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ACTION THRESHOLD TREATMENT REGIMENS FOR RED SPIDER MITE (ACARI: TETRANYCHIDAE) AND TOMATO FRUITWORM (LEPIDOPTERA: NOCTUIDAE) ON TOMATO

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ABSTRACT

The tomato fruitworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), is the foremost pest of tomato in the Mariana Islands. Similarly, the red spider mite, *Tetranychus marianae* McGregor (Acari: Tetranychidae), is a chief pest of vegetables particularly on tomato, *Solanum lycopersicum* L. (Solanaceae). However, the infestations by *T. marianae* are heavy during the early stages of crop growth, while infestations of *H. armigera* become prominent at later stages. Because no threshold levels are available for these pests, many growers apply up to 15 chemical applications per tomato cropping period. To reduce the regular spray schedules chemical applications and to prevent damage to foliage and fruit quality, the present study was undertaken for the development of action threshold levels for the timing of chemical applications for *T. marianae* and *H. armigera* on tomato in the Mariana Islands. Therefore, different threshold levels were evaluated for timing applications of Sun-spray 6E® horticultural oil against *T. marianae* and Aza-Direct®, neem against *H. armigera* on tomato in the wet and dry seasons at 2 locations, Dededo and Inaranjan, in Guam, USA during 2011 and 2012. Based on *T. marianae* infested leaves, incidence of *T. marianae* and yield levels, the plots sprayed at 8-12 mites/leaf in the dry season and 8-14 mites/leaf during the wet season had significantly lower leaf damage and *T. marianae* densities compared to a greater number of mites/leaf, regular based sprays and control plots. Likewise, an initial spray scheduled when 2 eggs of *H. armigera* were detected on 10 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae were detected per 50 immature fruit resulted in lower percent fruit damage and higher marketable yield compared to other threshold levels or a regular spray schedule.

Key Words: action thresholds, *Tetranychus marianae*, *Helicoverpa armigera*, tomato

RESUMEN

El gusano del fruto del tomate, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), es la principal plaga del tomate en las Islas Marianas. Del mismo modo, la araña roja, *Tetranychus marianae* McGregor (Acari: Tetranychidae), es una plaga principal de hortalizas particularmente en el tomate, *Solanum lycopersicum* L. (Solanaceae). Sin embargo, las infestaciones por *T. marianae* son pesados durante las primeras etapas de crecimiento de los cultivos, mientras que las infestaciones de *H. armigera* se vuelven prominentes en etapas posteriores. Debido a que no se dispone de niveles de umbral para estas plagas, muchos productores aplican hasta 15 aplicaciones químicas por período de cultivo de tomate. Para reducir los horarios de pulverización aplicaciones químicas regulares y para evitar daños en el follaje y la calidad de la fruta, el presente estudio se llevó a cabo para el desarrollo de los niveles de umbral de acción para el momento de las aplicaciones químicas para *T. marianae* y *H. armigera* de tomate en las Islas Marianas . Por lo tanto, se evaluaron diferentes niveles de umbral para aplicaciones de tiempo de Sun-spray 6E® aceite de horticultura contra *T. marianae* y Aza-Direct®, neem contra *H. armigera* en el tomate en las estaciones húmedas y secas en 2 lugares, Dededo y Inaranjan, en Guam, EE.UU. durante 2011 y 2012. Basado en *T. marianae* hojas infestadas, la incidencia de *T. marianae* y niveles de rendimiento, las parcelas fumigadas en 8-12 ácaros / hoja en la estación seca y 14.08 ácaros / hoja durante la estación lluviosa tuvieron significativamente menor daño foliar y *T. marianae* densidades en comparación con un mayor número de ácaros / hoja, aerosoles basados en regulares y parcelas de control. Del mismo modo, una pulverización inicial programada cuando se detectaron 2 huevos de *H. armigera* en 10 de las muestras, seguido de una pulverización adicional sólo si se detectaron 2 frutos dañados o larvas *H. armigera* por fruto 50immature resultó en un menor daño a la fruta por ciento y más comercializable producir en comparación con otros niveles de umbral o un horario aerosol regular.

Palabras Clave: umbrales de acción, *Tetranychus marianae, Helicoverpa armigera*, tomate

The red spider mite, *Tetranychus marianae* McGregor (Acari: Tetranychidae), is one of the most serious pests on vegetable crops, particularly on eggplant (*Solanum melongena* L.; Solanaceae) and tomato (*Solanum lycopersicum* L.; Solanaceae), in the Mariana Islands (Reddy et al. 2011). This mite species is widespread in the Pacific Islands, including the Mariana Islands, where it was first reported (Reddy & Bautista 2012). In fact this species was described first from specimens collected in Tinian, Mariana Islands (McGregor 1950). *Tetranychus marianae* is also a pest of several annual crops and certain perennials (Reddy et al. 2013). This mite could also become important in pasturelands and rangeland (Reddy & Kikuchi 2011). Heavily infested tomato leaves become yellowish-green to yellowish brown (Wene 1956). Moreover, feeding due to *T. marianae* causes a silvering on the shoulders of the fruit, and this silvery area become russet brown in appearance. Denmark (1970) stated that the mites cause tomato leaves to become chlorotic and to curl. This species has been shown to migrate 10 m from one field to another (Wene 1956). While *T. marianae* is known to be polyphagous, it prefers to feed and live on solanaceous plants (Bolland et al. 1998).

