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Use of Pheromone Timed Insecticide Applications Integrated With Mating Disruption or Mass Trapping Against *Ostrinia furnacalis* (Lepidoptera: Pyralidae) in Sweet Corn

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ABSTRACT Mating disruption and mass trapping of *Ostrinia furnacalis* (Génuéé), often called the Asian corn borer, were incorporated with insecticides to reduce pesticide use. Pesticides alone are often ineffective owing to problems in timing applications before the larvae enter the protection of corn stalks. In addition, overuse of insecticides has caused environmental contamination and concerns about consumer health. In 2010, 15 insecticides were compared with mating disruption or mass trapping at various dispenser (disp.) densities for reducing egg masses, trap captures, and ear damage. Mass trapping with 30 and 40 disp./ha, mating disruption with 300 disp./ha, or endosulfan, chlorpyrifos, and monosultap (0.55, 0.35, and 0.55 kg/ha, respectively) gave ≈50% ear protection. In 2011, an insecticide alone, no treatments, pheromone alone, and pheromone + insecticide were examined. The same insecticides in combination with mating disruption or mass trapping at ≧200 or≧20 disp./ha gave >90% ear protection even when chemical applications were reduced to 1 from 3, and the rates were reduced 50–75%. Pheromone dispensers contained >50% of their initial load 30 d after exposure.

KEY WORDS sex attractant, Asian corn borer, corn damage, chemical reduction

Sweet corn is one of the most important fresh market crops in China. It is grown on ≈1.15×10^6 ha, or 1% of the total cropped land there.

Ostrinia furnacalis (Génuéé), often known as the Asian corn borer, is distributed throughout China, especially in the northeast region known as the Chinese Golden Corn Belt (Zhou et al. 1995; Wang et al. 2000, 2006; He et al. 2002; Chen et al. 2007; Yang et al. 2011). The Asian corn borer can also be found throughout East Asia, especially in South Korea, The Philippines, India, and Indonesia, and has been introduced into Australia and the Solomon Islands (Klun et al. 1980; Nafus and Schreiner 1991; Park and Boo 1993a,b; Boo and Park 1998; Zhang et al. 2010a).

The Asian corn borer has been the primary component in the complex of corn insect pests for ≈60 yr, and causes damage during the late first and subsequent generations in NE China (Wen et al. 1992; Wang et al. 2006, 2008). Damage is caused by larvae boring into the stalk and tunneling inside, feeding on the pith, and resulting in dropped ears or lodging. Larvae also feed on silks and tassels, thus interfering with kernel formation, and finally, feeding on immature kernels, leaving frass, which facilitates fungal infections and ear contamination. All of this causes a loss in quantity and quality, and severely reduces the market value. Sweet corn is a favorite of Chinese people, and consumers prefer it clean and perfect, so any frass, fungi, or physical damage to kernels or silks indicating Asian corn borer infestation, reduces its market value to near zero. Consequently, the requirement for near perfection prompts frequent chemicals sprays, leading to chemical overuse. However, because this has caused damage to the environment and farmers' health in the past, there is an increasing movement toward more organic products with less chemical residue on the kernels. Now, consumers accept sweet corn only when the kernels look healthy, and are free of insect damage, fungal infections, and chemicals. Therefore, pest control must be highly efficient, leaving little or no pesticide residue.

Sex pheromones are highly compatible with pesticide use, are an ideal component of integrated pest management (IPM) programs (Liu and Zhang 2006, Chen and Li 2011), and are a suggested tactic for moth mating disruption when the proper number of dispensers are placed in fields (Stelinski et al. 2008, Witzgall et al. 2008). Pheromones can help accurately time applications of chemicals and consequently result in reduced chemical use (Hu and Jiang 1995, Cork

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Table 1. *O. furnacalis* egg masses, trap captures, and damage to corn ears following application of various insecticides and pheromones—2010

