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Crop Protection 21 (2002) 359–366

Crop Protection

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Major insect pests and economics of fresh-market tomato in eastern Virginia

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Received 23 February 2001; received in revised form 31 July 2001; accepted 9 August 2001

Abstract

Major insect pests of fresh-market tomato, *Lycopersicon esculentum* Miller, in eastern Virginia were identified as those responsible for reducing marketable fruit yield from 1998 through 2000. Nineteen arthropod pest species infested spring- and fall-grown tomato crops, but only thrips, stink bugs, and Lepidopterans, particularly the corn earworm (*Helicoverpa zea* [Boddie]), reduced yield. Fruit injury by thrips and stink bugs was greater in the spring crop than in the fall crop, whereas fruit injury by Lepidopterans was greater in the fall crop. Marketable fruit yield in untreated spring and fall crops averaged 34% (range = 12–51%) and 33% lower (range = 26–38%), respectively, than fruit yield in treated plots. Based on these reductions and typical prices for fresh-market tomato, the loss in return per hectare in an untreated tomato field was estimated to range from $US3015 to $US17,883 in the spring crop and $US2555 to $US11,074 in the fall crop. Development of an integrated pest management program for tomato in eastern Virginia should focus initially on thrips, stink bugs and Lepidopterans such as the corn earworm. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Thrips; Stink bugs; Lepidopterans; *Helicoverpa zea*; Tomato; Economic loss

1. Introduction

Fresh-market tomato, *Lycopersicon esculentum* Miller, production in Virginia ranks third in the US, grossing $US41.5 million in 1999 (Virginia Agricultural Statistics Service, 2000). Most of the 1578 hectares of tomato are located on Virginia's Eastern Shore where the crop is staked and grown on plastic mulch, and crop production is intensive and expensive, costing > $US14,800 per hectare. In order for growers to produce high fruit yields and meet the stringent cosmetic standards of the industry, pesticides are relied upon heavily to protect the crop from insects and disease.

Tomato crops are typically attacked by a few major insect pests and by many minor pests (Lange and Bronson, 1981). The status of an insect pest may differ among regions and with the use of the crop (Zalom and Fry, 1992). In eastern Virginia in the mid-1970s, the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), and corn earworm, *Helicoverpa zea* (Boddie), were considered the major pests of spring- and fall-grown tomato, respectively (Hofmaster, 1977). During this period, other serious insect pests of tomato included the potato flea beetle (*Epitrix cucumeris* [Harris]), aphids (*Macrosiphum euphorbiae* [Thomas] and *Myzus persicae* [Sulzer]), cutworms (*Agrotis ipsilon* [Rottemburg] and *Peridroma saucia* [Hübner]), fall armyworm (*Spodoptera frugiperda* [Smith]), stink bugs (*Acrosternum hilare* [Say] and *Euschistus servus* [Say]) and cabbage looper (*Trichoplusia ni* [Hübner]). On occasion, beet armyworm (*S. exigua* [Hübner]), hornworms (*Manduca sexta* [L.] and *M. quinquimaculata* [Haworth]), blister beetles (*Epicauta* spp.), leafminers (*Lyriomyza* spp.), whiteflies (*Trialeurodes vaporariorum* [Westwood]), pinworms (*Keiferia lycopersicella* [Walsingham]), mites (*Tetranychus urticae* Koch) and fruit flies (*Drosophila melanogaster* [Meigen]) were a problem.

Pest status may change over time as populations are affected by changes within the agroecosystem, such as new cropping patterns, agricultural practices and

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PII: S0261-2194(01)00103-X

technological innovations (Kennedy and Storer, 2000). Since 1975, vegetable acreage in Virginia has declined by 41% (USDA, 1976), primarily due to the loss of the processing industry. In contrast, production of row crops including wheat, soybean, corn and cotton has increased. Tomato production practices in Virginia also have changed dramatically during this period. In the past, tomato cultivars were determinate and most were direct seeded and grown on bare ground. Currently, most cultivars are indeterminate and all are transplanted into raised beds covered with plastic mulch and supported by a trellis as they grow. The possibility exists that changes in production practices and the agricultural landscape over the past 25 years have changed the status of insect pests that infest tomato.

