). In Indonesia, resistance to DDT was first observed in DBM populations in West Java in 1951 (Ankersmit 1953). Since then, DBM has developed resistance to several organophosphates and synthetic pyrethroids (Sastrosiswojo *et al.* 1989), and even to the microbial insecticide, *Bacillus thuringiensis* Berliner (Bt) (Tabashnik *et al.* 1990). In 1987, insecticide use on cabbage represented approximately 56% of production costs in West Java (Hardjono 1991). Resistance has lead to increases in the dosage and frequency of pesticide use resulting in a "pesticide treadmill" (Hansen 1987).

Biology

The host range of DBM is limited to plants containing mustard glucosides, characteristic of the family Cruciferae (Ooi 1986; Pivnick 1990).

Eggs are deposited singly or in small groups on leaves of the host plant (Marsh 1917; Harcourt 1954, 1961; Beirne 1971; Tabashnik & Mau 1986). There are four larval instars

(Vos 1953; Harcourt 1956). First instar larvae are leaf miners in the spongy mesophyll layer (Harcourt 1954). Later instars feed primarily on the lower leaf surface, skeletonizing the leaves, resulting in a "windowing" effect (Harcourt 1954, 1957). When disturbed, larvae characteristically wiggle backwards or drop on a silken thread (Harcourt 1957; Ho, 1965). Mature fourth instars spin an open-netted cocoon, lie quiescent therein for one or two days, and pupate (Harcourt 1957). Distribution patterns of immature stages of DBM on cabbage are contagious (Harcourt 1960; Sivapragasam *et al.* 1986).

Adults are small, slender, and grayish-brown (Harcourt 1956). When at rest, the wings show the characteristic white diamond-shaped pattern, which extends dorsally from the head to the tip of the wings (Ho 1965). Females are typically lighter and less distinct in color than males (Harcourt 1956), which can also be recognized by their prominent claspers at the tip of the abdomen (Moriuti 1986).

During the daytime, adults rest on the lower leaf surfaces of the host plant (Harcourt 1957). They are weak fliers, and when disturbed, make short and unsteady flights in search of shelter on the host plant (Harcourt 1957; Ho 1965). Adults become active at dusk, and mate early in the scotophase, primarily on the first day of emergence (Harcourt 1957; Pivnick *et al.* 1990). Harcourt (1957) observed that females only mated once in the field, while

Moller (1988) observed multiple matings in laboratory investigations. Fecundity is dependent primarily on larval nutrition which affects female pupal weight (Salinas 1986; Moller 1988). The number of eggs laid may depend on the presence of suitable host plants (Pivnick *et al.* 1990). Harcourt (1957) noted that females laid 18 to 365 eggs (mean = 159), with 50% more eggs laid on the upper than lower leaf surface; however, Marsh (1917) observed oviposition to be preferentially on the lower leaf surface.

In Ontario, Butts & McEwen (1981) found that DBM life stages showed peaks each year, although both life stages and generations overlapped. This is in contrast to studies by Harcourt (1957) (also in Ontario), where peaks were less evident. In the Cameron Highlands in Malaysia, generations were not distinct (Ho 1965).

Threshold temperatures and thermal constants for the development of one generation of DBM have been calculated by Harcourt (1954) and Umeya & Yamada (1973). Umeya & Yamada (1973) determined that one generation of DBM from Malang, East Java required 250 degree-days above a threshold of 8.6°C.

Sudarwohadi (1975) reported that lowest population densities of DBM were correlated with maximum rainfall during the growing season. This is supported by Sastrodihardjo (1986) who reported that dry months triggered outbreaks. During the rainy season in the Cameron Highlands in Malaysia, DBM populations also decrease (Ho 1965), and in

Canada rainfall is a major limiting factor in DBM population dynamics (Harcourt 1963). Larvae are washed away by rainfall or swept into leaf axils where they drown in accumulated water (Harcourt 1963; Talekar *et al.* 1986). Rain may also disrupt the flight of adults which may disturb oviposition (Talekar *et al.* 1986).

Potential for Pheromones in Management of DBM in Indonesia

Much research has been conducted in the development of treatment decision criteria, such as action thresholds for controlling cabbage lepidoptera, including DBM (Chalfant *et al.* 1979; Workman *et al.* 1980; Shelton *et al.* 1982; Simonet & Morisak 1982; Shuster *et al.* 1984; Hoy *et al.* 1986; Cartwright *et al.* 1987; Stewart & Sears 1989). In Indonesia an action threshold of 0.5 larva per plant has been developed (Sastrosiswojo 1990).

Sampling of DBM requires training and time. DBM larvae are small and tend to be concealed in the heart leaves (Baker *et al.* 1982). Under the Indonesian context, a larval density threshold system may be limited by farmers' accessibility to extension services, uncertainty in sampling procedures and time constraints (Hallett 1992). Development of a practical monitoring tool for adults might assist in determining subsequent larval density. Field studies by Hallett (1992) in North Sulawesi, Indonesia showed that catches of DBM on yellow sticky traps were predictive of

larval populations and might have practical applications in Indonesia.

The female sex pheromone of DBM has been identified as (*Z*)-11-hexadecen-1-ol acetate (*Z*-11-16:Ac) and (*Z*)-11-hexadecenal (*Z*-11-16:Ald) (Chow *et al.* 1974; Tamaki *et al.* 1977). On the basis of electroantennogram (EAG) assays, it was found that one or more other pheromone components including (*Z*)-9-tetradecen-1-ol acetate (*Z*-9-14:Ac) and (*Z*)-11-hexadecen-1-ol (*Z*-11-16:OH) may be involved (Chow *et al.* 1974, Ando *et al.* 1979, Chisholm *et al.* 1979).

The development of pheromone-baited traps as a predictive tool for numerous insect species suggests that a pheromone-based monitoring system (Campion & Nesbitt 1981), could provide Indonesian farmers with a useful indicator of DBM population levels, allowing them to schedule spray applications and reduce their frequency. Relationships between adult and larval populations and/or damage levels have been demonstrated in forest (Sanders 1988), orchard (Smith & Borden 1990) and field crop (Shelton & Wyman 1979, Tingle & Mitchell 1981, Judd *et al.* 1985) systems. For example, Shelton & Wyman (1979) found that pheromone trap catches of male potato tuber moth, *Phthorimaea operculella* (Zeller), were significantly correlated with foliar larval counts made one week later. Similarly, Tingle & Mitchell (1981) found significant correlations between trap catches of male tobacco budworm, *Heliothis virescens* (F.), and larval counts made one or two weeks later. Baker *et al.*

(1982) showed that when mean adult catches of DBM were compared with mean larval populations, significant correlations were obtained when larval populations were offset by 11 to 21 days, in 40% of the fields. Correlations were probably not obtained in the remaining fields due to insecticides killing the larvae. Koshihara (1986) also showed significant correlations between DBM catches and larval density when larval populations were offset by 0 to 15 days.

The development of mating disruption could logically ensue after the potential of pheromone-based monitoring was demonstrated. Mating disruption is a pest management tool that interferes with sexual communication of an insect species. It involves the permeation of the atmosphere with synthetic sex pheromone to disrupt orientation of males to females thereby reducing the frequency of mating and subsequent larval infestation (Campion & Nesbitt 1981; Kydonieus & Beroza 1982; Kirsch 1988). Several mechanisms have been described in explaining communication and mating disruption. These may include: 1) adaptation of antennal receptors and habituation at the central nervous system brought about by constant exposure to relatively high levels of pheromone such that a male cannot respond to signals from a potential mate; 2) diversion of males from calling females as responding males are presented with numerous 'false' trails or point sources of synthetic pheromone; 3) inability of responding males to distinguish individual odor trails of

calling females as natural female odor plumes are masked by a synthetic pheromone 'fog'; and 4) modification of male response as a result of use of high levels of a single component of the pheromone (Rothschild 1981; Bartell 1982; Campion *et al.* 1989). Pheromone-based mating disruption has been investigated for a number of lepidoptera (Rothschild 1981). The development of mating disruption could be of major benefit to Indonesian farmers as DBM may be controlled without the use (or reduced use) of chemical insecticides. The potential for mating disruption for control of DBM has been demonstrated in Japan (Ohbayashi 1989; Nemoto *et al.* 1992; Ohbayashi *et al.* 1992; Ohno *et al.* 1992), Taiwan (Chow *et al.* 1984; Chow 1992) and Canada (Chisholm *et al.* 1984).

OBJECTIVES

My objectives were to investigate the potential of using the DBM pheromone as a monitoring and control tool for DBM in Indonesia. Specific objectives were to:

1) determine an appropriate concentration and ratio of the DBM sex pheromone to be used as a trap lure;
2) evaluate the efficiency of a low-cost water pheromone trap;
3) establish the relationship between adult male moth trap catches and egg, larval and pupal DBM densities;
4) determine the effect of trap density on trap catches;
5) record patterns of diel flight activity;
6) determine the effectiveness of mating disruption to suppress DBM by assessing disorientation (measured by reduction in male trap catches), mating inhibition (evaluated using caged insects) and larval infestation levels.