Treatments a.i. formulation/kg/ha	Index of egg mean ± SE		Catches per trap (mean ± SE)/d		Ear damage	
	Mean ± SE	% reduction	Mean ± SE	% inhibition	% damage	% reduction
Endosulfan 35EC/0.55	10.1 ± 2.3ab	21.7g	2.9 ± 0.9a	12.1d	13.2 ± 0.3	55.7bc
Chlorpyrifos 40EC/0.35	10.4 ± 1.5ab	19.4h	2.9 ± 0.6a	12.1d	12.4 ± 1.3	58.4bc
Monosultap 90SP/0.55	10.5 ± 2.8ab	18.6h	2.9 ± 1.9a	12.1d	13.1 ± 1.6	56.0bc
Deltamethrin 2.5WP/0.3	11.8 ± 0.8ab	8.5i	3.2 ± 0.3a	3.0e	15.2 ± 0.4	48.9c
Dipterex 50WP/1.5	11.9 ± 1.7ab	7.8lj	3.1 ± 1.3a	6.1e	16.2 ± 1.9	45.6c
Cyhalothrin 10SP/0.35	12.2 ± 1.1ab	5.7jk	3.1 ± 1.6a	6.1e	16.5 ± 1.9	44.6c
Cartap 50WP/0.65	12.2 ± 0.8ab	5.7kl	3.2 ± 0.4a	3.0e	23.0 ± 1.8	22.8
Esfenvalerate 25EC/0.55	12.2 ± 1.9ab	5.7jk	3.2 ± 0.7a	3.0e	23.0 ± 2.1	22.8
Methomyl 25EC/0.65	12.1 ± 0.2ab	4.8kl	3.2 ± 1.9a	3.0e	17.2 ± 1.8	42.3c
Phoxim50EC/0.65	12.1 ± 1.7ab	4.8kl	3.0 ± 0.6a	9.0e	19.9 ± 1.8	33.2d
Bifenthrin 95SP/0.55	12.1 ± 2.1ab	4.8kl	3.0 ± 2.1a	9.0e	21.2 ± 3.5	28.9d
Fipronil 10EC/0.45	12.3 ± 0.9ab	4.7kl	3.2 ± 0.8a	3.0e	23.4 ± 3.2	21.5d
Imidacloprid 5EC/0.45	12.5 ± 1.8ab	3.1lm	3.2 ± 1.8a	3.0e	22.5 ± 2.6	24.5d
Cygon 40EC/0.55	12.6 ± 1.0ab	2.3m	3.2 ± 0.5a	3.0e	19.6 ± 1.9	34.2d
Permethrin 10EC/0.55	12.7 ± 1.7a	1.6m	3.2 ± 0.6a	3.0e	21.5 ± 0.6	27.9d
MD						
100/ha	9.3 ± 0.2ab	27.9f	2.2 ± 0.7b	33.3c	16.3 ± 2.1	45.3c
200/ha	7.3 ± 0.2ab	43.4d	1.6 ± 0.9c	51.5b	11.5 ± 0.8	61.4b
300 ha	6.3 ± 0.2b	51.2c	1.5 ± 0.6c	54.5b	8.1 ± 0.8	72.8a
MT						
20/ha	8.3 ± 0.2ab	36.6e	2.3 ± 0.8b	30.3c	13.2 ± 0.3	55.7bc
30/ha	5.3 ± 0.2b	58.9b	1.5 ± 0.2cd	54.5b	8.1 ± 1.3	72.8a
40/ha	3.3 ± 0.2b	74.4a	1.1 ± 0.3d	66.7a	6.1 ± 1.6	79.5a
Ck	12.9 ± 5.5a		3.3 ± 1.2a		29.8	
$F_{(20.42)}$/*P* value	78.6 < 0.01	113.2 < 0.01	13.6 < 0.01	158.5 < 0.01	109.9 < 0.01	187.5 < 0.01

Numbers in a column followed by the same letter are not significantly different (0.05%); egg masses control/reduction = % (egg mass/plant in ck − egg masses/plant in treatment/egg masses/plant in ck); Captures inhibition/control = % (captures/plant in ck − captures/plant in treatment/captures/plant in ck); Ear damage control/reduction = % (ear damage percentage/plant in ck − ear damage percentage/plant in treatment/ear damage percentage/plant in ck). MD, mating disruption; MT, mass trapping; Ck, check.

and Hall 1998, Sheng et al. 2003, Cork 2004, Chen et al. 2007, Chen and Klein 2012). Pheromones are also an effective alternative to the current labor-intensive method of field counts of egg masses, or spraying on a calendar basis.

The Asian corn borer sex pheromone was initially identified as a mixture of (Z)-12-tetradecenyl acetate (Z-12-14Ac), (E)-12-tetradecenyl acetate (E-12-14Ac), and tetradecanyl acetate (l4Ac) (Ando et al. 1980, Cheng et al. 1981, Du et al. 1986, Yeh et al. 1989, Kou et al. 1992). Later, the pheromone was determined to actually consist of the binary mixture of the first two compounds, Z-12Ac and E-12Ac, at a ratio of ≈1:1 (Park and Boo 1993b, 1994; Boo and Park 1998). Mass trapping and mating disruption techniques, based on accurate forecasting using pheromones, can augment chemical applications, and provide suppression of Asian corn borer at reduced insecticide rates.

Here, insecticides were selected from criteria outlined in detail by Chen and Klein (2012), basically low toxicity and short residue, efficiency against Asian corn borer, and common use in China or worldwide for corn or rice borers. Fifteen insecticides (Table 1) were selected based on these criteria.

The overall objective of this study was to assess the efficacy of using insecticides, mass trapping, and mating disruption, alone and in combination, as a control strategy against Asian corn borer. Specifically, we examined which combinations would provide at least 90% ear protection with reduced chemical usage to meet consumers' concerns. The appearance of male Asian corn borer was monitored with pheromone traps to optimize application timing. In addition, pheromone dispenser residues were assessed in the laboratory to evaluate the septa used in sweet corn fields.

Materials and Methods

Pheromone and Insecticides. In 2010, 15 insecticides were applied in a corn field to identify the most effective materials (Chen and Klein 2012). Mass trapping and mating disruption at various dispenser densities were tested at the same time in another field. In 2011, treatments were insecticide; mass trapping, or mating disruption with various dispenser densities; mass trapping or mating disruption in combination with insecticides; and an untreated control. The timing of these applications was aided by traps that evaluated Asian corn borer population dynamics.

The synthetic Asian corn borer pheromone (EI2-14Ac and Z12-14Ac at a ratio of 47:53), was impregnated into green rubber septa at 0.2 mg per septum for mass trapping and monitoring purposes (Cork 2004), and 0.5 mg per septum for mating disruption. The mass trapping lures were standardized and supplied by Sheng c-f. Mating disruption lures were supplied by Pherobio Technology Co. Ltd. (Beijing, China), and each had a sharp hook to fix it securely in the corn canopy to resist wind. The bell-shape of the septa provided rain protection.