Pest control decisions in eastern Virginia tomato fields are based largely on the presence of the pest, regardless of its current pest status. As a result, many growers intensively manage their crop by treating fields with insecticides $\geqslant 1$ time per week from the time seedlings are transplanted until harvest (total $\geqslant 15$ applications). In Florida and North Carolina, integrated pest management (IPM) programs for tomato include action thresholds for each major pest (Pohronezny et al., 1986; Linker et al., 1993). Adoption of these programs has been widespread in both states, resulting in the elimination of unwarranted insecticide applications. In an effort to develop a tomato IPM program appropriate for eastern Virginia, arthropod pests that are responsible for consistently reducing marketable fruit yield must be identified.

2. Materials and methods

2.1. Crop culture

Experiments were conducted at Virginia Polytechnic Institute and State University's Eastern Shore Agricultural Research and Extension Center near Painter, VA from 1998 through 2000. In the spring, tomato seedlings (cultivar 'Sunbeam') were transplanted on 7, 25 and 15 May 1998, 1999 and 2000, respectively. For the fall crop, seedlings (cultivars 'BHN-189', 'BHN-189' and 'Florida 47') were transplanted on 15, 30 and 31 July 1998, 1999 and 2000, respectively. Plants were spaced at 46 cm intervals in rows spaced 1.8 m apart. Rows were shaped as beds that were 0.8-m wide and 18 cm high. Beds then were mulched with black plastic in the spring and with a co-extruded white on black plastic in the fall. Beds were fertilized (10 : 10 : 10; N : P : K) at a rate of 1681 kg ha^{-1} and fumigated with methyl bromide at a rate of 224 kg ha^{-1} several days before transplanting. Weed and disease control during the season were implemented according to local recommendations (Alexander et al., 2001). As plants grew, they were supported by a trellis and irrigated through drip tubes underneath the mulch.

2.2. Identification of major arthropod pests

The number and composition of arthropod pests infesting tomato were determined by sampling both foliage and flowers in insecticide-free and insecticide-treated tomato plots throughout the season. Plots consisted of four, 6.1-m rows each flanked by an unplanted row. The number of plots sampled within each crop ranged from 5 to 10. Portions of 10 plants within each plot were inspected visually for arthropod eggs, larvae and adults. The sample included all plant material (e.g., leaves, stem and flowers) from the terminal down to and including the third most fully expanded leaf on a stem. Additionally, the number and species composition of thrips infesting flowers were determined by removing a total of 10 flowers from outside rows throughout the season. Flowers were removed from the upper half of the plant, placed in vials containing 70% EtOH, and then processed in the laboratory following procedures described in Cho et al. (1995). A black light trap was placed within 0.1 km of the test site to capture adult stink bugs. The number of stink bugs collected per night was recorded to identify the timing and level of adult activity and to provide an estimate of when stink bugs may colonize tomato fields.

2.3. Assessing crop loss

Tomato fruit yield reduction attributed to arthropod pests was determined by comparing marketable fruit yield in insecticide-treated and untreated plots. Fruit were inspected for three general types of arthropod injury such as (1) dimples on the fruit surface, (2) patches of yellow surrounding a dark, pinpoint-sized mark on fruit surface, and (3) deep to shallow holes. Each type of injury has been attributed to oviposition/-feeding by thrips, feeding by stink bugs and feeding by Lepidopteran larvae, respectively (Pohronezny et al., 1996, color plates 15, 19 and 17).