The tomato fruitworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), is a polyphagous pest attacking tomato, peas and all other crops that are grown in Guam and other neighboring islands (Reddy & Kikuchi 2011). Due to its high fecundity, polyphagous nature and high reproductive potential, control of this pest has become very difficult (Reddy & Manjunatha 2000). Females oviposit on the flowering and fruiting structures of these crops. Larvae feed voraciously, leading to significant crop losses (Reed & Pawar 1982). The capability of ovipositing females to find and exploit a wide range of hosts from a number of plant families is one of the main reasons contributing to the pest status of this species (Zalucki et al. 1986). *Helicoverpa armigera* larvae are enormously damaging because they prefer to feed and develop on the reproductive structures of crops which are rich in nitrogen (Fitt 1989). On tomato, the fruits are preferred for feeding, but flowers, stems and leaves can also be injured. Fruit damage can result in rot or attack of secondary pests. If larvae are big and the fruits are small, one larvae can attack more than one fruit per day (Reed & Pawar 1982).

Tomato growers in the Mariana Islands apply nearly 15 chemical sprays per cropping period, which often leads to the development of resistance of insect pests to the chemicals. The development of resistance in *H. armigera*, a wide range of pesticides has been documented (McCaffery et al. 1991; Joußen et al. 2012). Similarly, the concern for the development of resistance in *T. marianae* to insecticides and acaricides led to the search for alternative pesticides since at least 1964 (Wolfenbarger & Getzin 1964).

The use of action threshold in pest management programs results in reduced insecticide usage (Farrington 1977). However, no action threshold levels have been developed for *T. marianae* and *H. armigera* on tomato in the Mairana Islands. Growers in the Mariana Islands are unaware of the adverse effects of chemical sprays on natural enemies and of the benefits of using action threshold.

The objective of the present study was to develop action threshold levels for timing pesticide sprays for managing *T. marianae* and *H. armigera* on tomato.

Materials and Methods

Seedling Nursery

The tomato seeds of a cherry variety were sown in trays (40 × 30 cm) and seedlings were grown for 40 days in a nursery in a shade house (30-32 °C, 60-80% RH, and 14:10 h L:D) using the standard agronomic practices of the area.

Experiments were conducted at 2 locations: the University of Guam Agricultural Experiment Station, Inarajan (N 13° 61.963' E 144° 45.353') and a commercial farm at Dededo (N 13° 30.700' E 144° 51.173'). Identical trials were conducted on the development of action threshold for *T. marianae* during both the wet season (Jul-Dec 2011) and the dry season (Jan-May 2012) at both locations (Dededo and Inaranjan). However, trials for *H.armigera* were conducted only from Jul-Dec 2011 at the Dededo location and from Jan-May 2012 at the Inaranjan location.

Action Threshold Treatment Regimens with *Tetranychus marianae*

The treatment plots were 4 m × 4 m and were separated from other plots by 0.5 m buffer zones to minimize the effects of spray drift. Thirty five day-old tomato seedlings were transplanted at a distance of 75 cm between rows and 91.4 cm between plants in the row. Three replicates of each of 10 treatments produced a total of 30 plots for each experiment. Each plot consisted of 5 rows of 12 tomato plants, for a total of 60 plants per plot. The total area of the experimental tomato field was 480 m^2 at each site. All the fertilizer applications were followed according to Schulub & Yudin (2002).

Sun-spray 6E® (Sunoco, Inc R&M, Philadelphia; active ingredients: refined petroleum distillate: 98.8 wt % + emulsifier: 1.2 wt %) was chosen for the *T. marianae* studies, because it is environmentally friendly and is proven to be significantly effective against spider mites (Lancaster et al. 2002). Applications were made at the rate of 5 mL/liter within 12 h after reaching mean threshold levels of 8, 10, 12, 14 or 16 mites/ leaf. For the calendar-based chemical treatments, sprays were applied as shown below in the treatments T6 to T9. This spraying schedule was usually performed by growers. The growers usually spray according to the set time interval (growers' practice). The action thresholds were as follows:

T1: Threshold-based chemical sprays (TCS) (mean of 8 mites/leaf);

T2: TCS (mean of 10 mites/leaf);

T3: TCS (mean of 12 mites/leaf);

T4: TCS (mean of 14 mites/leaf);

T5: TCS (mean of 16 mites/leaf);

T6: Regular spray schedule (RSS) (15 DAT) initial spray applied 15 days after transplanting and then every 15 days thereafter;

T7: CCS: (30 DAT): initial spray applied 30 days after transplanting and then every 30 days thereafter;

T8: CCS: (45 DAT): initial spray applied 45 days after transplanting and then every 45 days thereafter;

T9: CCS: (60 DAT): initial spray applied 60 days after transplanting and then every 60 days after transplanting and then every 60 days thereafter;

T10: Control (no spray).

The amount of solution sprayed per application was 95 L/ha for small plants (up to 45 DAT) and 190.0 L/ha for larger ones (45 DAT until harvest). All the chemicals were applied with motorized backpack sprayers (Solo Brand; Forestry Suppliers, Jackson, Mississippi) equipped with an adjustable, flat spray, hollow cone, and jet stream nozzle, and pressure (45 psi = 310 kPa) was calibrated to deliver 20 gallon per acre (gpa).