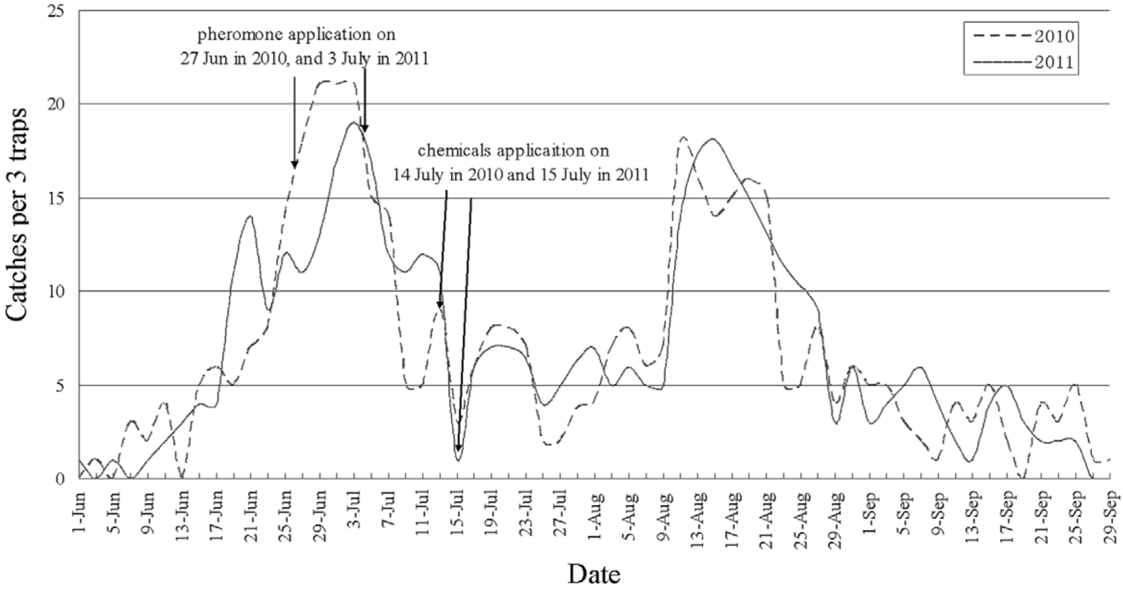


Fig. 1. Captures of *O. furnacalis* males in pheromone traps—2010–2011.

The percent of active ingredient (a.i.) and formulation (EC, emulsifiable concentrate; SP, soluble powder; WP, wettable powder) of the 15 insecticides are given in Table 1, along with the rates of application. The sources of these materials are listed in Chen and Klein (2012).

Male Moth Population Dynamics. An automated, water-supplemented, pheromone trap (Chen and Klein 2012, Wang and Chen 2012) was used to assess male moth appearance as a trigger for insecticide and pheromone application in both years. These traps were placed in an untreated field from 1 June to 30 September of 2010–2011, and in treated fields from 27 June to 2 August both years to evaluate treatment efficiency by counting and comparing the month capture to the control every 4 d. The early period covered Asian corn borer emergence from both the overwintering and first generations, and the later deployment covered the time from peak moth captures to corn harvest. Originally, traps were mounted on ≈1.5-m bamboo poles with the trap bottom 110–130 cm above ground, and later in July were raised to ≈1.8 m (to be at least 10 cm above the corn canopy). Traps were placed 20 m apart to give ≈7.5 mg of pheromone per hectare based on previous work (Zhao and Wang 1990, Zhou 1996, Zhang et al. 2010b). Traps were examined and moths removed and counted every 48 h, while lures were replaced every 4 wk.

Field Location and Layout. Tests in 2010 were conducted in 3.5-, 2.5-, and 2.7-ha sweet corn fields in Shuang Yang County, Changchun, China. The fields were located in an area with hills (≈20–30 m in height), used for corn hybrid breeding from 1960 to 1995, and after that for sweet corn production. Because corn had been grown in this area for a long time, and corn plants just left in the field resulting in an Asian corn borer larval overwintering harbor year after year, there was a big complex of corn pests here, especially Asian corn borer (Chen and Li 2011). Each field was bounded and spatially separated by hills, which provide about a 500-m buffer between the fields. These buffers reduced movement of Asian corn borer from outside the test area as shown by previous studies (Chen et al. 2007). However, Asian corn borer moth movement between plots within the test area was still possible. The 3.5-ha field was divided into nine plots (0.39 ha each) for the three densities of mating disruption (100, 200, and 300 dispensers [disp.]/ha), and the 2.5-ha field was divided into nine plots for mass trapping (20, 30, and 40 disp./ha). Each density was replicated three times with 35-m buffers between treatments. Because dispensers were located at least 7 m inside the subplots, plus the width of the buffer, the actual distance between treatments was >50 m. In addition, there is little wind because of the forests and hills. This created a buffer large enough to avoid the pheromone plumes from higher rates moving into plots treated with lower rates (Sheng et al. 2003). This lack of pheromone trespass from treated plots is further confirmed by the evaluations carried out below in the section "Pheromone Release Rates and Movement." The remaining 2.7-ha field was divided into 48 plots (0.056 ha each), where 45 plots were treated with three replicates of the 15 insecticide (Table 1) by foliar applications and three were controls. There was a 10-m buffer of bare ground between every two plots to diminish interactions between treatments. The specific application methods and apparatus involved are reported by Chen and Klein (2012). In 2010, the insecticide treatments were applied on 14 June and on 15 June of 2011(Fig. 1).

For mating disruption, the three dispenser densities were 10 by 10, 7.0 by 7.0, and 5.6 by 5.6 m. In the mass trapping trial, the traps were 22 by 22, 18 by 18, and 16 by 16 m apart. Dispensers were secured in corn plant tops for the mating disruption and placed in the traps for mass trapping on 27 June and removed on 2 August in 2010, and from 3 July to 3 August in 2011. The trial fields had all been treated with insecticides for >60 yr.