The treatments (insecticide-treated and untreated) were arranged in a randomized complete block design replicated between 5 and 10 times. One of the two middle rows from each plot (identical plot size as those described previously) was harvested twice in which all mature green, market-sized fruit were graded, counted, weighed and inspected for insect injury. Only US No. 1 grade fruit having a minimum diameter of $\geqslant 5.4$ cm were considered marketable (USDA, 1991). Fruit with physiological defects such as cuts, broken skin, puffiness, scars including those caused by catfacing, growth cracks and blossom end rot were discarded. Equal numbers of defected fruit were observed in insecticide-treated and untreated plots. The spring crop was harvested on 20 and 29 July 1998, 5 and 19 August 1999, and 27 July and 8 August 2000, whereas fall crops were harvested on 23 September and 19 October 1998, 6 and 27 October 1999, and 23 October 2000. Near the date of harvest, one of the outside rows in each plot was treated with ethephon [Ethrel® brand Ethephon, Aventis CropScience, Research Triangle Park, NC] at a rate of 1.4 kg a.i. ha^{-1} to accelerate fruit ripening in order to more easily observe injury by stink bugs and thrips. Seven to ten days after application, 50 red, market-sized fruit were randomly harvested from the treated row and inspected for thrips and stink bug injury.

Because fruit injury by thrips and stink bugs was not determined on a per area basis, yield loss had to be estimated. Therefore, the percentage of injured fruit was multiplied by the total number of market-sized fruit per plot to provide an estimate of the total number of injured fruit per plot. Next, the number of injured fruit per plot was multiplied by the average weight of a market-sized fruit to provide an estimate of yield loss per plot. Yield loss attributed to Lepidopteran feeding was determined directly by simply weighing damaged fruit in each plot. Collectively, yield loss attributed to the major groups of direct insect pests (i.e., thrips, stink bugs and Lepidopterans) was considered as the sum of fruit yield damaged by these pests. In contrast, actual yield loss was considered as the difference in marketable fruit yield between insecticide-treated and untreated plots. Thus, actual yield loss accounted for both direct and indirect feeding injury by insect pests.

Before analysis, marketable yields were converted from kg per plot to number of 11.3 kg boxes per hectare. Total marketable fruit yield was analyzed using an analysis of variance procedure in SAS (PROC GLM; $\alpha = 0.05$; SAS Institute, 1990). Mean percentage of marketable fruit in treated and untreated plots was then compared using a single-degree-of-freedom *F*-test (SAS Institute, 1990).

2.4. Insecticides

In treated plots, tomato seedlings were amended with a soil-applied application of imidacloprid [Admire® 2F, (flowable), Bayer Corp., Kansas City, MO] at a rate of 29.5 ml per 1000 seedlings 24 h before transplanting (see, Dively et al., 1997). Plots were treated weekly with esfenvalerate [Asana XL® 0.66 EC (emulsifiable concentrrate), E.I. DuPont de Nemours and Co., Wilmington, DE)] at a rate of 0.056 kg a.i. ha^{-1} in 1998 and with lambda-cyhalothrin [Warrior T® (capsule suspension), Syngenta Crop Protection Inc. Greensboro, NC)] at a rate of 0.034 kg a.i. ha^{-1} in 1999 and 2000. These insecticides were applied using a propane-pressurized backpack sprayer equipped with a three-nozzle (D3 disk/25 core hollow cone) single row boom. The center nozzle was positioned over the top of the row and the lateral nozzles were on drop pipes aimed at the side of the row. The sprayer was calibrated to deliver 140 l of spray ha^{-1} at a pressure of 275.7 kPa.

3. Results and discussion

3.1. Identification of major arthropod pests

Nineteen arthropod species were observed infesting tomato plants during this three-year study (Table 1). Of these species, 12 and 18 were recorded from plots in the spring and fall crop, respectively. Many of the arthropods recorded were encountered infrequently and densities were very low. Fruit were damaged primarily by three major groups of direct-feeding insect pests that included thrips, stink bugs and Lepidopterans (Table 2). Although potato aphid, *M. euphorbiae* (Thomas), was the most prevalent indirect pest (i.e., feed on leaves), populations were extremely low in the spring crop and low in the fall crop. Aphid density slightly exceeded the economic threshold (Walgenbach, 1997) on just a single sample date near the completion of the 1998 fall crop

Table 1
Arthropod pest species observed infesting spring- and fall-grown tomato plots near Painter, VA, 1998–2000