MATERIALS AND METHODS

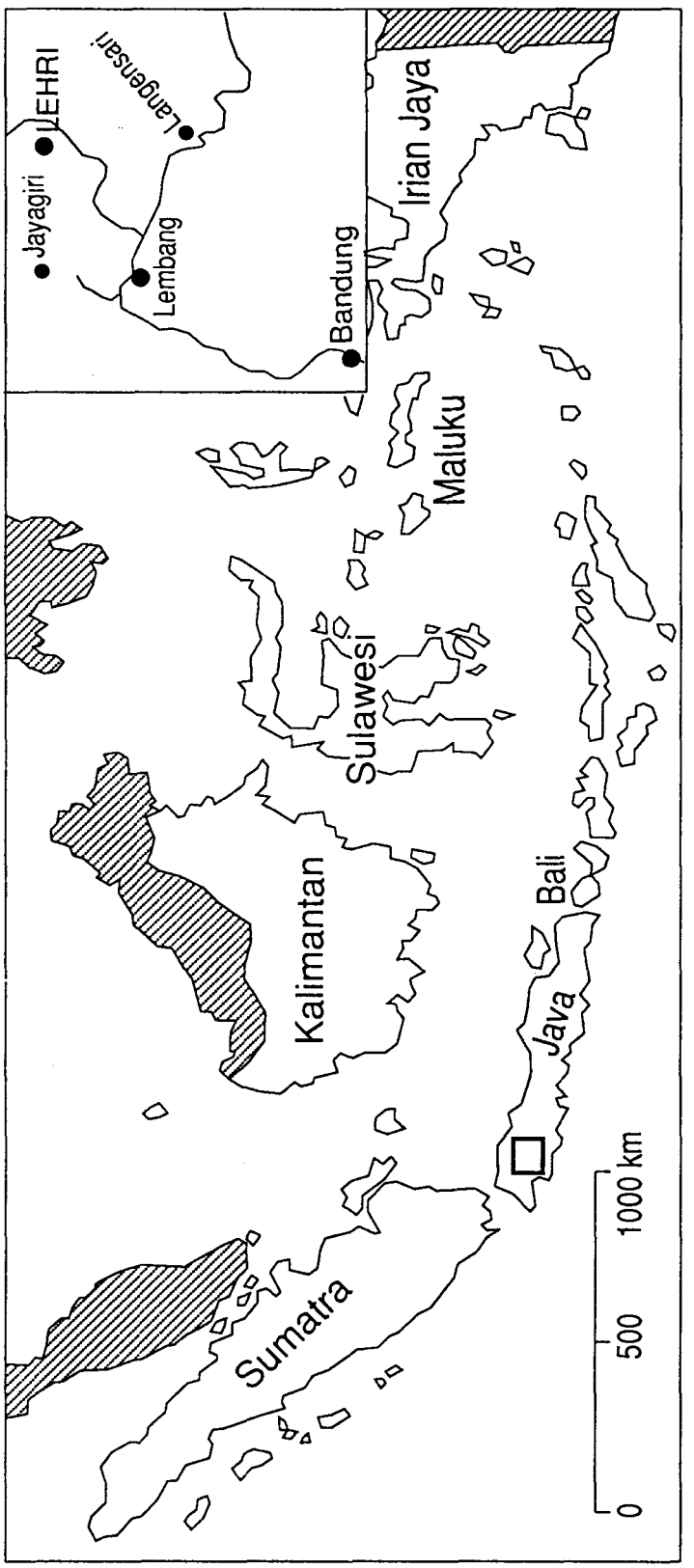
The Study Area

The study site was located in *Kecamatan* (subdistrict) Lembang, one of the major vegetable growing areas in West Java (Fig 1). Lembang is situated in the foothills of several volcanoes at an elevation of about 1250 m, about 20 km from Bandung, the provincial capital of West Java (Buurma 1989).

The agroclimate of West Java is characterized by 9 to 12 consecutive wet months and 0 to 3 consecutive dry months (between June and September). Wet and dry months are defined as months with >200 or <100 mm of rainfall, respectively (Buurma 1989). During the dry season, cabbage production is at its lowest due to lack of water for irrigation (pers. obs.).

Research was conducted on land rented at the Lembang Horticultural Research Institute (LEHRI) (*Balai Penelitian Hortikultura Lembang*) in *desa* (village) Margahayu, and on land rented from farmers in *desas* Langensari and Jayagiri. Langensari is about 4 km from the town of Lembang and is serviced by a good road. Jayagiri is in the hills about 2 km from the town center.

Fig. 1. Map of Indonesia, showing location of study site on Java (square) and in detail (inset).


Jayagiri
LEHRI
Langensari
Lembang
Bandung
Irian Jaya
Maluku
Sulawesi
Kalimantan
Bali
Java
Sumatra
0
500
1000 km

Cabbage Cultivation

The cabbage variety used throughout the study was 'Gloria Osena', typically used by upland farmers. Cabbage cultivation in all cropping seasons followed practices similar to those used by farmers, unless otherwise stated.

Seedbed was prepared by mixing a 1:1 ratio of horse or chicken manure with rice husk sieved to produce a very fine-textured mixture. Seeds were soaked in a systemic fungicide Previcur-N (Propamocarb) at 1 cc per 100 cc water for 1 h to reduce pre- and post-emergence damping-off before sowing. Black plastic was placed over the seedbed for 3 days to maintain high humidity necessary for germination. After 1 week, the seedlings were transplanted into banana leaf pots and left under a clear plastic roof until transplanted into the field about 3 to 4 weeks later. Seedlings were watered in the early morning every second day, or when necessary. A prophylactic insecticide-fungicide treatment of Orthene 75 SP (Acephate 75%) @ 1.5 g A.I. per liter water, and Antracol (Propineb 70%) @ 1.4 g A.I. per liter water, was generally applied twice a week.

Cabbage was transplanted into raised single rows 70 cm apart at an interplant distance of about 50 cm. After plowing, fields were prepared by applying dolomite lime at 2.5 to 3 tonnes per ha about 3 weeks before transplant for clubroot control, either by broadcasting the lime and then working it into the soil or putting the lime directly into

the transplant hole. Several days before transplanting, cow or horse manure @ 30 tonnes per ha and NPK 15:15:15 fertilizer at 1 tonne per ha were applied into the transplant hole. Urea @ 400 kg per ha was applied about 4 weeks after transplanting. Plants that died after transplanting were replaced until about 3 weeks after transplant. If necessary insecticide was sprayed for black cutworm, *Agrotis ipsilon* (Hufnagel) and *C. binotalis* at the seedling stage only, after which hand removal of unwanted cabbage pests was done twice weekly.

Pheromone and Traps

Pheromone solutions were prepared by Phero Tech Inc., Delta, B.C., Canada, using dichloromethane (CH_2Cl_2) as the solvent. One day before placement of pheromone traps in the field, 200 μL aliquots of pheromone solutions were loaded onto halobutyl rubber septa (The West Company, Phoenixville, PA) using a micropipette. Loaded septa were left for 1 h to allow the pheromone to adsorb onto the septa and then reloaded with 200 μL of solvent. Loaded septa were left overnight in the open and then were stored in sterilized glass jars at 4°C until used later the same day.

In all experiments, wing-type sticky traps (Phero Tech Inc., Canada) were attached to 'L-shaped' bamboo stakes, and placed at crop canopy height in a cabbage row, with long axis of the trap parallel to the row. Wind direction was

not measured and therefore not considered in placement of traps.

Intertrap distance in all experiments was dictated by field size and experimental design.

Cropping Regimes

Experiments extended over four cabbage cropping seasons from August 1991 to June 1992. Crop 1 extended over the end of the dry season, while the latter 3 crops extended over the wet season. Crop management followed the regimes described in Table 1.

Rearing DBM

DBM larvae and pupae were field-collected at LEHRI and reared in a screen house in 0.5 m^3 cages for use in experiments requiring virgin females. Approximately every five days, four fresh cabbage plants *cv* 'Gloria Osena' $\geq$ 3 weeks old, were put into cages containing adult DBM provided with a cotton wick of 10% sucrose solution. Egg-bearing plants from these mating-oviposition cages were then placed in separate larval rearing cages. When virgin insects were required, pupae from lab-reared generations were placed individually in 50 mL plastic vials with small holes in the lid and left to emerge. Newly-emerged adults were fed with 10% sucrose solution on a cotton wick.

Table 1. Cropping regimes for field experiments

Cropping duration	Sowing date	Transplant date	Description of planting site	Management practices	Insect Control			Date experiments began
					Target	Date	Treatment	
August-November 1991	12 Aug	7 Sept	2 adjacent fields approx. 0.1 ha each	Irrigation 2X/week; hand weeding 4 weeks after transplant;	*A. ypsilon*	18 Sept	Orthene	4 weeks after transplant
					C. binotalis H. undalis	2X/week	hand removed	
October 1991-February 1992	14,23 Oct	13-14 Nov	3 fields approx. 0.1 ha each	hand weeding 4 weeks after transplant	*A. ypsilon*	20 Nov	Orthene	4 weeks after transplant
					C. binotalis	28 Nov, 4 Dec	Orthene, Dursban, Curacron	
					C. binotalis, H. undalis	2x/week	hand removed	
January-April 1992	9 Jan	9 Feb	3 fields approx. 0.1 ha each	handweeding 4 weeks after transplant	*A. ypsilon*	18 Feb	Orthene	2 weeks after transplant
					C. binotalis, H. undalis	2X/week	hand removed	
March-June 1992	5[b], 9[a] March	3,4,11 April[b] 6 - 9 April[a]	2 fields in each of 2 villages[ab] approx. 0.02 and 0.1 ha each		clean up sprays	10,13 April[a] 13,16 April[b]; 10,24 May[b],2, 9,16,23, 30 May, 6 Jun[a]	Orthene, Anthracol Bt	2 weeks after transplant

[a] Sites at Jaya Giri
[b] Sites at Langansari

Factors Affecting Trapping Effectiveness

Dose Response and Ratio Experiments

Three experiments were conducted to establish a suitable pheromone blend and concentration for loading onto lures in subsequent experiments. Test blends were chosen because they elicited good responses under Asian climatic conditions (Koshihara *et al.* 1978; Chien & Chiu 1986).

Concentrations over five orders of magnitude of two blends were tested with the highest doses being 40:60 μg of *Z*-11-14:Ac : *Z*-11-16:Ald and 40:60:1 μg of *Z*-11-16:Ac : *Z*-11-16:Ald : *Z*-9-14:Ac. Control traps were baited with CH_2Cl_2. Dose responses for each blend were tested separately but concurrently in two adjacent fields. Traps were placed in 6 X 6 Latin squares with 3 m between traps. From 7 October to 4 November 1991, captured males were counted and removed every second day.

Best blends from these experiments were compared in a third experiment. Treatments included: 40:60 and 4:6 μg of *Z*-11-16:Ac : *Z*-11-16:Ald and 40:60:1 and 4:6:0.1 μg of *Z*-11-16:Ac : *Z*-11-16:Ald : *Z*-9-14:Ac and CH_2Cl_2 as control. Traps were placed 7 m apart in a 5 X 5 Latin square, extended over both adjacent fields. Within rows, traps were offset by 3.5 m in a zigzag pattern in order to minimize intertrap interference. Captured males were counted and removed daily from 13 to 25 November, 1991.

Z-11-16:Ac and *Z*-11-16:Ald were tested alone and in ratios of 8:2, 6:4, 5:5, 4:6 and 2:8 at 10 μg per 200 μL CH_2Cl_2 to determine the optimal ratio. Traps were set 3 m apart in an 8 X 8 Latin square. Captured males were counted and removed every third day from 15 to 22 June, 1992.