Another four fields, ≈2.3, 2.6, 2.8, and 1.1 ha, were added in 2011. The 2.7-, 2.3-, and 2.6-ha fields were mass trapped (with 10, 20, and 30 disp./ha, respectively) in combination with insecticides. The 2.8-, 2.5-, and 3.5-ha fields were used for mating disruption (100, 200, and 300 disp./ha) plus insecticides. Each field was divided into 39 plots, 36 plots for insecticides at 0.55, 0.42, 0.28, and 0.14 kg/ha for endosulfan and monosultap, and at 0.35, 0.27, 0.18, and 0.09 kg/ha for chlorpyrifos. These were ≈25, 50, 75, and 100% of the standard dose. The other three plots were used for pheromone alone. The 1.1-ha field was divided into 39 plots, 36 plots were used for the three insecticides, without pheromones, at the same doses listed above, while the others were untreated controls.

Treatment Efficacy. Efficacies of all treatments were determined by egg mass counts, trap catches, larvae in ears, and ear damage. The goal of completely healthy ears was noted above, and so any damage caused the ear to be considered damaged. These parameters are not equally critical to of treatment efficacy. The absence of egg masses and decrease in trap catches are good indications of treatment effectiveness. However, larvae in ears and the percent damaged ears provide the best assessment (Qiu et al. 1964, Howse 1998, Deng et al. 1999, Qiu 2004, He et al. 2006, Chen et al. 2007, Chen 2010).

Egg Masses. Four areas, ≈10 by 10 m, were randomly selected in each treated and control field, and Asian corn borer egg masses were counted on every corn plant. Sampling was done every 5 d during July. The average number of egg masses per 100 plants was calculated, and their reduction was an indication of treatment performance. Egg mass inhibition = (average egg masses/control plot − average egg masses/treatment plot)/average egg masses/control plot × 100.

Pheromone Trap Captures. In every treated plot, traps were placed at six traps per ha. Traps were examined, and moths counted and removed every 3 d from 25 June to 2 August. Trap catches in treatments and control plots were compared to verify the performance of the treatment. The capture inhibition = (average moth catches/control trap − average moth catches/treatment trap)/average moth catches/control trap × 100%.

Crop Damage Assessment. An evaluation of ear damage gives the best parameter for treatment efficiency. An ear with any Asian corn borer damage will be rejected in the fresh market by consumers. Therefore, damage was evaluated in late July of 2010 and 2011, by selecting ≈100 immature ears at random from every plot. The number of damaged ears per hundred immature ears was established.

Pheromone Release Rates and Movement. During 2010 and 2011, the two pheromone components (Z-12/E-12-14Ac) present at 3-d intervals in the field were monitored. Forty-five dispensers were put out, and three were removed for pheromone residue assessment every 3 d. This covered 10 evaluations from day 5–45 after exposure. Dispensers were stored at −18°C until analyzed by pressurized solvent extraction using a One PSE apparatus (Applied Separations, Bethlehem, PA). Extraction conditions were 100 bars, 60°C, and nine cycle extractions using dichloromethane as solvent. Each cycle lasted 5 min. The resulting extracts were concentrated under reduced pressure to 1 ml and analyzed by GC using a capillary column (SP-2330, Beijinghausheng Apparatus Group Co., Ltd., Beijing, China; 30 m by 0.25 mm by 0.2 mm). The amount of the main component (Z12-14Ac) was calculated using an internal standard (tridecyl acetate). A 1- by 1-m sheet of Ray-crosslinked polyethylene foam plate (Liaoningn Taicang Teaching and Research Material Group, Shengyang, China) was placed in the buffer between plots ≈1.3 m in height (equal to the height of corn plants) for 12, 24, and 36 h and then taken back to the lab and treated like the pheromone dispensers. In addition, leaves from corn plants at 1 m height in the control were collected and treated as above at 12, 24, and 36 h after treatments were established.

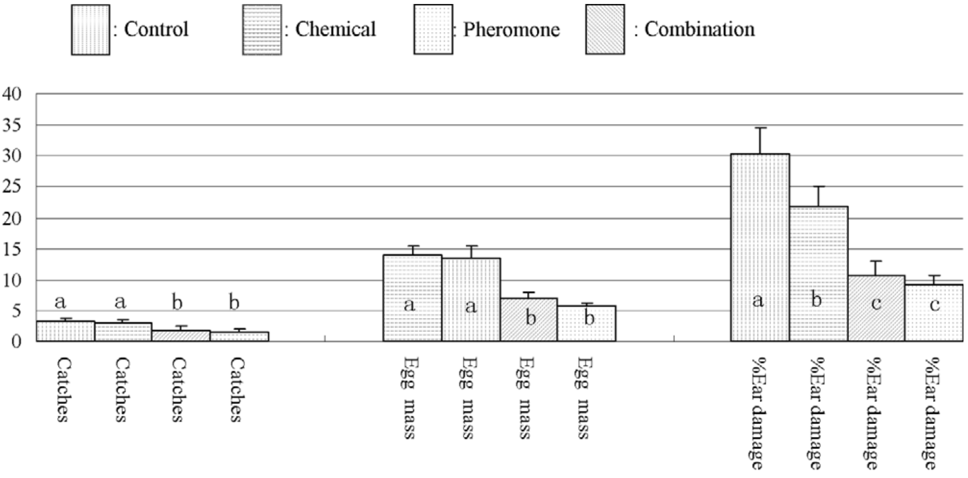
Data Analysis. Trap captures and ear damage data were transformed by square root (x) and log ($x + 1$), respectively, to normalize the data. After transformation, data were analyzed by two-way analysis of variance (ANOVA) using SAS software (version 9.1 2003; locations and treatments), followed by a least significant difference (LSD) test to establish statistical differences.

Results

Moth Population Dynamics. The first overwintering male was captured on 3 June of 2010 (Fig. 1). The captures increased steadily for ≈3 wk, peaking on 29 June, then falling and reaching a second peak on 11 August. Populations then diminished and reached zero on 27 September. The second generation spanned early August to late September, with slightly lower numbers than in the first generation.