Sampling Method for *Tetranychus marianae* Populations

To determine the *T. marianae* population level, 10 plants were selected randomly per plot. For each plant, 3 leaves were chosen randomly, 1 per top, middle and bottom of the plant (Reddy et al. 2013). On the underside of each of these leaves, the number of mites present was counted using a magnifying lens. The counts were done at weekly intervals. Similarly, the number of infested leaves by *T. marianae* per plot was recorded out of the 30 leaves counted in each plot. The plots were harvested when they were ready and the yield was recorded for each treatment plot. The data were averaged and expressed as the number of mites per leaf, the percent of infested leaves and yield per hectare.

Action Threshold Treatment Regimens with *Helicoverpa armigera*

The treatment plots and all other cropping details were same as in the case of experiments with mite threshold levels. Azadirachtin (Aza-Direct®) was chosen for the *H. armigera* experiments because Azadirachtin has been approved by the U.S. Environmental Protection Agency for application on food crops. It is non-toxic to birds, beneficial insects or humans and protects crops from many pest species. Application were made at 10 mL/liter based on the threshold levels. Carbaryl (Sevin®) was chosen for the regular spray schedule. All applications for the *T. marianae* experiments were made using the same equipment and the same delivery rates as for the refined oil. Action thresholds used to determine when to spray tomatoes for *H. armigera* control are shown below:

T1: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by added sprays every 10 days until the end of harvest.

T2: Initial spray scheduled when 2 *H. armigera* eggs is detected on 10 of the leaf samples, followed by added sprays every 10 days until the end of harvest.

T3: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 if the leaf samples, followed by added sprays every 10 days until the end of harvest.

T4: Initial spray scheduled when 2 *H. armigera* eggs is detected on 20 of the leaf samples, followed by added sprays every 10 days until the end of harvest.

T5: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by an added spray if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit.

T6: Initial spray scheduled when 2 *H. armigera* egg is detected on 10 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit.

T7: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit.

T8: Initial spray scheduled when 2 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit.

T9: Regular spray schedule: applications of carbaryl were initiated 12 DAT and about every 12 days thereafter.

T10: Untreated control (no spray).

Sampling Method for *Helicoverpa armigera* Populations

The egg and larval densities of *H. armigera* were estimated in a nondestructive fashion in each tomato plot approximately once a week. Egg densities were estimated by carefully examining the terminal part of the plant down to the first fully expanded compound leaf plus the third leaf down from the terminal part of the plant on 10 randomly selected plants in each plot (Kuhar et al. 2006). Larval infestation levels were estimated by randomly examining 50 unripe fruit per plot and recording the number of *H. armigera* larvae and damaged fruit.

Statistical Analysis

Data for the number of infested leaves on 10 plants per plot and overall yield levels in different treatments were analyzed using repeated measures ANOVA ($P < 0.05$) over multiple dates, and differences between treatments means were compared using the Tukey HSD test. All statistical analyses were carried out using SAS Version 9.3 (SAS Institute 2009). The 5% level of significance were used for all analyses.

Results

Action Threshold Treatment Regimens with *Tetranychus marianae*

During the dry season, *T. marianae* and infested leaves were significantly less ($F_{9,43} = 92.3$, $P < 0.05$) in T1 (8 mites/leaf), T2 (10 mites/leaf) and T3 (12 mites/leaf) compared to all other treatment regimens (Tables 1, 2 and 3). There were no significant differences among the T1, T2 or T3 treatments. During the wet season, the population level of *T. marianae* and infested leaves were significantly fewer ($F_{9,46} = 102.3$, $P < 0.05$) in T1 (8 mites/leaf) through T4 (14 mites/leaf) compared to all other treatment regimens. In both the dry and wet periods, the regular spray treatments T6 through T9 (15-60 DAT) recorded significantly fewer ($F_{9,47} = 80.6$, $P < 0.05$) *T. marianae* and infested leaves than T10 (control). Significantly ($F_{9,43} = 43.4$, $P < 0.05$) greater levels of *T. marianae* and infested leaves were recorded in control treatments compared to all other treatments in both locations and both seasons. The overall data from the action threshold and regular spray treatments indicated that the mean number of *T. marianae* and infested leaves were significantly fewer ($F_{9,54} = 128.1$, $P < 0.05$) in threshold treatments than regular spray treatments. During the dry season, the marketable yield (the amount of qualified fruits eligible to be sold) levels were significantly greater ($F_{9,43} = 23.7$, $P < 0.05$) in T1-T3 (8-12 mites/leaf) compared to the other treatment regimens in both locations (Fig. 1). However, in the wet season, the yield levels were significantly greater ($F_{9,55}$ =98.2, $P < 0.05$) in T1 over T4 compared to the other treatment regimens. In both the dry and wet seasons, the regular spray treatments T6 through T9 (15-60 DAT) noted significantly greater ($F_{9,28}$ =92.7, $P < 0.05$) yields than T10 (control) at both locations. The control (no spray) plots yielded significantly lower marketable yields (20.6-22.4 tons/ha) as an average for both the seasons and locations (Fig. 1). The average overall yield from the action threshold and regular spray treatments showed that the yield levels were significantly greater ($F_{9,66}$ =92.4, $P < 0.05$) in action threshold treatments than regular spray scheduled treatments.