Comparison of Natural with Synthetic Sex Pheromone

Three experiments were conducted to determine the potency of different numbers of virgin females against the standard lure (plus solvent) and solvent alone. In separate experiments, 5, 3 and 1 virgin female(s) were compared with 10 μg (4:6) *Z*-11-16:Ac : (*Z*)-11-16:Ald and CH_2Cl_2 (solvent) controls with 3 replicates of each treatment. One day old virgin females were caged in plastic cylinders, (3 X 5 cm) with ends covered by fine mesh hung inside the traps. A cotton wick soaked in 10% sucrose was placed in each female cage. Traps were placed 4 m apart in a 3 X 3 Latin square. Captured males were counted and removed for 2 days. Experiments for 5, 3 and 1 virgin females extended over 12 to 14, 16 to 18 and 19 to 21 June, 1992 respectively.

Times of Peak Moth Activity

A survey to determine diel patterns of DBM activity was conducted on 3 separate days. Eight traps baited with *Z*-11-16:Ac : *Z*-11-16:ALD at 4:6 μg were placed in a cabbage field in a 2 X 4 grid at an intertrap distance of 10 m, at 0800 h on 26 November, 1991, 4 February, 1992 and 10 April 1992. Captured males were counted and removed each hour for 24 h. Times of sunset and sunrise and phase of the moon for the three dates are given in Table 2.

Trap Type Comparison

An experiment was conducted to evaluate the trapping efficiency of a low-cost water pheromone trap against the standard wing-type pheromone trap. The water trap was constructed as designed by Sastrosiswojo (LEHRI, pers. comm.). A 3.5 L green plastic bowl (29 cm diam., 15 cm deep) was used as the trap base. The bowl was filled with water to which a small amount of detergent had been added to reduce surface tension. A 4 cm wide strip of sheet metal was attached to the bowl to form an arched handle to which a pheromone lure (*Z*-11-16:Ac : *Z*-11-16:Ald at 4:6 μg) was attached about 20 cm above the water level. About 1 cm below the rim of the bowl, two 4 X 2 cm windows were cut and covered with fine mesh to allow excess rain water to exit.

Table 2. Times (West Java time) of sunset and sunrise and moon phase for dates during which diel flight activity was monitored. [Source *Almanak Badan Meteorologi dan Geofiska,* 1991/1992.]

Date	Sunset	Sunrise	Phase of Moon
26-27 Nov 1991	1748	0522	between last quarter and full moon
4-5 Feb 1992	1815	0551	new moon
10-11 Apr 1992	1747	0551	first quarter

Traps were placed 10 m apart in a 2 X 2 Latin square. Captured males were counted and removed every 3 to 4 days from 4 to 28 February and 14 April to 8 May, 1992.

Relationships between DBM Trap Catches and Foliar Populations

Experiments over 2 cropping seasons were conducted to determine if DBM trap catches were predictive of subsequent foliar populations. Traps baited with *Z*-11-16:Ac : *Z*-11-16:Ald at 4:6 μg were placed in a grid within each of three fields at LEHRI (Table 3). From about three weeks after transplant to harvest, captured males were counted and removed every third day. On the same days, 20 plants (Dec. 14, 17, 20) then 30 plants per field were sampled by walking through the field in a "zigzag pattern" and stopping every 10 to 15 paces to sample one plant. Plants in the two edge rows on each side of the field and the three plants at the ends of each row were not sampled. All outer leaves and three to four wrapper leaves were observed for numbers of eggs, larvae (small and large), pupae and parasitized pupae of DBM. Plants were also assessed for accumulated damage, using a scoring system (Lim *et al.* 1986). Pheromone lures were replaced after 4 weeks.

Temporal relationships were determined by regressing foliar populations, offset by time lags of 0 to 27 days, on trap catches.

Table 3. Characteristics of experimental setup for testing the relationships between DBM trap catches and foliar density.

Dates of experiment	Field	No. of traps	Intertrap distance (m)	Field size (m^2)
11 Dec 1991 to	1	10	10	840
31 Jan 1992	2	6	20	1050
	3	1	-	1122
18 Feb to	1	10	10	540
6 April 1992	2	6	20	1170
	3	4	30	1369

Small-plot Evaluation of Mating Disruption

A randomized complete block experiment, with three treatments and two replicates, was set up to evaluate the potential of mating disruption in controlling DBM. Blocks were set up in two villages, Langensari and Jaya Giri, located about 5 km apart. Locations were similar with respect to the mixed vegetation surrounding each of the fields. In each location there was a large and a small field. The large field was divided into 2 plots.

Treatments included: 1) 'Konaga-con' DBM pheromone dispenser (Shin-Etsu Chemical Co., Tokyo, Japan) - a polyethylene tube with an aluminum wire containing a 1:1 ratio of *Z*-11-16:Ac : *Z*-11-16:Ald; 2) insecticide treatment, *Bacillus thuringiensis* (Bactospeine WP 16,000 IU/mg and Thuricide HP Berliner strain HD-1 var. *kurstaki*, serotype IIIa and IIIb 16,000 IU/mg, @ 1.5 g/L water) plus sticker (Agristik) @ 0.5 ml/L water, using an action threshold of 0.5 larvae per plant; 3) no treatment control. Bt was chosen because it is nontoxic to *D. eucerophaga*. Plots at the Langensari were 1140, 936 and 725 m^2 in the disruption, insecticide treated and control plots respectively, while the respective sizes at the Jaya Giri were 1539, 1150 and 600 m^2. The small and the large fields were approximately 80 and 200 m apart in Langensari and Jaya Giri, respectively.

Konaga-con ropes were placed within rows at 30-35 cm above the soil at approximately 8 m intervals. The ropes were supported by bamboo stakes at approximately 10 m intervals. One wing-type trap loaded with 4:6 μg of *Z*-11-16:Ac : *Z*-11-16:Ald was placed in the center of each plot. A mating cage (approx 1 m^3) was also placed near the center of each plot.

Mating disorientation was assessed by pheromone trap catches, while assessments of egg and larval density and crop damage measured efficacy of mating disruption. Males captured in pheromone traps were counted and removed each week. At the same time, 20 plants were sampled near the center of each plot by walking in a "zigzag pattern" and every 4 to 6 paces sampling a plant for numbers of eggs, small and large larvae, pupae, parasitized pupae and damage assessment.

Mating inhibition within treatment plots was assessed using mating cages. Each week (depending on availability of insects), 4 to 6 virgin females and males ($\leq$ 2 days old) were placed for 24 h in mating cages containing 4 potted cabbage plants and a cotton wick soaked in 10% sucrose solution. Females recovered after 24 h were preserved in 70% ethanol and later examined for the presence of spermatophores.

At Langensari, the pheromone rope was stolen sometime between 14-21 April and replaced on April 22. Against instructions, insecticide (Orthene) was sprayed in all plots

in Langensari on April 19 and 22. Therefore, data taken on April 23 were not counted.

Statistical Analysis

When necessary to correct for heterogeneity of variance and nonnormality (Zar 1984), data were transformed by $\log_{10}(1+x)$. Analysis of variance (ANOVA), the SNK test and t-tests (Zar 1984) were done using MSTATC (Michigan State), Version 1.4. Regression analysis was done using Minitab, Version 7.2. Chi-square analysis, multiple comparisons between proportions and the power test were done using SAS (SAS 1988). In all cases, $\alpha=0.05$.

Experiments comparing the effect of pheromone dose and ratio on male trap catch, and comparing synthetic pheromone with virgin females, were analyzed using 1-way ANOVA on transformed total numbers of males caught. Two-sample t-tests using transformed data were used to compare mean trap catches in wing-type and water traps.

The relationship between male trap catches and foliar populations of DBM, was analyzed by simple linear regression (Zar 1984). Mean egg, larval and pupal densities per plant (dependent variables), offset by 0, 6, 15, 21 or 27 days were regressed on mean numbers of male moths per trap per day (independent variable) for each field over an entire growing season.

To determine if trap density had an effect on moth captures, the total trap catch for each sample date was divided by field size to give a measure of moths per m^2. A 1-way ANOVA was conducted on transformed data for each trapping period.

Transformed data on disruption were analyzed by a 3-way ANOVA (sources of variation; treatment, block and sampling date) on mean number of moths per trap per week and mean eggs, larvae and pupae per plant over the cropping season between the three treatments. The frequencies of mated and nonmated females in the three treatments were subjected to chi square analysis.

RESULTS

Factors Affecting Trapping Effectiveness

Most males were captured with the 10 μg (4:6) dose of *Z*-11-16:Ac : *Z*-11-16:Ald, although all doses except 0.01 μg attracted some males (Fig. 2). A similar trend occurred with the 3-component blend, but trap catches baited with pheromone at the second lowest dose was not different from CH_2Cl_2 control traps (Fig. 2). There was no significant difference between responses to the most attractive doses of the 2- and 3-component blends (Fig. 3). Highest catches of males to the 2-component lure occurred at ratios of *Z*-11-16:Ac : *Z*-11-16:Ald between 8:2 and 4:6 (Fig. 4). Neither compound alone attracted male DBM.

Traps baited with 5 and 3 (but not one) virgin females captured significantly more males than those baited with the 2-component lure or the CH_2Cl_2 control (Table 4).

Flight activity of DBM, as indicated by male trap catches, peaked at about 1 h after sunset on three different days (Fig. 5).

In two experiments, captures of male DBM (mean ± SE) in wing and water traps, respectively, were 179.5 ± 46.5 and 43.0 ± 12.0 and 156.0 ± 23.0 and 5.5 ± 0.5. In both cases the wing trap was significantly superior at catching more males (t-test, $P < 0.05$).

Fig. 2. Numbers of male DBM captured in wing traps baited with 2- or 3-component lures on rubber septa at 5 doses. Bars followed by the same letter are not significantly different, SNK test, $P < 0.05$. Note different scales for captured males.