Species	Crop (Spring or Fall)
Acarina	
Tetranychus urticae Koch	Fall
Coleoptera	
Leptinotarsa decemlineata (Say)	Spring, Fall
Diptera	
Lyriomyza spp.	Fall
Heteroptera	
Acrosternum hilare (Say)	Spring, Fall
Euschistus servus (Say)	Spring, Fall
Homoptera	
Macrosiphum euphorbiae (Thomas)	Spring, Fall
Lepidoptera	
Helicoverpa zea (Boddie)	Spring, Fall
Manduca quinquimaculata (Haworth)	Spring, Fall
Manduca sexta (L.)	Spring, Fall
Ostrinia nubilalis (Hübner)	Fall
Spodoptera exigua (Hübner)	Fall
Spodoptera frugiperda (Smith)	Fall
Spodoptera ornithogalli (Guenee)	Fall
Trichoplusia ni (Hübner)	Spring, Fall
Thysanoptera	
Frankliniella fusca (Hinds)	Spring, Fall
Frankliniella tritici (Fitch)	Spring, Fall
Limothrips cerealium (Haliday)	Spring
Neohydatothrips variabilis (Beach)	Fall
Thrips tabaci Lindeman	Spring, Fall

Table 2
Percentage and yield of market-sized fruit injured by major groups of insect pests in untreated spring- and fall-grown tomato near Painter, VA, 1998–2000

Pests	Crop Grown	% Market-sized fruit injured			Mean (±SEM) loss in marketable fruit yield (No. of 11.3 kg boxes ha^{-1})[a]		
		1998	1999	2000	1998	1999	2000
Thrips	Spring	6	15	2	244±7	561±19	120±5
	Fall	0	3	2	0±0	30±2	30±2
Stink bugs	Spring	26	39	7	1095±33	1496±49	378±15
	Fall	3	4	2	92±3	43±3	27±2
Lepidopterans	Spring	3	2	2	146±36	67±11	101±20
	Fall	12	23	4	471±33	319±40	54±12

[a] Loss in marketable yield by thrips and stink bugs was estimated by multiplying the average percentages of injured fruit by the total number of market-sized fruit and then multiplying again by the average weight of a market-sized fruit. Loss in yield by Lepidopterans was determined directly by weighing damaged fruit.

study. For this reason, the discussion will concentrate on the three groups of major direct pests.

Thrips densities were greater in the spring crop than in the fall crop (Fig. 1A–C). Similarly, the percentage of thrips-injured fruit tended to be greater in the spring than in the fall (Table 2). Five species of adult thrips were collected from tomato flowers with the eastern flower thrips, *Frankliniella tritici* (Fitch) being most numerous (Fig. 1A–C). *F. tritici* is one of the most common thrips species reported to infest tomato flowers in western North Carolina (Cho et al., 1995) and northern Florida (Salguero Navas et al., 1991a). Salguero Navas et al. (1991b) reported that oviposition by *F. occidentalis* (Pergande) on developing fruit resulted in dimples on the fruit surface, whereas neither *F. fusca* (Hinds) nor *F. tritici* were shown to cause injury. *F. occidentalis* was not found in our study. It is not known whether *Limothrips cerealium* (Haliday) and *Neohydatothrips variabilis* (Beach) are capable of causing dimples on the fruit surface, although both species were collected in our samples. Because *F. tritici* was the most abundant adult thrips species and the highest infestations occurred concomitantly to peak thrips-injured fruit levels (i.e., 1998 and 1999 spring crops), the potential for *F. tritici* to cause dimpling on fruit is worthy of reexamination.