Action Threshold Treatment Regimens with *Helicoverpa armigera*

The number of insecticide sprays ranged from 2 to 15 applications based on the *H. armigera* actions thresholds (Table 4). The percent of damaged fruits were significantly ($F_{9,17} = 34.8$, $P < 0.05$) lower in T1, T2, T5 and T6 at the both the locations compared to other threshold levels of T3, T4, T7 and T8. Correspondingly, the marketable yield levels were significantly higher ($F_{9,46} = 84.7$, $P < 0.05$) T1, T2, T5 and T6 compared to T3, T4, T7 and T8 (Table 5). The T6 with initial spray scheduled when 2 *H. armigera* eggs were detected on 10 of the samples, followed by an added spray only if 2 damaged fruits or *H. armigera* larvae were detected per 50 immature fruits, resulted in only 3-4 sprays.

The whole data set from the action threshold and regular spray treatments indicated that the mean number of percent damaged fruits were significantly fewer ($F_{9,21} = 87.3$, $P < 0.05$) in threshold treatments than regular spray treatments. The control (no spray) plots yielded significantly lower marketable yields (20-23 tons/ha) as an average for both the seasons and locations (Table 5).

Discussion

This study indicated that an action threshold-based approach for determining when to use an insecticide application for pest control in tomato growing was operative and resulted in fewer insecticide applications. Growers should be recommended to follow the practice of action threshold-based chemical sprays in managing major pests for tomatoes and avoid the traditional regular

TABLE 1. THE DAY AFTER TRANSPLANTATION (DAT) AT WHICH A CHEMICAL TREATMENT WAS IMPOSED AFTER GETTING THE ESTIMATED THRESHOLD LEVEL OF MEAN NUMBER OF *TETRANYCHUS MARIANAE* IN COMPARISON TO REGULAR SPRAY SCHEDULE ON TOMATO.

	DAT at Dededo location				DAT at Inaranjan location			
Treatment schedule	Dry season	No. of sprays	Wet season	No. of sprays	Dry season	No. of sprays	Wet season	No. of sprays
T1: TCS (8 mites /leaf)	10, 18, 30, 40, 56, 72 and 88	7	8, 15, 33, 46, 55, and 62	6	8, 15, 22, 35, 54, 64, 73 and 85	8	10, 22, 34, 44, 56, 64 and 82	7
T2: TCS (10 mites /leaf)	18, 28, 37, 54 and 75	5	12, 24, 33, 44, 56 and 63	6	14, 28, 37, 47, 62 and 82	6	14, 25, 32, 42, 51, and 62	6
T3: TCS (12 mites /leaf)	20, 35, 62 and 85	4	15, 31, 44, and 52	4	20, 32, 43, 64 and 83	5	14, 28, 36, 48 and 52	5
T4: TCS (14 mites /leaf)	22, 35 and 50	3	18, 26 and 38	3	23, 38, 44 and 78	4	18, 34, 43 and 55	3
T5: TCS (16 mites /leaf)	30 and 66	2	26 and 47	2	34, 55 and 82	3	34 and 55	2
T6: RSS (15 DAT)	15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165 and 180	12	15, 30, 45, 60, 75, 90, 105, 120, 135 and 150	12	15, 30, 45, 60, 75, 90, 105, 120, 135 and 150	10	15, 30, 45, 60, 75, 90, 105, 120, 135 and 150	10
T7: RSS (30 DAT)	30, 60, 90, 120, 150, and 180	6	30, 60, 90, 120, 150, and 180	6	30, 60, 90, 120, 150, and 180	6	30, 60, 90, 120, 150, and 180	6
T8: RSS (45 DAT)	45, 90, 135 and 180	4	45, 90, 135 and 180	4	45, 90, 135 and	4	45, 90, 135 and 180	4
T9: RSS (60 DAT)	60, 120 and 180	3	60, 120 and 180	3	60, 120 and 180	3	60, 120 and 180	3
T10: Control (no spray)	—	—	—	—	—	—	—	—

Sun-spray 6E (5ml /liter) was sprayed within 12 h after reaching the threshold levels.
DAT = days of after transplantation
TCS = Threshold-based chemical sprays
RSS = Regular spray schedule

TABLE 2. PERCENTAGE OF MITE DAMAGED LEAVES BY *TETRANYCHUS MARIANAE* IN DIFFERENT TREATMENTS IMPOSED ON TOMATO.

Treatment schedule	Mean ±SE percent mite infested leaves			
	Dededo location		Inaranjan location	
	Dry season	Wet season	Dry season	Wet season
T1: TCS (8 mites/leaf)	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
T2: TCS (10 mites/leaf)	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
T3: TCS (12 mites/leaf)	2.3 ± 0.5 a	1.6 ± 0.4 a	3.2 ± 0.3 a	0.8 ± 0.2 a
T4: TCS (14 mites/leaf)	13.4 ± 0.4 b	3.8 ± 1.6 a	18.3 ± 1.2 b	1.7 ± 0.8 a
T5: TCS (16 mites/leaf)	18.2 ± 1.2 b	19.0 ± 2.3 b	20.1 ± 0.9 b	14.8 ± 1.7 b
T6: RSS (15 DAT)	29.3 ± 1.5 c	37.4 ± 3.2 c	34.5 ± 2.3 c	23.4 ± 2.6 c
T7: RSS (30 DAT)	32.4 ± 1.9 c	39.4 ± 2.2 c	37.8 ± 3.2 c	24.0 ± 3.2 c
T8: RSS: (45 DAT)	35.4 ± 2.3 c	43.5 ± 1.7 c	41.2 ± 1.5 c	27.3 ± 1.0 c
T9: RSS: (60 DAT)	36.2 ± 1.6 c	46.8 ± 4.5 c	43.4 ± 1.5 c	42.5 ± 3.4 d
T10: Control (no spray)	84.5 ± 2.1 d	78.5 ± 2.9 d	86.3 ± 4.7 d	80.2 ± 7.1 e

Means within the same column followed by the same letter are not significantly different $P > 0.05$ (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (±SE) of three replications. The mean number of infested leaves by *T. marianae* per plot was recorded out of the 30 leaves counted in each plot.
DAT = days of after transplantation
TCS = Threshold-based chemical sprays
RSS = Regular spray schedule

chemical sprays. From our results, the threshold-based chemical sprays could reduce infestation of both *T. marianae* and *H. armigera* better than the regular chemical sprays.