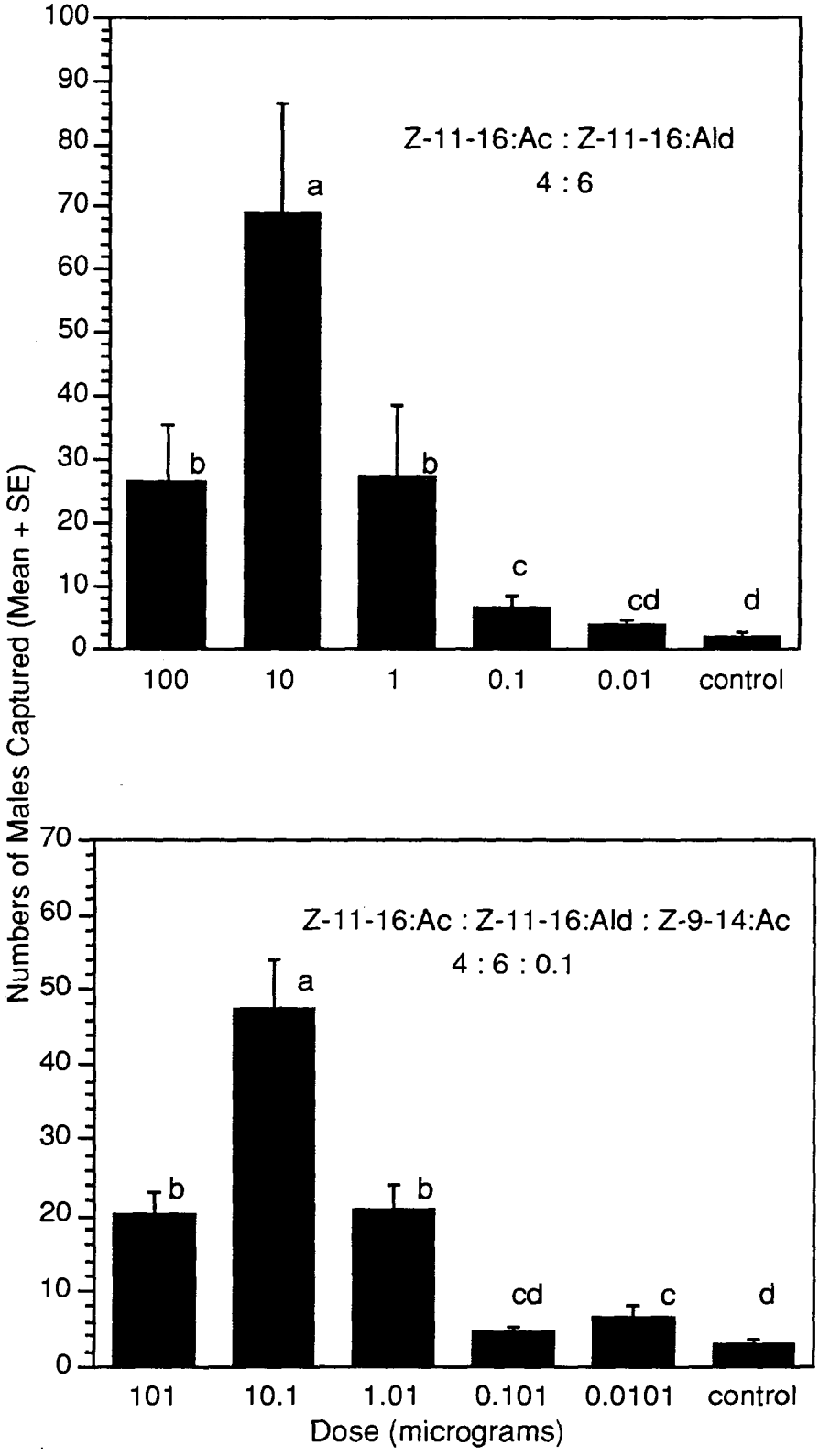

Z-11-16:Ac : Z-11-16:Ald
4 : 6
a
b
b
c
cd
d
100
10
1
0.1
0.01
control
Z-11-16:Ac : Z-11-16:Ald : Z-9-14:Ac
4 : 6 : 0.1
a
b
b
cd
c
d
101
10.1
1.01
0.101
0.0101
control
Numbers of Males Captured (Mean + SE)
Dose (micrograms)

Fig. 3. Numbers of male DBM captured in wing traps baited with 2- or 3-component lures on rubber septa at 2 doses. Bars followed by the same letter are not significantly different, SNK test, $P < 0.05$.

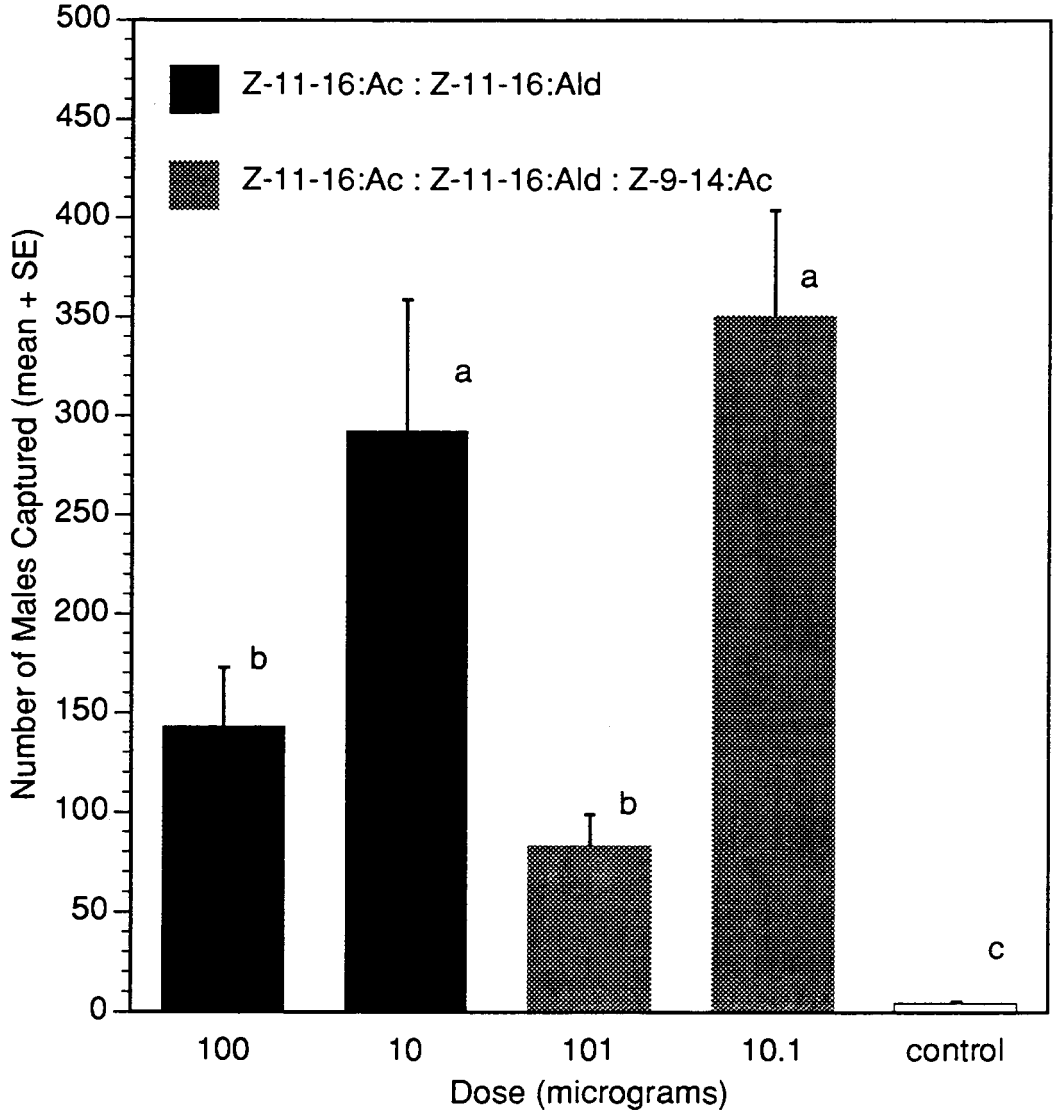

Z-11-16:Ac : Z-11-16:Ald
Z-11-16:Ac : Z-11-16:Ald : Z-9-14:Ac
Number of Males Captured (mean + SE)
500
450
400
350
300
250
200
150
100
50
0
a
a
b
b
c
100
10
101
10.1
control
Dose (micrograms)

Fig. 4. Response of male DBM to wing traps baited with single or 2-component lures on rubber septa at 5 different ratios. Bars topped by the same letter are not significantly different, SNK test, $P < 0.05$.