Two species of stink bugs, *A. hilare* and *E. servus*, were observed feeding on fruit and percentages of feeding injury by stink bugs were far greater in the spring crop than in the fall crop (Table 2). Kennedy et al. (1983) showed that fruit injury by *A. hilare* and *E. servus* was significantly greater in late-planted, spring-grown tomato (15 May) than in early planted, spring-grown tomato (25 April). In our study, each spring crop was considered late-planted; however, it is not known if a late planting date had the same influence on the severity of stink bug injury as it did in North Carolina. Adult activity occurred during both spring and fall crops, but more adults were active when fruit from the spring crop was available (Fig. 2A–C). Although few stink bugs were sampled within the crop, *A. hilare* adults were encountered more frequently in the blacklight trap than *E. servus*. Further research is needed to determine the actual densities of stink bugs within the crop and which species are responsible for the injury.

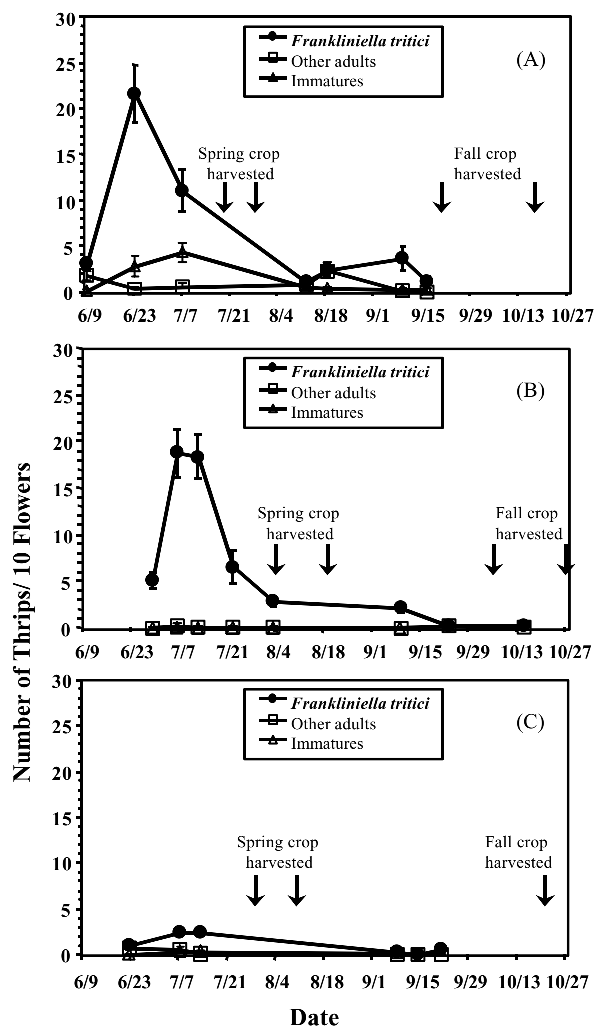

Fig. 1. Mean (±SEM) number of adult and immature thrips per 10 flowers collected from untreated tomato throughout the growing season near Painter, VA in (A) 1998, (B) 1999, and (C) 2000. Arrows denote harvest dates for the spring- and fall-grown crops.