During 2011, a similar pattern occurred (Fig. 1). From 1 June to 29 June the catches increased, followed by a sharp decrease by 7–17 July, and then low-level fluctuations until 9 August. Again this year, captures increased at that point and then declined by the end of August. September catches remained <5.

In both years, captures from 3 June to 27 July indicated that Asian corn borer completed one generation, and from 9 August to 27 September, a second generation occurred that did not require treatment, as sweet corn had already been harvested. Trap captures showed the important first peak was in late June, and pheromone treatments should have been applied on ≈27 June in 2010 and 3 July in 2011. There was so little variation between replicates during the 2 yr that deviations are not apparent (Fig. 1). The mean capture for the three traps in 2010 was 3.3 (coefficient of



Note: Data are pooled and "chemical" combines endosulfan, monosultap, and chlorpyrifos data. Combination = sex pheromone + insecticide treatments.
x-axis = result categories; and Y-axis = mean values

Fig. 2. *O. furnacalis* trap catches, egg masses, and ear damage following various treatments—2011.

variation [CV] = 0.142), while the mean for 2011 was 3.1, with a CV of 0.144.

Egg Masses. Most Asian corn borer egg masses in 2010 were seen in the controls and insecticide-only treatment plots. Numbers of egg masses were reduced during July–August in pheromone-treated areas (Table 1), significantly at 300 disp./ha for mating disruption, and 30 and 40 disp./ha for mass trapping, indicating that these treatments were the most effective. In addition, 40 and 30 disp./ha for mass trapping, and 300 disp./ha for mating disruption showed the greatest reductions in egg masses (Table 1). Slightly reduced, but not significant, numbers of egg masses were obtained in 20 disp./ha for mass trapping and 100 and 200 disp./ha for mating disruption plots. In 2011, most Asian corn borer egg masses were again in the controls and insecticide-only plots (12.3 and 16.5, respectively; Fig. 2). Reduction of egg masses was found in pheromone- and pheromone plus insecticide-treated areas.

With the mating disruption + insecticide combination, egg masses were reduced 50% with 100 disp./ha. Low egg mass numbers were also found with 200 disp./ha for mating disruption when combined with high rates of chlorpyrifos, endosulfan, and monosultap, and even lower numbers occurred with 300 disp./ha for mating disruption when integrated with all insecticides except for endosulfan (0.14 kg), chlorpyrifos (0.18 kg), and chlorpyrifos (0.09 kg). This indicates the efficacy of those treatments that gave >60% reduction in egg masses (Table 2).

With mass trapping + insecticides, >60% egg mass reductions were obtained for all insecticide combinations with dispenser densities of 40 or 30 disp./ha (Table 2). Furthermore, chlorpyrifos (0.35 kg), endosulfan (0.55 or 0.42 kg), and monosultap (0.55 kg) provided >90% egg mass reduction when combined with 40 disp./ha.

Trap Captures. In 2010, many Asian corn borer males were captured by pheromone traps in the chemical treatment plots (mean >2.9), and no significant differences were found from the control plots (3.3; Table 1). Average captures were reduced by mass trapping and mating disruption at all dispenser densities (Table 1). Average trap catches were lowest in the two highest mass trapping and mating disruption plots, and significantly less than all other treatments (Table 1). This correlated with inhibition of captures where densities of 40 and 30 disp./ha for mass trapping provided 67 and 54% reduction, and, 300 and 200 disp./ha for mating disruption gave 54 and 52% reductions, respectively.

In 2011, traps in the insecticide-only and control plots again captured significantly more Asian corn borer males than in the pheromone-only treatments. However, the lowest captures were in the insecticide + pheromone treatments, but not significantly lower than the pheromone-only treatments (Fig. 2). The 200 disp./ha for mating disruption with insecticides, except for the lowest endosulfan rate, provided 50–60% capture reduction. The same results were obtained with 300 disp./ha for mating disruption with all insecticides (Table 2; Fig. 3). The 30 disp./ha for mass trapping resulted in >70% reduction when integrated with chlorpyrifos (0.35 kg), endosulfan (0.55 or 0.42 kg), and monosultap (0.55 kg). Furthermore, >85% reductions were obtained with 40 disp./ha mass trapping combined with chlorpyrifos (0.35 kg), endosulfan (0.55, 0.42, or 0.28 kg), and monosultap (0.55 kg).

Crop Damage. As a fresh market product, sweet corn with any ear damage may not be acceptable to consumers in China. Therefore, damage assessment is the most important measure for showing the efficiency of Asian corn borer suppression techniques.

Table 2. *O. furnacalis* trap catches and egg masses after application of various treatments—2010