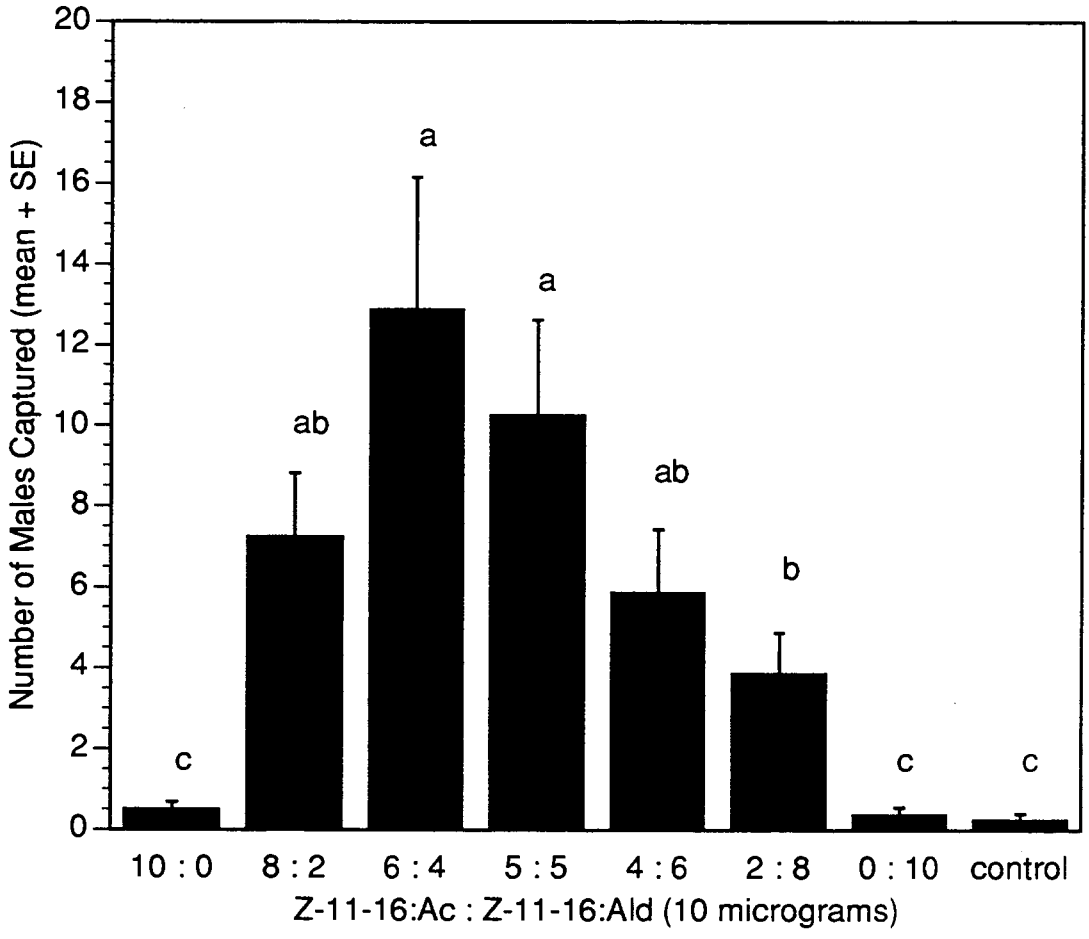
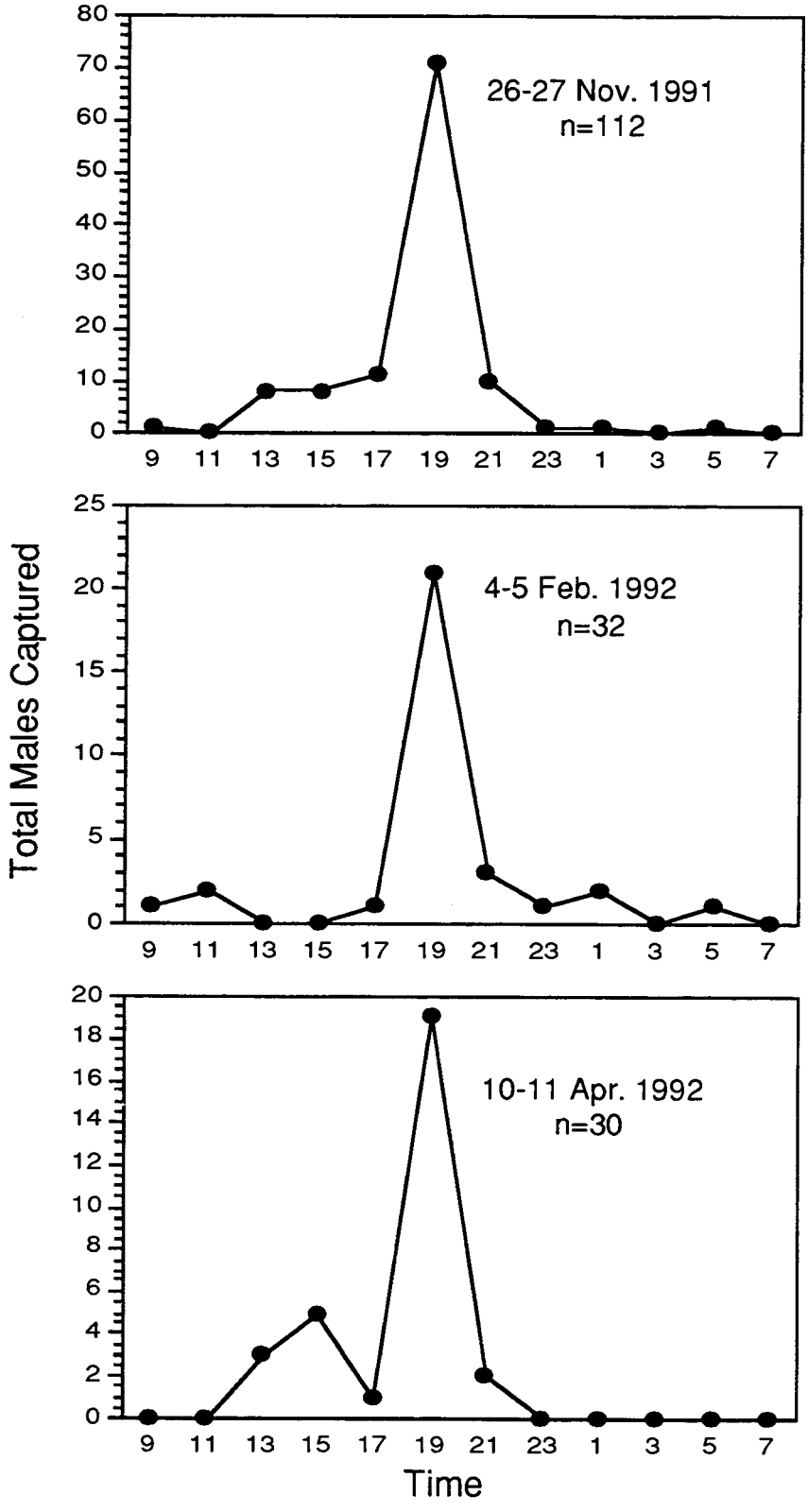

Number of Males Captured (mean + SE)
20
18
16
14
12
10
8
6
4
2
0
c
ab
a
a
ab
b
c
c
10 : 0
8 : 2
6 : 4
5 : 5
4 : 6
2 : 8
0 : 10
control
Z-11-16:Ac : Z-11-16:Ald (10 micrograms)

Table 4. Numbers of male DBM captured in three experiments comparing the two-component synthetic lure, *Z*-11-16:Ac : *Z*-11-16:Ald at 4:6 μg on rubber septa to virgin female DBM. Each experiment 2 days duration, n=3.

	Number of males captured (mean ± SE)[a]		
Treatment	Exp. 1	Exp. 2	Exp. 3
2-component lure	2.7±0.7 b	1.3±0.9 b	2.0±1.0 a
5 virgin females	65.0±34.8 a	-	-
3 virgin females	-	26.7±11.9 a	-
1 virgin female	-	-	3.3±0.9 a
CH_2Cl_2 control	0.3±0.3 c	0.7±0.7 b	1.0±0.6 a

[a] Means within a column followed by the same letter are not significantly different, SNK test, $P<0.05$.

Fig. 5. Diel periodicity in captures of male DBM in wing traps baited with 2-component lures on 3 days in 1991-2 in Java Indonesia. Times of sunset and sunrise given in Table 2.


26-27 Nov. 1991
n=112
4-5 Feb. 1992
n=32
10-11 Apr. 1992
n=30
Total Males Captured
Time
9 11 13 15 17 19 21 23 1 3 5 7

Relationships between DBM trap catches and foliar populations.

Population trends of DBM adults (as measured by male trap catches) (Fig. 6) were similar between fields within each cropping season. DBM pheromone trap catches and foliar densities of pooled large larvae and pupae were higher in the second experimental period than the first.

Moth trap catch was occasionally a significant predictor of DBM egg, larval or pupal populations at the time of trapping or at various times thereafter (Appendix 1). When counts of large larvae and pupae were pooled, trap catches were significant predictors of DBM populations in the field after 21 days in 2 of 3 fields sampled, and after 15 days in all 3 fields sampled in experimental periods 1 and 2, respectively (Appendix 2, Fig. 7). The offset relationship between trap catches and counts of large larvae plus pupae can be seen in Fig. 6.

Trap density had no significant effect on the number of moths captured per unit area of field ($P>0.05$)(Table 5).

Small-plot Evaluation of Mating Disruption

Significantly more males were caught in the control plots than in the Konaga con plots; numbers of males caught in the Bt-treated plots were intermediate between those in the Konaga con and control plots (Table 6). There were no significant differences in foliar large larval and pupal

Fig. 6. Population trends of DBM adults and foliar densities of pooled large larvae and pupae over 2 cropping seasons; Experimental period 1, 14 December 1991 - 31 January 1992; Experimental period 2, 4 February - 6 April 1992.

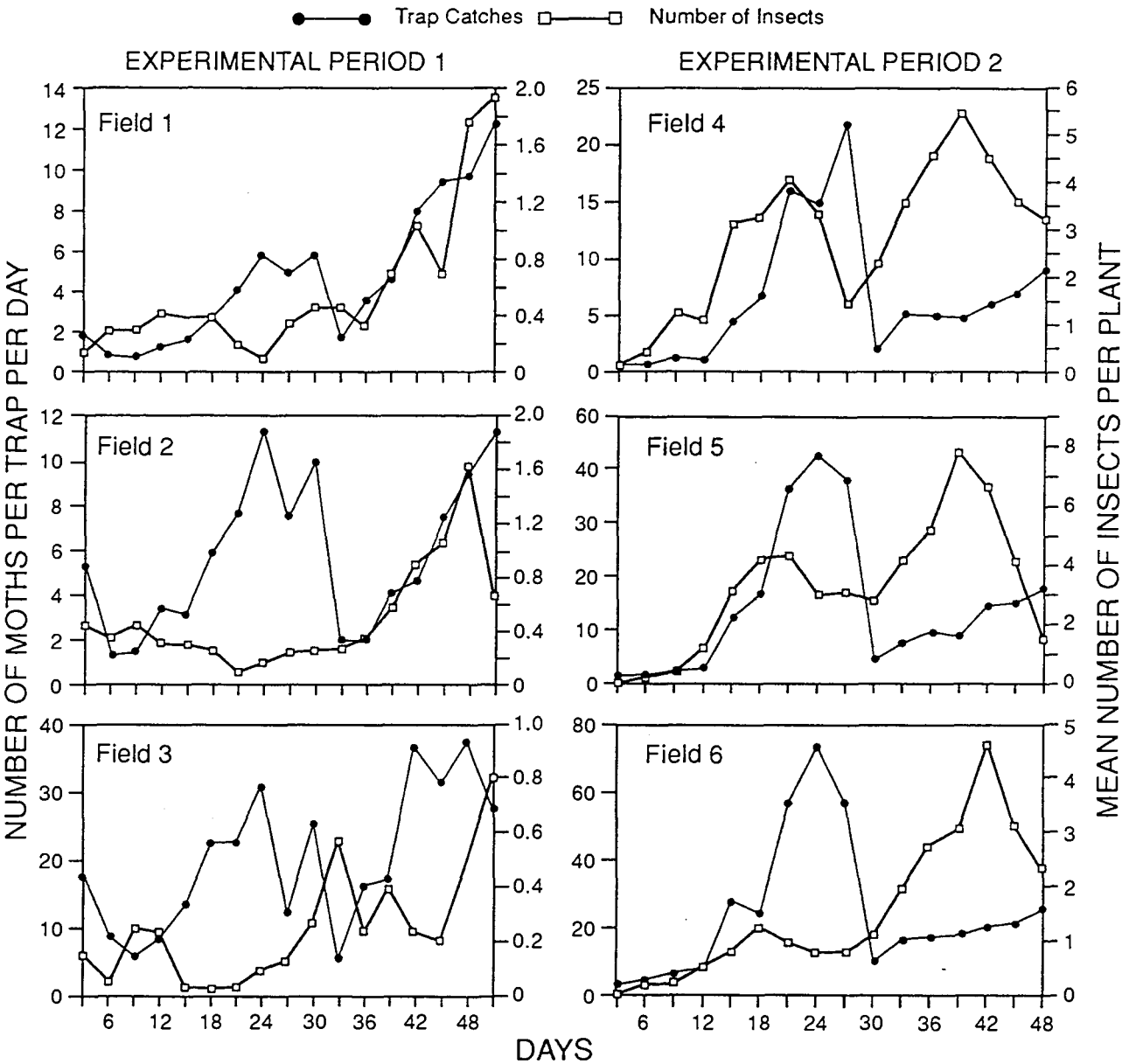

Trap Catches
Number of Insects
EXPERIMENTAL PERIOD 1
EXPERIMENTAL PERIOD 2
Field 1
Field 2
Field 3
Field 4
Field 5
Field 6
NUMBER OF MOTHS PER TRAP PER DAY
MEAN NUMBER OF INSECTS PER PLANT
DAYS
6 12 18 24 30 36 42 48

Fig. 7. Relationships between catches of male DBM in pheromone-baited traps, and numbers of pooled large larvae and pupae per plant 21 days later for individual fields in Experimental Period 1, 14 December 1991 - 31 January, 1992 and 15 days later for Experimental Period 2, 4 February - 6 April, 1992.