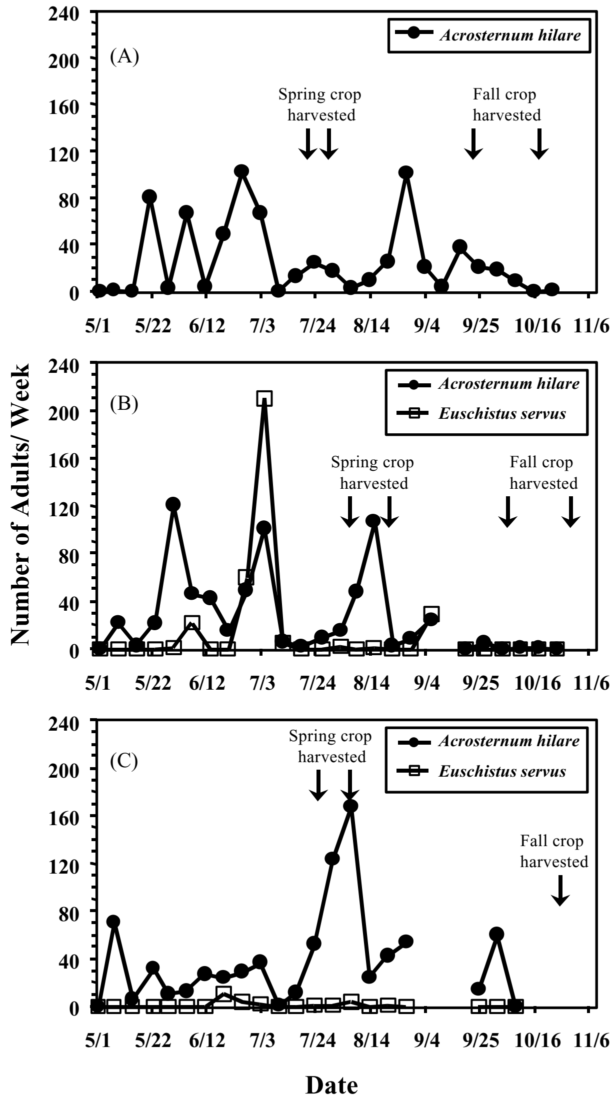

Fig. 2. Number of adult stink bugs captured per week using a blacklight trap that was located 0.1 km from small-plots of tomato near Painter, VA in (A) 1998, (B) 1999, and (C) 2000. Arrows denote harvest dates for the spring- and fall-grown crops.

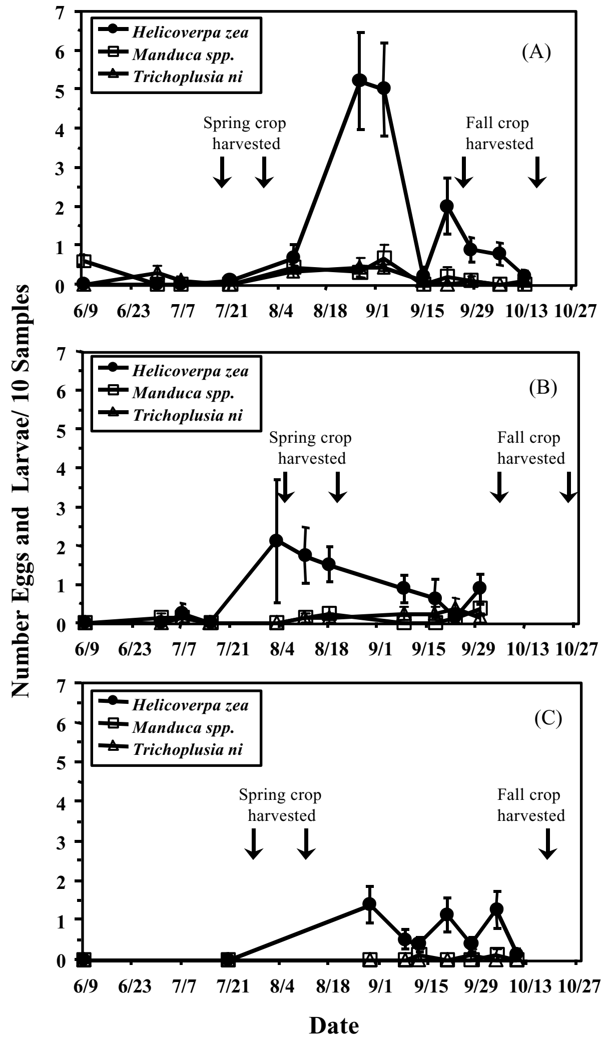

Fig. 3. Mean (±SEM) number of Lepidopteran eggs and larvae per 10 plant samples collected from untreated tomato throughout the growing season near Painter, VA in (A) 1998, (B) 1999, and (C) 2000. The sample included all plant material (e.g., leaves, stem and flowers) from the terminal down to and including the third most fully expanded leaf on a stem. Arrows denote harvest dates for the spring- and fall-grown crops.