The action threshold-based chemical spray has been used to control *T. marianae* with Sun-spray 6E on other crops such as eggplant, with the optimum threshold of 4 mites per leaf during the dry season and 8 mites per leaf in the wet season (Reddy et al. 2013). For our present study, the same Sun-spray 6E was used and resulted in the mean number of *T. marianae* and infested leaves of tomato plants being significantly fewer in threshold-based chemical spray treatments than in regular spray treatments. It was obvious that spraying the plants when 8-12 mites were observed per leaf diminished the infestation significantly. However, we found no significant difference in reducing infestation incidence among T1, T2, and T3 in the dry season and among T1,

TABLE 3. MEAN NUMBER OF *TETRANYCHUS MARIANAE* RECORDED IN DIFFERENT TREATMENTS IMPOSED ON TOMATO.

	Mean ± SE number of mites / leaf			
	Dededo location		Inaranjan location	
Treatment schedule	Dry season	Wet season	Dry season	Wet season
T1: TCS (8 mites/leaf)	6.5 ± 1.1 a	4.4 ± 0.4 a	5.5 ± 1.4 a	2.8 ± 1.3 a
T2: TCS (10 mites/leaf)	8.5 ± 0.6 a	5.8 ± 2.1 a	7.6 ± 0.5 a	4.3 ± 3.1 a
T3: TCS (12 mites/leaf)	10.6 ± 1.8 a	8.6 ± 3.2 a	8.6 ± 2.4 a	7.4 ± 3.3 a
T4: TCS (14 mites/leaf)	26.3 ± 2.2 b	9.8 ± 1.6 a	32.5 ± 1.2 b	7.7 ± 1.7 a
T5: TCS (16 mites/leaf)	30.4 ± 3.2 b	23.5 ± 0.3 b	34.5 ± 2.3 b	30.1 ± 0.6 b
T6: RSS (15 DAT)	68.8 ± 1.9 c	48.4 ± 1.9 c	71.6 ± 1.5 c	53.3 ± 2.4 c
T7: RSS (30 DAT)	72.4 ± 0.8 c	51.8 ± 0.7 c	73.2 ± 6.7 c	55.7 ± 3.3 c
T8: RSS: (45 DAT)	75.6 ± 1.7 c	54.3 ± 2.3 c	75.8 ± 3.6 c	56.6 ± 2.0 c
T9: RSS: (60 DAT)	80.8 ± 3.6 c	61.2 ± 1.7 c	79.4 ± 1.2 c	83.4 ± 3.5 d
T10: Control (no spray)	886.6 ± 5.2 d	685.6 ± 7.6 d	941.5 ± 8.3 d	866.2 ± 9.8 e

Means within the same column followed by the same letter are not significantly different $P > 0.05$ (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (± SE) of 3 replications. The mean number of *T. marianae* per plot was recorded out of the 30 leaves counted in each plot.
DAT = days of after transplantation
TCS = Threshold-based chemical sprays
RSS = Regular spray schedule