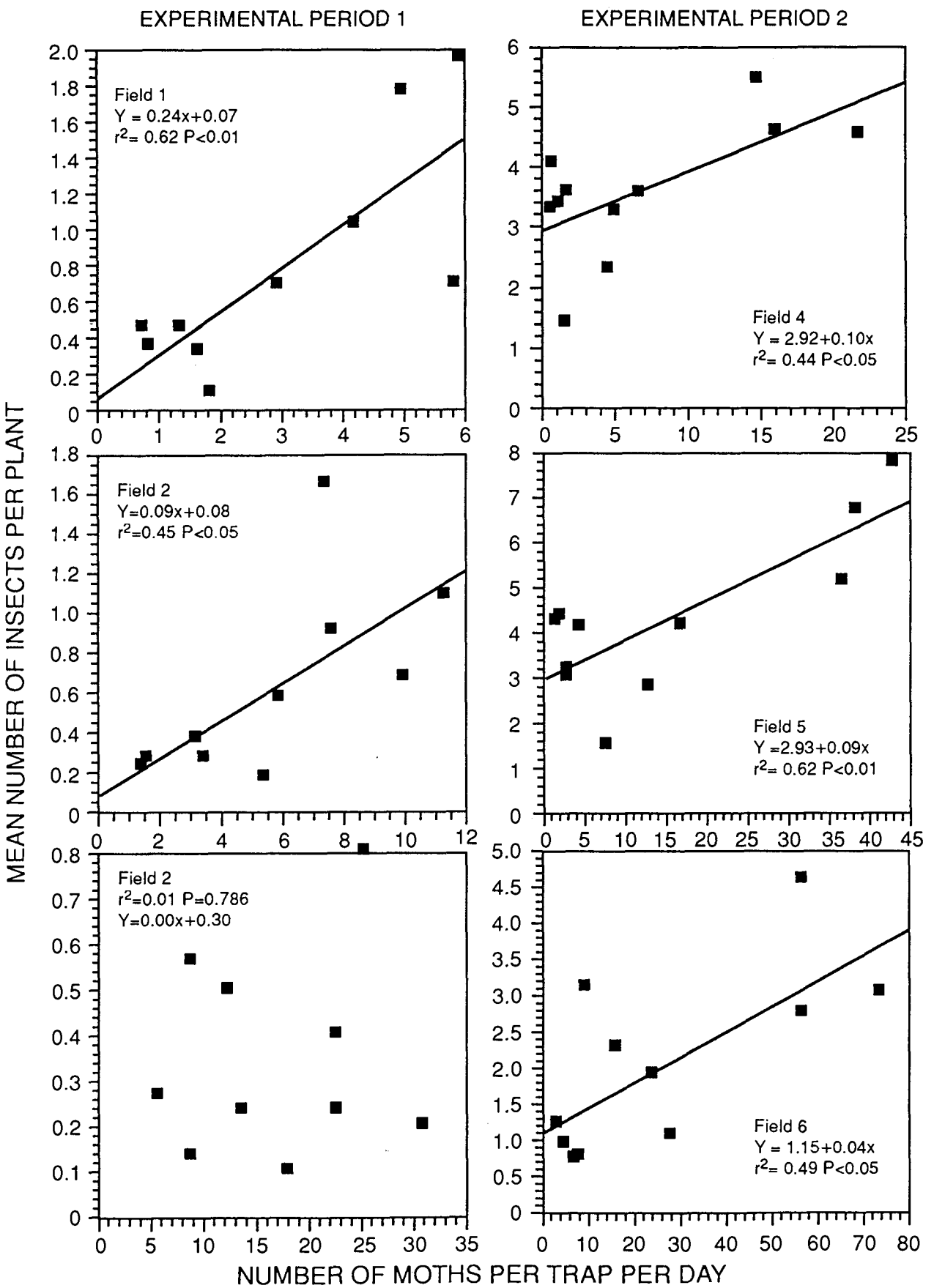

EXPERIMENTAL PERIOD 1
EXPERIMENTAL PERIOD 2
Field 1
Y = 0.24x+0.07
r2= 0.62 P<0.01
Field 4
Y = 2.92+0.10x
r2= 0.44 P<0.05
Field 2
Y=0.09x+0.08
r2=0.45 P<0.05
Field 5
Y =2.93+0.09x
r2= 0.62 P<0.01
Field 2
r2=0.01 P=0.786
Y=0.00x+0.30
Field 6
Y = 1.15+0.04x
r2= 0.49 P<0.05
MEAN NUMBER OF INSECTS PER PLANT
NUMBER OF MOTHS PER TRAP PER DAY

Table 5. Numbers of DBM males captured per unit area in 2 cropping seasons using several different trap densities. Trap catches at different sampling dates considered as replicates.

Number of traps per field	Trap density per ha	Number of males captured per m^2 (mean ± SE)[a]	
		Cropping season 1 n=17	Cropping season 2 n=16
10	119[b], 179[c]	0.2±0.0 a	0.4±0.1 a
6	57[b], 51[c]	0.1±0.0 a	0.2±0.1 a
4	29[c]	-	0.2±0.0 a
1	9[b]	0.1±0.0 a	-

[a] No significant difference between means within columns, ANOVA, $P>0.05$.
[b] cropping season 1; [c] cropping season 2.

Table 6. Numbers of DBM adults captured in traps and foliar counts on cabbage of eggs, larvae and pupae following pheromone-based disruption treatment or spraying with Bt. Sample date considered as a replicate, n=12.

	Numbers of DBM (mean ± SE)[a]				
Treatment	moths/ trap/ week	eggs/ 20 plants	small larvae/ 20 plants	large larvae/ 20 plants	pupae/ 20 plants
Konaga con rope	0.6±0.3 b	29.4±8.1 b	3.8±0.9 ab	11.1±2.4 a	10.3±3.7 a
Bt	3.3±0.8 a	70.9±21.2 a	12.3±3.1 a	10.9±1.3 a	9.6±2.1 a
control	9.0±10.4 a	28.8±10.4 b	1.5±0.7 b	9.7±1.2 a	5.8±1.8 a

[a] Means within a column followed by the same letter are not significantly different, SNK test $P<0.05$.

counts in the Konaga con treated, Bt- treated and control plots, but there were significant differences in foliar egg and small larval counts in the Bt-treated and control plots (Table 6). There was a greater frequency of nonmated females in the Konaga con plots than in the Bt-treated and control plots (X^2=65.012; DF=2);(Table 7).

Table 7. Mating status of caged DBM females after 24 h in small plots treated with Konaga con ropes, compared to that in control or Bt-treated plots at Langensari and Jaya Giri sites.

Number of Treatment	females	Percent of females mated[a]	X^2 probability compared to control
Konaga con ropes	44	9.1 a	<0.001
Bt	48	81.3 b	0.796
Control	42	83.3 b	-

[a] Percents followed by the same letter are not significantly different, multiple comparison test between proportions, $P<0.05$.

DISCUSSION

The peak response of males to the 10 μg dose of the 2-component blend (Fig. 2) is consistent with results of Koshihara *et al.* (1978), Anda (1979), Chien & Chiu (1986) and Macaulay *et al.* (1986), but in contrast to studies by Chisholm *et al.* (1979) who reported greatest trap catches at 100 μg. The decline in male response at the 100 μg dose (Fig. 2) indicates that male activity may have been inhibited by exposure to high concentrations of its pheromone and suggests an optimum concentration for behavioral response (Kawasaki 1984). The fact that addition of 0.1 μg of *Z*-9-14:Ac to the 2-component blend did not significantly enhance male trap catches (Fig. 3), indicates that either lure would be suitable for monitoring trends in adult male DBM populations. The 2-component lure was used in subsequent experiments because it appears to be as reliable as the 3-component lure and as it is a simpler blend, presumably cheaper.

The high response of DBM males to the 2-component lure at ratios between 8:2 and 4:6 (Fig. 4) is consistent with field results in Japan (Koshihara *et al.* 1978; Kawasaki 1984). The 2-component (4:6 μg) lure used as the "standard" lure in most experiments was predetermined based on results of (Koshihara *et al.* 1978), and may have been slightly less effective than the reciprocal ratio (Fig. 4).

Various reports from different geographic locations lead to the conclusion that there is variation in male response to synthetic female sex pheromone of DBM (Koshihara *et al.* 1978; Anda 1979; Chisholm *et al.* 1979, 1983; Maa *et al.* 1984, 1985, 1987; Chien & Chui 1986). Males respond to pheromone lures differentially depending on dose and ratio of pheromone components (Maa *et al.* 1984, Maa 1986)(Table 8). Such variability may be explained by genetic diversity, especially with geographically isolated populations, as well as by factors affecting male response, including climate, host plants and female age and mated status (Maa *et al.* 1984, 1987; Maa 1986; Roitberg & Angerilli 1986; McNeil 1991). Differences in pheromone blend for geographically isolated populations have been shown for European corn borers, *Ostrinia nubilis* (Hübner) in Europe and North America (Cardé *et al.* 1978) and obliquebanded leaf rollers, *Choristoneura rosaceana*, (Harris) in B.C. and Quebec (Thomson *et al.* 1991). In Canada, DBM pheromone blended with 70% aldehyde elicited high male response while in Taiwan, effective pheromone blends ranged between 50-69% acetate (Table 8). Variation in DBM male response *within* a geographic region was demonstrated in Taiwan (Maa *et al.* 1984, 1985) and Japan (Koshihara & Yamada 1980).

Geographic differences in male response to pheromone blends suggest that location-specific research be done to establish the optimal blend prior to incorporation of DBM sex pheromone into an IPM program. Moreover, the higher

Table 8. DBM pheromone doses and blends reported in different geographic locations.