Treatment/kg/ha	Mating disruption						Mass trapping						No pheromone	
	100/ha		200/ha		300/ha		20/ha		30/ha		40/ha			
	EM/C	% reduction	EM/C	% reduction	EM/C	% reduction	EM/C	% reduction	EM/C	% reduction	EM/C	% reduction	EM/C	% reduction
Chlorpyrifos/0.35 kg	7.3/2.2	45.1a/31.2b	5.3/1.3	60.2a/59.3b	4.3/1.3	67.7a/59.3b	7.5/1.8	43.6a/43.8b	3.3/0.6	75.2a/81.3	1.3/0.6	90.2a/81.2c	14.2/3.3	0b/0e
Endosulfan/0.55 kg	8.2/2.2	38.3b/31.2b	5.2/1.3	60.9a/59.3b	4.2/1.1	68.4a/65.6a	7.5/1.8	43.6a/43.8b	3.6/0.8	72.9a/75.0	1.2/0.7	90.9a/78.1c	12.3/3.1	7.5a/3.1d
Monosultap/0.55 kg	8.6/2.1	35.3bc/34.4a	5.3/1.2	60.2a/62.5a	4.3/1.2	67.7a/60.2b	7.2/1.7	45.9a/46.9a	3.3/0.8	75.2a/75.0	1.3/0.2	90.2a/93.8a	14.5/2.9	0b/9.4b
Endosulfan/0.42 kg	8.4/2.1	36.8b/34.4a	5.8/1.4	56.4b/56.3c	4.2/1.3	68.4a/59.3b	7.6/1.8	42.9/43.8b	3.3/0.9	75.2a/71.9	1.2/0.4	90.9a/87.5b	12.3/2.8	6.8a/12.5a
Endosulfan/0.28 kg	8.8/2.1	33.8bc/34.4a	5.6/1.4	57.9b/56.3c	4.8/1.6	63.9b/50.0e	7.8/2.1	45.1a/34.4c	4.2/1.1	68.4b/65.6	2.2/0.4	83.5b/87.5b	12.3/3.1	6.8a/3.1a
Monosultap/0.14 kg	9.2/2.5	30.8c/21.9e	6.4/1.5	51.9c/53.1d	4.8/1.3	63.9b/59.3b	7.7/2.1	42.1b/34.4c	4.8/1.1	63.9c/65.6	2.3/1.1	82.7b/65.6de	14.5/3.0	0b/6.3c
Monosultap/0.42 kg	9.2/2.3	30.8c/28.1c	6.2/1.5	53.4c/53.1d	5.3/1.1	60.2c/65.6a	7.8/2.1	45.1a/34.4c	4.2/1.1	68.4b/65.6	2.3/1.2	82.7b/62.5e	16.5/3.4	0b/0e
Monosultap/0.28 kg	93/2.2	30.1c/31.2b	6.8/1.6	48.9d/50.0e	5.2/1.6	60.9c/50.0e	7.8/2.1	45.1a/34.4c	5.1/1.6	61.7cd/50.0	2.3/1.2	82.7b/62.5e	13.6/3.2	0b/0e
Chlorpyrifos/0.27 kg	9.6/2.1	27.8cd/34.4a	6.9/1.6	48.1d/50.0e	5.3/1.7	60.2c/46.9f	7.5/2.1	43.6ab/34.4c	5.3/1.4	60.2d/56.3	3.3/1.3	75.2c/59.3e	13.9/3.2	0b/0e
Endosulfan/0.14 kg	9.9/2.5	25.6d/21.9e	6.5/1.8	51.5c/43.4f	5.5/1.4	58.6cd/56.3c	7.7/2.1	42.1b/34.4c	5.5/1.7	58.6d/46.9	3.2/1.0	75.9c/68.8d	13.0.3/3.1	0b/3.1d
Chlorpyrifos/0.18 kg	9.9/2.2	25.6d/31.2b	7.4/1.6	44.4e/50.0e	5.9/1.3	55.6d/59.3b	7.6/2.1	42.9ab/34.4c	5.3/1.3	60.2d/59.3	3.3/1.3	75.2c/59.4e	13.8/3.1	0b/3.1d
Chlorpyrifos/0.09 kg	9.9/2.1	25.6d/34.4a	7.8/1.6	41.4e/50.0e	6.2/1.5	53.4d/53.1d	7.9/2.1	40.6b/34.4c	5.2/1.4	60.9d/56.3	3.3/0.8	75.2c/75.0c	14.2/3.1	0b/3.1d
No chemicals	9.9/2.4	25.6d/25.0d	8.1/1.9	39.1f/40.6 g	6.2/1.6	53.0.4d/50.0e	8.2/2.2	38.3c/31.2d	5.1/1.5	61.7cd/60.2	3.8/1.1	71.4c/65.6de		
Control	13.3/3.2		13.3/3.2		13.3/3.2		13.3/3.2		13.3/3.2		13.3/3.2		13.3/3.2	$F_{(11.24)}/P$:
$F_{(12,26)}/P$ value		2.42/2.55		2.33/2.95		2.87/2.21		2.66/2.54		2.43/2.56		2.33/2.31		2.97/2.89

Numbers in a column followed by the same letter are not significantly different (0.05%); ck indicates check; EM/C = egg mass/trap captures. Egg masses reduction = % (egg mass/plant in ck − egg masses/plant in treatment/egg masses/plant in ck); Capture reduction = % (captures/plant in ck × captures/plant in treatment/captures/plant in ck).

In 2010, although no treatment gave >80% damage reduction (Table 1), ear protection in insecticide (endosulfan, chlorpyrifos, and monosultap), mass trapping, and mating disruption plots were significantly higher than other treatments (Table 1; Fig. 2). This indicated these methods had potential for Asian corn borer population control. In 2011, significantly more ear damage was seen in the control and insecticide treatments (Fig. 2.) than with pheromone alone or in combination with insecticides. Furthermore, some pheromone + insecticide combination treatments provided >90% control (Fig. 3).

With mating disruption + insecticide treatments, ear damage was significantly reduced (Fig. 3), with 200 disp./ha combined with endosulfan (0.55 or 0.42 kg/ha), and with 300 disp./ha plus chlorpyrifos (0.35 or 0.27 kg/ha), monosultap (0.55 kg/ha), and endosulfan (0.55 kg/ha) treatments. This efficiency was further supported, as these treatments had >90% reduction in ear damage and the differences from other plots were statistically significant.

In mass trapping + insecticide treatments (Fig. 3), 30 disp./ha rate with endosulfan (0.55 kg), chlorpyrifos (0.35 kg), and monosultap (0.55 kg) along with 40 disp./ha with endosulfan (0.55 or 0.42 kg), chlorpyrifos (0.35 or 0.27 kg), and monosultap (0.55 or 0.42 kg) resulted in less ear damage, which was consistent with the damage reductions of >96%, and indicated that these treatments were also effective.