Four species of Lepidopteran pests, *H. zea*, *M. sexta*, *M. quinquimaculata* and *T. ni* were commonly encountered in spring and fall tomato crops (Fig. 3A–C). Of these, *H. zea* was by far the most prevalent in plant samples (Fig. 3) and within damaged fruit (Nault, unpublished). *H. zea* has been reported as the most serious direct insect pest of tomato in the southeastern US (Kennedy et al., 1983; Walgenbach and Estes, 1992; Zehnder et al., 1995). In western North Carolina, estimated losses due to *H. zea* in unsprayed tomato ranged from \$US941 to \$US3385 ha^{-1} (Walgenbach and Estes, 1992). In our study, estimated yield losses resulting from Lepidopteran pests were similar and ranged from \$US270 to \$US3297 ha^{-1} (=weight of damaged fruit represented as number of 11.3 kg boxes × \$US5 to \$US7 per box, which are typical prices for fresh-market tomato in the fall). Lepidopteran egg and small larval populations were highest near or during harvest of the spring crop and coincided with flower and fruit development of the fall crop. Fruit injury by Lepidopterans tended to be greater in the fall crop than in the spring crop because densities were greater and there was a longer period available for larvae to feed on market-sized fruit (Table 2). In the spring crop, *H. zea* did not colonize the crop until near harvest and larvae tended to feed on under-sized fruit located in the top third of the canopy where they typically emerge from eggs (Nilakhe and Chalfant, 1981).

3.2. Assessing crop loss

The percentage of insect-damaged fruit in insecticide-treated plots was $\leqslant 0.5\%$, which is similar to the level typically observed in commercial tomato fields. Marketable tomato fruit yield in treated plots was above the 1998–1999 Virginia average of 3375 boxes per hectare in all spring crops and the 1998 fall crop, whereas yields from the 1999 and 2000 fall crops were below average (Virginia Agricultural Statistics Service, 1999, 2000) (Table 3). Poor growing conditions (e.g., hurricanes) and a late planting date were responsible for the low yields in the 1999 and 2000 fall crops, respectively.

Marketable fruit yield in insecticide-treated plots was significantly greater than yield in non-treated plots (Table 3). Fruit yield in untreated plots averaged 34% and 33% less than yield in insecticide-treated plots in spring-grown and fall-grown tomato, respectively. Based on these reductions and typical prices for fresh-market tomato, the loss in return per hectare in an untreated tomato field would range from $US3015 to $US17,883 in the spring crop and $US2555 to $US11,074 in the fall crop (Table 3). These results provide an estimate of the impact that insect pests would have on yield in the absence of insect control.

Tomato growers in Virginia spend less than 5% of their overall production costs on insecticides, despite the high frequency of insecticide use. For example, the cost of treating a one-hectare field 15 times (= one application per week from transplanting through harvest) with a broad-spectrum insecticide would be only $US569 (= cost of insecticide plus application), whereas the overall production cost for fresh-market staked tomato is > $US15,000 per hectare (= production, harvest and marketing costs). Given the high risk of fruit loss due to insect pests and the relatively low cost of using insecticides to prevent this loss, growers are unlikely to deviate from a calendar-based spray program, unless factors other than economics become far more important. Recently, public concerns about environmental risks associated with pesticide use has resulted in intensified scouting and increased use of bio-based pesticide products.

Percentages of marketable fruit loss attributed to the three groups of major pests accounted for more of the actual yield loss in the spring crop than the fall crop (Table 4). For example, nearly 100% of the actual fruit loss was attributed to injury by thrips, stink bugs and Lepidopterans in the 1999 and 2000 spring crops. In contrast, only 36%, 64% and 22% of the actual fruit loss in the fall crops were accounted for by the same insects in 1998, 1999 and 2000, respectively. It is unlikely that feeding injury by indirect pests such as, mites, lefminers, potatobeetles and aphids was responsible for significant yield loss because densities of these pests were very low to nonexistent. Rather, the unaccountable yield loss was likely due to Lepidopteran feeding. Wilson et al., 1983 reported that fruit < 2.5 cm will abort when fed on by *H. zea*. Because the number of Lepidopteran-infested fruit that had either rotted or prematurely aborted were not recorded, it is likely that the remaining percentage of fruit loss in the fall crop was due to Lepidopterans. Aborted fruit with evidence of Lepidopteran feeding and rotted fruit were commonly observed in untreated plots in the fall.