Lure	Optimal range	Dose	Location	Reference
Z-11-16Ac:*Z*-11-16Ald	1:1-3:1	10 μg	Taiwan	Chow *et al.* (1974)
Z-11-16Ac:*Z*-11-16Ald	6:4, 1:1	0.1-1.0 μg	Japan	Tamaki *et al.* (1977)
Z-11-16Ac:*Z*-11-16Ald	4:6, 5:5	10 μg	Japan	Koshihara *et al.* (1978)
Z-11-16Ac:*Z*-11-16Ald	3:7	100 μg	Canada	Chisholm *et al.* (1979)
Z-11-16Ac:*Z*-11-16Ald	5:5 5:5	10-100 μg 100-1000 μg[a]	Japan	Koshihara & Yamada (1980)
Z-11-16Ac:*Z*-11-16Ald: *Z*-11-16OH	5:5: (0.05-0.5)	10-100 μg		
Z-11-16Ac:*Z*-11-16Ald	3:7	100 μg	U.S.A.	Baker *et al.* (1982)
Z-11-16Ac:*Z*-11-16Ald: *Z*-11-16OH:*Z*-9-14Ac	30:70: 1:0.01	100.01 μg	Canada	Chisholm *et al.* (1983)
Z-11-16Ac:*Z*-11-16Ald: *Z*-11-16OH	5:5:0.1, 6:4:0.1, 7:3:0.1	50 μg	Taiwan	Maa *et al.* (1984)
Z-11-16Ac:*Z*-11-16Ald: *Z*-9-14Ac	1:1: (0.1-0.001)	10 μg	Taiwan	Chien & Chui (1986)
Z-11-16Ac:*Z*-11-16Ald: *Z*-11-16OH	1:1:0.02	50-100 μg	Taiwan	Chien & Chui (1987)
Z-11-16Ac:*Z*-11-16Ald	1:1	10 μg	Britain	Macaulay *et al.* (1986)

[a] winter dose

response by DBM males to traps baited with 5 and 3 virgin females than to the 2-component blend (Table 4), may indicate that the synthetic pheromone blend a short-range pheromone as well as be evidence of a missing pheromone component that could increase the efficacy of the pheromone. A world-wide study using coupled gas chromatography-electroatennogram detection (Arn 1975) could disclose any missing components.

The peak male activity about 1 h after sunset (*ca.* 1900 h) (Fig 5) is 1-3 h earlier than disclosed by a suction trap (Goodwin and Danthanarayana 1984), and 1-7 h earlier than with colored sticky traps (Hallett 1992). While pheromone traps may be more sensitive than visual stimuli provided by colored sticky traps, it appears that vision may play a role in host and mate finding (Hallett 1992). Catches in pheromone-baited traps may not provide an accurate measure of time of mating if females call later in the scotophase. In field studies by Harcourt (1957) and Pivnick *et al.* (1990), peak mating by DBM occurred early in the scotophase (>70% 4 h after sunset) on the day of emergence, while Tabashnik & Mau (1986) found DBM peak oviposition to be between 2000 and 2300 h. Thus, catches in pheromone-baited traps appear to be an accurate predictor of the occurrence of mating, and the onset of oviposition. During the photophase, adults rested on cabbage foliage and only undertook short flights when disturbed (pers. obs.).

The positive and significant relationships between male trap catches and mean numbers of large larvae and pupae per plant 15-21 days later, appear to reflect the life history of DBM in Indonesia (Vos 1953) and Malaysia (Ho 1965). Developmental time from egg to pupae for DBM in Pacet, West Java (elevation 1100 m; temperature 16-25°C) was 15.2 days, while in the Cameron Highlands, Malaysia (elevation 1500 m; mean temperature 15.6°C), development required 20.1 days. Daily temperature recordings based on a 5 year average from 1981 to 1985 for Lembang (1250 m) were between 12 and 25.7°C (Sastrosiswojo 1987), suggesting that DBM generation times might approximate those in Pacet and the Cameron Highlands. The relationship between adult trap catches and numbers of large larvae and pupae per plant in the two cropping periods (Fig. 6) suggests that developmental rate was fastest in experimental period 2. Using the Umeya & Yamada (1973) model of 250 degree-days above a threshold of 8.6°C for one generation of DBM, 578.3 and 549.2 degree-days (PASHEAT 1986) were accumulated, indicating 2.3 and 2.2 expected generations for experimental periods 1 and 2 respectively. Thus, calculations of numbers of expected generations for the two experimental periods did not account for the short 15 day offset between trap catches and ensuing larval-pupal populations in the second experimental period.

The assumption that the number of males caught in a pheromone trap is related to the number of females in an area may be confounded by differential female and male

movement in or out of an area (Roitberg & Angerilli 1986). An influx of mated females, and virgin females that compete with pheromone traps for males, as well as variability in sex ratio can cause inconsistencies in the relationships between catches of males in pheromone-baited traps and foliar counts of larvae (Sridhar *et al.* 1988). Pheromone-baited traps could also draw males from outside the sample area (Cardé & Elkinton 1984).

My results indicate that catches of male DBM in pheromone-baited traps at variable trap densities (Table 5) could be used to predict larval and pupal populations (Fig. 7). Wing traps may be preferable to less efficient traps e.g. water traps, for this purpose. However, the position of the pheromone lure (approximately 20 cm above the water level) on the water trap may have reduced the efficacy in trapping males. Further research should investigate the effect of seasonal and geographic differences on predictive capability. Because the Indonesian terrain is uneven, and crops are planted in small fields at variable times, it may be necessary to monitor fields individually as was required for carrot rust fly, *Psila rosae* (F.) in the lower Fraser Valley of British Columbia (Judd *et al.* 1985).

Even though accumulated damage assessments were made on each sample date, damage ratings were not analyzed due to difficulties in distinguishing between damage caused by DBM and other defoliators.

The reduced numbers of male DBM caught in pheromone-baited traps as well as reduction in mating frequency of caged females in the Konaga con treated plots (Table 6) provide evidence for successful disruption of male-female pheromone communication. The fact that mating disruption was achieved in the mating cages where males have a greater possibility of coming in contact with females, suggests an inhibition of male response to calling females by sensory adaptation or CNS habituation, brought about by prolonged exposure to relatively high levels of pheromone. This provides evidence of the important role that adaptation and habituation may play in reducing close-range responsiveness of males to calling females.

Reduction in oviposition and subsequent reduction in larval density was not achieved. Poor performance of mating disruption could have been caused by immigration of gravid females (Campion 1984; Howell *et al.* 1992), particularly in small plots only 80 to 200 m from control plots. This explanation seems probable as disruption was demonstrated. Although DBM is a weak flier (Harcourt 1957), long distance migration has been well documented (Chu 1986).

The fact that Bt was not effective in suppressing larval density (Table 6) is likely due to the insecticide not targeting the larvae (late instar larvae feed primarily on the lower leaf surface or within the cabbage head) rather than Bt resistance (Tabashnik *et al.* 1990), as Bt is not commonly used by growers in the area. As first instar

larvae are miners and protected from contact insecticides, timing of sprays should correspond with emergence of second instar larvae.

IPM in developing countries has often evolved as a direct result of failures in chemical control, whereas in industrialized regions of the world it has developed under the active leadership of the scientific community (Brader 1979). In many cabbage growing areas in Indonesia there is now widespread insecticide resistance by DBM (Sastrosiswojo 1989). Adoption of pheromone-based monitoring and control could lead to better timing and reduced applications of pesticides, lower costs and enhanced biological control by *D. eucerophaga* (Sastrosiswojo 1990). Constraints to implementation of a new technology include economic constraints (*i.e.* capital, credit, market uncertainty); availability of materials; limitations in extension, education and training, and sociocultural appropriateness of the technology (Oka 1983; Basuki & Koster 1990; Hallett 1992).

However, constraints can be overcome. Alternatives to chemical pesticides are needed, and my results show that pheromone-based technology has promise. Cooperation is necessary among government authorities, scientists, extension agents, village leaders and farmers in research development and implementation of such a technology within an IPM setting (Brader 1979). As crop production and protection are carried out mostly by small farmers with

limited resources in Indonesia and in developing countries in general, technologies that are cheap and effective and can be modified to suit local agro-ecosystems are more likely to be adopted (Brader 1979; Basuki & Koster 1990).

The use of pheromones for monitoring and control of many insect pests of major economic importance has been reported in a number of developing countries (Marks 1976ab; Campion & Nesbitt 1981; Hall *et al.* 1984; Crichley *et al.* 1991). With the present political will and the mandate for IPM development in Indonesia, the use of pheromones to monitor and control pest populations will receive more attention. I recommend that research on this subject continue and that large scale pheromone monitoring and control trials be implemented.

RECOMMENDATIONS

Several recommendations for further research and development are summarized below. A cooperative program could be developed by faculty and students at agricultural universities, such as *Institut Pertanian Bogor* in collaboration with government institutes such as *Balai Penelitian Hortikultura*, whose mandate is research and development of horticultural crops. Following its completion, training of extension workers and growers would be necessary to implement new, pheromone-based technology, along with reduced pesticide applications and resistance management, ensuring that all farmers have equal accessibility to information and training.

Recommendations

1) Reanalysis of the DBM pheromone should be done using coupled gas chromatography-electroatennogram detection to determine if additional components are present.

2) The relationship between trap catch and crop damage must be established.

3) Trap catch thresholds that can be used as decision-making criteria (*i.e.* action thresholds) should be developed on a regional basis.

4) The minimum number of traps required per unit area for adequate predictive capability should be determined.

5) Research dispersal capabilities of DBM females is recommended.

6) Further studies on the development of an efficient, low-cost pheromone-baited trap that could be used by subsistence farmers should be initiated.

7) Large-scale pheromone monitoring and control trials over a number of years should be established so that procedures are standardized and validated.

8) Costs of implementing and operating such a monitoring and control system should be assessed.

9) Long-term studies should be initiated on the integration of pheromone-based monitoring and control with other IPM strategies, *e.g.* trap cropping, use of resistant cultivars, biological control and selective pesticide use.

APPENDIX 1

Regression equations for numbers of DBM per plant on same day as trap catches, and 3, 6, 15, 21 and 27 days later regressed on moths per trap per day captured for individual fields. When relationship negative, r^2 values are in parentheses.