Pheromone Release Rates. The laboratory bioassay (Fig. 4) showed that pheromone was released from the rubber dispenser slowly. After 12 d, >80% of the pheromone remained, and the pheromone residual was ≈55% of the initial dosage after 30 d. This is consistent with a label description of a 35-d field life, as well as other reports (McDonough et al. 1989, Zhao and Wang 1990, Sheng et al. 2002, Zhang et al. 2010b). No pheromone was found on the sheets placed in the buffer or on leaves from the control.

Discussion

Through the years, a prophylactic insecticide treatment has been a mainstay for controlling Asian corn borer in China. Chemicals are only effective for a short period before larvae bore into the corn stem. Asian corn borer populations were high from mid-June to late July (Fig. 1.), during which time larvae feed on corn plants, especially on developing silk and kernels. This situation usually results in at least two sprays after kernel formation, with at least one spray for leaf whorl and tassel protection (Nafus and Schreiner 1991; Qu 1992; Zhou 1996; Wang et al. 2000, 2003, 2005; He et al. 2002; Liu and Zhang 2006; Chen et al. 2009; Luo et al. 2010; Han et al. 2012). This indicates why the single chemical spray here in 2010 provided <50% ear protection. Using the pheromone alone has provided

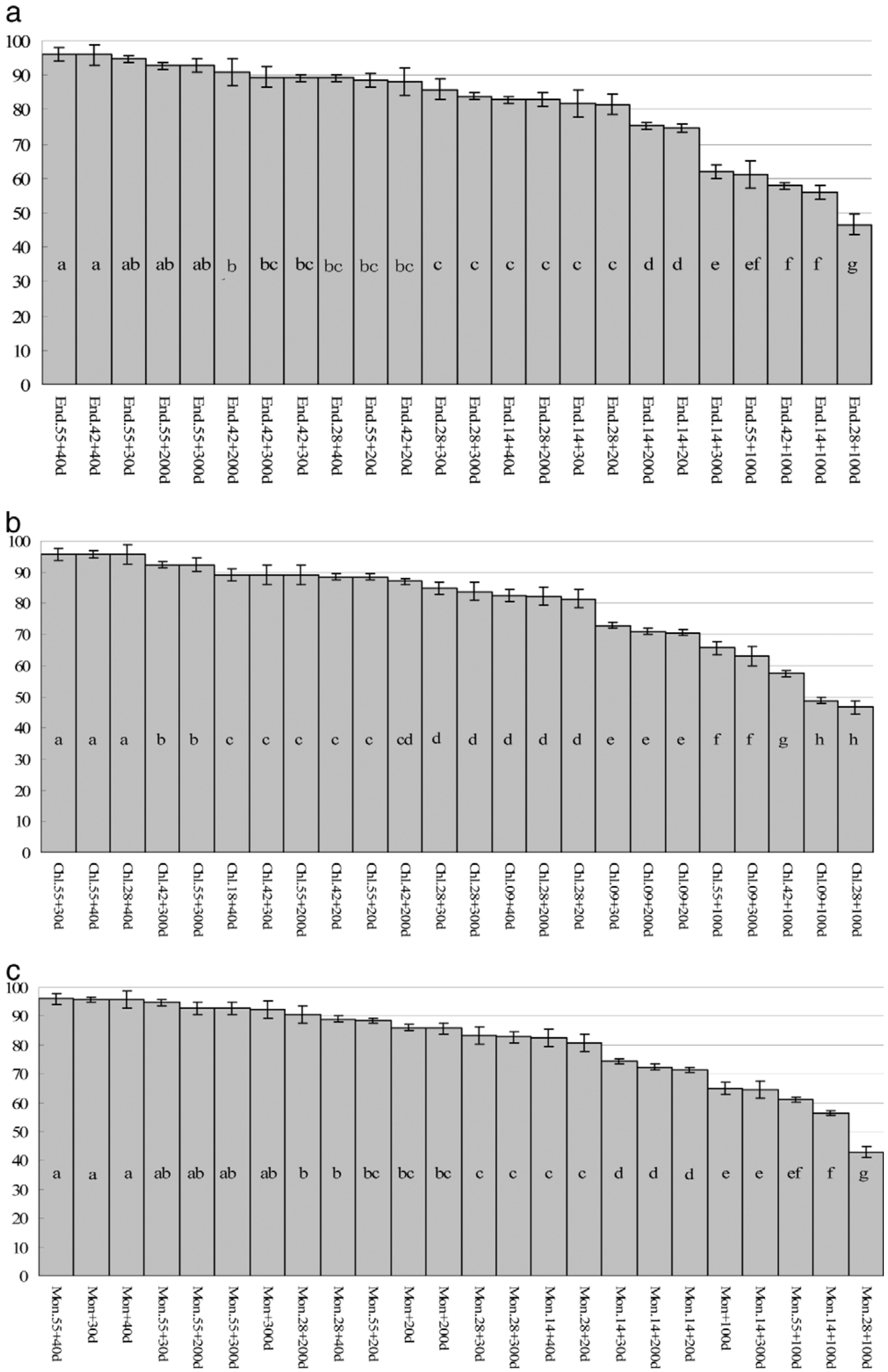


Fig. 3. Percent reduction in ear damage from *O. furnacalis* following insecticide and pheromone treatments—2011, (a) endosulfan, (b) chlorpyrifos, and (c) monosultap. Chemical rate + mass trapping (20, 30, and 40 disp./ha) and mating disruption (100, 200, and 300 disp./ha).