Over the past 25 years in eastern Virginia, the major insect pests of tomato have changed significantly in the spring crop, although not substantially in the fall crop. In the spring crop, thrips and stink bugs have replaced the Colorado potato beetle as the major pest(s), whereas

Table 3
Reduction and estimated US dollar loss in marketable tomato fruit yield due to insect pests on Virginia's Eastern Shore, 1998–2000. Small plots of tomato were either treated weekly with a broad-spectrum insecticide or remained untreated

Crop grown	Year	Treatment	*n*	Mean (±SEM) marketable fruit yield (Number of 11.3 kg boxes ha^{-1})	*F* statistic	df	Probability	Percentage of marketable fruit yield reduction	Estimated $US loss in return ($ha^{-1}$)[a]
Spring	1998	Treated	10	4814 ± 346					
		Untreated	10	2906 ± 274	599.35	1,9	< 0.0001	40	9540–17,172
	1999	Treated	5	3934 ± 274					
		Untreated	5	1947 ± 141	136.03	1,4	0.0003	51	9935–17,883
	2000	Treated	8	5058 ± 138					
		Untreated	8	4455 ± 178	14.12	1,7	0.0071	12	3015–5427
Fall	1998	Treated	9	4658 ± 257					
		Untreated	9	3076 ± 274	278.13	1,8	< 0.0001	34	7910–11,074
	1999	Treated	8	1596 ± 185					
		Untreated	8	986 ± 203	30.47	1,7	0.0009	38	3050–4270
	2000	Treated	8	1932 ± 67					
		Untreated	8	1421 ± 116	12.30	1,5	0.0171	26	2555–3577

[a] Losses are based on typical prices for spring-grown ($US5–$US9/box) and fall-grown ($US5 to $US7/box) tomato.

Table 4
Percentage of marketable yield loss that was accounted for by direct feeding injury from thrips, stink bugs and Lepidopteran larvae

Crop grown	Year	Loss of marketable fruit yield attributed to major pests (Number of 11.3 kg boxes ha^{-1})[a]	Actual loss of marketable fruit yield (Number of 11.3 kg boxes ha^{-1})[b]	Percentage of yield loss accounted for by major pests
Spring	1998	1450	1908	76
	1999	1942	1987	98
	2000	598	603	99
Fall	1998	563	1582	36
	1999	388	610	64
	2000	111	511	22

[a] Loss of marketable fruit yield attributed to major pests may be lower than the sum of marketable yield loss due to each group of pests because some fruits were injured by more than one group of pests. Fruit damaged by Lepidopteran pests that either aborted from the plant or rotted on the vine was not accounted for in this estimation of yield loss.
[b] Actual loss of marketable fruit yield was determined as the difference in yield between insecticide-treated and untreated plots.

Lepidopterans, especially the corn earworm continues to be the dominant fall crop pest. The considerable decline in potato acreage (76% over the past 25 years [USDA, 1976]) coupled with better management of the potato beetle in eastern Virginia potato fields are likely responsible for its low numbers in tomato fields. Specific factors responsible for the major pest status of thrips and stink bugs in spring-grown tomato are not known. In summary, our research has provided justification for tailoring a tomato IPM program for eastern Virginia that includes scouting procedures and action thresholds for thrips, stink bugs and the corn earworm in an effort to curtail the existing calendar-based spray program.

Acknowledgements

Assistance with data collection and crop maintenance by K. Brown, A. Drewer, T. Fulk, E. Hurst, D. Jolly, C. Moore, E. Peterson, and S. Willis were greatly appreciated. I especially thank J. Custis and H. Hohlt for preparing the field and for their advice on irrigating and maintaining the crop. R. Groves was very helpful in identifying adult thrips species and along with H. Hohlt provided valuable comments on an earlier draft of this manuscript. The Virginia Agricultural Council and the Virginia IPM program supported this research.

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