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
1	eggs	1	DBM_{0d} =-0.22+0.32moths	56.7	<0.001
14 Dec 1991-			DBM_{3d} = 0.13+0.30moths	34.4	<0.05
31 Jan 1992			DBM_{6d} =-0.00+0.38moths	44.5	<0.01
		2	DBM_{0d} = 1.14+0.05moths	1.0	NS
			DBM_{3d} = 0.87+0.12moths	5.1	NS
			DBM_{6d} = 1.16+0.09moths	2.4	NS
		3	DBM_{0d} =-0.08+0.06moths	27.5	<0.05
			DBM_{3d} = 0.34+0.04moths	12.6	NS
			DBM_{6d} = 0.19+0.04moths	15.2	NS
2		1	DBM_{0d} = 6.66+0.18moths	8.4	NS
4 Feb-			DBM_{3d} = 6.37+0.24moths	14.7	NS
6 April 1992			DBM_{6d} = 6.94+0.13moths	4.5	NS
		2	DBM_{0d} = 9.70-0.08moths	(6.2)	NS
			DBM_{3d} = 8.98-0.03moths	(0.8)	NS
			DBM_{6d} = 6.89+0.11moths	11.2	NS
		3	DBM_{0d} = 4.58+0.02moths	6.9	NS
			DBM_{3d} = 4.32+0.04moths	19.2	NS
			DBM_{6d} = 3.92+0.04moths	36.4	<0.05

[a] NS = $P>0.05$

APPENDIX 1 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
1	small larvae	1	DBM_{0d} = 0.05+0.02moths	18.6	NS
14 Dec 1991-			DBM_{6d} = 0.08+0.02moths	8.6	NS
31 Jan 1992			DBM_{15d}= 0.05+0.04moths	15.5	NS
			DBM_{21d}= 0.09+0.03moths	12.2	NS
		2	DBM_{0d} = 0.05+0.00moths	1.1	NS
			DBM_{6d} = 0.06+0.00moths	0.4	NS
			DBM_{15d}= 0.05+0.01moths	6.2	NS
			DBM_{21d}= 0.02+0.01moths	34.2	NS
		3	DBM_{0d} = 0.03+0.00moths	0.7	NS
			DBM_{6d} = 0.03+0.00moths	2.6	NS
			DBM_{15d}= 0.01+0.00moths	17.5	NS
			DBM_{21d}= 0.06+0.00moths	0.5	NS
2		1	DBM_{0d} = 0.95-0.05moths	(25.0)	<0.05
4 Feb-			DBM_{6d} = 0.67-0.01moths	(1.5)	NS
6 April 1992			DBM_{15d}= 0.40-0.01moths	(4.9)	NS
			DBM_{21d}= 0.54-0.03moths	(43.3)	NS
		2	DBM_{0d} = 1.99-0.04moths	(20.7)	NS
			DBM_{6d} = 1.25+0.01moths	1.4	NS
			DBM_{15d}= 1.02-0.00moths	(0.4)	NS
			DBM_{21d}= 1.72-0.04moths	(41.1)	NS

[a] NS = $P>0.05$

APPENDIX 1 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
2	small larvae	3	DBM_{0d} = 0.42-0.01moths	(9.3)	NS
4 Feb-6 April 1992			DBM_{6d} = 0.12+0.01moths	36.1	<0.05
			DBM_{15d}= 0.25+0.00moths	3.0	NS
			DBM_{21d}= 0.59-0.01moths	30.0	NS
1	large larvae	1	DBM_{0d} =-0.04+0.08moths	45.6	<0.01
14 Dec 1991-31 Jan 1992			DBM_{6d} =-0.10+0.01moths	52.1	<0.01
			DBM_{15d}= 0.34+0.01moths	0.3	NS
			DBM_{21d}=-0.06+0.16moths	43.9	<0.05
			DBM_{27d}=-0.11+0.26moths	76.9	<0.01
		2	DBM_{0d} = 0.23+0.01moths	0.6	NS
			DBM_{6d} = 0.37-0.02moths	(6.5)	NS
			DBM_{15d}= 0.22+0.01moths	0.7	NS
			DBM_{21d}= 0.03+0.05moths	26.6	NS
			DBM_{27d}= 0.21+0.03moths	8.4	NS
		3	DBM_{0d} = 0.09+0.00moths	1.4	NS
			DBM_{6d} = 0.06+0.00moths	11.9	NS
			DBM_{15d}= 0.06+0.00moths	11.4	NS
			DBM_{21d}= 0.13+0.00moths	0.8	NS
			DBM_{27d}= 0.17+0.00moths	0.2	NS

[a] NS = $P>0.05$

APPENDIX 1 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
2	large larvae	1	DBM_{0d} = 1.76+0.03moths	2.5	NS
4 Feb-6 April 1992			DBM_{6d} = 2.32-0.02moths	(1.3)	NS
			DBM_{15d}= 1.97+0.05moths	12.4	NS
			DBM_{21d}= 2.51-0.05moths	(12.3)	NS
			DBM_{27d}= 2.98-0.15moths	(51.5)	NS
		2	DBM_{0d} = 1.42+0.04moths	12.7	NS
			DBM_{6d} = 2.16+0.01moths	0.3	NS
			DBM_{15d}= 2.17+0.02moths	3.8	NS
			DBM_{21d}= 2.83-0.04moths	40.1	NS
			DBM_{27d}= 2.93-0.08moths	(58.5)	<0.05
		3	DBM_{0d} = 1.03-0.00moths	(0.1)	NS
			DBM_{6d} = 1.22-0.00moths	(1.4)	NS
			DBM_{15d}= 0.63+0.03moths	69.1	<0.001
			DBM_{21d}= 1.03+0.01moths	11.5	NS
			DBM_{27d}= 1.71-0.01moths	(2.9)	NS
1	pupae	1	DBM_{0d} = 0.07+0.04moths	62.3	<0.001
14 Dec 1991-31 Jan 1992			DBM_{6d} = 0.16+0.03moths	25.3	NS
			DBM_{15d}= 0.13+0.07moths	54.7	<0.01
			DBM_{21d}= 0.15+0.07moths	67.8	<0.01
			DBM_{27d}= 0.29+0.05moths	33.5	NS

[a] NS = $P>0.05$

APPENDIX 1 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
1	pupae	2	DBM_{0d} = 0.12+0.02moths	12.4	NS
14 Dec 1991- 31 Jan 1992			DBM_{6d} = 0.26-0.00moths	(0.1)	NS
			DBM_{15d}= 0.20+0.02moths	8.6	NS
			DBM_{21d}= 0.06+0.05moths	66.9	<0.01
			DBM_{27d}= 0.19+0.04moths	40.8	NS
		3	DBM_{0d} = 0.10+0.00moths	1.5	NS
			DBM_{6d} = 0.03+0.01moths	15.4	NS
			DBM_{15d}= 0.13+0.00moths	1.5	NS
			DBM_{21d}= 0.17+0.00moths	0.6	NS
			DBM_{27d}= 0.04+0.01moths	27.0	NS
2		1	DBM_{0d} = 0.67+0.03moths	5.7	NS
4 Feb- 6 April 1992			DBM_{6d} = 1.02+0.00moths	0.0	NS
			DBM_{15d}= 0.95+0.05moths	17.1	NS
			DBM_{21d}= 0.72+0.10moths	89.4	<0.001
			DBM_{27d}= 1.12+0.11moths	55.0	NS
		2	DBM_{0d} = 1.23+0.00moths	0.1	NS
			DBM_{6d} = 1.63-0.01moths	0.9	NS
			DBM_{15d}= 0.77+0.7moths	51.8	<0.05
			DBM_{21d}= 1.16+0.06moths	38.6	NS
			DBM_{27d}= 2.63-0.01moths	0.5	NS

[a] NS = $P>0.05$

APPENDIX 1 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
2	pupae	3	DBM_{0d} = 0.57-0.00moths	0.2	NS
4 Feb-6 April 1992			DBM_{6d} = 0.65-0.00moths	0.3	NS
			DBM_{15d}= 0.52+0.01moths	11.3	NS
			DBM_{21d}= 0.18+0.03moths	96.0	<0.001
			DBM_{27d}= 0.68+0.02moths	40.3	NS

[a] NS = P>0.05

APPENDIX 2

Regression equations for summed large larvae and pupae per plant on same day, and 6, 15, 21 and 27 days later regressed on moths per trap per day captured for individual fields. When relationship negative, r^2 values are in parentheses.

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
1	large larvae +	1	DBM_{0d} = 0.02+0.12moths	62.6	<0.001
14 Dec 1991-	pupae		DBM_{6d} = 0.06+0.15moths	53.0	<0.01
31 Jan 1992			DBM_{15d}= 0.45+0.09moths	7 7	NS
			DBM_{21d}= 0.07+0.24moths	61.8	<0.01
			DBM_{27d}= 0.17+0.31moths	82.5	<0.01
		2	DBM_{0d} = 0.35+0.03moths	4.7	NS
			DBM_{6d} = 0.63-0.02moths	3.2	NS
			DBM_{15d}= 0.42+0.02moths	3.1	NS
			DBM_{21d}= 0.08+0.09moths	45.4	<0.05
			DBM_{27d}= 0.40+0.06moths	20.4	NS
		3	DBM_{0d} = 0.19+0.00moths	2.0	NS
			DBM_{6d} = 0.09+0.01moths	18.9	NS
			DBM_{15d}= 0.19+0.01moths	5.4	NS
			DBM_{21d}= 0.30+0.00moths	1.0	NS
			DBM_{27d}= 0.22+0.01moths	21.2	NS

[a] NS = $P>0.05$

APPENDIX 2 continued

Exper. period and dates	DBM stage	Field	Regression equation	r^2	P^a
2	large larvae +	1	DBM_{0d} = 2.43+0.07moths	6.5	NS
4 Feb-	pupae		DBM_{6d} = 3.34-0.02moths	(0.9)	NS
6 April 1992			DBM_{15d}= 2.92+0.10moths	43.5	<0.05
			DBM_{21d}= 3.23+0.05moths	8.6	NS
			DBM_{27d}= 4.10-0.04moths	(5.4)	NS
		2	DBM_{0d} = 2.65+0.04moths	6.2	NS
			DBM_{6d} = 3.79-0.01moths	(0.2)	NS
			DBM_{15d}= 2.93+0.09moths	61.9	<0.01
			DBM_{21d}= 3.99+0.02moths	2.0	NS
			DBM_{27d}= 5.56-0.09moths	(27.3)	NS
		3	DBM_{0d} = 1.60-0.00moths	(0.2)	NS
			DBM_{6d} = 1.87-0.01moths	(1.0)	NS
			DBM_{15d}= 1.15+0.04moths	49.2	<0.05
			DBM_{21d}= 1.22+0.04moths	57.7	<0.05
			DBM_{27d}= 2.40+0.02moths	7.9	NS

[a] *NS* = $P>0.05$

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