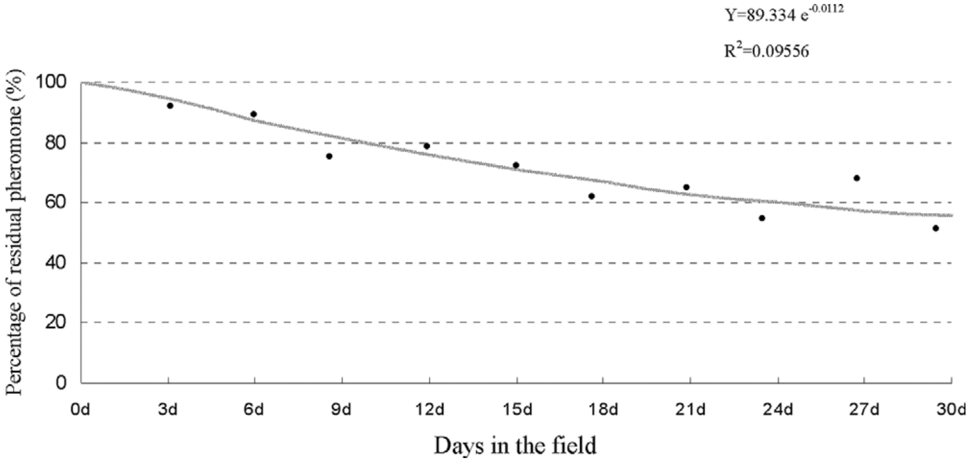


Fig. 4. Residual *O. furnacalis* pheromone in dispensers after various days in the field.

>50% protection in China against Asian corn borer larvae (Zhou 1996; Wang et al. 1997, 2003; Liu and Zhang 2006; Chen et al. 2010; Zhang et al. 2010b), which coincides with our 2010 results. In 2011, one spray with 0.05–0.75 of the standard dose resulted in only 10% ear damage when combined with ≧200 disp./ha for mating disruption or ≧30 disp./ha for mass trapping. These combinations significant reduced the quantity and frequency of chemical sprays.

The short time available to control the borer larvae, together with complex methods for predicting application times, has contributed to adoption of calendar-based chemical applications, and a subsequent overuse of chemicals. In general, one additional spray and at least a twofold increase in dosage are common in most Chinese sweet corn regions. This emphasizes the need for change and indicates that insecticide + pheromone combinations can play a unique role in reduced chemical use.

Monitoring stem borer populations with pheromones has developed into a mainstay in forecasting for the rice stem borer, *Chilo suppressalis* (Walker) (Sheng et al. 2003; Chen et al. 2003, 2007), and Asian corn borer (Hu and Jiang 1995, Liu and Zhang 2006, Linn et al. 2007, Chen et al. 2010). In 2010, pheromone trap captures became the primary technique for timing control applications in NE China. Compared with the previous methods of splitting corn plants to estimate pupae development, or counting egg masses in the field, pheromones are easier to use and provide a more accurate indication. An estimate of peak moth emergence and activity from pheromone traps has been used as a viable alternative to egg mass monitoring (Cork and Hall 1998, Cork 2004). During 2010 and 2011, peak captures with pheromone traps more accurately indicated spray 8 and 6 d earlier than the laborious counting of egg masses (Chen and Klein 2012). This study used 10 yr of research on the best trapping technology and the most effective pheromone septa (Wang and Xuan 2002; Sheng et al. 2002, 2003; Chen et al. 2003, 2007; Chen and Klein 2012). In addition, because pheromone dispensers have a limited field life (≈30–35 d here), there is a need to accurately time their placement to minimize changes and reduce costs when Asian corn borer is active. Historically, moths appeared in mid-June, and pheromone applications were started ≈25–30 May in NE China (Wang et al. 1997, Zhang et al. 2010b). Results here showed that applications could be put off to ≈1 July, saving many lures, especially with mating disruption.

The pheromone residue evaluation showed septa retained >50% of the initial dose for 30 d, supporting previous usage (Sheng et al. 2002, Chen et al. 2007, Chen and Klein 2012). Sweet corn is harvested in early August once kernel formation is complete (2–3 August in 2010–2011), so the control period is <35 d from peak moth captures to ≈10 d before harvest. Larvae from eggs laid within 10 d of harvest will not have time to hatch and damage the corn. Results here showed that pheromone dispensers completely cover the Asian corn borer damage period, including the final 10-d period that must be chemical free.

In 2010, neither mass trapping with 20–40 disp./ha nor mating disruption with 100–300 disp./ha provided <20% ear damage. In addition, lower efficacy was provided by the 15 insecticides tested. However, those results indicated that the pheromone techniques in combination with three pesticides gave significantly reduced ear damage.

This was supported in 2011 when ear damage was reduced >90% following pheromone + insecticide applications. Although the full dose of chlorpyrifos and endosulfan provided only 50% ear protection in 2010, in 2011, 75% of their standard rate provided ≈90% ear protection when combined with 200 and 300 disp./ha, or 30 and 40 disp./ha mating disruption or mass trapping. This demonstrates augmented control using insecticides and pheromones together.

The pheromone and insecticide combinations in 2011gave lower egg mass and moth captures, but the differences were generally not significant from the pheromone treatments alone (Fig. 3). Previous studies showed an interaction between Asian corn borer damage and white spotted flower chafer, *Potosia brevitaris* Lewis, adults (Chen and Zhao 2008). The chemicals used here could reduce *P. brevitaris* damage, and may lower the attraction of sweet corn ears to Asian corn borer moths.

In China, little literature is available on mass trapping of Asian corn borer (Wang et al. 1997, Chen et al. 2010, Zhang et al. 2010b), and there is none on mating disruption or the optimization of the techniques. However, pheromones and traps have been applied to $>10^7$ ha of corn fields in NE China for Asian corn borer monitoring during 2012 (C-F.S. and R-Z.C., unpublished data). With improvements in pheromone techniques and increased awareness of insecticide residue on of food, Asian corn borer control with pheromones and chemical + pheromone combinations can provide efficient pest control in the future.

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