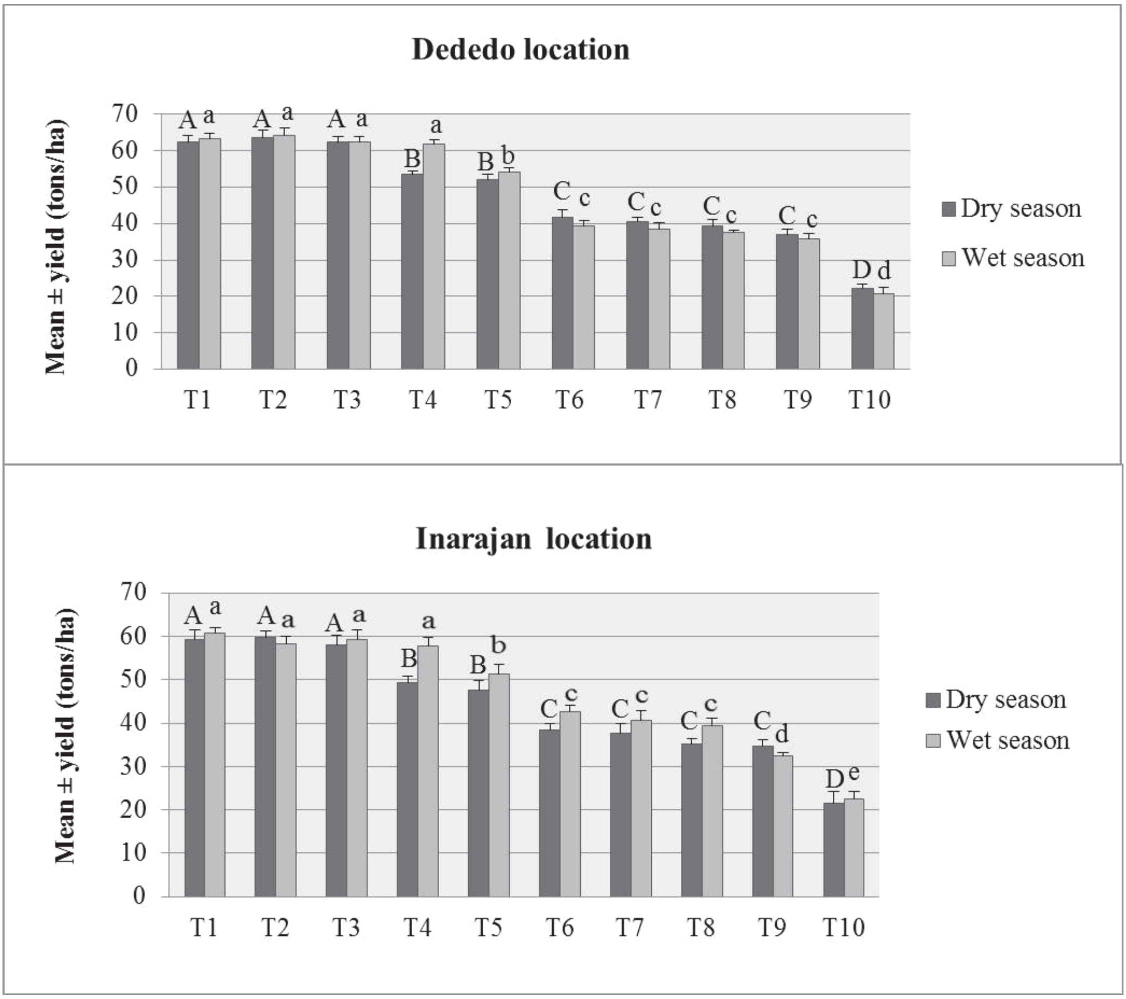

Fig. 1. Marketable yield (tonnes/ha) of tomato after chemical application in different treatments on tomato grown in dry and wet season T1: TCS (8 mites/leaf); T2: TCS (10 mites/leaf); T3: TCS (12 mites/leaf); T4: TCS (14 mites/leaf); T5: TCS (16 mites/leaf); T6: RSS (15 DAT); T7: RSS (30 DAT); T8: RSS (45 DAT); T9: RSS (60 DAT); T10: Control (no spray). Abbreviations: DAT = days of after transplantation; TCS = Threshold-based chemical sprays; RSS = Regular spray schedule.

T2, T3, and T4 in the wet season for both locations (Table 2, 3). Therefore, instead of spraying 7 times, the number of sprays could be reduced to 4 in the dry season and only 3 in the wet season (Table 1).

The season also affected the level of infestations for *T. marianae*. In the previous study conducted on eggplant, different threshold levels were indicated for *T. marianae* during the dry and wet seasons (Reddy et al. 2013), dry and warm climate contributes to higher potential for *T. marianae* populations to increase (Denmark 1970). This could be the explanation in the present study that T4 (14 mites/leaf) did not differ significantly from T1, T2 and T3 in the wet season (Table 2,3) but did for the dry season. Thus, a threshold of 12 mites/leaf would be indicated for the dry season, and a threshold of 14 mites/leaf would be indicated for wet season.

For *H. armigera*, the spray thresholds were based on surveys of the eggs in the field, but egg counts were found previously to be an unreliable criterion, due to high mortality rates of egg populations, while larval counts were shown to be more reliable indicators of the pest (Kfir & Vanhamburg 1983). Because *H. armigera* is a polyphagous pest, which damages many plant species, there have been some studies on using action threshold-based sprays to control this pest. For cotton genetically modified to express the endotoxin of *Bacillus thuringiensis*, the current spray threshold was set at 5 larvae/24 plants and 12 eggs/24 plants, with third instars each counted as 2 larvae (Basson 1987; Nel et al. 2002). Russell et

TABLE 4. THE DAY AFTER TRANSPLANTATION AT WHICH A CHEMICAL TREATMENT WAS IMPOSED AFTER GETTING THE ESTIMATED THRESHOLD LEVEL OF MEAN NUMBER OF *HELICOVERPA ARMIGERA* IN COMPARISON TO THE REGULAR SPRAY SCHEDULE ON TOMATO.

	Dededo location		Inaranjan location	
Treatment schedule	The day after DAT at which a treatment was imposed	Total number of sprays	The day after DAT at which a treatment was imposed	Total number of sprays
T1: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by added sprays every 10 days until the end of harvest	34, 44, 54, 64, 74, 84, 94, 104, 114, 124, 134, 144, 154, 164 and 174	15	41, 51, 61, 71, 81, 91, 101, 111, 121, 131, 141, 151, 161 and 171	14
T2: Initial spray scheduled when 2 *H. armigera* eggs is detected on 10 of the leaf samples, followed by added sprays every 10 days until the end of harvest	44, 54, 64, 74, 84, 94, 104, 114, 124, 134, 144, 154, 164 and 174	14	52, 62, 72, 82, 92, 102, 112, 122, 132, 142, 152, 162 and 172	13
T3: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 of the leaf samples, followed by added sprays every 10 days until the end of harvest	86, 96, 106, 116, 126, 136, 146, 156, 166 and 176	10	98, 108, 118, 128, 138, 148, 158 and 168	8
T4: Initial spray scheduled when 2 *H. armigera* eggs is detected on 20 of the leaf samples, followed by added sprays every 10 days until the end of harvest	97, 107, 117, 127, 137, 147, 157, 167 and 177	9	101, 111, 121, 131, 141, 151, 161, 171	8
T5: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by an added spray if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	38, 77, 94 and 104	4	43, 82, 103 and 118	4
T6: Initial spray scheduled when 2 *H. armigera* egg is detected on 10 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	46, 98 and 121	3	41, 69, 118 and 133	4
T7: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	44, 137 and 147	3	39, 89 and 114	3
T8: Initial spray scheduled when 2 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	54 and 142	2	48 and 154	2
T9: Regular spray schedule: Fifteen applications of carbaryl	12, 24, 36, 48, 60, 72, 84, 96, 108, 120, 132, 144, 156, 168, 182	15	12, 24, 36, 48, 60, 72, 84, 96, 108, 120, 132, 144, 156, 168, 182	15
T10: Untreated control (no spray)	—	—	—	—

Neem (Aza-Direct) (10ml /liter) was applied within 12 h after reaching the threshold levels.
DAT = days of after transplantation

TABLE 5. PERCENTAGE OF FRUIT DAMAGE AND MARKETABLE YIELD OF TOMATOES IN DIFFERENT TREATMENTS WITH VARIOUS ACTION THRESHOLDS FOR *HELICOVERPA ARMIGERA*.

Treatment schedule	Dededo location		Inaranjan location	
	% damaged fruits	Marketable Yield (tons/ha)	% damaged fruits	Marketable Yield (tons/ha)
T1: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by added sprays every 7 days until the end of harvest	2.6 ± 1.1 a	59.3 ± 3.3 e	1.9 ± 1.4 a	57.9 ± 2.7 d
T2: Initial spray scheduled when 2 *H. armigera* eggs is detected on 10 of the leaf samples, followed by added sprays every 7 days until the end of harvest	3.0 ± 0.2 a	60.6 ± 2.4 e	2.6 ± 1.0 a	58.4 ± 1.2 d
T3: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 of the leaf samples, followed by added sprays every 7 days until the end of harvest	12.4 ± 3.8 b	51.9 ± 4.1 d	13.6 ± 1.7 b	49.7 ± 3.3 d
T4: Initial spray scheduled when 2 *H. armigera* eggs is detected on 20 of the leaf samples, followed by added sprays every 7 days until the end of harvest	21.8 ± 3.8 c	43.5 ± 3.2 c	22.6 ± 3.1 c	40.3 ± 1.9 c
T5: Initial insecticide spray scheduled when 1 *H. armigera* egg is detected on 10 leaf samples, followed by an added spray if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	3.3 ± 0.8 a	58.2 ± 3.7 e	2.8 ± 0.6 a	59.7 ± 2.6 e
T6: Initial spray scheduled when 2 *H. armigera* egg is detected on 10 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	4.6 ± 0.6 a	60.3 ± 1.8 e	3.5 ± 1.2 a	59.1 ± 2.4 e
T7: Initial spray scheduled when 1 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 1 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	16.4 ± 3.8 d	24.9 ± 2.3 a	15.4 ± 2.3 d	25.2 ± 1.2 a
T8: Initial spray scheduled when 2 *H. armigera* egg is detected on 20 of the samples, followed by an added spray only if 2 damaged fruit or *H. armigera* larvae are detected per 50 immature fruit	18.9 ± 1.4 cde	23.8 ± 1.6 a	19.8 ± 2.2 cde	24.6 ± 3.7 a
T9: Regular spray schedule: Fifteen applications of carbaryl	36.2 ± 1.6 f	35.8 ± 2.2 b	43.4 ± 1.5 f	34.3 ± 3.4 b
T10: Untreated control (no spray)	84.5 ± 2.1 g	23.5 ± 1.3 a	86.3 ± 4.7 g	20.8 ± 3.2 a

Means within the same column followed by the same letter are not significantly different $P > 0.05$ (Repeated measure ANOVA, Tukey HSD). Each value represents the mean (± SE) of 3 replications. Neem (Aza-Direct®) applied at 10 mL/liter as a foliar spray.

al. (1998) suggested that an egg action threshold of 1 egg per cotton plant but the action threshold for larvae differed according to difference in stages in the crop's phenology. For tomato, Cameron & Walker (1988) developed a scouting procedure for the implementation of the economic thresholds when making early evaluation with *H. armigera* in New Zealand. They found larval populations to be significant predictors of damage in tomatoes. Spraying insecticide based on the 1- min scouting threshold of 1 larva per tomato plant was suggested for the control of *H. armigera* especially in temperate climate (Cameron et al. 2001).

Damage threshold levels have also been reported for other species of fruitworms including *H. zea* (Boddie). In fresh tomatoes (Kuhar et al. 2006), the action threshold regimen with the highest yields, lowest fruit damage and fewest number of insecticide applications was when the first spray was applied when *H. zea* eggs were observed on ≥ 10% of plants sampled, and when subsequent sprays were made only when ≥ 3 of 100 unripe fruits were observed with damage. In the present study, no differences in the percentage of damaged fruit occurred when the first insecticide sprays were applied when 1 or 2 *H. armigera* eggs were detected on 10 leaf samples and when subsequent sprays were applied either every 7 days until the end of harvest or when 1-2 damaged fruit or *H. armigera* larvae were observed per 50 immature fruits (T1, T2, T5, T6) (Table 5). These results are similar to those of Zehnder et al. (1995) which indicated that the application of sprays based on an action threshold of 1 egg/10 plants reduced the number of sprays needed for effective insect control. However, in the present study, applying the initial spray when 2 *H. armigera* eggs were detected on 10 of the samples, and applying subsequent sprays only if 2 damaged fruit or larvae were detected per 50 immature fruits (T6) could lead to the highest marketable yield.

A large number of pesticides are sprayed on tomato because this crop is subject to attack by multiple pest species from the time plants first emerge in the seed bed until harvest (Godfrey 2011). Spider mites and fruitworms threaten young plant-bed tomatoes. Spider mites often become a problem after applying pesticides, because natural enemies of the mites may be reduced and because certain insecticides may stimulate mite reproduction. Godfrey (2011) showed that spider mites reproduced faster following exposure to carbaryl. Pyrethroids are another group of pesticides which have been used widely to control mites (Godfrey 2011). Similarly, dicofol has been used to control *Panonychus ulmi* (Koch) and *Tetranychus urticae* Koch throughout the world for nearly 30 years (Dennehy & Granett 1984a, b), and has been found to be very effective. Dicofol continues to be an important acaricide for many crops such as California cotton (Dennehy & Granett 1984a, b), New York apples (Dennehy et al. 1988), and Brazilian and Japanese citrus (Inoue 1979; Gravena 1988). Recently, there have been new acaricides registered and introduced to control of spider mites; for example, milbemectin, fenproximate, acequincyl, spiromesifen. However, resistance to these acaricides could develop especially when excessive repeated applications occur such as in the case of dicofol, which was found to be resisted by spider mites (Singh 2010). Also *Tetranychus cinnabarinus* (Boisduval) was proven to have resistance to dicofol (Dağli & Tunç 2001).

There are also a number of plant extracts formulated as acaricides that exert an effect on spider mites. These include garlic extract, clove oil, mint oil, rosemary oil, cinnamon oil and others (Godfrey 2011). Another option to control mites is the use of horticultural oils, either petroleum or vegetable based. The primary mode of action of horticultural oil is suffocation. The oil blocks the spiracles through which insects breathe. Moreover, oils have also been shown to have anti-settling and anti-feeding effects for some insects such as aphids and leaf hoppers (Smith 2012). Sun spray oil is one horticultural oil, which is an effective acaricide with low toxicity to the environment (Miller 1997). Baxendale & Johnson (1988) reported that 3% oil was highly effective in controlling spider mites on greenhouse specimens of large-flowered tuberous dahlia (*Dahlia* spp.; Asteraceae) without phytotoxicity. However, the repeated applications of oil could also depress tomato yields due to its scorching effect, which leads to phytotoxicity (Muqit et al. 2006).

Helicoverpa armigera is also capable of becoming resistant to insecticides. Resistance to synthetic pyrethroids has been reported in Thailand and India, and *Heliothis virescens* has become resistant in the USA (Riley 1989). *Helicoverpa armigera* has a history of resistance to DDT and has also developed resistance to endosulfan (Forrester et al. 1993), carbamates and organophosphates (Gunning et al. 1992). A few alternative controls have been introduced to control the fruit worms including mating disruption with pheromone (Rothschild et al. 1982; Kehat & Dunkelblum 1993; Chen et al. 1995), neem extracts (Thakur et al. 1988; Rao et al. 1990), and microbial insecticides including nuclear virus (Tinsely 1979; Bell 1982; Mckinley 1982), also *Bacillus thuringiensis* and *Bacillus thuringiensis* (Bt) transgenic crops (Downes & Mahon 2012). The tetranotriterpenoid, azadirachtin, is the most promising insecticidal compound found in seeds and leaves of the neem tree (*Azadirachta indica* A. Juss; Meliaceae) (Butterworth & Morgan 1968; Spollen & Isman 1996). It has been reported that neem products are less toxic to natural enemies than synthetic pesticides and that they have several biological effects on insects including antifeedant, insect growth regulator and repellency effects (Zehnder & Warthen 1988; Saxena 1989). Wakil et al. (2012) reported that 2nd instars of *H. armigera* were more susceptible to the neem products than other life stages. The maximum mortality (50%) was observed in the treatment where the larvae were exposed 72 h to the neem leaf extracts and neem seed kernel oil. This same treatment resulted in 40% mortality of 4th instars at the same exposure interval. However, Reddy & Manjunatha (2000) proposed that no single method of control can be expected to provide an acceptable solution to all insect problems where a complex of pests is involved. They evaluated the use of parasitoids, NPV, chemical insecticides and pheromone in the control of *H. armigera* on cotton and suggested that the IPM strategy is the most profitable and sustainable in the management of this pest in order to minimize harm to the environment and delay the development of resistance.

Additional study is needed to evaluate if there is an interaction between the control of *H. armigera* and *T. marianae.* The Sun-spray 6E might have contributed to the control *H. armigera* also. The synergism or additive effects could occur because the dates of application overlapped.

In summary, the present study established thresholds to control 2 of the key tomato pests in a typical warm, tropical climate using environmentally friendly pesticides. For *T. marianae* initial sprays should be applied when 8 to 14 mites/leaf are observed during the wet season and when 8 to 12 mites/leaf are observed during the dry season. For *H. armigera*, the initial spray could be applied when 2 eggs are detected on 10 leaf samples and subsequent sprays would be applied only if 2 damaged tomatoes or 2 borer larvae are found per 50 immature tomatoes. The use of such action thresholds should enable growers to better time pesticide applications, and thus reduce the potential for resistance development and environmental harm.

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